WELDING Journal

June 2008

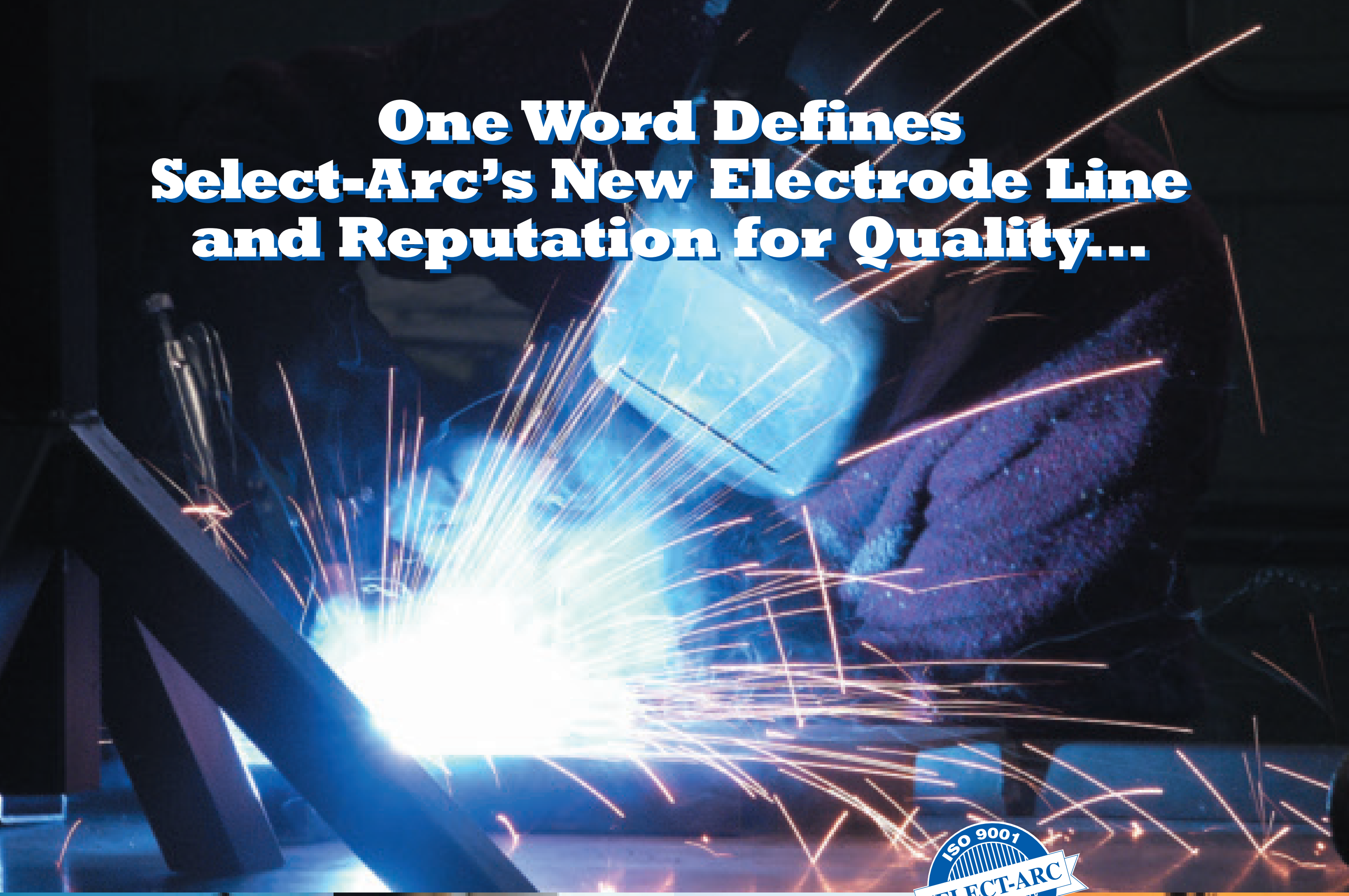
•Pipe Welding in the Power and Petroleum Industries

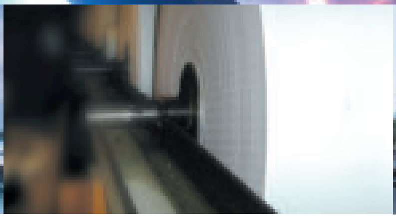
•Selecting Tubular Products

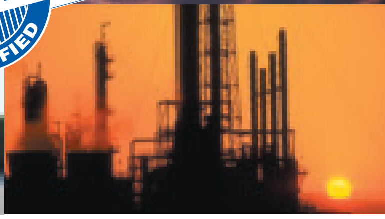
•Camp Inspires Welding Students

•Welder Displays Passion for Art and Metal

PUBLISHED BY THE AMERICAN WELDING SOCIETY TO ADVANCE THE SCIENCE, TECHNOLOGY, AND APPLICATION OF WELDING AND ALLIED JOINING AND CUTTING PROCESSES, INCLUDING BRAZING, SOLDERING, AND THERMAL SPRAYING





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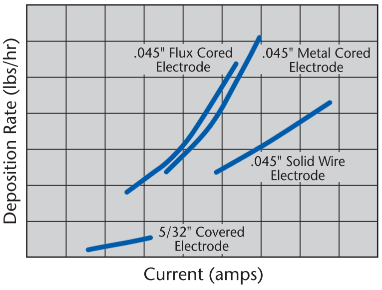
The chart below shows that SelectAlloy flux cored electrodes' higher deposition rates improve productivity and reduce welding costs.

Typical Deposition Rates for Various Stainless Steel Consumables



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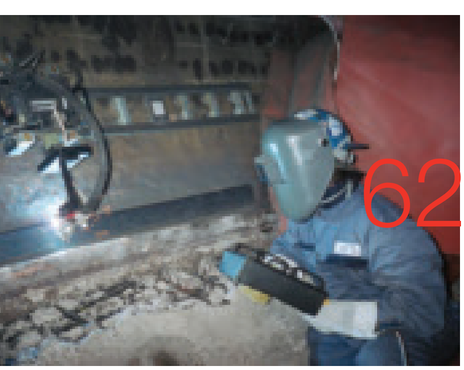

Features

Welding Research Supplement

AWS Web site *www.aws.org*

Departments

Welding Journal (ISSN 0043-2296) is published monthly by the American Welding Society for $120.00 per year in the United States and possessions, $160 per year in foreign countries: $7.50 per single issue for domestic AWS members and $10.00 per single issue for nonmembers and $14.00 single issue for international. American Welding Society is located at 550 NW LeJeune Rd., Miami, FL 33126-5671; telephone (305) 443-9353. Periodicals postage paid in Miami, Fla., and additional mailing offices. **POSTMASTER:** Send address changes to Welding Journal, 550 NW LeJeune Rd., Miami, FL 33126-5671. **Canada Post:** Publications Mail Agreement #40612608 Canada Returns to be sent to Bleuchip International, P.O. Box 25542, London, ON N6C 6B2

BY HUGH K. WEBSTER
AWS WASHINGTON GOVERNMENT AFFAIRS OFFICE

Legislation Introduced to Reinstate Research and Development Tax Credit

A bipartisan bill to reinstate the federal tax credit for research and development (R&D) by businesses was recently introduced in the U.S. Senate and is expected to be on a fast track. The R&D tax credit expired at the end of 2007, resulting in a de facto tax increase for manufacturers and other companies. The Alternative Minimum Tax and Extenders Relief Act of 2008 (S. 2886) also would assist U.S. companies doing business overseas by ensuring that these companies will not be subject to simultaneous foreign and U.S. taxes on their earnings.

$26 Billion Spent by Manufacturers on Pollution Prevention

Capital expenditures and operating costs of U.S. manufacturers for pollution prevention and treatment totaled $26 billion in 2005, according to a U.S. Census report just released titled, "Pollution Abatement Costs and Expenditures (PACE): 2005." This is the most recent year for which data have been analyzed. While the amounts reported are significant, they represent less than 5% of total new capital expenditures and less than 1% of total revenue for the manufacturing sector, respectively, in that year. The report is available at *http://yosemite.epa.gov/ee/epa/eed.nsf/pages/pace2005.html*.

Government Accountability Office Asked to Investigate 'Shadow Reporting' of Injuries

Two U.S. Senators, concerned that underreporting of workplace injuries has become prevalent in recent years, have asked the U.S. Government Accountability Office to investigate whether the Occupational Safety and Health Administration (OSHA) is effectively working to ensure that employers are accurately reporting injuries and illnesses in the workplace. Senators Murray (D-Wash.), chairman of the Senate HELP Subcommittee on Employment and Workplace Safety, and Kennedy (D-Mass.), chairman of the Senate Health, Education, Labor and Pensions Committee, expressed the view that, because OSHA uses the illness and injury information that businesses provide to determine which companies to inspect, there could be an incentive for businesses to underreport.

Public Hearing on Proposed Confined Spaces in Construction Rule Scheduled

The U.S. Occupational Safety and Health Administration (OSHA) announced it will hold an informal public hearing to receive testimony and documentary evidence on the proposed rule for Confined Spaces in Construction. The hearing is scheduled for 10 a.m. on July 22 at the Department of Labor in Washington, D.C. OSHA published the proposed Confined Spaces in Construction Standard last November, and a 60-day comment period followed.

Government Report Highlights Need for Skills Certification

"Manufacturing skills certification is one of several steps toward ensuring an adequate supply" of qualified workers that the U.S. manufacturing sector needs, according to a new government report, *Manufacturing the Future: Federal Priorities for Manufacturing R&D*, prepared by the Interagency Working Group (IWG) on Manufacturing R&D of the National Science and Technology Council's (NSTC) Committee on Technology.

The manufacturing sector will continue to be a major employer, and, according to this report, manufacturing's success "will depend on access to an innovative, technology-savvy, highly skilled workforce." The report also emphasizes that successful operation of a modern production facility requires workers with adequate preparation in fundamentals such as mathematics, science, reading comprehension, and writing; and strong workplace competencies, including computer literacy, teamwork, and critical thinking.

How International Competition Affects U.S.Manufacturers Explored

A report funded and issued by the U.S. Small Business Administration (SBA) analyzes the impact of competition from overseas on U.S. manufacturers. *The Impact of International Competition on Small-Firm Exit in U.S. Manufacturing* is available on the SBA Web site, *www.sba.gov*.

As global trade increases and currency exchange rates fluctuate, concerns about their impact on small U.S. manufacturers increase, which was the impetus for the study. Small manufacturers, by the nature of their scale of operations, are generally less able to insulate themselves from foreign competition than large manufacturers. Although not without costs, large manufacturers have greater leeway in managing the effects of international competition: They can move production offshore, sign long-term commodity contracts in foreign currencies, or use other tactics to weather global shifts.

The following are among the findings in the report:

• Increased international pressures in the form of currency exchange rates lead to increased exit rates among small manufacturers (those with fewer than 20 employees). Slightly larger manufacturers (20–499 employees) are less sensitive to changing conditions in the international marketplace.

• Exit rates of firms with fewer than 10 employees hovered around 14% from 1990 to 2004, around 7% for firms with 10–19 employees, and around 5% for firms with 20–99 employees and 100–499 employees.

• Consumer goods industries had higher rates of exit among small manufacturers.

Employer-Pay Personal Protective Equipment Rule Now in Effect

A final rule issued by the U.S. Occupational Safety and Health Administration (OSHA) requiring employers to pay for their employees' personal protective equipment (PPE) became effective May 15. The rule generally provides that employers must pay for protective equipment, including personal protective equipment that is used to comply with other OSHA standards. There are limited exceptions, such as for everyday clothing (e.g., long-sleeve shirts, long pants, street shoes, normal work boots) that could serve as PPE, as well as ordinary clothing or other items used solely for protection from the weather. ♦

Contact the AWS Washington Government Affairs Office at 1747 Pennsylvania Ave. NW, Washington, DC 20006; e-mail hwebster@wc-b.com*; FAX (202) 835-0243.*


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PRESS TIME NEWS

Lincoln Electric Supports AWS Foundation in Campaign to Relieve Welder Shortage

The American Welding Society (AWS), Miami, Fla., recently announced The Lincoln Electric Co. will donate $300,000 to the AWS Foundation to help relieve a nationwide shortage of welders. Lincoln and the AWS Foundation will collaborate on new marketing initiatives to promote welding careers and help bolster the ranks of welders.

The funds will be donated over a two-year period beginning this year. Also, Lincoln will contribute marketing support and partner with AWS to produce a promotional welding career video to be used online, in classrooms, and throughout industry. It will feature well-known personalities who have sponsorship agreements with the company.

The AWS Foundation's Welder Workforce Development Program will be supported by this donation as well.

"This generous contribution to our campaign will enable AWS to launch much-needed programs and marketing initiatives toward the promotion of welding careers," said Ronald C. Pierce, AWS Foundation chairman. "Lincoln Electric has always been a very important partner to AWS, and their continued support helps us build a stronger welding workforce for America."

The AWS Foundation will utilize this donation to fund new programs and marketing initiatives for the recruitment of welders and promotion of welding careers. Additionally, funds will support the Foundation's Solutions Opportunity Squad (SOS). They will further support local AWS Sections, businesses, and other organizations that have specific workforce development needs.

"We are proud to participate in these AWS programs," said Richard Seif, senior vice president, Global Marketing, Lincoln Electric, and AWS Foundation board trustee. "This campaign is new territory for all of us. We are excited about the direction in which AWS is headed to attract the best and the brightest to the industry, and we are particularly impressed with their SOS team. The shortage of welders is one of the most important issues facing our industry. It is absolutely critical that we make motivated, organized, and responsible individuals aware that welding is a safe and rewarding career option. We feel the video will also become an important tool since it will give us a way to directly reach those who are looking into new or different career paths."

TMK Installing New Large-Diameter Pipe Mill

The installation of a new large-diameter longitudinal welded pipe mill is underway at OAO TMK's Volzhsky, Russia, subsidiary.

The 650,000-ton mill will produce longitudinal welded pipes of X80 grade with diameters ranging from 530 to 1420 mm and wall thicknesses of up to 42 mm. Interior smooth coating and exterior anticorrosion coating capacities will also be added to this mill. These pipes are used in long distance oil and gas pipelines.

The company contracted HAEUSLER AG of Switzerland, a producer of welded pipe production equipment, to supply the new pipe mill for the production of large-diameter longitudinal welded pipes. The mill will include bending, welding, and finishing stations. Azovinteks Design and Construction LLC will install the equipment, and production of large-diameter longitudinal welded pipes is expected to start in the third quarter of 2008.

Following commissioning, its pipe capacity will amount to 1.2 million tons per year.

Report on Global Metals Industry Released

Deals in the global metals industry in North America soared to record levels in 2007, according to PricewaterhouseCoopers, indicating that the credit crisis in the United States has not hindered industry growth. *Forging Ahead: Mergers and Acquisitions Activity in the Global Metals Industry* reveals that 115 deals, totaling $77 billion in value, took place last year in North America. This accounts for 53% of total deal value in the global metals industry during 2007 and nearly matches the entire global metals industry deal value for 2006 ($86 billion).

North America's aluminum market was valuable in 2007, with 18 deals totaling $46.7 billion. On the other hand, the steel sector accounted for a great number of deals (71) but accumulated less total deal value than the aluminum sector, at $30 billion. In addition, 26 deals closed in the base metals industry, accounting for $300 million in North American deals last year.

WELDING journal

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Spread the Good News

The really good part of being AWS treasurer is I get to tell you how well the Society is doing financially in terms you need to know and that are not quite as tedious to get through as those in our formal financial statement. Our CFO, Frank Tarafa, is required to do the statistical report that goes into all the details on how much came in and to what line items we charged our outflow of cash and how much we had left over. That is all important, and as good stewards of the Society's finances you must be aware of these details. However, in my job as treasurer, I have the pleasure of letting you know that our financial position at this time is not only very strong, it is, in fact, the best it has ever been.

A year has sped by since I last had the opportunity to write an editorial informing you about our financial position. I'm pleased to report the auditors have completed their work, and the Society's finances again received a clean bill of health. The auditors found no discrepancies in our reports to you. AWS has a very good process of checks and balances in place that allow us to be certain that the numbers we present on a regular basis are in fact quite accurate for any given period of time as well as for the year overall. The Finance Committee examines the reports monthly, and I see them every two weeks. I may, from time to time, discuss with the Society's finance staff any items that may raise a question for me, and they give me a full accounting in detail at the time I call. The questions, I must add, generally are about receiving more income than anticipated. We try to make the financial reports very transparent so as to make all who see them comfortable with the numbers, and we are always ready and willing to go over them with anyone who has questions on the reports we generate.

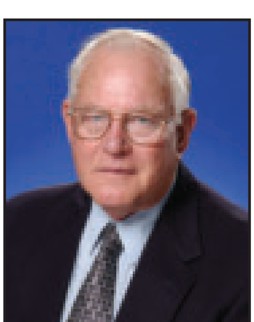
As I stated before, the Society's financial position at this time is very strong. The reserve fund is being built up so it will contain two years of operating capital, and we are more than halfway to that goal. The past few years have been the best AWS has ever had for consistent growth in all areas of the Society, and the future looks to be equally as bright.

AWS recently participated in Weldmex, its newest acquisition, a trade show it purchased in Mexico. The show was a tremendous success, both in participation by vendors and in attendance by the public. AWS also did well in signing up new members at this show.

The AWS Foundation's Work Force Development program has been going forward. The first of the Solutions Opportunity Squad (SOS) has been hired. Monica Pfarr brings all the credentials we hoped to find for this position. Pfarr worked for General Motors for 12 years in its production controls group and then moved on to Sinclair Community College where she was involved on its Work Force Development project. She also consulted for the state of Ohio on work force development strategies. Pfarr is presently covering the area commonly referred to as the "rust belt." She and Foundation Executive Director Sam Gentry have been busy contacting the Society's customers in that area to get a handle on their most pressing work force needs and how to assist them on finding a solution to their problems. AWS is also continuing to search for additional SOS members so we can be more effective in the rest of the country.

The Society's leadership is also starting to take a hard look at the AWS Miami facility to upgrade it to better fit our immediate needs and future growth. This project will be ongoing for several years. We realize that our constituents will keep looking to us for assistance, and we must be prepared to act effectively and efficiently in responding to their needs and requests.

Once again, I'm telling you that this is an exciting time to be a member of the American Welding Society. If you are not a member, you should join us, and if you are a member, I urge you to get even more involved in this vibrant, growing Society.

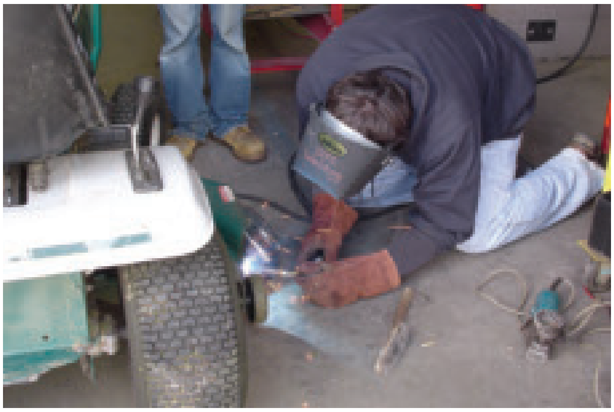


Earl C. Lipphardt
AWS Treasurer


Eye-Tech

Missouri College Students Fix Household Items for a Good Cause during Community Welding Day

Some of the welding students at Ozarks Technical Community College pose with their instructor for a group shot after a day of volunteering to mend belongings for community members and collect funds for St. Jude Children's Research Hospital. Shown (front row, from left) are Derrick Hudlow, Chad Conn, Kyle Smith, and Jim Bridwell; in the middle row are Andrew Shoults, Jared Dibben, Nicholas Leadbetter, Nick Puffe, and Travis Sims; and in the back row are Daniel McLinn, Tyler Schoen, and Travis Crabtree.



Tyler Schoen is pictured welding on a lawn mower deck. "Everybody's got something that needs a little spot of weld, and that's the people we were trying to reach out to," said teacher Jim Bridwell.

On Community Welding Day, fifteen students from Ozarks Technical Community College, Springfield, Mo., led by instructor Jim Bridwell, donated their time to repair items and raise donations for St. Jude Children's Research Hospital. Held on April 19, it took place in the school's welding lab located at the Industry Transportation and Technology Center.

Bridwell thought for a long time about holding a fund-raiser, but he did not talk to anybody about it. So recently, when a few students approached him about doing something after a local radio station put on a telethon for St. Jude's, he decided to go ahead with an event.

During the day, fourteen advanced welding students provided welding services and one beginning welding student also helped out. This group consisted of about 75% high school students (through a program they can take two years of welding classes at the college and graduate high school with 32 college credits upon successful completion) and 25% college students.

Two student organizations from the college were represented as well — the American Welding Society (AWS) Student Chapter at the college, of which Bridwell is the advisor, and SkillsUSA.

Various items were fixed at the event, including two-wheeled hand trucks (dollies); a lawn furniture table; a lawn mower deck; and two brackets were fabricated for a BBQ grill.

"They did top-notch work for the people who showed up, and the repairs that were made," Bridwell said. "We didn't have to turn anybody away."

Gas metal arc welding was used to fix carbon steel and aluminum pieces. Gas tungsten arc welding was also used on aluminum. Bridwell, an AWS Certified Welding Inspector, made sure the completed items were repaired properly.

It is possible that a community day could become an annual or semiannual event at the college. "I think we're looking at doing it maybe twice a year — once in the fall and once in the spring," Bridwell said. This may involve other departments along with supporting different charitable organizations.

Miller Electric Mfg. Co. sponsored the welding day by providing matching T-shirts for the student volunteers; these were ordered through company representative Ted Drower. The left over T-shirts were sold, too, and combined with the money collected during the event, more than $300 will go to St. Jude's.

The teamwork Bridwell saw his students display made him proud. "It was amazing," he said. "The cooperation that day was just pretty unbelievable because these guys are in class together five days a week most of the time, but I incorporated the morning and the afternoon class, and everybody worked together and jumped right in."

Navy Metalworking Center to Demonstrate Electron Beam Welding on the Virginia Class Submarine

The Navy Metalworking Center is executing a project for the Office of Naval Research that replaces traditional welding with electron beam welding in the fabrication of first reduction gears on the Virginia Class Submarine (VCS). Additionally, the center is working with the VCS Program Office (PMS450), Naval Sea Systems Command, and Northrop Grumman Electronic Systems-Marine Systems to carry out the "Electron Beam Welding of VCS First Reduction Gears Project."

The 14-month project is expected to reduce costs associated with the manufacturing process along with improving the quality of the welds. It will reduce fabrication time by incorporating single-pass, complete-joint-penetration welds; utilize narrow welds that improve fit-up and simplify machining operations on fabricated gears by reducing rim-to-shaft distortion; eliminate the need for closing plates on gear fabrication; and reduce magnetic particle testing requirements due to single-sided welds.

AMTDA and SME to Collaborate on Machine Tool Event

The American Machine Tool Distributors' Association

(AMTDA) and Society of Manufacturing Engineers (SME) will collaborate on the Machine Tool Experience — Las Vegas (MTELV) event to be launched in 2011.

MTELV is an industry event for machine tool professionals. It encompasses strengths of the corporate open house, customer training sessions, client appreciation events, and new product announcements.

The organizations will have equal representation on planning and operational committees. They will further work with representatives of builders, distributors, and customers to develop MTELV 2011.

Motoman and University of Dayton Establish Advanced Robotics Research Lab

Motoman Inc. is helping to establish the Motoman Robotics Laboratory at the University of Dayton School of Engineering.

The company is furnishing $371,000 worth of robots, including a 7-axis, actuator-driven IA20 robot; a 15-axis, actuator-driven and human-like dual-arm DIA10 robot; a 4-axis YS450 high-speed SCARA robot; two 6-axis HP3 articulated robots; and one HP3C 6-axis, articulated robot with a compact controller.

As part of the School of Engineering's electrical and computer engineering department, the laboratory will be located in approximately 800 sq ft of space in the Kettering Labs being renovated to accommodate six robot stations.

Also, the university has granted Motoman a $150,000 Electrical and Computer Engineering Research Credit that will allow the company access to robotics research and project opportunities. The new robotics laboratory is expected to be in operation in time for the start of the 2008–09 academic year.

2008 Awards of Excellence in Metalforming Winners Honored

The Precision Metalforming Association has acknowledged the winning companies of its excellence in metalforming awards. Sitting (from left) are Amanda Smith, E&E Mfg. Co., Inc.; Erick Ajax, E. J. Ajax & Sons, Inc.; Stuart Faria, SKD Automotive Group; Charlie Chamberlin and Tom Keane, OKAY Industries, Inc.; Larry Johnson, ITW CIP California; and Chuck Guiste, Penn United Technologies. Standing (from left) are Wes Smith and Richard Sbroglia, E&E Mfg. Co., Inc.; Jeff Aznavorian, Clips & Clamps Industries; George Woodhull and Richard Papeika, Ulbrich Stainless Steels & Special Metals, Inc.; Jeff Dec, Parkview Metal Products; Mike Jeroue, ITW CIP California; and J. L. Bates, Signature Technologies.

The Precision Metalforming Association's (PMA) 2008 Awards of Excellence in Metalforming winners were recently recognized. At a ceremony on April 1 during PMA's 2008 Regional METALFORM trade show in Birmingham, Ala., they received a plaque, commemorative flag, and a presentation led by PMA Chairman of the Board Ralph Hardt. Each winning company received a cash prize as well.

This year's winners, along with their respective awards, are as follows: ITW CIP California, Santa Fe Springs, Calif., Higgins-Caditz Design Award; E&E Manufacturing Co., Inc., Plymouth, Mich., Pitcher Insurance Agency Safety Award; SKD Automotive Group – Brampton Division, Brampton, ON, Canada, Signature Technologies Process Control Award; Penn United Technologies, Saxonburg, Pa., A.R. Hedberg Training and Education Award; OKAY Industries, Inc., New Britain, Conn., Parkview Metal Products Excellence in Quality Award; E. J. Ajax & Sons, Inc., Fridley, Minn., SKD Automotive Group Productivity Award; and OKAY Industries, Inc., New Britain, Conn., Ulbrich Award for Competitive Excellence in Product Development.

Great Designs in Steel Seminar — Highlights Innovative Steels for Automotive Applications

To demonstrate how new steel technologies can help with key issues in the automotive industry, the American Iron and Steel Institute's (AISI) Automotive Applications Committee held its 7th annual Great Designs in Steel seminar on April 9 at the Laurel Manor Conference Center in Livonia, Mich.

The seminar featured more than 30 presentations by automotive engineers and steel experts. Successful case studies were pre-

The show floor at the 7th annual Great Designs in Steel seminar held by the American Iron and Steel Institute's Automotive Applications Committee included many displays such as using laser-welded blanks in the body structure. Laser-welded blanks can reduce total vehicle mass by up to 380 lb when secondary weight savings are included.

sented, and components and full vehicles demonstrating the innovative use of steel, new materials, and processes were displayed on the exhibit floor.

Plus, AISI presented its 2nd annual Great Designs in Steel Automotive Excellence Award to the research and development team of the 2006 Honda Civic. The award winners were chosen based on presentations from last year's seminar and on the vehicle's evolutionary and cost-effective use of advanced high-strength steel.

ATI Industrial Automation Expands Facility, Opens Offices

ATI Industrial Automation, an engineering-based developer of robotic peripheral equipment, has recently undergone a major expansion. A second building has been constructed at the company's corporate and manufacturing facility in Apex, N.C.

The extra space has allowed for enhancements, including the following: a temperature-controlled metrology lab; a customized serial number tracking system for products and components; an integrated information infrastructure and improved enterprise resource planning system; reorganization of production workflow process; an improved RMA system for faster repairs; a new design control process; the Safe Launch Initiative, a cross-functional team and process consisting of employees representing each department; and new supplier corrective action processes.

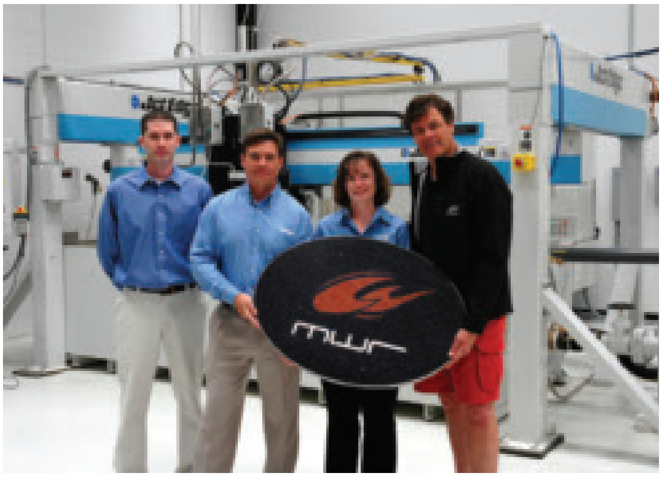
Additionally, it has opened new offices in Detroit, Mich., and Beijing, China.

Michael Waltrip Racing Installs Jet Edge Waterjet Cutting System

Michael Waltrip Racing (MWR) and Jet Edge, Inc., St. Michael, Minn., recently announced MWR has installed a Jet Edge precision waterjet cutting system at its fabrication shop in Cornelius, N.C. The racing company plans to use its system to cut parts for its three NASCAR Sprint Cup Series teams and NASCAR Nationwide Series team.

MWR selected Jet Edge's 4 × 8 ft High Rail Gantry waterjet system. Powered by a 50-hp, 60,000-lb/in.^{2} Jet Edge iP60-50 intensifier pump, the fully 3-axis programmable system features

For info go to www.aws.org/ad-index



Jet Edge management presents a waterjet cut logo to Michael Waltrip for MWR's conference room. The logo was fabricated out of Metron glass by Palmer Marble & Tile of West Palm Beach, Fla. The Metron was donated by Bisazza North America of Miami. Pictured (from left) are Kurt Horsch, manufacturing manager; David Arthur, regional sales manager; Nancy Lauseng, marketing manager; and Michael Waltrip. (Photo courtesy of Jet Edge.)

dual Permalign II abrasive cutting heads on a 4-ft spreader bar that are capable of cutting complex parts out of virtually any material. The system is also equipped with a digital readout for multihead positioning that digitally displays cutting head positions as well as a pneumatic drill for automatic prepiercing of materials prone to delamination prior to cutting them with waterjet.

Also, the companies announced their new technical partnership that will give MWR access to Jet Edge's latest waterjet-cutting technology.

Rockford Toolcraft Debuts Stamping Press

Rockford Toolcraft, Inc., Rockford, Ill., has a new 4400-ton Verson tandem transfer press — Brutus. The giant press is designed for producing heavy-gauge stampings and features a bed area of 6 × 27 ft. Capable of handling coil stock up to ½ in. thick and 60 in. wide, the press line is totally automated from coil entry to finished part, according to president Jerry Busse, and is supported by a 60-person modern tool room with ten skilled die designers using 3D CAD design and AutoForm® forming simulation software. Currently, Brutus is making heavy truck chassis cross members and is available for additional contract work.

American Welding Society

Friends and Colleagues:

The American Welding Society established the honor of *Counselor* to recognize individual members for a career of distinguished organizational leadership that has enhanced the image and impact of the welding industry. Election as a Counselor shall be based on an individual's career of outstanding accomplishment.

To be eligible for appointment, an individual shall have demonstrated his or her leadership in the welding industry by one or more of the following:

• Leadership of or within an organization that has made a substantial contribution to the welding industry. The individual's organization shall have shown an ongoing commitment to the industry, as evidenced by support of participation of its employees in industry activities.

• Leadership of or within an organization that has made a substantial contribution to training and vocational education in the welding industry. The individual's organization shall have shown an ongoing commitment to the industry, as evidenced by support of participation of its employee in industry activities.

For specifics on the nomination requirements, please contact Wendy Sue Reeve at AWS headquarters in Miami, or simply follow the instructions on the Counselor nomination form in this issue of the *Welding Journal*. The deadline for submission is July 1, 2008. The committee looks forward to receiving these nominations for 2009 consideration.

Sincerely,

Alfred F. Fleury
Chair, Counselor Selection Committee

BY TONY ANDERSON

Q: I have been informed that some aluminum alloys can be adversely affected by exposure to sustained temperatures above 150°F. Apparently there are some alloy groups that can become susceptible to stress corrosion cracking if exposed to temperatures within a certain range; the 5xxx series (Al Mg) alloys being particularly susceptible. I work with the 5xxx series alloys, and I know that they are commonly used in structural applications. What is stress corrosion cracking, and is it a problem when using the 5xxx series aluminum alloys? I would like to know more about this subject and how to avoid problems associated with this issue.

What Is Stress Corrosion Cracking?

A: Stress corrosion cracking (SCC) is an accelerated form of corrosion resulting from exposure of a susceptible material to the combined action of corrosive environment and high steady tensile stress, either applied or residual — Fig. 1.

With the combined action of continuous stress and a corrosive environment, cracking of some aluminum alloys may occur.

In terms of alloy susceptibility, stress corrosion cracking is usually limited to the aluminum alloys with the following chemistry:

- Aluminum-copper-magnesium 2xxx series alloys.
- Aluminum-zinc-magnesium-copper 7xxx series alloys.
- Aluminum-magnesium 5xxx series alloy that contain more than 3% magnesium.

Stress corrosion cracking is rarely seen in the aluminum-magnesium-silicon 6xxx series alloys and does not occur in the pure aluminum 1xxx series, aluminum-manganese 3xxx series alloys, or the aluminum-magnesium 5xxx series alloys with less than 3% magnesium.

The Susceptibility of the 5xxx Series Aluminum-Magnesium Alloys to SCC

This series of aluminum alloys has a wide range of magnesium content (from 1 to 5%) and are typically used in work-hardened tempers. Alloys with magnesium content in excess of 3% that have been work hardened can become susceptible to selective grain boundary precipitation. This grain boundary precipitation can occur to some degree at room temperature, but it is accelerated significantly at moderately elevated temperatures. If these materials are subjected to prolonged exposure to temperature between 150° and 350°F (66° and 180°C) precipitate can form that is highly anodic to the aluminum-magnesium matrix, and the continuous grain boundary network of precipitate produces susceptibility to SCC — Fig. 2.

The weldable, high-strength 5xxx series aluminum-magnesium alloys were introduced by the aluminum producers after many years of research and development, in which their stress corrosion cracking characteristics were established. The results of this research and of service experience show that stress corrosion cracking is unlikely to occur in welds during normal ambient temperature service of any of the weldable 5xxx series alloys, all those commercially available today from primary producers in the various tempers and forms, including filler metals.

However, research also shows that prolonged exposure of alloys containing more than 3% magnesium at temperatures of 150° to 350°F (66° to 180°C) should be avoided as this temperature range can produce a material structure very suscep-

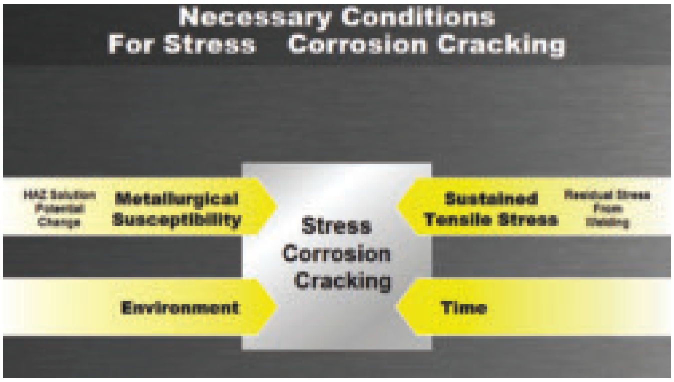


Fig. 1 — The conditions required to promote stress corrosion cracking.

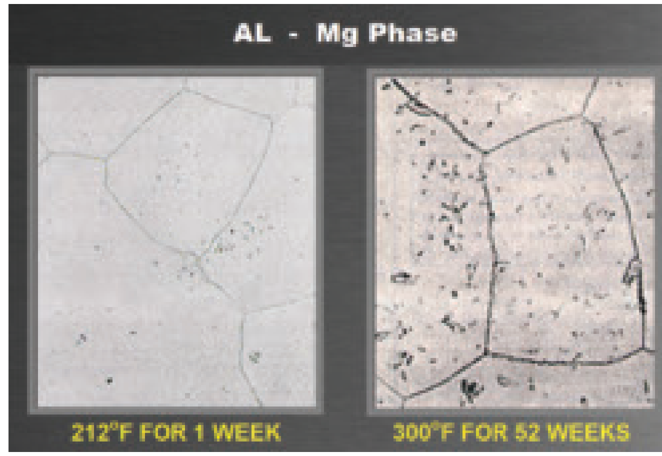


Fig. 2 — The selective grain boundary precipitation in two 5% Mg alloys.

tible to SCC. Exposure to higher temperatures (in excess of 350°F) results in a coarsening of the precipitates, producing a discontinuous grain boundary precipitate structure and reducing or eliminating SCC susceptibility.

Is SCC a Problem When Using the 5xxx Series Aluminum Alloys?

If we understand and respect this phenomenon and abide by the following rules, there is no reason why we should have problems with SCC when using the 5xxx series alloys.

- Base alloys or filler metals with more than 3% Mg should not be used for applications where prolonged exposure of temperatures between 150° and 350°F (66° and 180°C) can be expected.
- Filler metal ER4043 is a 5% silicon alloy and is often used for welding the 6xxx series base materials and the 5xxx series base materials with less than 2.5% magnesium. This filler metal has no magnesium added and is therefore suitable for elevated-temperature applications.
- The 5554 filler metal was designed to provide the improved strength and ductility characteristics of a magnesium-based filler metal that was also suitable for elevated-temperature applications. It contains 2.4 to 3.0% magnesium, thereby providing an alloy that is not susceptible to stress corrosion cracking, but has improved shear strength and improved ductility when compared to the 4xxx series filler metals.
- There are some base materials and filler metals of the 5xxx series that are designed specifically for elevated-temperature applications. One such combination that is frequently used in industry is 5454 base material welded with a 5554 filler metal. Both of these alloys have a controlled magnesium range of between 2.4 and 3.0%, and are therefore suitable for elevated-temperature applications and are not susceptible to SCC.◆

TONY ANDERSON is corporate technical training manager for ESAB North America and coordinates specialized training in aluminum welding technology for AlcoTec Wire Corporation. He is a Senior Member of TWI and a Registered Chartered Engineer. He is chairman of the Aluminum Association Technical Advisory Committee for Welding and holds numerous positions including chairman, vice chairman, and member of various AWS technical committees. Questions may be sent to Mr. Anderson c/o Welding Journal, 550 NW LeJeune Rd., Miami, FL 33126, or via e-mail at tanderson@esab.com.

BY R. L. PEASLEE

Q: Our company builds instrumentation and equipment for the cryogenic industry to handle the liquid forms of oxygen, nitrogen, argon, and helium, at the lowest temperatures possible. We have reviewed AWS A5.8/A5.8M:2004, *Specification for Filler Metals for Brazing and Braze Welding,* and want to know whether the BNi nickel-based brazing filler metals are suitable for joining base metals for our cryogenic applications.

A: Over the years, we have brazed many assemblies for the cryogenic industry. Most notable was the project for a valve company in Cincinnati. The company had been called upon to make 9000-lb/in.^{2} WOG (water, oil, gas) liquid-oxygen valves for use at missile sites throughout the United States — Fig. 1.

At that time, the cast quality for such a valve body was not suitable for this application. We worked with the customer on the design for a brazed valve using a wrought 316 stainless steel body and cast end bells, and other brazed components. The brazing filler metal used was BNi-2.

The valves were tested at 9000 lb/in.^{2}, –425°F (for service at 6000 lb/in.^{2}), and the brazed joints were found to be absolutely leak-free. In addition, the joints had no voids that could trap dirt.

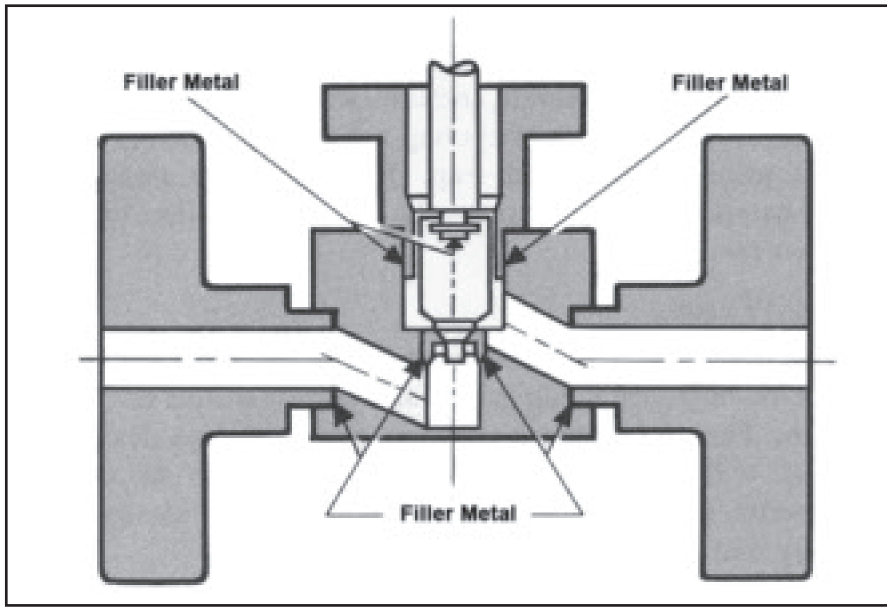


Fig. 1 — Sketch of a brazed valve for cryogenic service.

Brazing replaced the practice of welding the valve body to the two end flanges and the valve bonnet. Welding distorted the assembly causing the need for stress relief and machining to restore the proper dimensions so the valve would fit into the piping assembly.

The original valve seat was machined from the valve base metal. Since this was found to be unsatisfactory, a cobalt valve seat was welded in using a cobalt rod and gas tungsten arc welding, then it was machined to the valve seat profile. Unfortunately, half of the welded valve seats cracked and had to be machined out and replaced. This was expensive, so we recommended that a cast X-ray-sound seat be obtained that was finished-machined and this would be brazed into the valve body.

We were also able to finish machine all the detail parts before brazing. We used a stop-off product to protect the machined areas from accidental flow during furnace brazing. Furnace brazing eliminated distortion and also annealed and degassed the brazement and the base metal, without affecting the machined surfaces.

By eliminating the need for machining after fabrication, the costs were reduced more than enough to pay for the brazing operation. Another benefit of brazing was the parts were LOX (liquid oxygen) clean coming from the hydrogen atmosphere brazing furnace.

With white-glove handling and special packaging, the valves were delivered to the customers ready to assemble into their liquid-oxygen-handling systems.♦

R. L. PEASLEE is vice president emeritus, Wall Colmonoy Corp., Madison Heights, Mich. Readers may send questions to Mr. Peaslee c/o Welding Journal, 550 NW LeJeune Rd., Miami, FL 33126 or via e-mail to bobpeaslee@wallcolmonoy.com.

An Important Event on Its Way?

Send information on upcoming events to the Welding Journal Dept., 550 NW LeJeune Rd., Miami, FL 33126. Items can also be sent via FAX to (305) 443-7404 or by e-mail to *woodward@aws.org.*

Cutting Machines' Tool-Less Quick Disconnect Torches Reduce Set-up Time

Two models in the company's PowerCut™ line of Plasmarc™ manual cutting packages, PowerCut 1600 and 1300, make cutting easier with design features to simplify operation, reduce set-up time, and enhance consumable life. They offer the highest speeds and thickness capabilities in their class, as well as high duty cycles. A tool-less quick disconnect torch disconnects from the machine without the use of wrenches or special tools. A digital readout display shows the exact pressure or amperage; it also shows help codes. Blow back technology eliminates high-frequency startups that can disrupt CNC controls and nearby computer systems. The products further feature an automatic mode selection function that senses which cutting mode is in operation and adapts accordingly. An input voltage selector switch allows input voltage to be changed from 208 to 460. Additional features include a side-mounted automatic fan control; a built-in power line conditioner; and a torch wrap and spare parts kit holder. The 1300 model cuts 1¼ in. and severs 1½ in. The 1600 model cuts 1½ in. and severs 1¾ in.

ESAB Welding & Cutting Products
www.esabna.com
(800) 372-2123

Portable Pipe Saw Chain-Mount Bracket Sets Up Fast

The Esco Single Cut Bracket securely clamps its APS-438 air-powered saw onto a pipe or bar stock up to 4-in. OD and allows it to make square cuts with ±$\frac{1}{16}$-in. accuracy. Operating on 90 lb/in.^{2} air, this saw has a 3-hp motor; includes a standard grease fitting, safety throttle handle, and relief valve; and uses 10- or 12-in. fiberglass-reinforced abrasive blades. In addition, the fiberglass-reinforced blades are capable of cutting stainless steel, Inconel, and other hard materials. For structures up to 60-in. OD, other brackets are available.

ESCO Tool
www.escotool.com
(800) 343-6926

Bending Machine Features Programmable Control

The Ercolina® 050KD bending machine is useful for bending pipe, tube, squares, rectangles, solids, and other profiles. It also bends ferrous and nonferrous

materials ¼ to 2½ in. and accepts Ercolina's two-axis A40/P positioning table for multiple and sequential bends. A gear case accommodates radii up to 11⅞ in. centerline radius. Easy-to-use control programs bend angles to 180 deg with individual springback setting. A standard motor brake ensures bend angle accuracy. The product's patented swing-away counter-bending die vise allows quick loading and unloading of the workpiece. The hex mount patented tooling system allows rapid changeover. An optional remote foot pedal provides hands-free operation.

CML USA Inc.
www.ercolina-usa.com
(563) 391-7700

Electrofusion Welding Unit Monitors and Records Welding Process

The Hurner Electrofusion Welding Unit is designed for PE, PP, and PVDF pipes. It includes a user menu, liquid crystal display, electrodes, and a bar scanning probe that automatically sets up welding parameters and identifies the pipe, fittings, and welder. Suited for use in tight spaces, it monitors the welding process to detect errors such as heater coil shorts or

power supply failure, and can record up to 1800 welds in memory as well. The unit is able to generate several reports, comes equipped with a USB port for uploading data, and is Windows® compatible. Designed for weld pipe fittings up to 28 in. diameter, it weighs 35 lb, operates on 110/230 V, and is supplied in a metal carrying case.

Malcom Co., Inc.
www.malcomcompany.com
(800) 289-7505

Line of Low-Hydrogen Manual Electrodes Offers Rapid Pool Formation

The Excalibur® covered electrode line features consistent starting, quick pool creation, and reduced porosity. A slag system results in good pool control and clarity. Coating burn off is uniform and useful for jobs requiring steep rod angles on out-of-position welds. Tie-ins eliminate undercutting, reducing grinding and slag inclusions. Typically, the product is applied to structural steel and bridges or welding of piping, fittings, and tie-ins in the petrochemical and power-generation industries. It allows all-position welding of mild steels and some high-strength, low-alloy steels. The product also tolerates steels with poor weldability.

The Lincoln Electric Co.
www.lincolnelectric.com
(888) 355-3213

Saw Blades Designed to Eliminate Tooth Stripping

The Beast™ reciprocating saw blades were designed for multiple cuts through double-wall stainless tubing, pipe, stainless steel, mild steel, structurals, and conduit in one pass with one blade. They can be used to cut through die and nickel-based steels, too. The patent-pending blades incorporate a variable set tooth geometry and a specific tooth configuration to eliminate the pitching and vibration that produce heat and cause tooth stripping. Additionally, they are available in 6- and 8-in. 18 TPI configurations.

Simonds International
www.simondsinternational.com
(800) 343-1616

— continued on page 27

Auto-Darkening Welding Helmet
Python
By
ArcOne®
Special Rebates June 1 - Aug. 31
Limited Time Bonus:
(included in product box)
Free Designer Series Eyewear
Two Additional Outside Scratch-Proof Polycarbonates
Free Helmet Accessory Bag
Rebate Form ($20-$40)
Be Unique™
Spirit
Silver/Grey
UpTown
Blue Fusion
Red Fusion
Green Fusion
Silver Fusion
Fighting Tiger
Student Promo Only:
Additional Free
BSX
Stryker Jacket
with Python A.D. Helmet Purchase
Rebates on helmet/filter combos 6/1/08-8/31/08
$20 Rebate
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4000V
5000V
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Auto-Darkening Filters
For info go to www.aws.org/ad-index

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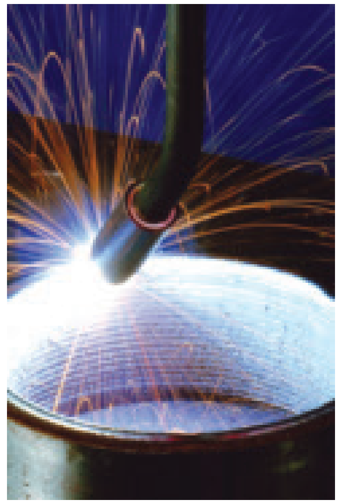
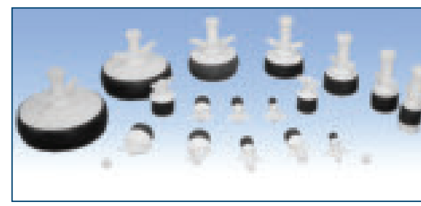
Automatic Weld Restores Worn ID Bore of Cylinderical Parts



BoreClad is a system for weld cladding or restorative buildup of the inside of pipes, tubes, nozzles, and nearly any cylindrical workpieces. The system uses the gas metal arc [solid or flux core (0.023 to 0.045) wire] weld process in conjunction with the company's patented step method to position weld beads inside round components. It rotates the workpiece while maintaining the optimal torch angle for bead quality and deposition rate. The system can weld mild steel and all stainless steel and nickel alloys. The standard model machine has a current capacity of 200 A at 100% duty cycle. Standard guns work within IDs of 1.2 up to 13 in. Maximum size range and piece weight capacity for standard models are 15 in. OD, 48 in. long, and 300 lb.

Bortech Corp.
www.bortech.com
(603) 358-4030

Redesigned Pipe Plugs Cover a Range of Sizes



The company's range of nylon Pipestopper plugs now provides a better seal. The plugs incorporate improved expanding rubber ring seals used by many manufacturing industries for sealing pipes and tubes during pressure testing. The Pipestopper plugs are manufactured using corrosion-resistant engineering polymers and cover the range of 12 to 160 mm in diameter. They have a central hollow shaft for use in pressure testing, gas and water entry and exit, and cable/wire feed through.

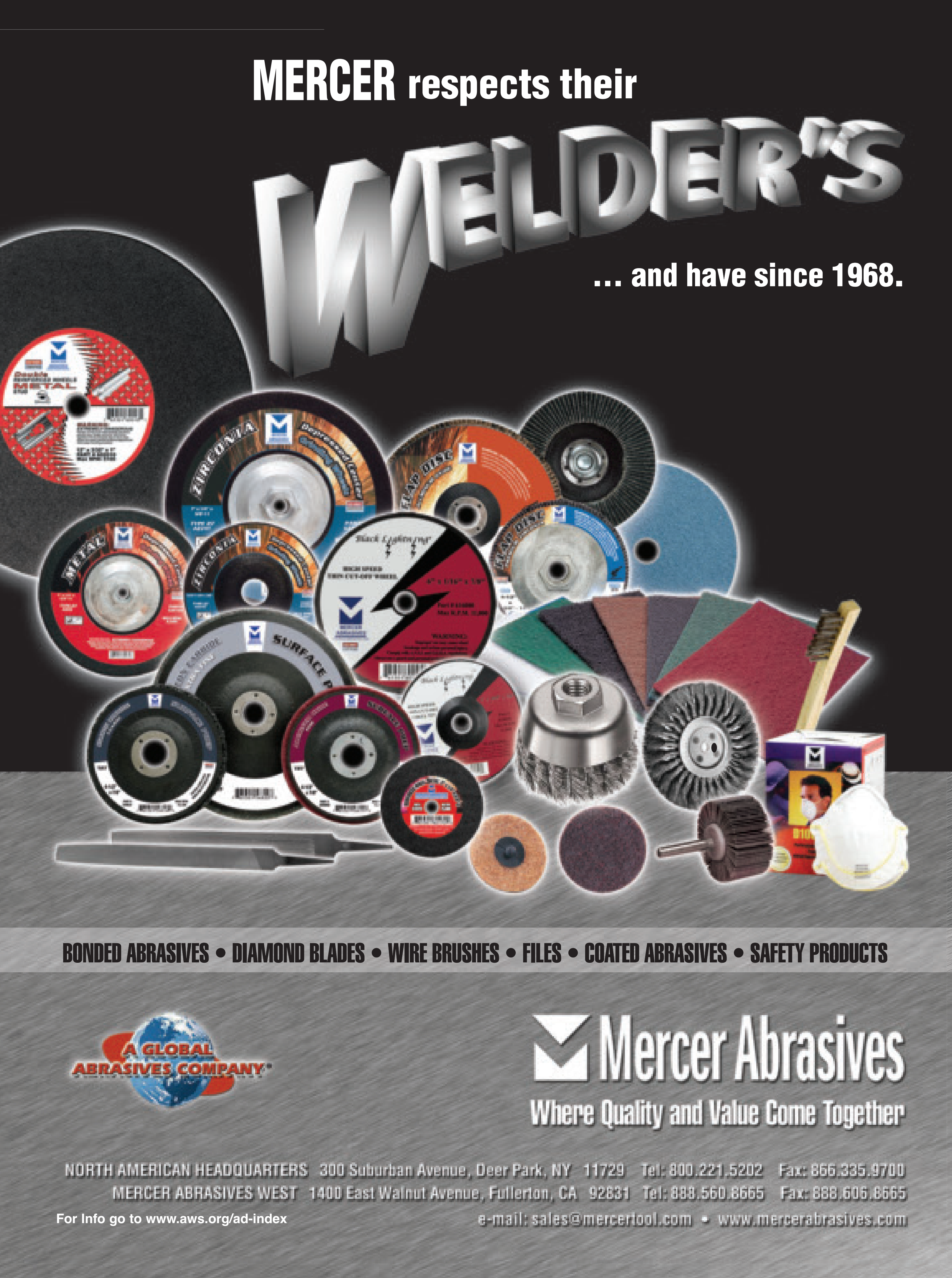
Huntingdon Fusion Techniques Ltd.
www.huntingdonfusion.com
44 1 554 836 836

Welding Generator Designed for Pipe Welding Applications

The next-generation PRO 300 diesel welding generator features improved reliability. An optional 4-cylinder, 24-hp Deutz engine provides more power for using larger electrodes and gouging with carbons up to ¼ in. diameter. The improved product also offers better E6010 performance for downhill pipe welding, as well as better gas metal arc, flux cored, and gas tungsten arc starts. Designed for pipe welding applications, construction fleets, and small contractors, it provides 20 to 410 A of welding power and 12,000 W of peak generator power. A single circuit board is housed in the company's

"Vault" created out of two aluminum halves sealed with silicone, along with a watertight harness for connections. When shielded metal arc welding, four-position control (A, B, C, D) positions adjust the arc force. To improve gas metal arc/flux cored arc welding performance, digital voltage control was added. The product features better gas tungsten arc starts and stops; this includes enhanced Lift-Arc and new Auto-Stop functions. It also features a low-fuel feature that shuts down the engine before fuel runs out.

Miller Electric Mfg. Co.
www.millerwelds.com
(920) 734-9821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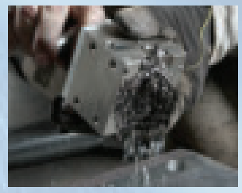
Changing the way things

Magswitch tools are lighter and stronger pound for pound than any other switchable magnet system. Unlike competitive products, when the Magswitch is off, it allows debris to fall away.

On



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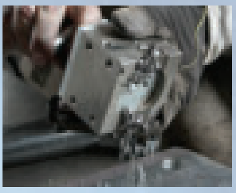


Welding Clamps

- Saves time and money.
- No more searching for or creating a ground location.
- Grounds instantly, turn on Magswitch and start welding.
- Attaches to flat or pipe.
- No more tacking on tabs in large sheet jobs.
- Stays clean.
- Available in three sizes:
  - 600-amp
  - 300-amp
  - 200-amp

MagSquares

- Simple and fast workholding.
- No need for tedious clamping.
- Grips on three sides.
- Precise positioning, holds on flat or round surfaces.
- Use MagSquares to mount workholding jigs.
- Stays clean.
- Available in three sizes, with breakaway force up to:
  - 150-lbs (30MM)
  - 550-lbs (50MM)
  - 1000-lbs (70MM)

Hanging Hooks

- Perfect for temporary holding of lines, hoses, tools or loose nuts and bolts.
- Perfect for use around the job site or shop.
- It's like having an extra hand.
- Precise positioning, attaches to flat or round surfaces.
- Quickly secure and hold just about anything, anywhere.
- Available in two sizes, with working loads up to:
  - 25-lbs (30MM)
  - 40-lbs (50MM)

Boomerangles

- Adjustable magnetic angle featuring two Magswitches.
- Fast and easy on/off control.
- Versatile rotating Magswitches for virtually any angle.
- Precise positioning.
- Preset positions for 90-degree inside and out.
- Non-marring hold.
- Stays clean.
- Available in two sizes:
  - 10-inch (50MM)
  - 8-inch (30MM)

AMERICAN WELDING SOCIETY AND AWS FOUNDATION FINANCIAL REPORT

Treasurer's Comments on the Fiscal Year Ending December 31, 2007

Each year, in the June issue of *Welding Journal*, the American Welding Society discloses its full financial position. The year-end audit has been completed and as CFO Frank Tarafa reports below, the Society has grown and its finances reflect that growth. Tracking the Society's diverse operational expenses is an important responsibility; therefore, we make every effort to be transparent in the financial presentations to show all data in an understandable format. These past several weeks have been intense for the Society's Accounting Department staff and, as usual, their report has been well done. It is always a pleasure to work with such a dedicated group of employees.

As you read through these statements, you will see the Society has achieved true growth in all departments, and the excess of revenues over expenses comes from the Society's growth. Although the Society's costs have increased, it has been able to maintain a favorable margin because of the growth in revenues.

Fiscal 2007 year in review — CFO and Deputy Executive Director Frank Tarafa

We are pleased to report that in 2007 AWS achieved several financial milestones as noted below and in our audited financial statements. For the second consecutive year, it was a year of outstanding financial performance and growth. AWS continues to be financially sound as a result of an overall increase in its revenues during fiscal 2007. The Society's operating revenues were $22.7 million, representing a 21.5% increase over 2006. The surplus of revenues over expenditures in the operating funds reached a milestone as the highest surplus ever attained.

As a result, Total Net Assets climbed more than $7.6 million to an all-time high of $27 million, an extraordinary increase of 39.6% over 2006.

The Society's Statement of Financial Position is the healthiest it has ever been in the history of the Society. Total assets at the end of 2007 exceeded $30 million for the first time in its history and were at $30.2 million.

The AWS Board of Directors approved the acquisition of the WELDMEX welding show in Mexico to continue expanding AWS's international presence. The first AWS/WELDMEX show, held January 29–31, 2008, was extremely successful. It had a record number of exhibitors and attendees. The details of the acquisition can be found on page 42 Note 9 of the audited financial statements.

Additionally, there were two Board programs commissioned in 2007:

- A Certification study to conduct a professional survey of end-users of AWS certification products. Results of the survey will assist the Certification Committee to prioritize their program development activities and to help the Committee develop operational details of the programs that will prove to be the most beneficial to the end-users.
- A Membership Web-based member-satisfaction survey to gain better understanding of member needs and expectations.

In 2006, the AWS Foundation inaugurated the **Welding for the Strength of America Capital Campaign** to add financial support to assist with the critical shortage of welders in the United States. In the two-year period, our initiatives have added more than $2.7 million to assist in these efforts. The effort has two goals: establish additional scholarships to support entry-level students and those already in the welding profession, and to build a fund to support the American Welding Society Welder Workforce Development Program. The focus of those efforts is welder "Recruitment to Retirement." The campaign success will determine the financial support that we have to actively address this crisis in our industry. There is a predicted shortage of 200,000 welding professionals by 2010. We, as the American Welding Society, must assume this critical role, but to do so we must have the financial support from our industry partners. For more information, contact AWS Foundation Executive Director Sam Gentry at *sgentry@aws.org.*

Looking ahead at our strong Statement of Financial Position, coupled with the projected double-digit increase in revenues for 2008, continues to gives us the ability to provide and fund future programs and opportunities for our members, volunteers, and the welding industry.

The AWS Board of Directors and AWS Foundation Trustees are dedicated to fulfilling their responsibilities and would like to express their appreciation to all of our members, volunteers, industry leaders, and the cooperation of organizations with whom we share common goals in helping us make this a very successful year.

Highlights for 2007:

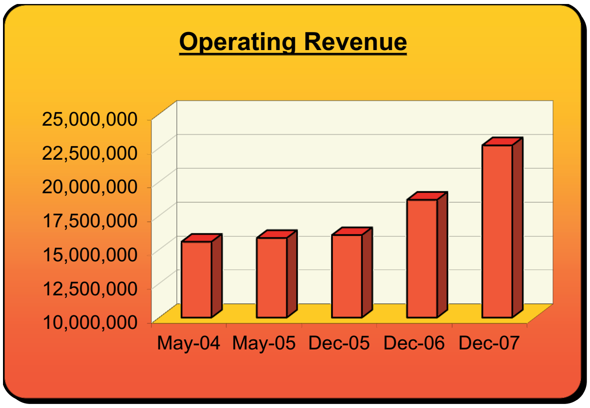
- The AWS and FABTECH alliance continues to be very successful and the third FABTECH International & AWS Welding Show was held in November 2007 in Chicago. The convention revenue square footage for AWS was 163,000 net square feet (NSF), an increase of 35,300 NSF, or 27% more than Atlanta in November 2006. This was the highest since Chicago in 2000.
- Educational CWI Seminars saw continued growth during 2007 and reached record levels for both attendees and revenues.
- Membership attained a record high of 52,654.
- The Certified Welding Inspector program continues to show healthy growth with the total number of Certified Welding Inspectors reaching a record high of 23,932, a 5.3% increase over 2006.
- Technical – The change AWS made in the order fulfillment partners to WEX (World Engineering Exchange) has continued to be very beneficial in having a dedicated focus on AWS publications that has resulted in improved customer service. The favorable trend in book sales continued in FY 2007 and sales exceeded the budget and expectations.
- *Welding Journal* advertising increased by 18% and recorded the highest revenues for advertising since FY 2001.

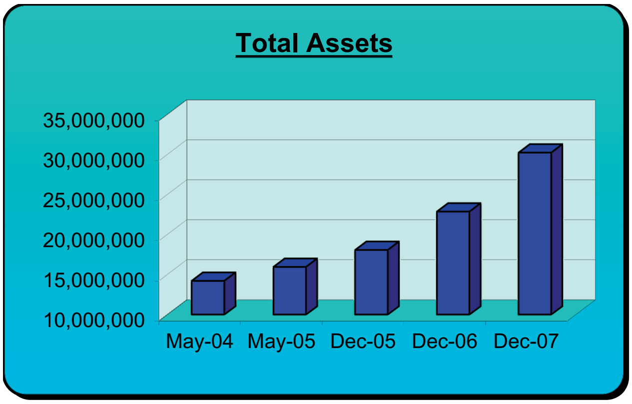
AMERICAN WELDING SOCIETY AND AWS FOUNDATION FINANCIAL REPORT

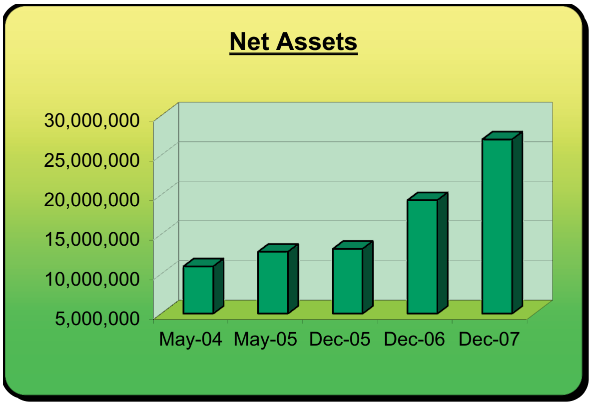
Growth at a Glance

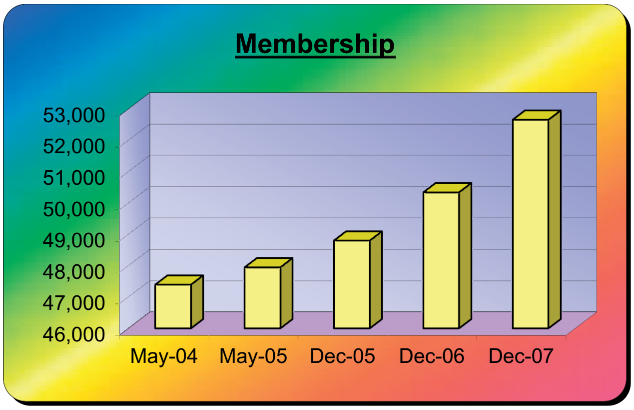
Five year comparisons

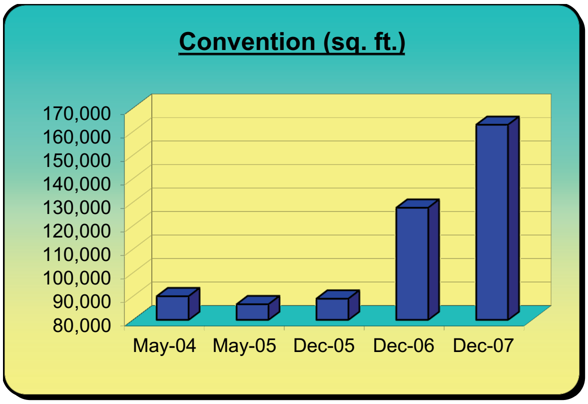
	May-04	May-05	Dec-05	Dec-06	Dec-07
Operating Revenue	15,588,027	15,870,374	16,082,208	18,689,442	22,705,914
Total Assets	14,223,410	15,955,292	18,078,856	22,862,536	30,238,890
Net Assets	10,969,677	12,812,957	13,189,728	19,339,264	27,003,910
Membership	47,392	47,946	48,798	50,337	52,654
Convention (sq. ft.)	90,100	86,700	89,100	127,700	163,000











REPORT OF INDEPENDENT CERTIFIED PUBLIC ACCOUNTANTS

To the Board of Directors
American Welding Society, Inc. and AWS Foundation

We have audited the accompanying combining statement of financial position of American Welding Society, Inc. and AWS Foundation (the Organizations) as of December 31, 2007, and the related combining statements of activities and cash flows for the year ended December 31, 2007. These combining financial statements are the responsibility of the Organizations' management. Our responsibility is to express an opinion on these combining financial statements based on our audit. Information for the year ended December 31, 2006 is presented for comparative purposes only and was extracted from the audited combining financial statements presented for that year.

We conducted our audit in accordance with auditing standards generally accepted in the United States of America. Those standards require that we plan and perform the audit to obtain reasonable assurance about whether the combining financial statements are free of material misstatement. An audit includes consideration of internal control over financial reporting as a basis for designing audit procedures that are appropriate in the circumstances, but not for the purpose of expressing an opinion in the effectiveness of the Organization's internal control over financial reporting. An audit also includes examining, on test basis, evidence supporting the amounts and disclosures in the combining financial statements, assessing the accounting principles used and significant estimates made by management, as well as evaluating the overall financial statement presentation. We believe that our audit provides a reasonable basis for our opinion.

In our opinion, the combining financial statements referred to above present fairly, in all material respects, the financial position of American Welding Society, Inc. and AWS Foundation as of December 31, 2007, and the changes in their net assets and their cash flows for year then ended in conformity with accounting principles generally accepted in the United States of America.

Morrison, Brown, Argiz & Farra, LLP
Certified Public Accountants
Miami, Florida
April 16, 2008

American Welding Society

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Miami, Florida 33126

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305-443-9353
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www.aws.org/foundation/index.html

AMERICAN WELDING SOCIETY, INC. AND AWS FOUNDATION
COMBINING STATEMENT OF FINANCIAL POSITION

DECEMBER 31, 2007 (WITH COMPARATIVE TOTALS FOR DECEMBER 31, 2006)

	Operating Fund	Reserve Fund	AWS Foundation	Total 2007	Total December 31, 2006
ASSETS:					
Cash and cash equivalents	$ 1,301,146	$ 100	$ 219,913	$ 1,521,159	$ 3,201,802
Certificates of deposit	2,098,490	46,866	-	2,145,356	44,667
Accounts and other receivables, net of allowance for doubtful accounts of approximately $154,300 and $117,500 at December 31, 2007 and 2006, respectively	1,424,231	-	-	1,424,231	1,130,516
Pledges receivable	-	-	951,840	951,840	1,016,098
Inventory	183,226	-	-	183,226	151,416
Prepaids and other assets	360,585	-	87,142	447,727	312,805
Deposits and other receivables	23,304	-	13,083	36,387	24,454
Investments	-	14,957,601	6,010,148	20,967,749	14,432,436
Property and equipment, less accumulated depreciation	2,561,215	-	-	2,561,215	2,548,342
TOTAL ASSETS	$ 7,952,197	$ 15,004,567	$ 7,282,126	$ 30,238,890	$ 22,862,536
LIABILITIES:					
Accounts payable and accrued expenses	$ 1,031,367	$ -	$ 8,627	$ 1,039,994	$ 1,557,183
Deferred membership, subscription and seminar income	2,194,986	-	-	2,194,986	1,966,089
TOTAL LIABILITIES	3,226,353	-	8,627	3,234,980	3,523,272
COMMITMENTS AND CONTINGENCIES					
NET ASSETS:					
Unrestricted	4,725,623	15,004,567	404,558	20,134,748	13,199,820
Temporarily restricted	221	-	3,477,346	3,477,567	2,883,380
Permanently restricted	-	-	3,391,595	3,391,595	3,256,064
TOTAL NET ASSETS	4,725,844	15,004,567	7,273,499	27,003,910	19,339,264
TOTAL LIABILITIES AND NET ASSETS	$ 7,952,197	$ 15,004,567	$ 7,282,126	$ 30,238,890	$ 22,862,536

The accompanying notes are an integral part of these financial statements.

AMERICAN WELDING SOCIETY, INC. AND AWS FOUNDATION
COMBINING STATEMENT OF ACTIVITIES

FOR THE YEAR ENDED DECEMBER 31, 2007
(WITH COMPARATIVE TOTALS FOR THE YEAR ENDED DECEMBER 31, 2006)

	Unrestricted Net Assets			Temporarily Restricted Net Assets	Permanently Restricted Net Assets	Total 2007	Total December 31, 2006
	Revenues	Expenses	Net				
OPERATING ACTIVITIES:							
Convention	$ 1,771,746	$ 424,423	$ 1,347,323	$ -	$ -	$ 1,347,323	$ 896,685
Educational Services	3,857,982	2,984,459	873,523	-	-	873,523	630,732
Marketing and corporate communications	-	540,868	(540,868)	-	-	(540,868)	(466,605)
International activities and governmental affairs	10,752	196,121	(185,369)	-	-	(185,369)	(125,480)
AWS Foundation	-	302,303	(302,303)	-	-	(302,303)	(309,568)
WEMCO	103,610	229,686	(126,076)	-	-	(126,076)	(100,880)
RWMA	91,664	193,718	(102,054)	-	-	(102,054)	(98,153)
Membership	2,626,326	1,451,837	1,174,489	-	-	1,174,489	902,107
Certification	7,248,245	1,994,522	5,253,723	-	-	5,253,723	3,927,574
Technical	3,422,705	1,549,348	1,873,357	-	-	1,873,357	1,582,157
Publications	3,410,285	2,663,212	747,073	-	-	747,073	533,972
Administration	99,266	3,855,506	(3,756,240)	-	-	(3,756,240)	(3,371,135)
Building operations	63,333	63,333	-	-	-	-	-
Board approved programs	-	89,700	(89,700)	-	-	(89,700)	-
Safety and Health	-	-	-	73	-	73	(58,752)
TOTAL OPERATING FUND	22,705,914	16,539,036	6,166,878	73	-	6,166,951	3,942,654
RESERVE:							
Gain on investments	220,571	-	220,571	-	-	220,571	598,730
TFPS, Inc.	2,199	-	2,199	-	-	2,199	1,358
Interest and dividends	454,145	-	454,145	-	-	454,145	237,440
TOTAL RESERVE FUND	676,915	-	676,915	-	-	676,915	837,528
AWS FOUNDATION:							
Donations	184,859	-	184,859	581,444	131,682	897,985	1,426,028
Interest	175,414	-	175,414	113,772	-	289,186	148,119
Gain on investments	33,503	-	33,503	9,507	-	43,010	264,763
Net assets released from restrictions by satisfaction of purpose restrictions	106,760	-	106,760	(110,609)	3,849	-	-
Operating expenses	-	113,321	(113,321)	-	-	(113,321)	(128,869)
Scholarships	-	192,195	(192,195)	-	-	(192,195)	(190,931)
Fellowships	-	80,556	(80,556)	-	-	(80,556)	(125,000)
Fundraising and other	-	23,329	(23,329)	-	-	(23,329)	(24,756)
TOTAL AWS FOUNDATION	500,536	409,401	91,135	594,114	135,531	820,780	1,369,354
Change in Net Assets	-	-	6,934,928	594,187	135,531	7,664,646	6,149,536
Net Assets, Beginning	-	-	13,199,820	2,883,380	3,256,064	19,339,264	13,189,728
Net Assets, Ending	$ -	$ -	$ 20,134,748	$3,477,567	$ 3,391,595	$27,003,910	$ 19,339,264

The accompanying notes are an integral part of these financial statements.

AMERICAN WELDING SOCIETY, INC. AND AWS FOUNDATION
COMBINING STATEMENT OF CASH FLOWS

FOR THE YEAR ENDED DECEMBER 31, 2007
(WITH COMPARATIVE TOTALS FOR THE YEAR ENDED DECEMBER 31, 2006)

	Operating Fund	Reserve Fund	AWS Foundation	Total 2007	Total December 31, 2006
CASH FLOWS FROM OPERATING ACTIVITIES:					
Change in net assets	$ 6,166,951	$ 676,915	$ 820,780	$ 7,664,646	$ 6,419,536
Adjustments to reconcile change in net assets to net cash provided by operating activities:					
Gains on investments	-	(220,571)	(43,010)	(263,581)	(863,493)
Depreciation	245,465	-	-	245,465	264,651
Provision for losses on accounts receivable	45,000	-	-	45,000	45,000
Changes in operating assets and liabilities:					
(Increase) decrease in accounts and other receivables	(338,715)	-	-	(338,715)	(1,422,574)
(Increase) decrease in pledges receivable	-	-	64,258	64,258	(972,098)
(Increase) in inventory	(31,810)	-	-	(31,810)	(31,494)
(Increase) decrease in prepaids and other assets	(139,234)	-	4,312	(134,922)	63,029
(Increase) decrease in deposits and other receivables	(10,991)	-	(942)	(11,933)	19,905
Increase (decrease) in accounts payable and accrued expenses	(524,313)	-	7,124	(517,189)	(1,493,546)
Increase in deferred membership, subscription and seminar income	228,898	-	-	228,898	127,690
NET CASH PROVIDED BY OPERATING ACTIVITIES	5,641,251	456,344	852,522	6,950,117	4,731,754
CASH FLOWS FROM INVESTING ACTIVITIES:					
Increase in certificate of deposits	(2,098,490)	(2,199)	-	(2,100,689)	(2,185)
Purchases of property and equipment	(258,338)	-	-	(258,338)	(188,537)
Purchases of investment securities	-	(5,454,145)	(817,588)	(6,271,733)	(2,778,213)
NET CASH USED IN INVESTING ACTIVITIES	(2,356,828)	(5,456,344)	(817,588)	(8,630,760)	(2,968,935)
CASH FLOWS FROM FINANCING ACTIVITIES:					
Interfund transfers	(5,000,000)	5,000,000	-	-	-
NET CASH (USED IN) PROVIDED BY FINANCING ACTIVITIES	(5,000,000)	5,000,000	-	-	-
NET (DECREASE) INCREASE IN CASH AND CASH EQUIVALENTS	(1,715,577)	-	34,934	(1,680,643)	1,762,819
CASH AND CASH EQUIVALENTS, BEGINNING	3,016,723	100	184,979	3,201,802	1,438,983
CASH AND CASH EQUIVALENTS, ENDING	$ 1,301,146	$ 100	$ 219,913	$ 1,521,159	$ 3,201,802

The accompanying notes are an integral part of these financial statements.

NOTE 1. NATURE OF ORGANIZATION AND SIGNIFICANT ACCOUNTING POLICIES

Organization and Purpose

The accompanying combining financial statements include the accounts of American Welding Society, Inc., its wholly-owned subsidiary TFPS, Inc. and its affiliate, AWS Foundation (collectively, the “Organizations”).

All material inter-organization accounts and transactions have been eliminated in the combination. American Welding Society, Inc. and AWS Foundation are not-for-profit entities, exempt from income tax under Section 501(c)(3) of the Internal Revenue Code and are primarily engaged in welding technology, education and research activities. For income tax purposes, publication advertising revenue and rental income are “considered unrelated business income” and subject to income tax. TFPS, Inc., a taxable organization, engages in profit-oriented activities.

Basis of Accounting

The financial statements of the Organizations are prepared on the accrual basis of accounting.The accounts of the Organizations are maintained for internal reporting purposes in accordance with the principles of fund accounting.

Basis of Presentation

Financial statement presentation follows the recommendations of the Financial Accounting Standards Board (“FASB”) and the provisions of Statement of Financial Accounting Standards (“SFAS”) No. 117, Financial Statements of Not-For-Profit Organizations. Under SFAS No. 117, the Organization is required to report information regarding its financial position and activities according to three classes of net assets: unrestricted net assets, temporarily restricted net assets, and permanently restricted net assets based on the existence or absence of donor-imposed restrictions. The three classes of net asset categories are as follows:

Unrestricted — Net assets which are free of donor-imposed restrictions; all revenues, gains, and losses that are not changes in permanently or temporarily restricted net assets.

Temporarily Restricted — Net assets where the use by the Organization is limited by donor-imposed stipulations that either expire by passage of time or that can be fulfilled or removed by actions of the Organization pursuant to those stipulations.

Permanently Restricted — Net assets where the use by the Organization is limited by donor-imposed stipulations that neither expire with the passage of time nor can be fulfilled or otherwise removed by actions of the Organization.

The transactions of the Organization are categorized into separate funds. The purpose and net asset classification are as follows:

Operating — This fund is used to account for all unrestricted net assets of American Welding Society, Inc., except for those accounted for in the reserve fund. The operating fund also provides administrative support to the AWS Foundation.

Reserve — This fund is used to account for Board designated reserve funds which are to be used to supplement the cash needs of the operating fund and to account for the activities of TFPS, Inc.

AWS Foundation — AWS Foundation’s temporarily restricted net assets consists of donor-restricted contributions to be used for awards and scholarships. Permanently restricted net assets consist solely of an endowment fund.

Membership Fees and Services

Membership and subscription revenues are deferred when received and recognized as revenue over life of the membership and subscription.

Contributions

In accordance with SFAS No. 116, Accounting for Contributions Received and Contributions Made, contributions received are recorded as unrestricted, temporarily restricted or permanently restricted support depending on the existence and/or nature of any donor restrictions.

Support that is restricted by the donor is reported as an increase in unrestricted net assets if the restriction expires in the reportong period in which the support is recognized. All other donor-restricted support is reported as an increase in temporarily or permanently restricted net assets, depending on the nature of the restriction. When a restriction expires (that is, when a stipulated time restriction ends or purpose restriction is accomplished), temporarily restricted net assets are reclassified to unrestricted net assets and reported in the combining statement of activities as net assets released from restrictions.

Promise to Give

Contributions are recognized when the donor makes a promise to give to the Organizations, that is, in substance, unconditional. All other donor-restricted contributions are reported as increase in temporarily or permanently restricted net assets depending on the nature of the restrictions.

When a restriction expires, temporarily restricted net assets are transferred to unrestricted net assets. The Organizations had unconditional promises to give of $951,840 as of December 31, 2007 (NOTE 2).

The Organizations use the allowance method to determine the estimated unconditional promise to give that are doubtful of collection. The allowance is based on prior years’ experience and management’s analysis of specific promises made.

Cash Equivalents

The Organizations consider all highly liquid investments with an initial maturity of three months or less to be cash equivalents.

NOTE 1. NATURE OF ORGANIZATION AND SIGNIFICANT ACCOUNTING POLICIES (CONTINUED)

Certificate of Deposits

At December 31, 2007, the Organization had various Certificates of Deposit amounting to $2,145,356. The Certificates of Deposit bear interest between 5.25% and 5.40% and mature at various dates through August 23, 2008.

Investments

The Organizations report their investments under SFAS No. 124, Accounting for Certain Investments Held by Not-For-Profit Organizations. Under SFAS No. 124, a not-for-profit organization is required to report investments in equity securities with readily determinable fair values and all investments in debt securities at fair value. The fair value of marketable securities is determined by quoted market prices. Investment income, including realized and unrealized gains and losses are reported as either unrestricted, temporarily restricted or permanently restricted, depending on the existences of donor imposed restrictions on the income from the investments in the statement of activities and changes in net assets.

Risk and Uncertainties

The Organizations have investments in mutual funds that are exposed to various risk, such as interest rate, market and credit risk. Due to the level of risk associated with certain investment securities and the level of uncertainty related to changes in the value of investment securities, it is at least reasonably possible that changes in risks in the near term would materially affect the combining statement of activities. The Organizations, through their investment advisor, monitor the Organizations' investments and the risks associated on a regular basis, which the Organizations believe minimizes these risks.

Property and Equipment

Property and equipment are defined by the Organizations as assets with an initial, individual cost of more than $1,000 and an estimated useful life in excess of one year. Property and equipment is stated at cost and is depreciated using the straight-line method over the following estimated useful lives of the respective assets:

	Estimated Useful Lives (Years)
Building and improvements	14-29
Furniture and equipment	5-7

Inventory

Inventory consists primarily of work-in-process relating to various publications and is valued at cost. Cost is determined by the actual expenditures incurred in the production process.

Concentration of Credit Risk

Financial instruments that potentially subject the Organizations to a concentration of credit risk is cash and certificates of deposit. The Organizations maintain their cash and certificates of deposit with a commercial bank. Accounts at the bank are insured by the Federal Deposit Insurance Corporation up to $100,000 per bank. At December 31, 2007, the Organizations maintained cash balances totaling approximately $1,474,000, at an institution in excess of this federally insured limit; of this amount, approximately $1,398,000 was invested in overnight repurchase agreements to obtain optimum investment income. At December 31, 2007, Certificates of Deposit amounted to $2,145,356. The Organizations maintain their deposits in high quality, financial institutions which the Organizations believe limits this risk.

The Organizations' investments are subject to the normal "market risks" of these types of investments, which are traded on equity markets.

Volunteer Services

A large number of people have contributed significant amounts of time to the activities of the Organizations. The combined financial statements do not reflect the value of these contributed services because they do not meet the recognition criteria of SFAS No. 116, Accounting for Contributions Received and Contributions Made.

Allocation Expenses

The cost of performing the Organizations' various activities have been summarized on a functional basis in the accompanying combining statement of activities. Certain occupancy costs have been allocated among the activities benefited.

Prepaids and Other Assets

Prepaids and other assets consist primarily of work-in-process costs relating to various publications that have not yet been released for distribution. Once the publication is complete and ready for its intended use, the costs are amortized over the life of the publications, usually between two to three years. Additionally, expenditures which relate to programs for the next fiscal year are reported as a prepaid asset and are expensed during the next year as the related program function takes place.

Impairment of Long-Lived Assets

The carrying value of long-lived assets is reviewed if the facts and circumstances, such as significant declines in revenues, earnings or cash flows, or material adverse changes in the business climate indicate that they may be impaired. The Organizations perform their review by comparing the carrying amounts of long-lived assets to the estimated undiscounted cash flows relating to such assets. If any impairment in the value of the long-lived assets is indicated, the carrying value of the long-lived assets is adjusted to reflect such impairment based on the fair value of the impaired assets or an estimate of fair value based on discounted cash flows.

NOTE 1. NATURE OF ORGANIZATION AND SIGNIFICANT ACCOUNTING POLICIES (CONTINUED)

Use of Estimates

The preparation of financial statement in conformity with accounting principles generally accepted in the United States of America requires management to make estimates and assumptions that affect the reported amounts of assets and liabilities and disclosure of contingent assets and liabilities at the date of the financial statements and the reported amounts of revenues and expenses during the reporting period. Actual results could differ from those estimates.

Income Taxes

American Welding Society, Inc. and AWS Foundation are not-for-profit corporations and are exempt from federal income taxes under Section 501(c)(3) of the Internal Revenue Code. Accordingly, no provision for federal or state income tax is required for revenues derived from its tax-exempt function. The Organizations are taxed on unrelated business income less the related expenses. During the year ended December 31, 2007, there was no net income generated from unrelated business activities.

Reclassifications

Certain items included in the December 31, 2006 combining financial statements have been reclassified to conform to the December 31, 2007 presentation.

Recently Issued Accounting Standards

Fair Value Measurements

In September 2006, the FASB issued SFAS No. 157, "Fair Value Measurements" which defines fair value, establishes a framework for measuring fair value in accordance with generally accepted accounting principles, and expands disclosures about fair value measurements. SFAS No. 157 is effective for financial statements issued for fiscal years beginning after November 15, 2007. Early adoption is permitted. On February 12, 2008, the FASB issued FASB Staff Position ("FSP") No. FAS 157-2, "Effective Date of FASB Statement No. 157." This FSP is a one-year deferral of Statement No. 157's fair-value measurement requirements for nonfinancial assets and liabilities, except for items that are recognized or disclosed at fair value in the financial statements on a recurring basis (at least annually). The Organizations are currently reviewing the impact of adopting SFAS No. 157 on its results of operations and financial position.

The Fair Value Option for Financial Assets and Financial Liabilities

In February 2007, the FASB issued SFAS No. 159, "The Fair Value Option for Financial Assets and Financial Liabilities". SFAS No. 159 permits entities to choose to measure many financial instruments and certain other items at fair value that are not currently required to be measured at fair value. The objective is to improve financial reporting by providing entities with the opportunity to mitigate volatility in reported earnings caused by measuring related assets and liabilities differently without having to apply complex hedge accounting provisions. SFAS No. 159 also establishes presentation and disclosure requirements designed to facilitate comparisons between entities that choose different measurement attributes for similar types of assets and liabilities. SFAS No. 159 is effective for fiscal years beginning after November 15, 2007. The Organizations are currently reviewing the impact of adopting SFAS No. 159 on its results of operations and financial position.

NOTE 2. PLEDGES RECEIVABLE

Unconditional promises to give that are expected to be collected within one year are recorded at net realizable value. Unconditional promises to give that are expected to be collected in future years are recorded at the present value of the estimated future cash flows. Amortization of the discounts is included in donations in the combining statement of activities.

Pledges receivable include the following unconditional promises as of December 31, 2007:

Amounts due in:		
Less than one year	$	378,000
One to five years		630,390
More than five years		2,500
Total		1,010,890
Less: Unamortized discount		59,050
Net unconditional pledges	$	951,840

Pledges receivable in the amount of $947,940 as of December 31, 2007, are restricted for awards and scholarships. Management believes that all pledges are fully collectible and, therefore has not recorded an allowance for collection losses.

NOTE 3. INVESTMENTS

Investments, which are comprised entirely of mutual funds, are presented in the combining financial statements at their fair market values and consist of the following at December 31, 2007:

Vanguard Investments — Reserve Fund

High-Yield Corporate Fund	$	890,483
Intermediate – Term Corporate Fund		1,257,851
Intermediate – Term Bond Index Fund		810,660
Long – Term Bond Index Fund		885,083
Short – Term Bond Index Fund		985,779
Short – Term Investment Grade Fund		1,172,971
Explorer Fund		579,002
Total Stock Market Index Fund		472,883
Strategic Equity Fund		1,765,956
Morgan Growth Fund		613,710
Total International Stock Index Fund		3,599,155
U.S. Growth Fund		670,685
Windsor II Fund		1,253,383
Reserve Fund Investments		14,957,601

NOTE 3. INVESTMENTS (CONTINUED)

Vanguard Investments — AWS Foundation

Prime Money Market Fund	$	8,468
High – Yield Corporate Fund		488,105
Intermediate – Term Bond Index Fund		597,687
Long – Term Bond Index Fund		650,563
Short – Term Bond Index Fund		648,819
Intermediate – Term Investment Grade Fund		722,958
Short – Term Investment Grade Fund		895,964
Explorer Fund		195,298
Total Stock Market Index Fund		1,373,641
Strategic Equity Fund		180,162
Morgan Growth Fund		246,707
Total International Stock Index Fund		714,224
U.S. Growth Fund		244,487
Windsor II Fund		444,344
Less: Section Fund Investments		(1,401,279)
AWS Foundation Investments		6,010,148
Total Investments	$	20,967,749

AWS Foundation administers investments on behalf of certain affiliated sections. The investments aggregated $1,401,279 at December 31, 2007 and are not included in the combining financial statements.

Investment income consisted of the following for the year ended December 31, 2007:

	Reserve Fund	AWS Foundation
Interest and dividends	$ 456,344	$ 289,186
Net realized and unrealized gains on investments	220,571	43,010
	$ 676,915	$ 332,196

Interest and dividends under the Reserve Fund include the activities of TFPS, Inc.

NOTE 4. PROPERTY AND EQUIPMENT, NET

Property and equipment consist of the following as of December 31, 2007:

Land	$	816,726
Building and improvements		4,796,310
Furniture and equipment		4,354,851
		9,967,887
Less accumulated depreciation		7,406,672
	$	2,561,215

Depreciation expense was $245,465 for the year ended December 31, 2007.

NOTE 5. TEMPORARILY RESTRICTED NET ASSETS

Net assets of the AWS Foundation in the amount of $3,477,567 as of December 31, 2007, are restricted for awards and scholarships. Net assets of $106,760 were released from donor restrictions by granting awards and scholarships for the year ended December 31, 2007.

NOTE 6. PERMANENTLY RESTRICTED NET ASSETS

Net assets in the amount of $3,391,595 as of December 31, 2007, are permanently restricted endowments which are to provide a source of funds predominantly for educational, research and other charitable purposes.

NOTE 7. BOARD APPROVED PROGRAMS

American Welding Society, Inc.'s Board of Directors periodically approves expenditures for special programs designed, among other things to further the development and public awareness of welding technology, education and standards. Expenses incurred for special board approved programs during the year ended December 31, 2007 amounted to $89,700.

NOTE 8. COMMITMENTS AND CONTINGENCIES

Operating Leases

During July 2004, the Organizations entered into an operating lease agreement involving equipment. The lease term was set to expire in March 2008. On February 29, 2008 the Organizations renewed the terms of the operating lease agreement for an additional 48 months requiring minimum monthly payments in the amount of $14,403. Minimum annual payments on the non-cancellable portion of the lease are as follows:

2008	$	168,000
2009		173,000
2010		173,000
2011		173,000
2012		29,000
Total	$	716,000

Royalty Agreement

On October 26, 2005, the American Welding Society, Inc. (the "Organization") entered into a Publication Sales Agreement with World Engineering Exchange ("WEX"), whereby WEX has been given non-exclusive worldwide rights to duplicate, package, facsimile transmit, price, promote, distribute, sell and or lease the Organization's documents and technical publications through paper and electronic media formats and compilations. On May 8, 2007, the term of the agreement was amended to extend the initial period to sixty (60) months commencing on January 1, 2006. The agreement can be renewed for two (5) year periods with the same terms and conditions except for the pricing which shall be negotiated by the parties in good faith.

WEX will pay the Organization royalties based on the percentages indicated per the agreement. The agreement is contingent

NOTE 8. COMMITMENTS AND CONTINGENCIES (CONTINUED)

Royalty Agreement (continued)

upon the Organization's continued performance, which includes the production and release of new and revised publications periodically. In addition, the list price shall be no less than the prices as indicated in the Organization's catalog. Under the terms of this agreement, the Organization earned approximately $3,290,000 during the year ended December 31, 2007. Such amount has been included in revenues in various departments in the combining statements of activities.

On April 2, 2007 the Organization entered into an agreement with The American Society of Mechanical Engineers ("ASME"), whereby ASME has the nonexclusive right to reproduce the Organization's Standards. ASME will pay the Organization royalties equal to 20% of the net sales per quarter. Under the terms of this agreement, the Organization earned approximately $465,000 during the year ended December 31, 2007.

NOTE 9. WELDMEX LLC

On December 5, 2007, the Organization entered into an agreement with Trade Show Consulting, LLC ("TSC") to create a limited liability company known as Weldmex LLC (the "LLC") to acquire and operate the Weldmex Trade Show, a show solely owned by TSC.

In consideration for the sale, transfer and assignment of the Weldmex Trade Show to the LLC, TSC is to be paid an initial sum in the amount of $400,000 on January 2, 2008. At the end of the 2008 Weldmex show, the Organization is to pay TSC $122,000 no later than sixty days from the completion of the show. The Organization is to also pay TSC $122,000 at the end of the 2009 Weldmex show. The existence of the LLC shall continue through January 30, 2013 at which point the LLC is to purchase the entire percentage interest of TSC for an amount equal to 45% of the earnings before interest, taxes, depreciation and amortization calculated for the 2012 Weldmex show multiplied by a factor, 6.5. Funds for the purchase of the Weldmex Trade Show shall come from the LLC, or, if the LLC does not have sufficient funds, the Organization shall make the payment.

The percentage interest of the Organization in the LLC is 55% and the percentage of TSC in the LLC is 45%. Each Member is entitled to vote its percentage interest with respect to any action required or permitted to be taken by the Members under the Operating Agreement entered into or the Florida Limited Liability Act. The business and affairs of the LLC, including strategic direction and budget approval is to be overseen under the direction and control of the Executive Director at the Organization and the President of TSC. Allocations of profit or loss will be allocated to the Members in accordance with the percentage interest of each member. The Organization will be responsible for the management and administration of the finances of the LLC.

The initial payment in the amount of $400,000 was made by the Organization on January 2, 2008.

NOTE 10. EMPLOYEE BENEFIT PLAN

The Organizations have a simplified employee pension plan for all full-time employees. Full-time employees are eligible for participation in the plan the first day of the month after they are employed. Effective June 1, 2006, the Organizations will contribute a maximum of 5.5% of the employees' base salary, composed of a 3.5% initial contribution and a match of 50% of the first 4% of an employee's voluntary contribution. The Organizations made contributions totaling approximately $269,000 during the year ended December 31, 2007.


Just About the Only Type
of Positioner We Don't Make.
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Locust I & II
Welding Head
Manipulators
HD Series
Gear Driven
Positioner
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Turning Rolls
Koike Aronson positioning equipment can't tee up your 392-dimple favorite, but we have you covered nearly everywhere else — from 100 lbs. to 4 million lbs., at any angle. Koike Aronson/Ransome can help you weld just about any type of piece more profitably. Call us to find out how we can make your welding operation more efficient.
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New Socket Weld Repair Method: Strong and Effective

An economical alternative to joint removal and replacement, overlay repair may help reduce costly downtime at nuclear power plants

BY STEVE McCRACKEN, SHANE FINDLAN, AND GREG FREDERICK

Fig. 1 — Power plants have thousands of socket welded joints that are susceptible to fatigue failures.

Power plant reliability is more critical than ever as society grows increasingly dependent on an uninterrupted supply of economical electricity. Shutting down a major power plant — or prolonging a scheduled outage — to repair or replace components halts the production of electricity and revenue, and impacts the operation of regional power grids. The cost of downtime at a nuclear plant can run from hundreds of thousands of dollars to more than a million dollars per day. Plant operators, therefore, are highly motivated to minimize downtime by improving repair and replacement practices.

Weld failures are a common cause of power plant downtime, especially as plants age and fatigue takes its toll. In particular, socket welded joints account for 80% of all fatigue failures in nuclear power plant piping. A new approach for repairing socket welded joints by overlay welding can reduce plant downtime and costs by eliminating the need for replacing a leaking joint segment in the pipe.

Tests and analyses show that socket welds repaired with the overlay method have equivalent or better fatigue strength than standard socket welds. The test results and analyses helped support ASME *Boiler and Pressure Vessel Code Case N-666*, which permits the use of this overlay repair technology for online repairs of leaking socket welds caused by high-cycle fatigue in operating nuclear power plants.

Socket Weld Failures: A Growing Problem

Power plants have thousands of socket welds, many located in critical systems — Fig. 1. Socket weld failures due to high-cycle vibration have become an increasing problem at nuclear power plants. Socket welded joints are commonly used for small-bore pipe couplings, elbows, tees, branch connections, and valves.

Socket weld failures occur most often in small-bore vent or drain lines at the connection to a larger process pipe due to vibration-induced bending stresses. The majority of socket weld failures occur in piping systems that have been in service

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for many years, exposed to thousands or even hundreds of thousands of cycles. Fatigue strength in this high-cycle regime is more sensitive to minor material imperfections, weld details, and residual mean stresses than in the low-cycle regime.

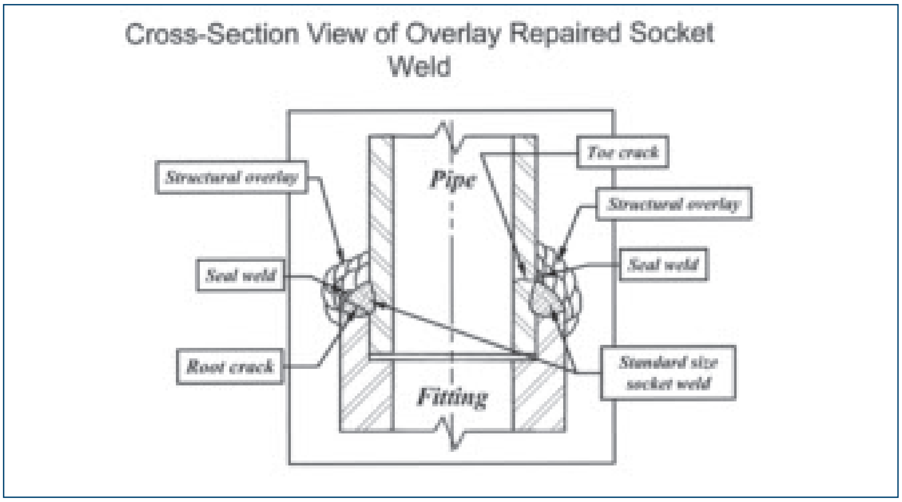

Fig. 2 — This cross-sectional view illustrates the overlay weld process for both a root and toe crack. A crack is first peened, then seal welded, and the overlay weld metal installed.

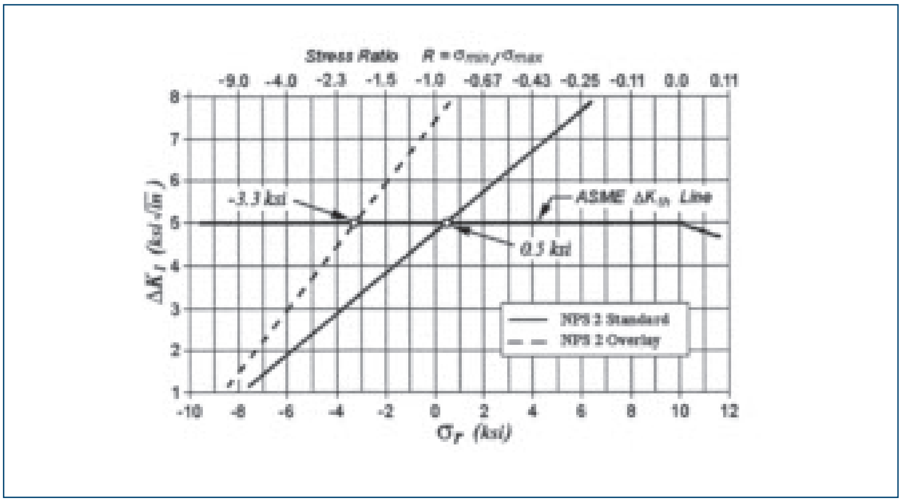

Fig. 3 — Comparison between applied weld residual stress and allowable residual stress. The variables are defined as follows: ΔK_I = stress intensity factor range, σ_r = weld residual stress, and ASME ΔK_{th} = ASME Code allowable stress intensity factor range threshold line.

Traditional Repair Is Costly

The standard method for repairing socket weld failures (and currently the only code-acceptable repair method) is to isolate the leak and cut out and replace the leaking joint, or replace the entire small-bore pipe section. In some cases, the entire system must be taken out of service to replace the leaking socket weld. This may force the nuclear plant to shut down, which can cost up to $1 million per day in lost electricity revenue.

The Alternative: Overlay Repair

To reduce costs associated with vibration fatigue failures of small-bore socket welds, the Electric Power Research Institute (EPRI) conducted several studies to improve socket weld design, fabrication practices, and repair applications to address high-cycle fatigue. One of the options studied — an overlay repair of the leaking socket welded connections — can extend the life of a failed connection or allow replacement of the connection to be scheduled during a routine outage.

The repair method may be applied to fatigue cracks that initiate at the socket weld toe and propagate through the pipe wall and also to fatigue cracks that initiate at the socket weld root and propagate out to the weld face. The weld overlay may be installed at system pressure and at temperatures less than or equal to 200°F.

The overlay repair method is a three-step process that does not require removing the fatigue crack or replacing the entire small-bore pipe section. First, the active leak is controlled by peening weld metal over the fatigue crack. Second, a shielded metal arc welding seal pass is installed over the peened area to seal the leak. If not successful the first time, the seal pass may be removed, peening repeated, and the seal pass attempted again. This process may be repeated as many times as necessary until the leakage is no longer visible. Third, the structural overlay weld metal (generally a filler metal that matches the base metal chemistry) is installed once the leak is successfully sealed — Fig. 2. The seal pass is not considered part of the structural overlay.

The structural weld overlay may be installed by gas tungsten arc welding or shielded metal arc welding. The overlay is installed 360 deg around the joint. The structural overlay throat thickness (not including the seal pass) must be equal to or larger than the minimum required fillet weld leg size for the standard/initial socket weld joint.

A final magnetic particle test or liquid penetrant test is performed on the overlay weld. A final visual test may be performed if temperature does not permit a meaningful surface examination.

Fatigue Testing

To validate the effectiveness of the technology, EPRI researchers conducted a vibration fatigue testing program for overlay repaired socket welds.

High-cycle vibration fatigue cracks were initiated and propagated to failure (leaking with a through-wall crack) in NPS 2 stainless steel and carbon steel standard-sized socket welds on a shake table. Fatigue testing on a shake table is comparable to the high-cycle, low-amplitude vibration fatigue conditions in a power plant and is considered a more representative simulation for socket weld failures than four-point bending or rotating bending fatigue testing.

EPRI repaired the failed socket welds according to the methodology of Code Case N-666. Researchers controlled the structural overlay dimensions to the minimum required size to ensure conservatism in the test program. All overlay repairs in the test program were done with ambient-temperature water in the pipe and at various pressures up to 2500 lb/in.^{2}.

The overlay repaired socket welds were fatigue tested again on the shake table to failure (leaking with a through-wall crack) or to run-out to establish S-N (stress vs. number of cycles) fatigue strength curves. These data allowed a direct comparison to the original socket weld fatigue life.

Results of the fatigue testing showed

Fig. 4 — Socket weld repaired by weld overlay.

Table 1 — Applied and Allowable Residual Stress in Root of Standard Socket Weld and Crack Tip Region of Overlay Repaired Socket Weld

	Residual Stress, σ_r (ksi)		
Joint Configuration	Applied	Allowable	Difference
NPS 2 Std Socket(1)	58	0.5	57.5
NPS 2 Overlay(2)	–22(4) to –16(5)	–3.3	–18.7 to –12.7
NPS 2 Overlay(3)	–32(4) to –9(5)	–3.3	–28.7 to –5.7

Notes:
(1) No special weld pass sequencing
(2) Two weld layers without water backing (N-666 requires minimum of two layers)
(3) One weld layer with water backing
(4) Pipe-to-fitting weld progression
(5) Fitting-to-pipe weld progression

that overlay weld repair is an effective method for repairing cracked socket welds subjected to high-cycle fatigue. The tests also demonstrated that overlay-repaired socket welds perform at least as well as, and often superior to, standard socket welds.

Modeling Explains Results

The result was somewhat surprising. Why would an overlay repaired socket weld have fatigue strength equivalent or better than a standard socket weld? After all, a fairly large fatigue crack is beneath the overlay weld metal, while solid base metal lies beneath the standard socket weld. To find the answer, researchers used asymmetric finite element models to analyze standard and overlay repaired socket weld geometries for NPS 2 Schedule 80 carbon steel (SA-106 Gr B and SA-105) piping.

The geometric stress intensity factor in the weld root area of a standard socket weld and at the crack tip encapsulated by weld overlay may be used to evaluate and compare fatigue strength behavior. The stress intensity factor, K_I, describes the local stress field ahead of a sharp crack or defect in terms of the remote stress and defect size (Table 1). Accurate determination of K_I at the root of a standard socket weld and at the crack tip encapsulated by weld overlay is necessary to properly assess susceptibility to crack propagation.

Researchers used the finite element models to more accurately determine K_I for fatigue cracks initiating from the socket weld root area. Results of the analyses show the K_I at the crack tip in an overlay repaired socket weld is only about 1.56 times greater than the stress intensity factor at the root of a standard socket welded joint. This implies that the overlay repaired socket weld would be more susceptible to fatigue crack propagation compared to a standard socket weld.

To more accurately compare fracture-mechanics-based fatigue strength behavior, researchers derived an allowable weld residual stress value for standard and overlay-repaired socket weld geometries using stress intensity factor range curves. The allowable weld residual stress was determined at the point where the applied stress intensity factor range curve crosses the ASME stress intensity factor range threshold line. Negligible fatigue crack growth is predicted when the actual applied weld residual stress is less tensile (more compressive) than the allowable weld residual stress — Fig. 3.

Finite element thermal-mechanical analyses show a high tensile residual stress is likely at the root of a standard socket weld, whereas a compressive weld residual stress occurs at the crack tip encapsulated by an overlay repair. The compressive residual stress suppresses the slightly higher geometric stress intensification that occurs at the encapsulated crack tip and enhances the fatigue performance of a socket weld repaired by weld overlay.

Conclusion

Weld overlay repair of a cracked and leaking socket weld per ASME Code Case N-666 provides a weld joint with acceptable fatigue properties as demonstrated by vibration fatigue testing — Fig. 4. Fracture mechanics and weld residual stress analyses provide supporting data and evidence that corroborate the robust vibration fatigue strength exhibited by overlay repaired socket welds.◆

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Dave Snyder works diligently on one of his many projects. Having started to weld as a boy, he currently makes art pieces using skills he has learned over the years.

BY SUE ANDERSON

Ohio Welder Combines Artistry with Practicality

You could describe Dave Snyder as a Renaissance man with a welding torch, but he's really just a guy with a passion for art and metal. From touting the value of functional art that holds true to the visions of luminaries like Claes Oldenburg to operating a fabricating business in Gallipolis, Ohio, Snyder is making his mark on the art world with steel.

Early Years Build Interest in Metalworking, Art

Snyder has followed in the footsteps of his father, Jack, who was as handy with a piece of wood as he was with steel. Jack fabricated dump trailers in Pennsylvania during the 1970s and spent his free time carving wood and drawing. These weren't idle hobbies — he was good. Year after year he won art competitions at the state's farm show. In fact, he was so good that winning one contest landed a piece of his artwork in the Smithsonian.

His father died when Snyder was 10 years old. Rick Seiler, Snyder's brother-in-law, took the boy under his wing and taught him welding as a way to pass the time. It started out as a weekend pastime, but by the time Snyder was 14, he was making a decent paycheck as a welder.

"He (Seiler) owns and operates a fabrication shop (Rick Seiler Welding)," recalled Snyder. "We did everything from building bleach and dye houses to trailer repair and sewer plant jobs. My brother-in-law pushed me to learn hydraulics and electricity. With the contracting we did, we had to know it all."

By the age of 18, Snyder had the experience of a seasoned welder but needed a change, so he spent eight years in the Army. After serving as an infantryman and as a specialist working on M1 tanks, he rejoined the civilian ranks by working at a foundry in West Chester, Pa. There he helped build parts for such vastly different vehicles as the space shuttle and miniature locomotives for kids at amusement parks.

SUE ANDERSON is district manager, Smith Equipment Co., Watertown, S.Dak.

Dave Snyder can do most anything in his welding shop, but he likes building functional artistic items the best

In 2002, Snyder enrolled in the woodworking program at the University of Rio Grande with the intention of learning how to make 18th century-style furniture. He completed the two-year program in a year, during which he also taught woodcarving in the evenings, and was offered a scholarship to the school's art program.

Still, Snyder could never quite get away from welding. While working and studying at Rio, he helped maintenance crews with any welding projects that came up. One day he was called in to help fix the lift gate on a truck, and the benefactor of his welding skill was a sculpture professor at Marshall University in West Virginia. That meeting led to a position at Marshall as a studio technician in the university's sculpture department. In between sharpening knives and calibrating equipment, Snyder found time to set up a blacksmithing furnace to help the department.

Fig. 1 — Snyder created this Dual Guard welding torch that stands 6 ft tall. He recently gave the figure to Smith Equipment.

Forming a Company, Taking on Challenging Projects

Combining all of these experiences, Snyder started his own business in June 2007, Dave Snyder Steel Fabricators. Instead of falling back on the standard projects most welders take on as independent contractors, he has vowed to use his unique combination of skills to work on projects that challenge him both as a welder and as an artist.

"I try to do more sculpture than anything else," said Snyder, "but I'll do any kind of fabrication."

One of his first projects was to design and build a 12-ft-long, 6-ft-tall grill in the image of a smoking revolver for a grillmaster in Ohio. Not only is it visually impressive, it's also entirely functional.

"The revolver breaks open," explained Snyder, "and the cylinder where the bullets go splits in half and you can put 40 pounds of meat in it. The grip is actually a door for the firebox, and the grip housing is the firebox. I made a brass bead for the front side and that is attached to a rod that controls the flue."

His design was such a functional and visual success that another client had him build a grill in the image of a steam tractor where the steam boiler is the grill, and the tractor's firebox functions as the grill's firebox.

Fig. 2 — Shown beside Snyder are some of his artistic designs, including a small buffalo and a few birds, complete with a nest, perched on branches.

'Artistic Industrial Applications' Go on Display

Snyder calls his work "Artistic Industrial Applications" — he's just as likely to work on a 40-ft stainless steel sculpture as he is to repair a weld on a trailer or a grit separator for the local sewer plant. He mixes materials and processes (gas tungsten arc welding, shielded metal arc welding, oxyfuel, gas metal arc welding, and so on) to create unique works of functional art that are visually striking. His style can best be described as mixing the surrealism of Salvador Dalí with the "larger-than-life" creations of Oldenburg.

In addition to the grills he has built, he's also fabricated a life-size, 600-lb buffalo for Power Building Supply in Georgia. Recently, he constructed a 6-ft-tall Smith Dual Guard welding torch, which he donated and shipped to the company's headquarters in Watertown, S.Dak. — Fig. 1.

"My brother-in-law always used Smith torches," explained Snyder, "so I always used them."

Snyder is currently plotting his next big sculpture: a globe consisting of a 4-ft-tall, spherical propane tank.

"I'll carve out all of the longitude and latitude lines with an abrasive saw," describes Snyder. "Then I can braze on all of the continents out of brass and weld on stainless steel in the shape of all the mountain chains. When it's done, the oceans will rust brown, and I'm going to treat the brass so it turns green."

Snyder's most recent exhibition, a one-month display at the French Art Colony in Gallipolis, included a scaled-down version of his buffalo and a wide array of birds (a steel raptor pulling a trout out of water where the waves are layered welding beads; a bird nesting in a tree built out of steel pipe) — Fig. 2.

Future Ambitions

By combining his past experiences, the skills taught to him by others, and a few tricks he's picked up along the way, Snyder is poised to make his own waves in the art world.

"I'm working at something I really love to do and creating art that everyone can enjoy," said Snyder. "And it's not the same thing every time. I have a policy: If I make something for someone that is an artistic piece, I will never do it again. It ensures that each piece is truly unique and that I never get bored."◆

When to Specify Welded, Welded and Drawn, or Seamless Tubing

BY DAVE O'DONNELL AND MICHAEL M. JAMES

Here's help in understanding the different types of tubing and how to select the right tubular products for your application

The process for determining whether to use welded, welded and drawn, or seamless tubing can be complex. Some alloys are inherently better welded alloys, while some are typically produced by a seamless alloy route. Product attributes and alloy properties should dictate the process used to produce the tubing. This article is intended to assist in this process by comparing and contrasting welded, welded and drawn, and seamless tubing.

Significant money and time can often be saved through the use of welded tubing. Near seamless metallurgy, and superior wall tolerances can be supplied in many alloys using automation and, possibly, high-energy-density welding processes such as laser beam welding (LBW) particularly when followed by cold working of the weld and subsequent annealing. This article principally speaks to some of the intricacies of tube production where a longitudinal seam weld is made, the weld bead is typically cold worked and subsquently annealed. Welding is typically required by specification to be autogenous without the use of filler metals. This article does not speak to field welding strategies where overmatching filler metals can and often should be used to avoid preferential weld attack in corrosive service.

Avoiding Problems

There is a tendency to place significant effort in specifying the tubing manufacturing process rather than measurable tubing quality requirements such as corrosion tests, dimensional limits, and strength. This hampers effective communication of the consumer's actual needs. For instance, specifying "seamless" manufacturing process for tubing does not mean defect free, nor is it any guarantee that the producer optimized its process or heat treatment. Specifying water quench does not mean the cooling has been applied promptly, adequately, or that the proper temperature was achieved. Vendor qualification or selection of an appropriate quality test (corrosion, metallographic, or leak testing) does provide assurance of appropriate processing and some measure of communication of critical attributes.

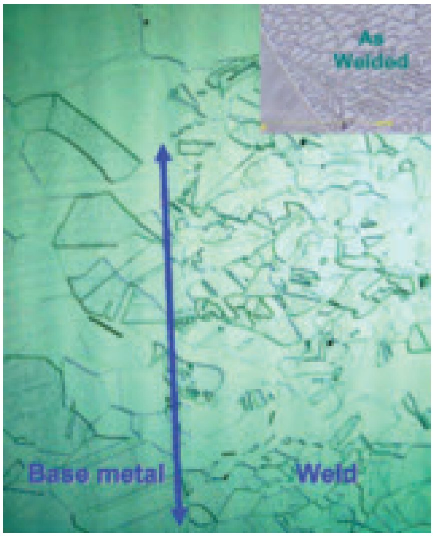

Fig. 1 — A transverse section in welded C-276 (UNS N10276) finished product from RathGibson. Welding, cold working, and annealing have been controlled to produce this desirable, homogeneous, near-seamless outcome, starting from the as-welded inset at top right. Please note the horizontal flow lines in the base metal, residual segregation from the original casting.

Communication can be critical as producers are typically very proficient in optimizing their processes for critical attributes, provided they understand what the critical characteristics are. For example, with 304L for nitric service, the producer can often select a heat of steel more ideal for nitric acid service (very low carbon) to optimize corrosion resistance. Another example would be tubes for bending and subsequent polishing. Such tubes require careful processing controls to prevent "orange peel" in the weld and the base metal microstructure.

Understand Your Application

What attributes or qualities are the essential features?

- **OD and wall tolerances.** Examples of applications in which outside dimensions and wall tolerances are important include telescoping tubes, hydraulic or pneumatic cylinders requiring ID and OD machining, and bending with ID tooling.
- **Wall and eccentricity tolerances** for orbital welding.
- **Extreme consequences of a leak.** Examples include an air-cooled ex-

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changer with high fins installed and lethal service.

- **Aqueous corrosion.** Types of corrosion include general, pitting, stress corrosion cracking (SCC), and microbial induced corrosion (MIC).
- **High-temperature degradation.** Examples include oxidation, sulfidation, carburization, and metal dusting.
- **Cleanability.** Industries calling for hygienic applications include pharmaceutical, biopharmaceutical, and food and beverage.
- **OD cosmetic.** Applications requiring OD polishing include OD compression fittings that seal at high pressure.
- **ID cosmetic.** Applications requiring a highly cosmetic appearance on the inside diameter include hydraulic flare seal ends.

What Constitutes Quality?

Homogeneity. All wrought or seamless products start as castings. Casting and fusion welding are similar processes in terms of metallurgy (segregation of solutes, areas of enrichment, and depletion), only differing in scale. Seamless or wrought products are hot worked, cold worked, and annealed in order to correct deficiencies. This should result in recrystallization and homogeneity to the point the product is considered "wrought."

An example of a homogeneous, near-seamless C-276 product is shown in Fig. 1.

Both the welded and welded and drawn processes offer more consistent wall thicknesses or tighter tolerances by virtue of the strip used and its processing route relative to seamless. The accuracies associated with the cold rolling operations for welded and welded and drawn strip result in minimal radial wall variations in a cross section. As a point of comparison, 0.065-in. average wall welded would typically average 0.061 ±0.002 in. around a cross section in a bead-worked product, where seamless would see approximately ±0.006 in. in a cross section.

In many diameters and wall thicknesses, weld bead reinforcement can be cold worked flush on both the ID and OD; subsequent annealing results in a "full-finished" tubular. The major disadvantage of welded is potential residual solute segregation in the weld nugget. The magnitude is determined by the alloy, OD, wall, welding process, and response to heat treatment.

Welded Equal to Seamless

Since commercially pure metals contain no other additions, there can be no solute segregation or potential for preferential weld attack by corrosion in such welds. Relative to corrosion, the alloying elements of concern are principally chromium (Cr), molybdenum (Mo), and nitrogen (N). Examples of engineered materials ostensibly free of such alloying elements are as follows:

1. Commercial pure (CP) titanium (Ti) in Grades 1, 2, and 16
2. Nickel (Ni) in Grades 200 and 201
3. Copper (Cu)
4. Ni/Cu alloys such as Alloy 400
5. Mild steel (Fe)
6. Aluminum (Al) Alloy 1100

For most of the above materials, welded tubulars are the industry standard. However, some of these are common seamless alloys simply because they are soft and can be extensively cold worked before softening by annealing. Examples of these would be Nickel 200 or 201 and Alloys 400 and 600.

A significant source of defects in seamless tubulars is hot extrusion. This process (Fig. 2) uses an ID mandrel that is water cooled (to retain strength). Any delay in the extrusion after loading the heated billet results in cooling and disagreeable surface temperatures for hot working. The result is a potential for ID hot tears, which is why ultrasonic inspection (UT) is required in many of the specifications for seamless products. Glass is typically used as a high-temperature lubricant so ID slag is not uncommon. The second most common source is annealing contamination from trace lubricants left in the ID during heat treatment.

Seamless tubulars typically exhibit significant wall thickness variation around (circumferentially) any cross section. This derives directly from the difficulty of accurately piercing a metallic billet. This effectively results in an eccentricity of the ID with the OD.

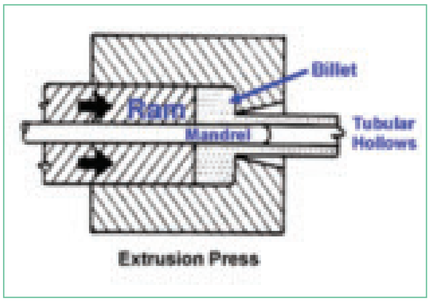

Fig. 2 — Schematic of a seamless tubular product extrusion press.

Significant advantages of the seamless process are excellent OD tolerances and the ability to produce very heavy wall products (high wall/OD ratios).

Duplex stainless steel alloys are interesting examples of better welded alloys. RathGibson has produced approximately 10 million feet of welded duplex alloy tubing per year for more than ten years and has not seen a single case of preferential weld attack. This represents a significant metallurgical advantage for welded duplex tubular product.

On the cautionary side: Duplex alloys are thermodynamically unstable and should be purchased from qualified vendors or with a requirement for an industry standard corrosion test (ASTM A923/C) to ensure proper thermo processing.

For some applications, a significant advantage of welded or welded-and-drawn products is the ability to supply long lengths without the need for circumferen-

Table 1 — Attribute Summary

	Type of Tubing		
Attribute	Seamless	Welded & Drawn	Welded
Wall Tolerances	poor	best	best
OD Tolerances	best	best	acceptable
Heavy Wall/OD	best	best	acceptable
Cost	poor	acceptable	best
Grain Structure	best	best	acceptable

Table 2 — Leak or Integrity Testing of Tubular Products

Method	Hydrostatic	Air Under Water (AUW)	Pressure Decay	Pressure Differential
Sensitivity (Std cc/s)	poor	sensitive	5×10^{-2}	1×10^{-3}
Automation	poor	poor	best	best
Contamination	poor ID water contamination	poor OD water contamination	best	best
Temperature insenstivity	best tests mechanical integrity	best	best	poor

Table 3 — A Selected Listing of the ASTM Corrosion Tests Available for Verifying Thermal Processing of Most Alloys

ASTM Corrosion Tests		Comment	Time	Alloys	Special Processing	Type of Test
G28	A	Intergranular corrosion susceptibility — ferric sulfate - sulfuric acid	Alloy dependant	All alloys		Std Practice
	B	23% H_2SO_4, 1.2% HCl, 1% $FeCl_3$ + 1% $CuCl_2$	24 h	622, 59, 686, 276		Std Practice
	G36	Boiling 45% magnesium chloride for stress corrosion cracking resistance (SCC)	24 h	All alloys	✓✓	Std Practice
G48	A	Ferric chloride (6% $FeCl_3$) pitting test (22 and 50°C)	72 h Standard	All alloys		Std Practice
	B	Ferric chloride (6%) **Crevice** corrosion test (22 and 50°C)	72 h Standard	All alloys		Std Practice
	C	Ferric chloride (6%) Critical pitting temperature test	72 h Standard	All alloys		Std Practice
	D	Critical **crevice** corrosion test	72 h Standard	All alloys		Std Practice
A249	S7	Weld Decay	1 h*	304, 316, 317	None Laser	Acceptance
A262	A	Detecting susceptibility to intergranular attack - oxalic acid etch screening				Acceptance and Screening
	B	Detecting susceptibility to intergranular attack - ferric sulfate		Not for Mo containing		Acceptance
	C	Nitric acid (65%) (Huey test)	10 days	304L, never 316L	304L	Acceptance
	E	Copper - copper sulfate - sulfuric and (A249 S6)	24 h	All alloys		Acceptance
	F	E with 50% sulfuric for castings	120 h	All alloys		Acceptance
A923	A	Sodium hydroxide etch test		Duplex		Acceptance and Screening
	B	Charpy impact test, requires thick wall		Duplex		Acceptance
	C	ferric chloride corrosion test pH=1 25°C for 2205	24 h	Duplex		Acceptance
Green Death*		11.9% H_2SO_4 + 1.3% HCl + $FeCl_3$ +1% $CuCl_2$	72 h	High-nickel pitting alloys		Acceptance

*Not ASTM

tial field welding. Welded coiled tubing provides a number of important advantages to a seamless product for many coiled tubing applications. In addition to being a preferred, cost-effective solution to seamless tubing, the welded product provides inherent advantages such as consistency of wall thickness and tube concentricity. Coiled welded products may exhibit an orbital weld every 3000 to 15,000 ft versus a frequency of 80 to 100 ft for seamless coils.

For very-high-temperature applications, the welded grain structure is a significant disadvantage. At high temperatures (above 1400°F), grain boundaries are the weak link. Welded tubes typically have a fairly straight (noninterlocked) boundary from ID to OD.

As a generalization, welded and drawn tubulars have the advantages of seamless while retaining those of welded, namely, the welded wall tolerances, the seamless OD tolerances, and the ability to make heavy wall/OD tubulars.

Understand Your Application

What attributes or qualities are the real or essential requirements?

Once these are defined, the appropriate product and commensurate testing requirements should also be clearer. The information listed in the "Understand Your Application" section of this article should be helpful, as should the suggestions listed below and the attributes listed in Table 1. These are generalizations; alloy specifics can easily impact the final selection. When listed attributes are important, the indicated manufacturing method will provide the most desirable results.

1. **OD and wall tolerances.** Welded and drawn typically. For bending applications, welded can be used with special tolerances applied.
2. **Wall tolerances.** Welded or welded and drawn.
3. **Extreme consequences of a leak.** Integrity testing is strongly suggested no matter what type of tubular product is selected. If the process is also critical or lethal service, additional elective NDE and/or corrosion evaluation should be considered.
4. **Aqueous corrosion.** In these cases, many like to specify seamless or welded tubing with additional NDE, corrosion evaluation, and special processing techniques to optimize weld integrity and corrosion resistance. If standard corrosion

evaluation tests are not suitable, specialized corrosion evaluation tests using solutions that mimic or closely match the process into which the tubing will be placed can also be designed.

5. **High-temperature degradation.** Welded and drawn or seamless. Users need to consider selecting alloys specific to the type of service (oxidizing, sulfidation, carburization, and metal dusting).

6. **Cleanability/hygienic applications.** Typically welded; seamless is the standard for diameters that are 0.500 in. and smaller.

7. **OD cosmetic.** Any type of tubular product. Strongly consider OD polished to communicate the critical need for OD finish requirements.

8. **ID cosmetic.** Welded if ID polished, otherwise seamless.

Process Severity, Consequence of Failure

The selection of welded or seamless tubing would not be complete without evaluating the severity of the process under which it will be used and the consequence of a tube leak (Table 2). Consideration should be given to the corrosivity of the process, the potential for preferential weld corrosion, process hazard potential, process quality, and the effect a leak will have on unit up time and/or capacity. Evaluating these factors will influence the selection of welded or seamless tubing, the amount of nondestructive examination (NDE) required, and the need for corrosion evaluation.

Some process conditions are fairly benign and could be considered low risk, such that should a leak occur there would be no detrimental effects to personnel safety, process quality, or capacity. This could include processes that can tolerate water ingress or cross contamination, or exchangers that can be taken out of service without affecting unit utility. A good example of a low hazard potential situation is process-to-process heat exchangers where the process on both the shell side and tube side is essentially the same and a leak cannot be detected. In these applications the most cost-effective option, without sacrificing safety or utility, may be to specify welded tubing with the standard NDE required in the ASTM specifications.

As process conditions become more severe and the consequences of failure more intolerable (medium risk), consideration should be given to performing additional NDE or corrosion evaluation of the tubing. This includes processes where leaks can be tolerated for only a short time or the unit can only operate for a short time without the exchanger. An example might be a reboiler in a process that can tolerate water for only a short time or a process-to-process exchanger where temperature profiles are critical and a leak could cause process upset.

Finally, there are conditions that some term process critical or PSM critical — call them high risk. These are exchangers where leaks have an immediate detrimental effect on unit utility, process quality, or pose a significant environmental and/or personnel hazard. These are processes where water or steam intrusion causes an immediate shutdown, lethal service processes, explosive processes, or highly corrosive or reactive processes that could damage downstream equipment. In these cases many like to specify seamless tubing instead of welded. Regardless of which type of tubing is specified, but especially if welded tubing is selected, it is probably best to specify NDE that goes beyond the ASTM specification requirements, such as air underwater testing or supplemental electric tests (eddy current, ultrasonic, or flux leakage) and corrosion evaluation testing.

It needs to be stated that injurious defects are not exclusive to welded tubing. Seamless tubing can also have defects in the base metal that result from the manufacturing process. These include laps, scratches, tears, or laminations. Several failures and leaks in seamless tubing that were caused by manufacturing defects have been seen. This means seamless tubing is not a cure-all and should be inspected similarly to welded tubing as part of the quality control process. Typically, seamless tubing is inspected using ultrasonic testing and air underwater testing.

Corrosion tests exist for verifying appropriate thermal processing for most alloys (Table 3). For most stainless alloys such as 304L, 316L, and 317L, ASTM A262 Practices A or E are generally appropriate. A262 addresses intergranular corrosion resistance in a number of different types of environments depending on the Practice (A or E), but all attempt to determine if the material has been sensitized due to inappropriate thermal processing.

ASTM A262 Practice C (Huey test) is a ten-day test for nitric acid service. Alloy 316L will not perform as well as 304L in this service and in fact will not pass Practice C consistently. For Alloy 316L, Practices A or E may be more appropriate. Similarly, high-carbon grades may not be compatible with Practice C testing. Stabilized grades are normally tested with Practice E.

For duplex stainless steels, ASTM A923 Practice A or C may be appropriate. Depending on the service environment, other standard corrosion tests may be appropriate.◆

An ambitious welding instructor implements an intensive training experience that's become an annual event

BY HOWARD M. WOODWARD

Weld Camp is the brainchild of Daniel Turner, an AWS CWI (Certified Welding Inspector), who teaches welding at Yuba Community College in Marysville, Calif. Looking up at the big Welcome to Weld Camp banner (lead photo) Turner said, "My goal in establishing Weld Camp is to pass on my passion for welding and welding education to the students. I hope to further their training, add a certificate of training to their portfolios, and introduce the students to welding equipment and processes they may not have been able to use in their shops." In addition to offering a unique training experience to the students, Weld Camp invites local welding instructors to attend a customized two-day program. "We separate the high school welding instructors from the students so the instructors can receive personalized instruction that applies specifically to their shops," Turner said.

The trainers at Weld Camp include manufacturing representatives who are knowledgeable about the latest welding equipment and techniques assisted by a number of college-level welding students. "Our aim," Turner said, "is to introduce the students and instructors to the latest technology that may not be available at their schools. For example, at the Weld Camp most students are introduced for the first time to gas tungsten arc welding (GTAW), since most of the local schools do not have that process taught in their welding courses."

Chuck Tabor (far right), from Miller Electric, provided one-on-one hands-on training using a gas tungsten arc welding machine.

Student Weld Camp Activities

On the first day for the students, training starts promptly at 8:00; lunch is at noon, and they're finished for the day around 4:30.

Turner explained, "We divide the students into two groups, A and B. On the first day, Group A receives training on GMAW and FCAW using various wires, including metal cored, while Group B is instructed on industrial cutting/oxyfuel and GTAW. The next day, the students swap their courses of study. Since each group is limited to about 25 students, each attendee receives plenty of individual attention from the trainers.

"For training aids, we use the Miller student and instructor packs, and we usually have three or four trainers from Miller, one or two from Hobart Brothers, and two or four from MJB, the local welding supply house. Plus, we have three trainers from the college, and about five or ten college students who excel in each process to assist with the training. In addition, Mark Smith from Shasta College instructs the students on welding procedures, and qualification

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Everyone showed up for this Weld Camp group shot of industry representatives, welding instructors, and students.

Dan Turner, the instructor behind the magic of Weld Camp, sets up for the first day.

No one dozes during a Weld Camp class — the topics are interesting, several pop quizzes are expected, and valuable prizes await those who earn the best scores.

keyed to AWS D1.1, *Structural Welding Code — Steel,* as well as giving a lesson on machining and manufacturing. We have a superb machine shop on campus with an excellent instructor, Bruce Kirk, who does the shop demonstrations."

Turner noted, "We do not conduct any kind of welding competition during Weld Camp, but the students' welds are evaluated in compliance with the AWS D1.1, *Structural Welding Code — Steel.*" All of the trainers have knowledge of this code, and Turner oversees everything as a CWI.

"An important feature of Weld Camp," Turner said, "is the students have trainers working with them in their booths to refine their welding techniques." Their weldments are then promptly evaluated.

"We also demonstrate destructive bend testing for the students, so they can understand what is required to certify to the AWS D1.1 Code.

"To keep the students focused during the classroom studies, several short written quizzes are presented to appraise their knowledge about power sources, electricity, polarities, filler metals, and general welding information. To add additional interest and incentive, the students receiving the higher test scores are awarded valuable prizes.

"The graduation dinner at 5:00 p.m. is the highlight of the busy second day for everyone involved in the program. During the ceremony, the students receive their certificates of completion, T- shirts, and many attractive prizes donated by program benefactors."

The Welding Instructors' Agenda

On the welding instructors' first day, they attend training sessions including refreshers and updates on the fine points of GTAW and FCAW, equipment maintenance, changing GMAW liners, types of power sources, power ratings of equipment, duty cycles, and new technologies. Each instructor has the opportunity to work in a welding booth on a hands-on project to strengthen his or her skills using the latest equipment. They work directly with the trainer, who is a factory representative for the equipment being used. The instructors also have an opportunity to discuss their shop-specific equipment needs with representatives of local companies that specialize in working with school welding programs and offer school discounts. During the instructors' second day, they tour the facilities of local industries that are of interest to welders.

"We usually have one or two instructors from each participating high school," Turner said, "who attend the training and industry tours program. Last year, the instructors toured SWECO in Sutter, Calif., and Davis Machine in Meridian, Calif. In 2006, the instructors toured Gerlinger Steel and Supply in Redding, Calif."

The Follow-up to Weld Camp

"Currently," Turner said, "there is no formal follow-up for the students. I make

The young lady behind the mask is Turner's 4-year-old daughter. "You can't start them welding too young," Turner said.

Making Weld Camp happen are area welding teachers (from left) Jim Rogers, Dan Turner, Nick Dreesman, Roger Christianson, Casey Hendricks, Gary Lederer, Travis Barker, and Mike Pahl. They represent, respectively, Las Plumas H.S., Yuba College, Gridley H.S., Live Oak H.S., Lindhurst H.S., Sutter H.S., East Nicholas H.S., and Placer H.S.

a point to visit the various participating high schools to inquire about the students' progress. I also talk to the students in my classes at the college. We encourage all students to attend a community college or tech school to further their welding skills to enhance their career opportunities. Currently, we are preparing a follow-up survey to send to the instructors to fill out about the success of the students who attended Weld Camp.

"In my classes, we are working on developing a team to participate in the SkillsUSA competition. I am also working on establishing an AWS-certified Accredited Test Facility (ATF) for the Schools Excelling through National Skills Standards Education (SENSE) program. I take my students to the AWS Sacramento Section meetings to meet the people in our welding community, and urge them to become active AWS Student Members. We also bring in people from industry to keep the students current on industry trends."

How Weld Camp Got Started

Turner's interest in welding began when he was eight years old helping his father repair farm equipment. Later, he honed his welding skills at Kelseyville H.S. where he got the idea that teaching welding would be a great job, a goal that he realized after graduation from the University of California, Davis.

Turner said, "Weld Camp was an idea I came up with after attending a number of events about improving education. But the ideas presented were of no help in making a direct impact on my students. After attending those events, I kept asking myself, 'Why doesn't any of this focus on teaching kids usable skills for their futures? Isn't that what I am supposed to be doing as a teacher?'"

So, Turner shared his Weld Camp plans with Shasta Welding in Redding, Calif., and the company contacted Silvio Modena from Miller Electric who thought it was a great idea. Turner said, "We conducted the first Weld Camp in spring 2006 at the Foothill High School in Redding, Calif., where I had taught for 12 years.

"In 2007, we moved the event to Yuba College in Marysville, about 40 miles north of Sacramento. That first year, we held the training lecture in the college's theater. We have since decided to train small groups in small classrooms to create a more personal setting. This also allows the students to develop a closer connection to their trainers, feel more comfortable asking questions during the classroom instruction, and be more at ease to approach the trainers while working in the labs."

Who Goes to Weld Camp?

Turner explained, "To qualify to attend Weld Camp, the students have to be enrolled in welding courses in their high schools. We accept about 50 students from the local high schools and up to ten from Yuba College. The students are selected by their instructors. Some instructors use an application and interview process, but most use a sign-up list, and then they select the students based upon the criteria they set for themselves. We allow students who have already attended to return, but most are newcomers. The instructors generally bring their juniors and seniors, so some of the students just 'wait for their turn.' Most instructors and students consider attending Weld Camp as a reward since it is recognized as an enjoyable training event where the participants stay busy all of the time with hands-on activities — unlike many welding events where attendees are idle much of the time. The additional trainers are selected from several of the top college-level welders."

Other Event Details

Turner said scheduling the event was critical since so many people were involved. He said, "For us, the best arrangement is to hold Weld Camp on a Wednesday and Thursday rather than on a weekend. This schedule allows instructors to teach the first two days of the week, then be back in time for school on Friday to close the week. The vendor-trainers also prefer to have Friday as a travel day to get back to their jobs. Everyone seems to appreciate not having to give up their weekend." Turner noted, "It is necessary, however, for about a quarter of the attendees to stay overnight in nearby motels and hotels. I work with the hotels to get them a special rate."

Turner makes sure his Weld Camp gets all the publicity it deserves. He said, "We attend the regional teacher meetings, use flyers, mailers, and e-mails. I also have appeared on local radio and television shows. The first year, we invited and had representatives come from several California Senate and Assembly offices. We had representatives from the offices of Sen. Tim Leslie, Assemblyman Doug La Malfa, and former state Sen. Maurice Johnnessen.

"We start sending out the invitations and reservation forms about two to three months ahead of time so the instructors can make the necessary preparations and arrangements with their schools to be absent for the two-day event. The word is already out about Weld Camp," Turner said. "I receive inquiries all year about the next event. I am planning a welding competition next year in the fall or for just after the winter break."

Turner acknowledged that Weld Camp owes much of its success to the presentations by Mark Smith from Shasta College; Alan Lindgren, district manager at Smith Equipment; Silvio Modena, Chuck Tabor, and Dan Geissbuhler, district managers at Miller Electric; Willie Stubblefield, district manager at Hobart Brothers; Marlon Santos, a consultant; and the support and participation of Gerlinger Steel and Supply, All Metals Industrial Metals, Miller Electric Mfg. Co., Hobart Brothers, Smith Equipment, MJB Welding Supply, Shasta Welding Supply, Airgas, Davis Machine, Bernard, Master Plans and Design, and Yuba College.

Some Observations about the Weld Camp Experience

"Weld Camp is, without a doubt, our best recruiting effort for career and technical programs at Yuba College," said Kevin Trutna, vice president.

Paul Mendoza, president of Yuba College, reported that "Turner's efforts to collaborate with industry, business, and area high schools has created a much-needed focus toward the training and development of future welding professionals."

"My students were especially interested in the talks presented about careers in welding, the qualities employers are looking for in an employee, and how to get and keep a job," said Roger Christianson, Live Oak H.S. instructor.

Jim Rogers, a Las Plumas H.S. instructor, said, "I made some great contacts and my students had a blast and couldn't wait to tell me all that they had learned."

Matt Joiner, an instructor from Las Plumas H.S., said his students consider it a privilege to be selected to attend Weld Camp.

"Weld Camp provided a great opportunity for instructors from different schools to meet in small groups to share their ideas for an extended period of time, and my students valued their time at Weld Camp as much I did," said Sutter H.S. instructor Gary Lederer.

Nick Dreesman, Gridley H.S., noted, "The students are excited about the welding industry when they leave Weld Camp."

Future Plans and Concerns

Plans are under way to expand the Weld Camp program into welding sheet metals and autobody repair, and adding new pulse GMA and GTA welding machines to the workstations. "Our students should leave school prepared for what industry is using," Turner said.

"I truly believe that I can make a better community by teaching welding. I teach skills that enable my students to get jobs that will support them and their families. I also encourage all of my students to pursue an associate's degree. This opens the doors to many additional careers. I also want to stress some new ideas I call "Clean and Green Welding." This program stresses upgrading ventilation systems in welding shops and upgrading to more efficient welding power sources using inverter technologies.

"We plan to meet in the near future to evaluate this year's Weld Camp and to determine the dates for the next year's event. We will base the date selection on when the local schools schedule their spring breaks and their standardized testing dates.

"However," he said, "we are concerned about the funding for next year and are actively looking for additional sponsors for the event."

For more information, e-mail Dan Turner at *dturner@yccd.edu,* or call (530) 741-6932. ♦


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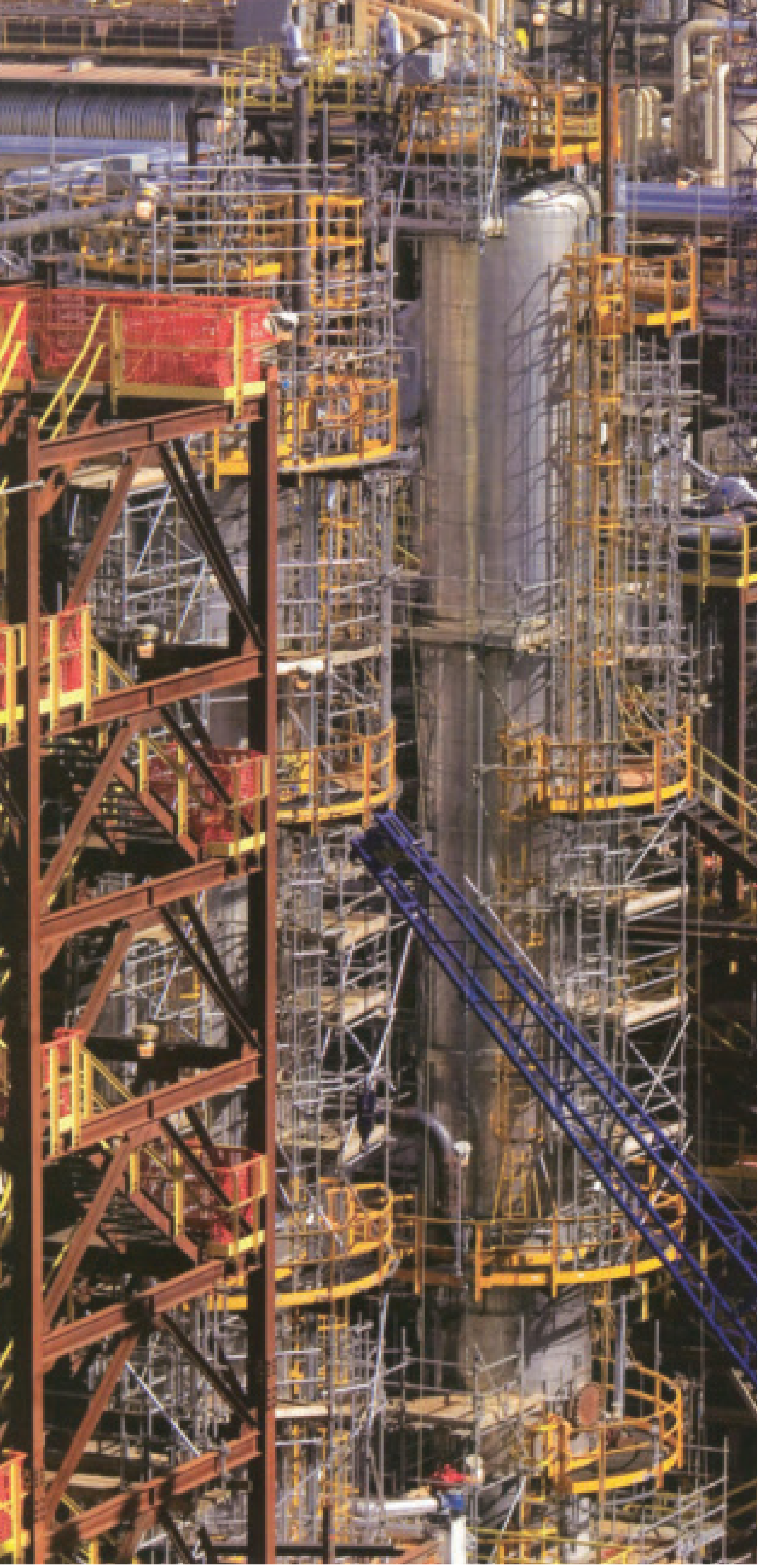

Fig. 1 — The cylindrical tower of a typical coker.

Mechanized Weld Buildup Repairs Coker

Few Americans realize that their neighbor to the north, Canada, currently supplies 17% of the total U.S. crude oil demand. While much of this crude comes from conventional wells, a large contribution comes from the vast oil sands located in the province of Alberta. There, however, the oil is found in a semisolid tar-like form mixed with sand, variously called oil sands, tar sands, and bitumen. According to U.S. Dept. of Energy estimates, Alberta's oil sands contain between 1.7 and 2.5 trillion barrels of reserves, of which 300 billion barrels are recoverable with today's technology. Stretching across 54,000 square miles, these reserves are largely untapped because of the expense and complications of removing the oil from the sands. The deposits are mined in massive open pits. It takes about two tons of sand to extract one barrel of oil. Special facilities/refineries must first chemically process the bitumen to yield an oil grade known as synthetic light crude, which is then conventionally refined to various petroleum products.

Mining the Tar Sands

Several companies are now active or in the developmental stages of mining the tar sands. The largest producer so far, Syncrude Canada Ltd., came on stream in 1978. It is jointly owned by several of the largest North American oil companies. It operates a large facility 25 miles north of Fort McMurray equipped with the special capabilities required to process the oil sands. Another company with both mining and processing facilities is Suncor, which came on stream in 1967. Shell operates a mine, but does no processing on site, instead transporting the bitumen in a diluted form by pipeline to its upgrader and refinery at Scotford, Alberta.

Syncrude pioneered a technique called hydrotransport to move the tar sands from mine to extraction plant. The oil sand is mixed with water to form a slurry that can be economically transported via pipeline. After oil extraction, the sand is returned and the land reclaimed to its original condition.

Growth prospects for oil derived from the tar sands were hampered by the low price of oil in the 1980s and 1990s, and the assumption that prices would remain low in the future. Recent technological breakthroughs have brought down costs, while oil prices have risen. Syncrude's $7.8 billion UE-1 expansion project was completed in early 2006, which boosted production by 44% to 360,000 barrels a day.

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The use of mechanized pipe welding equipment allowed control of the welding process away from the heat of the preheated surface and fast job completion

BY JOHN PAGE AND JOHN EMMERSON

Vessel Wall Corrosion Dictates Buildup Repair

Turning bitumen into synthetic crude involves a process called "coking," which removes some of the carbon. A fluid coker can stand up to 23 stories high — Fig. 1. Maintenance involves shutdown of the giant unit. A recently completed shutdown project for one of the industry majors involved repairing a 50-ft-diameter burner vessel (adjacent to the coker) that had lost 0.5 in. of wall thickness due to corrosion over the years. The preheat requirement of 300°F made for an extremely hot working environment for manual welders. A local contractor was awarded the maintenance contract. The contractor turned to Edmonton-based John W. Page Welding Consulting Ltd., which assisted as a subcontractor to provide mechanized welding equipment and technician services. John Page has 30 years of experience in orbital pipe and mechanized welding projects, and has accumulated a fleet of orbital gas tungsten arc welding (GTAW) and flux cored arc welding (FCAW) systems. Page recommended that the contractor use several Magnatech Pipeliner systems for the weld buildup. Conventionally used for orbital FCAW of pipe from 6 to 60 in. in diameter, the weld heads can also be used on larger diameters using Flx-Track. These flexible, 7½-ft-long tracks can be magnetically mounted on a large-diameter vessel wall and be joined together for longer continuous runs.

The union welders were trained in equipment operation prior to the job start — Fig. 2. The Alberta Boiler Safety Association (ABSA) mandated that the welders qualify the weld procedure as a butt joint weld, because the weld buildup required was not a corrosion-resisting alloy cladding, but rather was replacing the carbon steel base metal, similar to doing fill and cap passes on a butt joint weld.

Access to the areas requiring weld buildup required cutting 9-ft-wide windows (17 of them) in a surrounding stainless steel "skirt" — Fig. 3. Equipment installation was simple and straightforward. The welding power sources, controllers, and coolers are modular, and were lowered through a manhole in the grid floor to a scaffold in the middle of the 50-ft-diameter vessel. From there, the 50-ft-long extension cables allowed the wire feeders, control pendants, and weld heads to fan out and reach every area around the circumference. The welders reached in and slapped the 7½-ft tracks on the wall with magnets. They then installed the weld head on the track in seconds using a unique push-button pneumatic clamping system.

Cladding was done at 18 in./min travel speed. As the pendant has motorized steering, with a dial counter from 0 to 1000, the welder lays the first pass on at a dial setting of 1000, which is the maximum distance away from the weld head and track. At the end of that pass, a toggle switch reverses the travel direction, and the welder decreases the steering dial counter by an increment, such as 50 per

Fig. 2 — Shown are the welders being trained at the Edmonton Boilermakers training center, prior to the buildup project.

Fig. 3 — Nine-ft-wide windows were cut out of the inner skirt to allow access to the corroded steel shell.

Fig. 4 — An optional gun axial slide bracket, combined with wide stroke steering, minimized the need for repositioning tracks.

pass, to create a "step-over" increment for perfectly uniform and stacked passes. Once the step-over increments have counted down to zero, a second layer is applied in the same fashion. To continue higher up the wall, the extended mechanical gun slide bracket is quickly repositioned allowing the motorized steering to start counting down from 1000 again. Using the mechanized and motorized adjustments, the track had to be only repositioned once to complete the job — Fig. 4. "As the flexible tracks conform to the curved wall, and are quickly mounted using magnets, it requires only minutes to move the track, check it for level, and continue welding," Page said.

An all-position formulation of an 0.045-in.-diameter Air Liquide wire (–E71T-12MJ) was used. This wire met the new, more stringent requirements for 4 mL of hydrogen per 100 grams of weld metal and had excellent low-temperature impact properties (125 ft/lb at –50°F). All welding fume and dust were well evacuated by the Smogbusters company, professionals at air quality in confined spaces, which also used some of its air-movement systems to bring in fresh cool air, greatly welcomed by the welders due to the high preheat temperature used for the walls.

Shortening the Shutdown Duration

The decision to hire the services of a specialized consultant can drastically reduce project mobilization time. Hiring a specialist (with additional technical staff if required) can greatly reduce the training learning curve and provide speedy solution of problems that appear once the job gets underway at the work site. "Very often the contractor jobsite personnel and the craftspeople on a project are new to mechanized welding," explained John Emmerson, president of Magnatech. "If a problem appears, it's sometimes difficult to determine the root cause: equipment, consumables, welding technique. If the problem is not quickly resolved, it can quickly lead to frustration on the part of the welders and equally for the contractor's staff, under deadline pressures. I can't count the number of times we've been told that an equipment malfunction was causing porosity in the weld. Porosity can result from a defective regulator or gas line connection aspirating air, bad gas, hydrocarbon contamination of the weld joint, welding technique, moisture in the flux core wire due to improper storage, etc. This often leads to a retreat to the 'safety' of manual welding, forgoing the original goal of getting the job done faster with a substantially lower repair rate."

Page brought up the point that "many contractors or fabricators have doubts about flux cored wires due to porosity problems they've seen, but almost no one doing semiautomatic welding with flux cored wires realizes how the guns are rated. For example, that oh-so-popular 300-A gun is designed for 100% CO_2 gas, which helps keep the gun parts cool, but most distributors and wire manufacturers recommend the much hotter 75% argon/25% CO_2 shielding gas for the modern wires. If you read the fine print in the gun manufacturer's manual, the gun rating is actually cut in half for mixed gas, and you need a heavier-duty gun, at least in the front end parts. Using a typical gas-cooled gun with mixed gas will often lead to porosity after a few minutes of welding, as the front end parts overheat. The light-duty contact tips seize on the wire, and the thin-walled brass nozzle expands and sucks in air. But that's what you get with light-duty components." Use of a liquid-cooled gun, with heavy-duty tips, and high-quality, heavy-walled copper nozzles for continuous weld buildup jobs eliminates porosity defects.

Automated FCAW equipment is typically six times as fast as manual SMA welding for these larger jobs. It is also much faster than hand-held, semiautomatic welding with similar wires, due to the high duty cycle of mechanization, and there is a dramatic improvement in uniformity of the weld, according to Page.

By allowing the welder to remotely control the welding process away from the intense heat of the preheated surface, the job was done in record time, while improving safety — Fig. 5. "Manual welders working inside the vessel with the bottom preheated to 300°F (177°C) can only work 15 minutes before retreating outside for one hour to cool off," Page said.◆

Fig. 5 — The orbital welding equipment is shown on the workpiece, which was preheated to 300°F.


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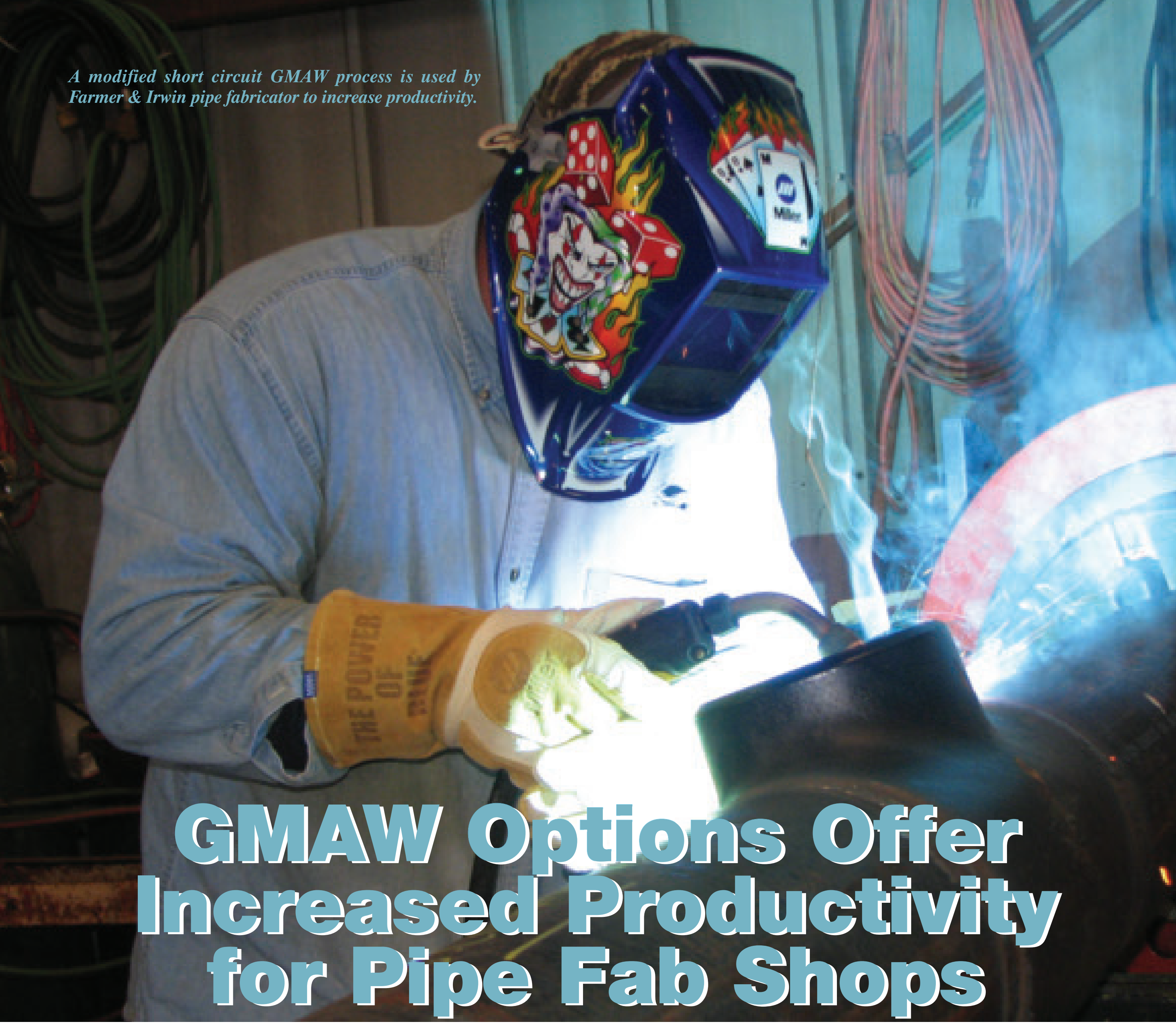

A modified short circuit GMAW process is used by Farmer & Irwin pipe fabricator to increase productivity.

GMAW Options Offer Increased Productivity for Pipe Fab Shops

Typically, pipe fabrication shops use only a few processes to perform root passes on pipe welds. Gas tungsten arc welding (GTAW), with a travel speed of 2 to 4 in./min, is recognized for high-quality welds but requires a highly skilled operator. Shielded metal arc welding (SMAW) has a faster travel speed of 5 to 8 in./min, but it requires the welder to chip slag and grind between passes. Traditional short circuit gas metal arc welding (GMAW-S) is a third choice, but many contractors and their customers avoid it because of the skill required to produce code-quality welds.

However, modified or "regulated" short circuit processes, such as Miller's Regulated Metal Deposition (RMD™) process, offer a viable option. A modified short circuit gas metal arc welding process can increase travel speed to 6 to 12 in./min, possibly eliminate the hot pass, is tolerant of differences in work-to-contact tip distances, and produces quality welds with minimal training.

The same wire and gas combination may also be used for the fill and cover passes using a new pulse process designed for pipe welding, such as Pro-Pulse™, which is also tolerant of variations in work-to-contact tip distances and can substantially increase travel speed and deposition rates. This pulse process uses both constant current (CC) and constant voltage (CV) to create a cooler weld pool than conventional pulsed GMAW.

Improving Productivity

Farmer & Irwin, a mechanical contractor based in Riviera Beach, Fla., fabricates carbon steel pipe from 1¼ in. up to 16 in., using SMAW to weld Schedule 40 carbon steel pipe in a fixed position. Joints were being completed in three passes using ⅛-in.-diameter E6010 electrodes for the root pass and ⅛-in.- and 3/32-in.-diameter E7018 electrodes for the intermediate and cover passes.

With a large work load accumulating, new ways were sought to refine the weld

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Modified short circuit and pulsed gas metal arc welding technologies increase pipe welding productivity, improve quality, and ease training

BY JIM CUHEL

processes to maintain production. Larry Wrye of Farmer & Irwin wanted to increase productivity.

Conventional short circuit GMAW was tried with a few different arrangements, but the root pass was not satisfactory. “We always ended up with excessive penetration, which caused keyholes and ‘stalactites’ on the inside of the pipe,” explained Wrye. The company continued using SMAW until it tested one of the new modified short circuit GMAW processes for the root pass, and the new pipe welding pulsed spray transfer process for subsequent passes.

As a result, production rates increased by 100% on 3-in.-diameter pipe and by up to 500% on 12-in.-diameter pipe (the larger the pipe diameter, the greater the percentage of increase). Before implementing the new technology, one pipe fitter could bevel and tack weld enough pipe to keep two or more welders busy. Now one welder keeps two fitters busy, according to Wrye.

Modified vs. Traditional Short Circuiting Transfer

In traditional GMAW-S, the short circuits occur at irregular intervals and are of varying intensity. This agitates the weld pool, causing it to splash onto the sidewall of the pipe, which can lead to incomplete fusion, as well as spatter. Thus, this process requires a relatively high level of skill to produce code-quality welds, and many companies shy away from it.

The new modified short circuit GMAW technology allows the metal transfer process to be precisely regulated, resulting in a uniform droplet deposition, which makes the weld pool easier to control. It also creates only small ripples in the pool. With a more stable weld pool, it is far easier to create consistent tie-ins with the sidewall.

The modified short circuit process maintains a consistent arc length regardless of electrode extension. This is especially helpful for novices and others who have trouble maintaining a constant tip-to-work distance. Novice welders quickly gain confidence in the quality of their welds.

Because the process produces a faster-freezing, calmer weld pool, it provides the potential to eliminate the need for a hot pass. Typically, SMAW, GTAW, and traditional GMAW create root passes ³⁄₃₂ in. to ⅛ in. thick, depending on the operator. This requires a subsequent pass to add more metal so subsequent passes with FCAW or spray transfer GMAW do not blow through the root pass.

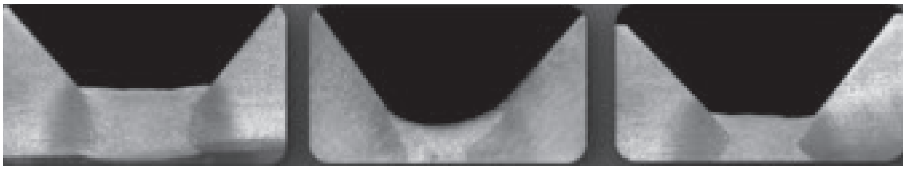

Fig. 1 — Comparison of root passes performed by modified short circuit GMAW (left), GTAW (center), and traditional short circuit GMAW (right).

The modified short circuit process creates a root pass (³⁄₁₆ in. or greater) thick enough to support the heat input requirements of pulsed GMAW or FCAW intermediate passes — Fig. 1. Since the weld metal in a faster freezing pool stays where it is directed, the modified short circuit process is also more forgiving of high-low misalignment, being able to bridge root openings up to ³⁄₁₆ in.

Current Control during Transfer

With the modified short circuit process, the software controls the electrode current during all phases of the droplet transfer. After the droplet on the end of the wire wets out in the weld pool, current is increased to a level sufficient to start pinching the droplet. The current is then gradually increased further until the short circuit is about to occur. Once the short circuit happens, the current is rapidly decreased and the droplet is transferred into the weld pool.

After the end of the wire clears, the current is then increased to form a droplet for the next short circuit cycle. The current is monitored and, if necessary, dropped even further to avoid an arc force that could agitate the pool.

Welding with the new process is simple to learn, and if the operator can already weld with GMAW, he or she can become productive with the modified short circuit GMAW process in approximately two hours. The recommended fit up for this process includes pipes prepared with a minimum ⅛-in. root opening to ensure proper root reinforcement. The root face can range from a knife edge to ¹⁄₁₆ in. and the included angle is typically 75 deg. Once the weld pool is established, the electrode is positioned in the center of the weld. Only when welding in the 5-G fixed position, at the 12 and 6 o’clock areas, is a weave technique recommended. If the joint is misaligned, it is not necessary to favor the high side. The equipment will automatically compensate. It is effective in both the 1-G rolled or 5-G fixed position.

Compared to conventional short circuit GMAW, the modified short circuit GMAW 1) is designed specifically for root pass welding, 2) can replace GTAW in many applications, 3) is tolerant of joints with high-low misalignment, 4) reduces spatter, 5) reduces heat input, 6) allows less-skilled welders to deposit quality welds, 7) is very tolerant of changes in tip to work distance, and 8) has excellent fusion and reduced toe angles (smooth transitions) that reduce grinding on the face of the weld.

Pulsed Gas Metal Arc for Pipe Welding

CMN Steel Fabricators of Miami, Fla., was also able to take advantage of the pulsed GMAW process for pipe welding. The company fabricates pipe for the waste energy and other industries. Recently, CMN was contracted to weld 66 joints of chromium-molybdenum alloy, commonly called P11, on the New Hope Power Partnership (an expansion of the Okeelanta Cogeneration Plant). Its welding procedure specifications (WPS) required the GTAW process for the root and the first fill passes.

The WPS also called for an additional 15 SMAW passes using ⅛-in. E8018-B2 electrodes; however, by switching to the pipe welding pulsed GMAW process, CMN was able to fill the joint with only seven passes (< 3 lb/h for a ⅛-in. E7018 electrode for SMAW vs. 4.0 to 17.0 lb/h for an 0.045-in. ER70S-6 electrode for pulsed GMAW).

As a result, the company finished the project in six weeks instead of eight and reduced welding time by 64% with each weld passing ultrasonic testing (UT) on the first try.

When using conventional pulsed GMAW, different wire extension lengths can change the overall parameters; however, the pipe welding pulsed GMAW process maintains the optimum arc length and weld parameters within a broad range of wire extensions (up to 1 in. is possible) and travel speeds. This makes it far easier to train new welders and even easier for experienced welders to make consistently high-quality welds.

It also allows the welder to hold a shorter arc length than with older technology. The shorter arc length helps eliminate undercuts and allows the operator greater control over the weld pool.

With this pulsed GMAW technology, both current and voltage stay within the optimum range for a specific wire type and diameter, wire feed speed, and gas combination. Each pulse starts by ramping up the current. Once the target current is reached at the beginning of the peak phase, the constant current (CC) control turns off and the constant voltage (CV) control loop turns on. The CV loop modulates the current within a range that maintains the target voltage. This occurs independently of the contact tip-to-work distance.

It is during the peak phase that the droplet at the end of the wire is transferred across the arc into the molten weld pool. After the CV peak phase times out, the CC control loop turns back on to bring the current to the lower level background phase. After the current reaches the commanded background level, the CV loop turns back on and allows the pool to solidify while forming the droplet at the end of the wire for the next pulse.

As a result of faster and tighter control over parameters, this technology provides shorter arc lengths and a more focused arc column. Compared to older pulsed GMAW technology, the pool is easier to control (thus the process is easier to learn) and improves fusion at the toes of the weld. Like the modified short circuit process, this process is more tolerant of contact tip-to-work-distance variation, which helps when encountering tack welds, welding in tight corners or on pipe beveled with steep angles, and when training new welders.

Power Source Control

These benefits are possible due to the fast reaction time of today's power sources coupled with advanced software that can shape every aspect of the arc. Together, the hardware and software of the systems remove the burden of setting a complex set of parameters. The operator enters the wire type and diameter, shielding gas composition, and desired wire feed speed. Then the equipment selects the optimum parameters from an extensive library. The operator is able to customize the arc length and width by making adjustments at the wire feeder or power source.

These new processes have the capability to drastically alter a pipe shop's productivity, according to Wrye. "We have come to the conclusion that the larger the pipe, the more efficient we are," said Wrye, because larger-diameter pipe has a greater percentage of arc-on time compared to preparation time. "I would venture to say that on 12-in.-diameter, Schedule 40 pipe, the new wire welding technologies out-produce SMAW by a 5 to 1 ratio. On 3-in.-diameter pipe, wire welding out-produces SMAW by 2 to 1."◆

Dear Readers:

The *Welding Journal* encourages an exchange of ideas through letters to the editor. Please send your letters to the Welding Journal Dept., 550 NW LeJeune Rd., Miami, FL 33126. You can also reach us by FAX at (305) 443-7404 or by sending an e-mail to Kristin Campbell at *kcampbell@aws.org*.


Welding in Aircraft and Aerospace Conference
The aircraft and aerospace industry is making great strides in cost reduction. One aspect of this is utilizing composites in place of aluminum. Another innovation is to build critical parts from the ground up, rather than ordering expensive forgings and castings that have to be machined down to size.
Welding is in the very thick of it on both fronts. Improved processes are being developed to weld carbon fiber composite structures. In the world of “born to shape parts,” innovative welding processes like electron beam, laser, and others are getting the job done efficiently and economically.
September 16-17, 2008
Wichita, Kansas
AWS
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At this AWS conference in Wichita, emphasis will be given to friction stir welding, fiber laser welding, and the gas-shielded welding processes. The role of titanium is growing, and the emergence of a number of new aluminum-lithium alloys poses new welding challenges. Ultrasonic welding, a front-runner for the welding of thermoplastic composites, will be on the agenda, as well.

Plans for vehicles to carry humans to the moon by 2010 (and later, to Mars) will also be discussed.

Titanium Friction Stir Welding and Laser Welding Development for Commercial Aircraft
Daniel G. Sanders, Senior Technical Fellow, Director of M&P Science, Materials & Process Technology, The Boeing Co., Seattle, WA

Potential Uses for Fiber Lasers in Aerospace Applications
Paul Denney, Laser Researcher, Connecticut Center for Advanced Technology, Inc., East Hartford, CT

Friction Stir Weld Assembly of the Eclipse 500 Very Light Jet
Brent Christner, Manager, Materials and Process Engineering, Eclipse Aviation, Albuquerque, NM

Electron Beam System Technology for Welding and Additive Manufacturing
Robert C. Salo, Sales Manager, Western Region, Sciaky, Inc., Chicago, IL

High Powered Ultrasonics and Thermal Stir Welding
Jeff Ding, Aerospace Welding Engineer, NASA Marshall Space Flight Center, Huntsville, AL

Advanced Manufacturing and Repair of Nickel and Titanium Alloys
Nick Kapustka, Applications Engineer, Arc Welding, Lasers & Automation, Edison Welding Institute, Columbus, OH

Development of Third Generation of Aluminum Lithium Alloys
Michael Niedzinski, Director of Technology and Standardization USA, Alcan Aerospace, Chicago, IL

Returning to the Moon: Welding and Fabrication of the Ares I Upper Stage Hardware at Marshall Space Flight Center
Jeff Ding, Aerospace Welding Engineer, NASA Marshall Space Flight Center, Huntsville, AL

Path Independence of Friction Stir Welding
Dr. Dwight Burford, Senior Research Scientist, Director, Advanced Joining & Processing, National Institute for Aviation Research, Wichita State University, Wichita, KS

Aerospace Gas Tungsten Welding
Wyatt Swaim, Chief Executive Officer, WJS Consulting Inc., Geuda Springs, KS

Developments in Usage of Fiber Lasers for Aerospace Welding Applications
Eric Stiles, Applications Manager, IPG Midwest Operations, IPG Photonics, Wixom, MI

Laser Weldbonding of Thin Aluminum Structures
George Ritter, Technology Leader, Plastics and Adhesives, Edison Welding Institute, Columbus, OH

Metal Part Fabrication and Component Repair with Laser Engineered Net Shaping
Rich Plourde, Director, Aerospace and Defense Business Development, Optomec, Inc., Albuquerque, NM

Eddy Current Array and Ultrasonic Phased-Array Technologies as Reliable Tools for Inspection of Friction Stir Welds
Michael Turner, Advanced Technical Sales, Olympus NDT, Kansas City, MO; and Andre Lamarre, Business Development Director, Aerospace and Defense, Olympus NDT, Quebec City, Canada

AWS Welding in Aircraft and Aerospace Conference
Broadview Hotel • Wichita, Kansas
September 16-17, 2008

To register or to receive a descriptive brochure, call (800) 443-9353 ext. 455, (outside North America, call 305-443-9353), or visit www.aws.org/conferences

American Welding Society®

Founded in 1919 to advance the science, technology and application of welding and allied processes including joining, brazing, soldering, cutting and thermal spraying.

Induction Welding of Pipe and Tubing

The welding of continuous-seam pipe and tubing is a predominant application of high-frequency induction welding. The pipe or tube is formed from metal strip in a continuous-roll forming mill and enters the welding area with the edges to be welded slightly separated. In the weld area, the open edges of the pipe or tube are brought together by a set of forge pressure rolls in a vee shape until the edges touch at the apex of the vee, where the weld is formed. The weld point occurs at the center of the mill forge rolls, which apply the pressure necessary to achieve a forged weld.

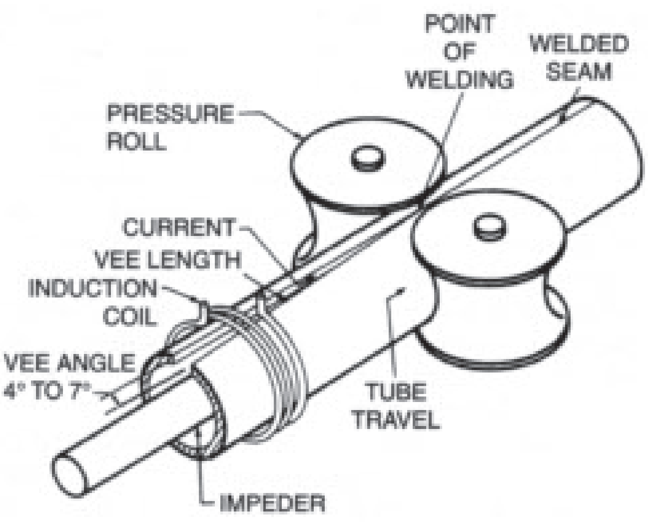
An induction coil, typically made of copper tubing or copper sheet with attached water-cooling tubes, encircles the tube at a distance equal to one to two tube diameters ahead of the weld point. This distance, measured from the weld point to the edge of the nearest induction coil, is called the vee length. The induction coil induces a circumferential current in the tube strip that closes by traveling down the edge of the vee through the weld point and back to the portion of the tube under the induction coil. Figure 1 illustrates the process.

The high-frequency current flows along the edge of the weld vee due to the proximity effect, and the edges are resistance-heated to a shallow depth due to the skin effect.

The geometry of the weld vee is such that its length usually is between one and one half to two tube diameters long. The included angle of the vee generally is between 3 and 7 deg. If this angle is too small, arcing between the edges may occur, and it will be difficult to maintain the weld point at a fixed location. If the vee angle is too wide, the proximity effect will be weakened causing dispersed heating of the vee edges, and the edges may tend to buckle. The best vee angle depends on the characteristics of the tooling design and the metal to be welded. Variations in vee length and vee angle will cause variations in weld quality.

The welding speed and power source level are adjusted so that the two edges are at the welding or forge temperature when they reach the weld point. The forge rolls press the hot edges together, applying an upset force to complete the weld. Hot metal containing impurities from the faying surfaces of the joint is squeezed out of the weld in both directions, inside and outside the tube. The upset metal normally is trimmed off flush with the base metal on the outside of the tube, and sometimes is trimmed from the inside, depending on the application for the tube being produced.

An impeder, which is made from a magnetic material such as ferrite, generally is required to be placed inside the tube. The impeder is positioned so that it extends about 1.5 to 3 mm ($1/16$ to $1/8$ in.) beyond the apex of the vee and equivalent of 1 to 2 workpiece diameters upstream of the induction coil. The purpose of the impeder is to increase the inductive reactance of the current path around the inside wall of the workpiece. This reduces the current that would otherwise flow around the inside of the tube and cause an unacceptable loss of efficiency. The impeder also decreases the magnetic path length between the induction coil and the tube, further improving the efficiency of power transfer to the weld point. The impeder must be cooled to prevent its temperature from rising above its Curie temperature, which is where it becomes nonmagnetic. For ferrite, the Curie temperature typically is between 170° and 340°C (340° and 650°F).♦



Note: The vee length extends from the point of welding to the induction coil.

Fig. 1 — High-frequency induction welding of a tube.

Excerpted from the *Welding Handbook,* Vol. 3, ninth edition.

NOTE: A DIAMOND (♦) DENOTES AN AWS-SPONSORED EVENT.

♦**Trends in Welding Research™, 8th Int'l Conf.** June 1–6, Callaway Gardens Resort, Pine Mountain, Ga. Sponsored by ASM International, *www.asminternational.org/trends;* cosponsored by the American Welding Society, *www.aws.org.*

World Congress on Powder Metallurgy & Particulate Materials. June 8–12, Gaylord National Resort and Convention Center, National Harbor, Md. Sponsored by Metal Powder Industries Federation and APMI Int'l. Visit *www.mpif.org.*

Automatica 2008: Assembly-Robotics-Vision. June 10–13, Munich, Germany. Visit *www.automatica-muenchen.de.*

20th Canadian Materials Science Conf. June 18, 19, Univ. of Alberta, Edmonton, Alb., Canada. Visit *http://cmsc.ualberta.ca.*

19th AeroMat Conf. & Expo. June 23–26, Austin Convention Center, Austin, Tex. Cosponsored by NASA and ASM Int'l. Visit *www.asminternational.org/aeromat/website/default.htm.*

Coatings for Africa 2008. Aug. 19–21, Champagne Sports Resort, Central Drakensberg, Kwazulu-Natal, South Africa. E-mail *rosalie@coa.co.za;* visit *www.coatingsforafrica.org.za.*

2nd Int'l Orthotropic Bridge Conf. Aug. 25–29, Sacramento, Calif. Sponsored by the American Society of Civil Engineers. Visit *www.orthotropic-bridge.org;* call (916) 961-2723.

♦**Welding in Aircraft and Aerospace Conf.** Sept. 16, 17, Wichita, Kan. Contact American Welding Society (800/305) 443-9353, ext. 455; visit *www.aws.org/conferences.*

Canadian Manufacturing Week — Metal Finishing Expo. Sept. 23–25. Int'l Centre, Toronto, Canada. Society of Mfg. Engineers. Call (313) 425-3187; visit *www.sme.canada.ca/cmw.*

Guangzhou Int'l Trade Fair for Moldmaking and Tooling, Design, and Application Development. Sept. 24–26, Guangzhou Int'l Convention & Exhibition Center, Guangzhou, China. Visit *www.asiamold-china.com.*

♦**FABTECH International & AWS Welding Show.** Oct. 6–8, Las Vegas Convention Center, Las Vegas, Nev. This show is the largest event in North America dedicated to showcasing the full spectrum of metal forming, fabricating, tube and pipe, welding equipment, and technology. Contact American Welding Society, (800/305) 443-9353, ext. 455; visit *www.aws.org.*

♦**New Technologies in Thermal Cutting.** Oct. 6, Las Vegas Convention Center, Las Vegas, Nev. In conjunction with the FABTECH International & AWS Welding Show. Contact: American Welding Society, (800/305) 443-9353, ext. 455; visit *www.aws.org.*

♦**New Nondestructive Testing Technologies Conf.** Oct. 7, Las Vegas Convention Center, Las Vegas, Nev. In conjunction with the FABTECH International & AWS Welding Show. Contact American Welding Society, (800/305) 443-9353, ext. 455; visit *www.aws.org.*

♦ **Friction Stir Welding Conf.** Oct. 8, Las Vegas Convention Center, Las Vegas, Nev. In conjunction with the FABTECH International & AWS Welding Show. Contact American Welding Society, (800/305) 443-9353, ext. 455; visit *www.aws.org.*

ISR '08, 39th Int'l Symposium on Robotics. Oct. 15–17, COEX Convention Center, Seoul, Korea. Visit *www.isr08.org.*

ICALEO® 2008, 27th Int'l Congress on Applications of Lasers & Electro-Optics. Oct. 20–23. Pechanga Resort & Casino, Temecula, Calif. Laser Institute of America. Call (800) 345-2737, (407) 380-1553; visit *www.icaleo.org.*

♦ **Welding of Engineering Plastics and Composites Conf.** Nov. 11, 12. Contact American Welding Society (800/305) 443-9353, ext. 455, visit *www.aws.org/conferences.*

8th Int'l Symposium of the Japan Welding Society. Nov. 16–18, Kyoto, Japan. Visit *www.nta-aps.jp/8WS/.*

♦ **4th Int'l Brazing and Soldering Conf. (IBSC).** April 26–29, 2009, TBA. Contact American Welding Society, (800/305) 443-9353, ext. 455; visit *www.aws.org.*

JOM-15, 15th Int'l Conf. on the Joining of Materials, and **6th Int'l Conf. on Education in Welding.** May 3–6, 2009, Helsingør, Denmark. Contact JOM Institute, *jom_aws@post10.tele.dk.*

Educational Opportunities

AWS Certified Welding Supervisor (CWS) Examination (CWS 550), Preparation Course. A one-week-long course beginning June 23, Aug. 25, and Nov. 17. Contact Hobart Institute of Welding Technology, *www.welding.org;* call (800) 332-9448; (937) 332-5000.

Advanced Concepts in Laser Safety. Aug. 11–13, Orlando, Fla. Contact: Laser Institute of America. Call (800) 345-3737; visit *www.laserinstitute.org*.

Automotive Body in White Training for Skilled Trades and Engineers. Orion, Mich. A 5-day course covers operations, troubleshooting, error recovery programs, and safety procedures for automotive lines and integrated cells. Contact: Applied Mfg. Technologies. Call (248) 409-2000; visit *www.appliedmfg.com.*

Basic Plate and Sheet Metal Welding. A six-week course beginning on the following dates: June 23, Aug. 4, Sept. 15, Oct. 27. Courses presented at The Lincoln Electric Co., Cleveland, Ohio. Visit *www.lincolnelectric.com/knowledge/training/weldschool/courses.asp;* (216) 486-1751.

Boiler and Pressure Vessel Inspectors Training Courses and Seminars. Columbus, Ohio. Call (614) 888-8320; visit *www.nationalboard.org*.

CWI/CWE Course and Exam. This is a ten-day program. Contact: Hobart Institute of Welding Technology. Call (800) 332-9448; visit *www.welding.org*.

CWI/CWE Prep Course and Exam and NDT Inspector Training. Courses. An AWS Accredited Testing Facility. Courses held year-round in Allentown, Pa., and at customers' facilities. Contact: Welder Training & Testing Institute. Call (800) 223-9884, *info@wtti.edu;* visit *www.wtti.edu.*

CWI Preparation. Courses on ultrasonic, eddy current, radiography, dye penetrant, magnetic particle, and visual at Levels 1–3. Meet SNT-TC-1A and NAS-410 requirements. Contact: T.E.S.T. NDT, Inc. Call (714) 255-1500; visit *www.testndt.com.*

CWI Preparatory and Visual Weld Inspection Courses. Classes presented in Pascagoula, Miss., Houston, Tex., and Houma and Sulphur, La. Contact: Real Educational Services, Inc. Call (800) 489-2890; e-mail *info@realeducational.com*.

Environmental Health and Safety-Related Web Seminars. These 30-min-long Web seminars on various topics are online, real-time events conducted by industry experts. Most seminars are free. Visit *www.augustmack.com/Web%20Seminars.htm.*

EPRI NDE Training Seminars. EPRI offers NDE technical skills training in visual examination, ultrasonic examination, ASME Section XI, and UT operator training. Contact: Sherryl Stogner. Call (704) 547-6174; e-mail *sstogner@epri.com*.

Essentials of Safety Seminars. Two- and four-day courses are held at numerous locations nationwide to address federal and California OSHA safety regulations. Contact: American Safety Training, Inc. Call (800) 896-8867; visit *www.trainosha.com*.

Fabricators and Manufacturers Assn. and Tube and Pipe Assn. Courses. Call (815) 399-8775; visit *www.fmametalfab.org*.

Firefighter Hazard Awareness Online Course. A self-paced, ten-module certificate course taught online by fire service professionals teaches how to detect commonly encountered gas hazards. Fee is $195. Contact: Industrial Scientific Corp. Call (800) 338-3287; visit *www.indsci.com/serv_train_ffha_online.asp*.

Fundamentals of Brazing Seminars. A 2½-day course beginning Sept. 9, Toronto, Ont., Canada; Oct. 21, Milwaukee, Wis. Topics include technology overview, fundamental steps of brazing, braze design, filler metals, heating methods, and problem solving. Call

(414) 769-6000, ext. 505; visit *www.lucasmilhaupt.com.*
Gas Detection Made Easy Courses. Web-based and classroom courses for managing a gas monitoring program from technology of gas detection to confined-space safety. Contact: Industrial Scientific Corp. Call (800) 338-3287; visit *www.indsci.com/serv_train.asp.*

Hellier NDT Courses. Contact: Hellier, 277 W. Main St., Ste. 2, Niantic, CT 06357; (860) 739-8950; FAX (860) 739-6732.

Industrial Ventilation Conf. Oct. 13–15, Birmingham, Ala. Both lectures and hands-on problem sessions will be used to present step-by-step training in the design of ventilation systems. Visit *www.engineering.arizona.edu/ visitors/epd/conferences.html.*

Laser Safety Officer Training Courses. July 14–16, Nashville, Tenn.; Aug. 11–13, Denver, Colo.; Dec. 8–10, Orlando, Fla. Contact: Laser Institute of America. Call (800) 345-3737; visit *www.laserinstitute.org*.

NACE Int'l Training and Certification Courses. Contact: Nat'l Assoc. of Corrosion Engineers. Call (281) 228-6223; visit *www.nace.org*.

NDE and CWI/CWE Courses and Exams. Welder Training and Testing Institute, Allentown, Pa., and at customer's facility, nationwide. Call (800) 223-9884; visit *www.wtti.edu.*

Laser Safety Officer with Hazard Analysis Training June 9–13, Chicago, Ill.; Sept. 15–19, San Francisco, Calif.; Nov. 3–7, Boston, Mass. Contact: Laser Institute of America. Call (800) 345-3737; visit *www.laserinstitute.org*.

Certification Seminars, Code Clinics and Examinations

Application deadlines are six weeks before the scheduled seminar or exam. Late applications will be assessed a $250 Fast Track fee.

ertified Welding Inspector (CWI)

OCATION	SEMINAR DATES	EXAM DATE
hoenix, AZ	Jun. 22-27	Jun. 28
rlando, FL	Jun. 22-27	Jun. 28
iami, FL	EXAM ONLY	Jul.17
os Angeles, CA	Jul. 13-18	Jul. 19
ouisville, KY	Jul. 13-18	Jul. 19
orpus Christi, TX	EXAM ONLY	Jul. 19
eaumont, TX	Jul. 20-25	Jul. 26
ilwaukee, WI	Jul. 20-25	Jul. 26
leveland, OH	Jul 27-Aug. 1	Aug. 2
enver, CO	Jul 27-Aug. 1	Aug. 2
hiladelphia, PA	Jul 27-Aug. 1	Aug. 2
iami, FL	Aug. 3-8	Aug. 9
an Diego, CA	Aug. 3-8	Aug. 9
harlotte, NC	Aug. 10-15	Aug. 16
an Antonio, TX	Aug. 10-15	Aug. 16
ochester, NY	EXAM ONLY	Aug. 16
akersfield, CA	Aug. 17-22	Aug. 23
ortland, ME	Aug. 17-22	Aug. 23
alt Lake City, UT	Aug. 17-22	Aug. 23
ouston, TX	Sept. 7-12	Sept. 13
ittsburgh, PA	Sept. 7-12	Sept. 13
eattle, WA	Sept. 7-12	Sept. 13
iami, FL	EXAM ONLY	Sept. 18
as Vegas, NV	Sept. 14-19	Sept. 20
inneapolis, MN	Sept. 14-19	Sept. 20
t. Louis, MO	Sept. 14-19	Sept. 20
orpus Christi, TX	EXAM ONLY	Sept. 20
nchorage, AK	EXAM ONLY	Sept. 20
iami, FL	Oct. 19-24	Oct. 25
ew Orleans, LA	Oct. 19-24	Oct. 25
ulsa, OK	Oct. 19-24	Oct. 25
ong Beach, CA	Oct. 26-31	Nov. 1
ewark, NJ	Oct. 26-31	Nov. 1
ortland, OR	Oct. 26-31	Nov. 1
leveland, OH	Nov. 2-7	Nov. 8
tlanta, GA	Nov. 16-21	Nov. 22
allas, TX	Nov. 16-21	Nov. 22
oanoke, VA	Nov. 16-21	Nov. 22
orpus Christi, TX	EXAM ONLY	Nov. 22
acramento, CA	Nov. 30-Dec. 5	Dec. 6
pokane, WA	Nov. 30-Dec. 5	Dec. 6
yracuse, NY	Nov. 30-Dec. 5	Dec. 6
t. Louis, MO	EXAM ONLY	Dec. 6
iami, FL	Dec. 7-12	Dec. 13
eno, NV	Dec. 7-12	Dec. 13

For information on any of our seminars and certification programs, isit our website at **www.aws.org/certification** or contact AWS at (800/305) 43-9353, Ext. 273 for Certification and Ext. 455 for Seminars. Please **pply early** to save Fast Track fees. **This schedule is subject to change ithout notice.** Please verify the dates with the Certification Dept. and onfirm your course status before making final travel plans.

9-Year Recertification Seminar for CWI/SCWI

LOCATION	SEMINAR DATES	EXAM DATE
Orlando, FL	Sept. 8-13	NO EXAM
Dallas, TX	Oct. 20-25	NO EXAM
Miami, FL	Dec. 1-6	NO EXAM

For current CWIs and SCWIs needing to meet education requirements without taking the exam. If needed, recertification exam can be taken at any site listed under Certified Welding Inspector.

Certified Welding Supervisor (CWS)

LOCATION	SEMINAR DATES	EXAM DATE
Minneapolis, MN	Jun. 23-27	Jun. 28
Atlanta, GA	Jul. 14-18	Jul. 19
Philadelphia, PA	Aug. 18-22	Aug. 23
Atlanta, GA	Sept. 15-19	Sept. 20
Tulsa, OK	Oct. 20-24	Oct. 25
Atlanta, GA	Nov. 17-21	Nov. 22
Long Beach, CA	Dec. 8-12	Dec. 13

CWS exams are also given at all CWI exam sites.

Certified Radiographic Interpreter (CRI)

LOCATION	SEMINAR DATES	EXAM DATE
St. Louis, MO	Aug. 18-22	Aug. 23
Denver, CO	Sept. 15-19	Sept. 20
Philadelphia, PA	Oct. 20-24	Oct. 25
Seattle, WA	Nov. 17-21	Nov. 22
Jacksonville, FL	Dec. 8-12	Dec. 13

Radiographic Interpreter certification can be a stand-alone credential or can exempt you from your next 9-Year Recertification.

Certified Welding Educator (CWE)

Seminar and exam are given at all sites listed under Certified Welding Inspector. Seminar attendees will not attend the Code Clinic portion of the seminar (usually first two days).

Senior Certified Welding Inspector (SCWI)

Exam can be taken at any site listed under Certified Welding Inspector. No preparatory seminar is offered.

Code Clinics & Individual Prep Courses

The following workshops are offered at all sites where the CWI seminar is offered (code books not included with individual prep courses): Welding Inspection Technology (general knowledge and prep course for CWI Exam-Part A); Visual Inspection Workshop (prep course for CWI Exam-Part B); and D1.1 and API-1104 Code Clinics (prep courses for CWI Exam-Part C).

On-site Training and Examination

On-site training is available for larger groups or for programs customized to meet specific needs of a company. Call ext. 219 for more information.

International CWI Courses and Exams

AWS training and certification for CWI and other programs are offered in many countries. For international certification program schedules and contact information, please visit *http//:www.aws.org/certification/inter_contact.html*

American Welding Society

Friends and Colleagues:

I want to encourage you to submit nomination packages for those individuals whom you feel have a history of accomplishments and contributions to our profession consistent with the standards set by the existing Fellows. In particular, I would make a special request that you look to the most senior members of your Section or District in considering members for nomination. In many cases, the colleagues and peers of these individuals who are the most familiar with their contributions, and who would normally nominate the candidate, are no longer with us. I want to be sure that we take the extra effort required to make sure that those truly worthy are not overlooked because no obvious individual was available to start the nomination process.

For specifics on the nomination requirements, please contact Wendy Sue Reeve at AWS headquarters in Miami, or simply follow the instructions on the Fellow nomination form in this issue of the *Welding Journal*. Please remember, we all benefit in the honoring of those who have made major contributions to our chosen profession and livelihood. The deadline for submission is July 1, 2008. The Committee looks forward to receiving numerous Fellow nominations for 2009 consideration.

Sincerely,

Nancy C. Cole
Chair, AWS Fellows Selection Committee

SOCIETY NEWS

BY HOWARD M. WOODWARD

The Many Faces of AWS Technical Volunteers

Welding Journal ***asked several AWS Technical Committee members to comment on what they derive from working on these committees. Their replies are presented here***

A D1K and International Committee Member Finds Satisfaction in Volunteer Work

Damian Kotecki is an AWS past president and a past chair of the A5 Committee on Filler Metals and Allied Materials, among many other volunteer positions.

Kotecki said, "I've worked on a number of AWS and international ISO standards over the last 30 years. There are two that have a special place in my heart — ISO 2560, because it took 25 years to overcome all of the objections, primarily from Europe, to get it published, and AWS D1.6, *Structural Welding Code — Stainless Steel.* Development of the original D1.6 and the first revision of it are special to me because we in the D1K Subcommittee 11 on Stainless Steel Welding took an existing framework (D1.1, *Structural Welding Code — Steel*) and totally remodeled it to bring out a new code. In D1.6, there is little concern for hydrogen-induced cracking and hydrogen control, but we instead were concerned with solidification cracking and ferrite control.

"The first publication, warts and all, proved to be a useful tool for the building industry, and it has been very satisfying to me to see the document being called out in construction contracts.

"The first revision of D1.6 has, I believe, removed most of the warts, and has significantly enhanced the utility of the code. It features major additions such as the table of 'Suggested Filler Metals for Various Combinations of Stainless Steel and Other Ferrous Base Metals,' which spans 21 pages. It has been a joy to work with the many volunteers in developing this code."

Damian Kotecki

D14 and A5 Committee Members Tell Why They Serve

Tom Landon, manager, corporate welding technologies, CB&I, Plainfield, Ill., said, "I became active on the D14 Technical Committees for Machinery and Equipment more than ten years ago when I was managing my company's fleet of construction equipment. After experiencing some problems with welding quality on certain pieces of equipment, CB&I felt it was good business to have a voice in the requirements for the fabrication and manufacture of the equipment we rely upon to do our work. I made inquiries into the activities of AWS code committee members and eventually volunteered to serve on both the main D14 Committee for Machinery and Equipment and its D14C Subcommittee. The D14C Subcommittee authors D14.3, *Specification for Welding Earthmoving, Construction, and Agricultural Equipment.*

"My role on both of these committees is to represent 'users' of construction equipment in the development and application of welding technology. My input is taken into consideration along with that from other users, from manufacturers of the equipment, and from general interest welding experts in an effort to supply guidance and direction to those in the business of manufacturing this classification of equipment. I have found the experience to be extremely gratifying both from a personal and professional perspective. The peers who make up the committees on which I work are leading professionals in their businesses and in their areas of technology. The work is professional with no thought given to agendas or personal interests. The people are like minded in their interest to see the welding profession developed and strengthened. I intend to continue my volunteer work throughout my professional career."

Tom Landon

Dave Fink

Dave Fink, manager, compliance engineering (consumables), The Lincoln Electric Co., Cleveland, Ohio, said, "I have been involved in AWS technical committee work for well over 30 years and an active member of the A5 Committee on Filler Metals and Allied Materials for more than 20 years, being the immediate past Chair. I am also a member of TAC, ISAC, and am the U.S. Delegate to ISO TC44 SC3 and IIW Commission II.

"I first started working on AWS com-

— D14 continued on next page

— D14 continued from page 85

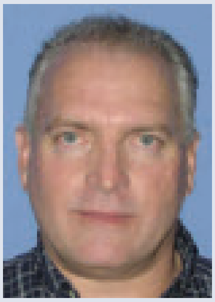
mittees because my boss at the time here at Lincoln Electric, Bob Shutt, wanted me to substitute for him at various subcommittee and working group meetings. I remember vividly his advice prior to my attending my first meeting: 'All you have to remember is to do what is best for the welding industry, and everyone will benefit.' That advice has been foremost in my mind through all the committee activities, both U.S. and international, that I have been involved in throughout my career. To my mind, it is impossible to overestimate the value of participation in the work of technical committees. From a commercial standpoint, we work and do business in a world that increasingly relies on standards and regulations to protect public welfare and safety and to deal with international commerce issues, to name just a few. To put it bluntly, you cannot complain about the decisions made or the decision-making process if you do not take every opportunity to participate and 'take a seat at the table.' My work on technical committees, both AWS and international, has given me personal opportunities I would never have thought possible when I began my career in the welding industry 37 years ago. I have been privileged to meet and become friends with and be mentored by many of the leaders and 'giants' in our industry and have benefitted immensely from the professional networking that takes place. My work on international standards over the last 20 years has provided me the opportunity to travel all over the world and extend my technical contacts accordingly. I have to be clear on the fact that I have been able to maintain these activities only by the strong support of The Lincoln Electric Co. I am extremely fortunate that corporate management is convinced of the benefits to be derived from a long-term commitment to these activities, both domestic and international."

B2 and C1 Chairs Promote Their Committees' Work

Jeff Fluckiger, recently elected chairman of the B2 Committee on Procedure and Performance Qualification, said, "I would certainly like to promote a spotlight on the AWS B2 Committee. We committee members are pursuing a long-needed consolidation of a standard method for qualifying weld procedures and performers and this could be a vehicle to boost that effort. May I refer you to the abstracts of papers for the 1997 AWS Annual Meeting in Los Angeles. The B2 Committee presented in Session E4, pages 266–270, providing a historical and application perspective of 'one standard.'

"As the chairman of the AWS B2 Committee, I endorse the AWS Board of Directors' and the Technical Activities Committee's efforts and actions to consolidate procedure and performance qualification into one standard, and commit to doing so. We have made great strides with several application codes that now refer to B2. I look forward to working with committees that are struggling with consolidation in order to provide a product that is usable and useful to the industry while maintaining sufficient technical control of the critical variables.

"I commend the members of the B2 committee and the work effort they have provided over the past several years. Past chairmen remain active on the committee because they see the value and the expected benefit of consolidation. The staff



Jeff Fluckiger

Nigel Scotchmer

members at AWS headquarters have been great to work with and kudos should be given to Staff Engineer and B2 Staff Secretary Selvis Morales for her assistance.

"The B2 Specification is a well thought out method for validating mechanical property compatability of base and filler metals and testing and evaluating the ability of welding machines and welding operators in order to provide an increased level of confidence that the work will meet requirements and meet customer expectations. As science and technology advance, the B2 Specification will incorporate information to keep pace. To do so will require those in industry to participate and volunteer to work on the committee.

"I find that my participation on the AWS standards committees is extremely rewarding. I associate with the top professionals in the world, discuss common issues, find solutions to problems and provide my employer with the current, state-of-the-art information."

In summary, he said, "I must have a nut or two loose, though, when I find myself reading AWS standards during a Christmas break."

Nigel Scotchmer, president of Huys Industries, chairs the C1 Committee on Resistance Welding. He has been involved with preparing AWS and SCC (Standards Council of Canada) technical documents for about ten years. He has also been very active with WEMCO (Welding Equipment Manufacturers Committee) and helped to establish the initial ISO fund.

Regarding his C1 Committee work, Scotchmer said that in addition to networking and meeting new people and new customers, he has gained new perspectives from other professionals that "adds to my own understanding and greatly enriches my knowledge. After all," he added, "most of our lives are spent at work, so it makes work that much more interesting when I can gain new, or richer, understanding through different perspectives." Scotchmer said, "I think it is very rewarding to get involved in AWS technical committees, and I strongly recommend that AWS members to get involved, since AWS was the first to start the process of writing welding standards anyway!"

D10 Chair Touts the Committee's 'How to' Recommended Practices

Michael Lang, chair, D10 Committee on Piping and Tubing, and a CWI, is dedicated to producing recommended practice documents that address pipe and tube welding. "The committee," he said, "is proud to have some of the most talented people in the welding industry as members. Several of our members are world-renowned experts in their fields. But what makes D10 truly work is the diversity of its membership.

"D10 has published many documents on different processes. In recent years, the committee has taken a progressive approach in new areas such as orbital welding, fabrication of vehicle frames for the automotive industry, and welding different alloys. D10 recently released D10.7M/D10.7, *Guide for the Gas Shielded Arc Welding of Aluminum and Aluminum Alloy Pipe.* Read more about this document in the article on page 90.

The Committee's documents include:

D10.4, *Recommended Practices for Welding Austenitic Chromium-Nickel Stainless Steel Pipe and Tubing*

D10.6, *Recommended Practices for Gas Tungsten Arc Welding of Titanium Piping and Tubing*

D10.7, *Recommended Practices for Gas Shielded Arc Welding of Aluminum and Aluminum Alloy Pipe*

D10.8, *Recommended Practices for Welding of Chromium-Molybdenum Steel Piping and Tubing*

D10.10, *Recommended Practices for Local Heating of Welds in Piping and Tubing*

D10.11, *Recommended Practices for Root Pass Welding of Pipe without Backing*

D10.12, *Recommended Practices for Welding Mild Steel Pipe*

D10.13, *Recommended Practices for Brazing of Copper Pipe and Tubing for Medical Gas Systems*

D10.14, *Recommended Practices for Orbital Machine Welding Refining and Petrochemical* (in process)

D10.17, *Recommended Practices for Tubular Steel Vehicular Structures* (in process)

D10.18, *Guide for Welding Duplex Stainless Steel Pipe and Tubing* (in process)

D10.21, *Guide for Welding High-Performance CrMo Alloys* (in process)

"If you want join a 'how-to' Committee," Lang said, "I invite you to check out the D10 Committee on Pipe and Tube Welding."

Peaslee Recalls the Early Days of Brazing Handbook

In 1947, Bob Peaslee was the welding engineer at Wright Aeronautical Corp., division of Curtiss-Wright Corp., working on the development of jet engines. "I joined the American Welding Society at this time, in order to increase my knowledge of welding processes."

That same year, Wright Aeronautical decided to develop brazing techniques similar to those the Germans used during WWII for brazing turbine blades.

"I was given the task of developing a program for brazing of stainless steel and heat-resistant base metals without using any flux. At that time, I could only find three engineers in research laboratories who were able to process these base metals in a furnace atmosphere that would allow the brazing filler metal to flow and braze, and the parts to come out of the furnace bright and clean.

"The only high-temperature brazing filler metal available was 85 Ag-15 Mn, which had been brought to the United States from Germany, after WW II, by Handy & Harmon. We were able to produce good brazed joints with this filler metal; however, the U.S. jet engines were operating hotter and, when the jet engine overheated, the 85 Ag-15 Mn filler metal would melt and be blown out of the joint. The engineers asked for a brazing filler metal that would braze at normal brazing temperatures, and after brazing, would not remelt at higher temperatures. This led to the invention of a Ni-Cr-Si-B brazing filler metal that had the desired properties — a normal brazing temperature and a much higher remelt temperature. A three-year research program verified the usefulness of this brazing filler metal in the jet engine. A year after the Wright Aero division closed, I left.

"On May 1, 1950, I joined Wall Colmonoy Corp. in Detroit, Mich., and soon after, joined the AWS Committee on Brazing and Soldering whose members were in the process of writing the first *Brazing Manual.* At that time, brazing was defined as a welding process. I do not have any records that indicate a name for this committee, or if it was specified as the C3 Committee.

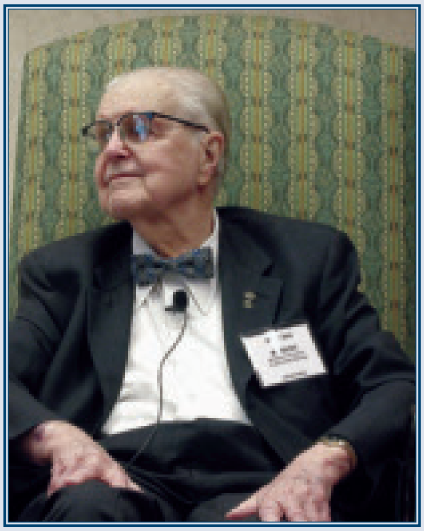
"All the committee's meetings were held in New York City at the AWS headquarters at 33 W. 39th St., in the garment district. The AWS secretary for this committee was **S. A. Geenberg.** I wrote the chapter on high-temperature brazing titled "Heat Resistant Alloys" for the first *Brazing Manual,* published in 1955. When the committee finished its work, the Committee on Brazing and Soldering was disbanded, and no more meetings were planned.

"Around 1959, AWS decided that the *Brazing Manual* should be revised and updated. A new Brazing and Soldering Committee was organized to work on the revisions. During this time, the AWS headquarters was moved to the United Engineering Center, 345 E. 47th St., in New York City. At that time, the AWS secretary of the Brazing and Soldering Committee was **Edward A. Fenton.** The second edition of the *Brazing Manual* was published in 1963, and again, when the committee completed its work, the committee was disbanded.

"In 1967 or early 1968, Secretary Fenton asked me to take the chairmanship of the Committee on Brazing and Soldering. At this time, AWS had decided to move the Society out of New York City and the United Engineering Center. Fenton suggested that I get a new group of volunteers together, but not start on the next edition of the *Brazing Manual* until AWS had found a new location and moved.

"The AWS board of directors appointed a search committee to find a new location, and they looked everywhere. The decision was made to move to Florida, where many of the engineers were retiring, and there was plenty of support help available. The Society bought an unused church at 2501 NW 7th St., Miami, Fla., and moved in.

"The AWS C3 Committee on Brazing and Soldering was officially established on June 1, 1968, with 33 members. Its membership grew to 41 members by the time the third addition of the *Brazing Manual* was published. During this time, **Tony J. Olivera** was the AWS technical secretary for the C3 Committee. I organized six subcommittees to start collecting data for the next edition.



Bob Peaslee is shown at the 3rd International Brazing & Soldering Conference (IBSC), held April 23–26, 2006, in San Antonio, Tex.

"Since we had much to do, I planned three-day meetings twice a year, with a Friday afternoon plant tour through the brazing facilities of the company that was hosting the committee. Various chapters of the *Brazing Manual* were assigned to the volunteers to revise, update, and bring to the next meeting. It had been customary to review each chapter line by line, so that the widely diverse brazing committee members could comment and suggest engineering changes. Each member was an expert in a particular field, but few knew all of the requirements of all fields. These reviews became a learning experience for most of the members, and this procedure was used when writing the first *Brazing Manual.* It was also used when revising the second *Brazing Manual*, and continued through the third *Brazing Manual* revision.

"Since I was the chair of the newly constituted C3 Committee, my primary task after AWS moved to Florida was to have the committee review and update the

Brazing Manual. I assigned the Design chapter to myself, and the other members selected their chapters. The original author of the Design chapter in the first *Brazing Manual* felt joint design fell into two categories — good and bad. I did not like that connotation, and took exception. In the second edition of the *Brazing Manual,* the author humored me by characterizing the Brazed Joint Design as "recommended" and "not recommended." However, I believed those weren't the proper classifications.

"Some years earlier, I had been asked to present a brazing paper at the Society of Mechanical Engineers, of which I was a member. Since I would be speaking to the designers and mechanical engineers, I chose to write a detailed paper on the *Design of Brazed Joints* because at that time, most braze failures were design failures. With a few updates, the ASME paper fit in to the Design chapter in the third edition of the *Brazing Manual*.

"The third edition of the *Brazing Manual* was approved by the AWS board of directors Feb. 25, 1975, and published in 1976. My six years (two terms) as chairman were completed May 31, 1974. Little progress on chapter revisions was realized for a number of years despite the efforts of several different chairmen. The members' company assignments took presidence to the *Brazing Manual* work. After seeing no progress, I offered to be the whip on the project. A dedicated push resulted in the 4th edition of the text, renamed *Brazing Handbook,* being published in hardcover in 1991.

"In 2001, **Cynthia Jenney,** who previously worked with the Welding Handbook Committee, was assigned as staff secretary for the C3 Committee. Her assignment was to work with the committee to update, develop, and publish a vastly expanded and updated 5th edition of the *Brazing Handbook*. Until her untimely death, she worked tirelessly to ensure the best technical writing.

"The 5th edition of the *Brazing Handbook* was published earlier this year with **Stephen Borrero,** AWS staff engineer, serving as C3 secretary."

Robert L. Peaslee (bobpeaslee@wallcolmonoy.com) *is vice president emeritus, Wall Colmonoy Corp., Madison Heights, Mich. His column, Brazing Q&A, appears bimonthly in the* Welding Journal.

The *Brazing Handbook,* as well as all AWS publications, may be purchased in the United States and Canada from World Engineering Xchange (WEX), Ltd. Visit *www.awspubs.com,* e-mail *orders@awspubs.com,* or call toll-free (888) 935-3464; elsewhere, call (305) 824-1177.

A catalog listing all American Welding Society standards and documents can be downloaded from the AWS Web site, *www.aws.org/catalogs.* ♦

Tech Topics

AWS was approved as an accredited standards-preparing organization by the American National Standards Institute (ANSI) in 1979. AWS rules, as approved by ANSI, require that all standards be open to public review for comment during the approval process. Draft copies of AWS national standards may be obtained from Rosalinda O'Neill, (800/305) 443-9353, ext. 451, *roneill@aws.org.* The review expiration is shown.

New Standard Project

Development work has begun on revised standard F1.6:200X, *Guide for Estimating Welding Emissions for EPA and Ventilation Permit Reporting.*

This document will assist companies in estimating emissions from welding processes for EPA reporting purposes by choosing the simplest applicable method and following its steps. Example calculations are included. Stakeholders: Companies required to estimate emissions from welding operations.

Affected persons are invited to contribute to its development. Contact staff engineer Steven Hedrick, ext. 305.

Errata A5.02/A5.02M:2007

Specification for Filler Metal Standard Sizes, Packaging, and Physical Attributes

The following error has been identified and incorporated in the current reprint of this document.

Page 3, left-hand column: Change subclause numbers 4.2.1 and 4.2.2 to 4.1.1 and 4.1.2, respectively. Corrected subclause numbers are shown in italic font on page 3.

Standards for Public Review

B1.10:200X, *Guide for the Nondestructive Examination of Welds.* Revised — $28. 6/16/08.

D1.1/D1.1M:2008, *Structural Welding Code — Steel.* Revised — $262. Fourth BSR-8. 6/2/08.

D1.2/D1.2M:200X, *Structural Welding Code — Aluminum.* Revised — $112. Second BSR-8. 6/16/08.

D3.9:200X, *Specification for Classification of Weld-Through Paint Primers.* New — $25. 6/16/08.

D10.10/D10.10M:200X, *Recommended Practices for Local Heating of Welds in Piping and Tubing.* Revised — $57.50. 6/16/08.

ISO Standards for Public Review

Copies of the following draft International Standards are available for review and comment through your national standards body, which in the United States is ANSI, 25 W. 43rd St., 4th Fl., New York, NY 10036; (212) 642-4900. Any comments regarding ISO documents should be sent to your national standards body. In the United States, if you wish to participate in the development of International Standards for welding, contact Andrew Davis, *adavis@aws.org;* (305) 443-9353, ext. 466. Otherwise contact your national standards body.

ISO/DIS 6947 — *Welds — Working positions — Definitions of angles of slope and rotation*

ISO/DIS 11666 — *Nondestructive testing of welds — Ultrasonic testing of welded joints — Acceptance levels*

ISO/DIS 17635 — *Nondestructive testing of welds — General rules for metallic materials*

ISO/DIS 17640 — *Nondestructive testing of welds — Ultrasonic testing of welded joints — Methods and testing levels*

ISO/DIS 23279 — *Nondestructive testing of welds — Ultrasonic testing — Characterization of indications in welds.*

Standards Approved by ANSI

C7.4/C7.4M:2008, *Process Specification and Operator for Laser Beam Welding.* New standard. 3/13/08.

A5.01M/A5.01:2008 (ISO 14344:2002 MOD), *Procurement Guidelines for Consumables — Welding and Allied Processes — Flux and Gas Shielded Electrical Welding Processes.* Revised. 4/4/08.

Technical Committee Meetings

All AWS technical committee meetings are open to the public. Persons wishing to attend a meeting should dial (305) 443-9353 and the extention of the staff secretary of the committee listed below.

June 18, Safety and Health Committee. Columbus, Ohio. Contact: S. Hedrick, ext. 305.

July 25, Committee on Personnel and Facilities Qualification. Pittsburgh, Pa. Contact: J. Gayler, ext. 472.

Technical Committee Help Wanted

C5: Arc Welding

The C5 Committee on Arc Welding and Cutting seeks volunteers to assist in the preparation of its recommended practices. Much of the content of the *Welding Handbook* chapter on arc welding and cutting processes is taken from these documents. Contact John Gayler, (800) 443-9353, ext. 472; *gayler@aws.org*.

J1: Resistance Welding

Share your expertise by contributing to the development of AWS standards. Volunteers are needed by the J1 Committee on Resistance Welding Equipment to help prepare standards related to RW consumables, components, and machinery. Contact Annette Alonso, (800) 443-9353, ext. 299; *aalonso@aws.org*.

D1I : Reinforcing Bars

Volunteers are sought to serve on the D1I Subcommittee on Reinforcing Bars. Members are currently revising D1.4, *Structural Welding Code — Reinforcing Steel.*

To learn more about how you can contribute to this committee's work, contact Selvis Morales, (800) 443-9353, ext. 313; *smorales@aws.org.*

Dave Fink Honored by A5 Filler Metals Committee

A5 Chair Jon Lee (left) presents Dave Fink an appreciation plaque for serving as chairman of the A5 Committee on Filler Metals and Allied Materials from June 1, 2001, through Dec. 31, 2007. His plaque reads, "Presented to David A. Fink in appreciation of your professionalism and tireless efforts in the advancement of welding technology and the AWS A4 and A5 specifications."

Nominees Solicited for Prof. Masubuchi Award

November 3 is the deadline for submiting nominations for the 2009 Prof. Koichi Masubuchi Award. The award is presented each year to one person, 40 years old or younger, who has made significant contributions to the advancement of materials joining through research and development. The award, presented during the FABTECH International & AWS Welding Show, includes a $5000 honorarium. Send a résumé listing background, experience, publications, honors, awards, plus at least three letters of recommendation from researchers to Prof. John DuPont, *jnd@lehigh.edu.* The award is sponsored by the Dept. of Ocean Engineering at Massachusetts Institute of Technology.

AWS Publishes First-Ever Aluminum Welding Q&A Resource Guide

Welding Aluminum — Questions and Answers, by Tony Anderson, was developed as a practical guide for troubleshooting aluminum welding problems. The book touches on the dramatic changes in aluminum welding due to the emergence of new welding techniques and advanced materials. It includes chapters on the advancement of aluminum and aluminum welding within several manufacturing industries, an overview of aluminum alloys and metallurgy, aluminum welding discontinuities, weld testing, processes, procedures, and codes and standards. The book also provides an overview of the history of aluminum welding and common welding processes.

Aluminum is one of the most widely used metals due to its light weight and versatility, but it can also present a host of challenges for even the most skilled welders. This first-of-its-kind resource manual includes a comprehensive listing of frequently asked questions and answers, general information and guidelines, and feature articles on welding aluminum.

Author Tony Anderson is a 40-year welding industry veteran. His numerous technical articles relating to welding engineering have been published in various journals and magazines worldwide, including a bimonthly column in *Welding Journal.* He is an AWS Certified Welding Engineer, Certified Welding Inspector, Certified Welding Educator, and a Registered Chartered Engineer with the British Engineering Council. He is the chairman of the Aluminum Association Technical Advisory Committee for Welding.

Welding Aluminum — Questions and Answers contains 192 pages, eight chapters, ten reference tables, and 77 figures. The list price is $124, $93 to AWS members. It is available in print and electronic formats.

All AWS publications may be purchased from World Engineering Xchange (WEX) online at *www.awspubs.com;* or call toll-free in the United States and Canada (888) 935-3464; elsewhere, call (305) 824-1177; or FAX (305) 826-6195.

Nominees Sought for Robotic Arc Welding Awards

December 31 is the deadline for submitting nominations for the 2009 Robotic and Automatic Arc Welding Award. The award consists of a $1500 honorarium and a plaque. Funded by private contributions, the award is presented during the FABTECH International & AWS Welding Show. It recognizes individuals for their achievements in the area of robotic arc welding, including the introduction of new technologies, establishment of the proper infrastructure (training, service, etc.) to enable success, and any other activity that significantly improved the state of a company and/or industry.

The nomination packet should include a summary of the candidate's accomplishments, professional experience, publications, and awards. Send your nomination package to Wendy Sue Reeve, 550 NW LeJeune Rd., Miami, FL 33126. Contact Reeve at *wreeve@aws.org,* or call (800/305) 443-9353, ext. 293.

The award was established in 2004 by the AWS D16 Robotic and Automatic Arc Welding Committee, with the approval of the AWS board of directors.

Welding Aluminum Alloy Pipe Guide Published

BY TONY ANDERSON
D10.7 Committee chair

The AWS D10 Committee on Piping and Tubing has approved a 4th edition of D10.7M/D10.7, *Guide for the Gas Shielded Arc Welding of Aluminum and Aluminum Alloy Pipe.* This fourth edition has been revised to include a new comprehensive guide for the selection of filler metals. Fifty-six different base metals are organized into 17 groups as the basis for selection from 13 filler metals that are evaluated against six weld attributes. As stated in Section 7.3 of the standard, often it is possible to weld one specific aluminum base alloy with a number of different filler metals, and in order to select the most appropriate filler for a particular application, we need to understand the various filler metals and their specific performance characteristics. Also, the selection of filler metals for welding aluminum must be based on the welded component's performance requirements and the completed component's operating conditions. This new section provides detailed discussion on filler metal selection based on weldability, the relative freedom from weld cracking, strength of welded joint, ductility, corrosion resistance, sustained temperature service, color match after anodizing, and postweld heat treatment. In addition, typical longitudinal and transverse shear strengths are provided for nine aluminum filler metals. Also contained in this section is information about some general considerations with regard to filler metal selection for specific applications.

The purpose of this guide is to facilitate the selection and specification of welding processes and procedures for aluminum and aluminum alloy pipe. This recommended practice has been prepared by the Subcommittee on Aluminum Piping of the AWS Committee on Piping and Tubing and is intended to provide information that may be used to minimize or avoid difficulties in the welding of such pipe. The data given in this document are presented as initial guides to operating conditions. The first edition of this document, AWS D10.7-60, was written to present the advances made in aluminum pipe welding during and subsequent to WW II. The second edition, D10.7-86, updated AWS D10.7-60. The AWS D10.7M/D10.7:2000, third edition, changed the document from a Recommended Practice to a Guide and updated the processes and procedures. The most significant change in the fourth edition is the inclusion of the comprehensive guide for the selection of filler metal. In addition to the new filler alloy selection chart and associated information, the Standard introduces the reader to the properties of aluminum that are important to the successful welding operation. Specific WPS guidance, including joint designs, is provided with a discussion of welding technique and heat treatment considerations that are unique to welding aluminum alloys. This new standard has 31 pages, five figures, and 13 tables, and is NASA Preferred and ANSI approved.

All AWS publications may be purchased in the United States and Canada from World Engineering Xchange (WEX), Ltd. Visit *www.awspubs.com,* e-mail *orders@awspubs.com,* or call toll-free (888) 935-3464; elsewhere, call (305) 824-1177. A catalog listing all AWS standards and documents can be downloaded from the AWS Web site, *www.aws.org/catalogs.*

New AWS Supporters

Affiliate Companies

ACME Machine & Welding
PO Box 1099, Punxsutawney, PA 15767

Blount Boats Inc.
461 Water St.
Warren, RI 02885

Dogwood Industries
PO Box 1491
Woodinville, WA 98072

Eastland Fabrication LLC
14273 Illinois Rte. 73
Lanark, IL 61046

General Dynamics Ordnance and Tactical Systems
1200 N. Glenbrook Dr.
Garland, TX 75040

Heffernan Insurance Brokers
499 NW 70th Ave., Ste. 106
Plantation, FL 33317

HIBROENG
Ste. 9063, PO Box 0832-1665
World Trade Center, Panama

Jain Welding Electrodes Pvt. Ltd.
G-1-318-C, Rd. No. 6 I.P.I.A.
Kota Rajasthan 324-005, India

Maynard Inc.
7175 S. McGuire
Fayetteville, AR 72704

Meldrum Mechanical Services
4455 S. Ave.
Toledo, OH 43615

Power Plant Service Inc.
#1 PPSI Cir.
Charleston, WV 25312

Radian Communications Services, Inc.
6718 W. Plank Rd., Peoria, IL 61604

S2M Steel Detailing
2399 E. 24 N.
Idaho Falls, ID 83401

Scott Heavy Equipment, Inc.
6100 Hanson Rd.
Madisonville, KY 42431

Somerset Welding & Steel Inc.
10558 Somerset Pike
Somerset, PA 15501

Superior Welding Service Inc.
2061 Paco Rd.
Henderson, NV 89011

Membership Counts

Member Grades	As of 5/1/08
Sustaining	495
Supporting	318
Educational	453
Affiliate	430
Welding distributor	51
Total corporate members	**1,747**
Individual members	48,224
Student + transitional members	5,112
Total members	**53,336**

The Welding Expert
41 Birch Dr.
Plainview, NY 11803

Welding Metallurgy, Inc.
110 Plant Ave.
Hauppauge, NY 11788

Sustaining Member Companies

American Spaceframe Fabricators International
443 SW 54th Ct., Ocala, FL 34474
www.asfi.net
Representative: **Bernard H. Coyle Jr.**

American Spaceframe Fabricators International (ASFI) develops creative tension fabric structure designs to meet client's specific needs and budgets.

Bourque Industrial Ltd.
85 Industrial Dr.
Saint John, NB E2R 1A4, Canada
www.bourqueindustrial.com
Representative: **Jack MacQuarrie**

Since 1946, the Bourque name has reprepresented steel manufactured products of the highest quality with exceptional services. Its advanced equipment and highly trained personnel enable the company to meet the most demanding schedules and requirements.

Burtek Inc.
50405 Patricia
Chesterfield, MI 48051
www.burtekinc.com
Representative: **Steve Esders**

Burtek is a highly competent engineering and manufacturing defense contractor with 21 years of experience. Its extensive experience in supplying specialized equipment and services to defense contractors including Northrop Grumman, Lockheed Martin, Raytheon, AM General, ITT Gilfillan, General Dynamics, Harris Corp., and Tacom.

Cete Apave Sudeurope
Z.I. Av. Gay Lussac
33370 Artigues-pres-Bordeaux, France
Representative: **Nicolas Markov Odin**

Apave offers services in inspection, technical assistance, construction, civil engineering, training, and consulting. It has 120 agencies, eight laboratories and test centers, and 100 training platforms in France. With the support of its subsidiary network and partnerships, it conducts missions in 98 countries worldwide.

Computers Unlimited
2407 Montana Ave.
Billings, MT 59101
Representative: **Heidi Thometz**

Computers Unlimited offers the TIMS fully integrated software system for industrial, specialty gas, and welding supply distributors. Its applications include cylinder tracking and management, integrated order entry for gases, hard goods, rental equipment, inventory, warehouse management, and truck routing.

Cornell Welding & Fabricating Ltd.
960 Keyes Dr.
Woodstock, ON N4S 0A7, Canada
Representative: **Al J. Shipp**

Cornell markets custom metal fabrications and welded aluminum components utilized in the production of LRT and rail car parts, tanks, electrical enclosures, recycling equipment, transportation applications, construction equipment, and automotive fixtures.

Global Diving & Salvage, Inc.
3840 W. Marginal Way SW
Seattle, WA 98106
Representative: **Mike Langen**

Global Diving & Salvage, Inc., founded in 1979, maintains offices in Seattle, Wash., and Rio Vista, Calif. Services include ship husbandry, marine salvage, underwater construction, upland and marine remediation, preventative booming, and saturation diving to 1000 ft. Current projects are ongoing in Washington, Oregon, California, New York, Ohio, and Gulf of Mexico.

Medalist LaserFab, Inc.
2840 Bradley St.
Oshkosh, WI 54902
Representative: **Brenda Tadman**

Medalist LaserFab, Inc., is a speciality metal fabricator using state-of-the-art equipment. It has built a reputation for responsiveness to customers and its commitment to providing high-level service, exceptional quality, and on-time delivery to meet its clients needs.

VCI, Inc.
1500 Progress St., PO Box 7034
Sturgis, MI 49091
Representative: **Eugene R. Harrison**

VCI, Inc., offers a broad range of welding, robotic welding, laser cutting, and metal fabricating services. It specializes in material-handling racks and carts used in shipping and work-in-progress applications. It also provides fabricated parts and weldments to original equipment manufacturers.

Supporting Companies

CINC Industries, Inc.
2500 Arrowhead Dr., Unit #2
Carson City, NV 89706

DOYLES
2038 McAulty Rd.
Houston, TX 77032

Fabrico, Inc.
10 Old Webster Rd.
Oxford, MA 01540

Fabritek Co., Inc.
416 Battaile Dr.
Winchester, VA 22601

Lindinger Inspection Engineers, Inc.
4242 Bluebonnet
Stafford, TX 77477

MMI Tank, Inc.
1034 S. Lewis Mesa
Mesa, AZ 85210

Welding Distributor

A-OX Welding Supply
4100 N. Cliff Ave.
Sioux Falls, SD 57118

Educational Institutions

Birdville Career Center
6010 Walker St.
Haltom City, TX 76117

Edinburg Career Center
1000 E. Ebony Ln.
Edinburg, TX 78541

Flint River Technical College
1533 Hwy. 19 S.
Thomaston, GA 30286

Liberty University School of Engineering & Computational Science
1971 University Blvd., Lynchburg, VA 24502

National Energy Skills Center
Corner Rivulet & Southern Main Rds.
Point Lisas, PO Bag 957
Couva, Trinidad & Tobago

SW Collegiate Institute for the Deaf
3200 Ave. C
Big Spring, TX 79720

SRI Ramakrishna Advanced Training Institute
Vattamalaipalayam, N.G.G.O
Colony Post, Coimbatore
Tamilnaud 641022, India

Trapper Creek Job Corp.
5139 W. Fork Rd.
Darby, MT 59829

U.A. Local 343 Training Center
425 Nebraska St.
Vallejo, CA 94590

Outstanding Student Chapter Members Recognized

The following AWS Student Members are recipients of the Student Chapter Member Award.

Matt Haubert, AWS Whitmer Career & Technology Center Student Chapter, has been selected by **Craig Donnell,** Chapter advisor, to receive the AWS Student Chapter Member Award.

Matt is a member of the National Technical Honor Society and has maintained a 4.0 in the welding program and a 4.1 GPA overall while at Whitmer CTC. He has been honored at the Whitmer CTC Superintendent Luncheon for Community Service in recognition of his volunteer work on numerous community and school projects.

Tyler Baggitt (see photo), AWS Career Institute of Technology Student Chapter, has been selected by **Chris Kipp,** Chapter advisor. Baggitt is a member of the CIT Honor Roll and the National Technical Honor Society. He was the 2008 SkillsUSA winner in his District, and also received a $7000 scholarship to attend Baran Institute of Technology in Windsor, Connecticut.

John T. McCarley, AWS Lawson State Community College Student Chapter, has been selected by **Roy Ledford,** Chapter advisor. He received a certificate in welding technology and is a member the President's List/Dean's List with a 3.518 GPA. McCarley received the Outstanding Student Award in Welding Technology and was the Alabama SkillsUSA representative for Lawson State Community College.

Tonya Almond, AWS Central Piedmont Community College Student Chapter, has been selected by **Ray Sosko,** Chapter advisor. Almond is working toward her AS degree in welding technology, maintaining a greater than 3.0 GPA. She has been a successful solicitor of donations from area businesses for the Student Chapter and various school functions. Almond is active in projects to assist disabled American veterans, and has welded handrails to assist a blind war veteran.

Harper Farish, AWS Columbiana County Career and Technology Center Student Chapter, has been selected by **Huck Hughes,** Chapter advisor. Farish is in the top 5% of his class. He is a leader in community service projects, which include Habitat for Humanity and a church rail rebuild. Farish served as the 2007–08 Student Chapter secretary and 2006–07 treasurer.

Chris Palmer, AWS Tennessee Technology Center at Crossville Student Chapter, has been selected by Advisor **Joe Livesay** to receive this award. Palmer is currently serving as the Chapter chairman and has been instrumental in recruiting new AWS Student Members. He won the 2007 regional SkillsUSA competition at the high school level, and has received certificates for Entry-Level Welder, API, Combination Welder, and AWS Level II Welder.

Brent Kammerdeiner, AWS Beaver Valley Student Chapter, has been selected by Chapter Advisor **Tom Geisler** to receive the Student Chapter Member Award. He is a member of the Aliquippa Stars Program, the Principal's List, and a member of the High Honor Roll from 2005 to the present. Kammerdeiner displays leadership qualities as a volunteer in school and community projects, and participates in Student Chapter activities. He currently is serving as Chapter secretary.

Shawn Bates and **Nate Price,** AWS York County School of Technology Student Chapter, have been selected by Chapter Advisors Mr. **Seitzer** and **Brian Yarrison** to receive the AWS Student Chapter Member Award. Bates is a Junior and Senior Honor Roll member. He participated this year in the Dual Enrollment Pilot Program between YCST and Penn State University. He also held the number-one class ranking for the National Occupational Competency Testing Institute, and achieved senior year cooperative education placement at Freezing Equipment Systems in Emigsville, Pa. Bates, who regularly attends Student Chapter meetings, donates his personal time to mentoring welding students on his days off from the co-op. Active in the community, he participates in outreach programs and neighborhood improvement projects.

Nate Price is the recipient of the 2003 and 2008 National Presidential Academic Achievement Award, and has received the ESAB EU Welding Course Gold Star. He made both the Freshman and Sophomore Distinguished Honor Roll, and was the YCST Freshman Student of the Month (February 2007). Price currently serves as the YCST Student Chapter secretary, and is an active volunteer in local community projects.

Erik Soderstrom, AWS Colorado School of Mines Center Student Chapter, has been selected by **Stephen Liu,** Chapter advisor, to receive the AWS Student Chapter Member Award. Erik received his BS in mechanical engineering, MS degree in metallurgical engineering and specialty welding engineering, and is currently a PhD candidate in metallurgical engineering with a focus in welding sciences. He has guided Student Chapter activities, providing leadership to AWS student members. Erik, who is an AWS Foundation Graduate Fellowship winner, is currently serving as an officer of the AWS Colorado Section, and is also a member of the Section's executive committee.

The AWS board of directors established the Student Chapter Member Award to recognize AWS Student Members whose Student Chapter activities have produced outstanding school, community, or industry achievements. This award also provides an opportunity for Student Chapter advisors, Section officers, and District directors to recognize outstanding students affiliated with AWS Student Chapters, as well as to enhance the image of welding within their communities. To qualify for this certificate award, the candidate must be an AWS Student Member affiliated with an AWS Student Chapter. The criteria and nomination form can be downloaded from the AWS Web page *www.aws.org/sections/awards/student_ chapter.pdf,* or call (800) 443-9353, ext. 260.

Tyler Baggitt (left) receives his AWS Student Chapter Member Award certificate from Ronald Roth, director of the Career Institute of Technology.

District 20 Awardees Named

District 20 Director **Bill Komlos** has nominated the following AWS members to receive the District Director Award for 2007–08 for their contributions to the activities of their Sections and District.

Rex Harrison, Utah
Jeff Staples, Utah
Tom Lienert, New Mexico
Tom Kienbaum, Colorado
Bob Teuscher, Colorado
Lee Corn, S. Colorado
John Cantlin, S. Colorado
Nancy Carlson, Idaho/Mont.
Paul Tremblay, Idaho/Mont.
Russell Rux, Wyoming
Carl Schiner, Wyoming

SECTION NEWS

Speaker Tim Irving (left) is shown with Boston Section chair Tom Ferri on April 7.

Dale Powel demonstrated soldering and brazing of copper pipe at the March Boston Section program.

District 1

Director: Russ Norris
Phone: (603) 433-0855

BOSTON

MARCH 19
Speaker: **Dale Powel,** regional manager
Affiliation: Copper Development Assn.
Topic: Copper, the wonder element
Activity: The Section members participated in demonstrations of soldering and brazing of large-diameter copper pipe. The program was held at the Assabet Valley Regional Vocational School in Marlboro, Mass.

Boston Section Chair Tom Ferri (far left) is shown with Dennis Thebault (far right) and three welding students at the April 7 program.

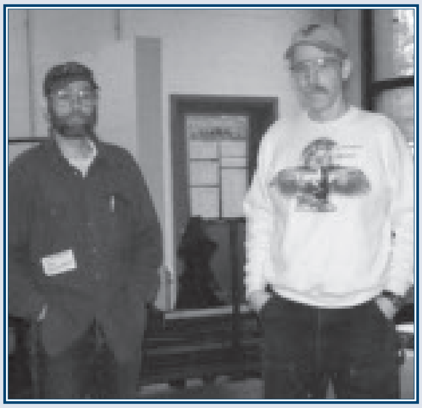
APRIL 7
Speaker: **Timothy Irving,** compliance assistance specialist
Affiliation: OSHA
Topic: Clearing up misconceptions about OSHA procedures, employer rights, and standards
Activity: At this Boston Section program, Quincy High School welding instructor **Dennis Thebault** and Center for Technical Education Culinary Arts department were presented plaques of appreciation for their contributions to the Section's program.

APRIL 14
Activity: The Boston Section executive board met at Artisan Industry in Waltham, Mass., to discuss plans for the upcoming District 1 conference. Chairing the event is the incoming Chair **Jim Shore.** Presented was a proclamation from the governor's office naming April as Welded Products Month in Massachusetts. Attendees included Chair **Tom Ferri, Dave Paquin, Dick Jones, Laurie Jones, Carl Richardson, Warren Ballard, Rick Moody, Jim Shore, Bob Lavoie,** and **Neil Mansfield.**

Shown at the Boston Section April 14 board meeting are from left to right (seated) Dave Paquin, Dick Jones, Laurie Jones, Carl Richardson, and Warren Ballard; (standing) Rick Moody, incoming Chairman Jim Shore, Tom Ferri, Bob Lavoie, and Neil Mansfield.

Shown at the Green & White Mountains meeting in April are (seated, from left) Gary Buckley, Jim Reid, Joe Tokarski, and Ernie Plumb; (standing, from left) Chairman Ray Henderson, John Steel, Jerry Ouellette, Phil Witteman, and Marc Shattuck.

Maine Section Chair Scott Lee (left) and Adam Fallon from Lincoln inspect the students' welds at the SkillsUSA contest.



Green & White Mountains Section Chairman Ray Henderson (left) and Geoff Putnam chaired the welding contest in March.

Russ Norris (left), District 1 director, is shown with Ray Henderson, chair, Green & White Mountains Section.

Student welders stand tall at the Maine Section SkillsUSA welding contest.

GREEN & WHITE MOUNTAINS

MARCH 15

Activity: The Section hosted a testing program for the SkillsUSA contestants. Chairman **Ray Henderson** and **Geoff Putnam** served as cochairs of the activity. The students were tested using oxyfuel and plasma arc cutting, and gas tungsten arc, gas metal arc, and shielded metal arc welding techniques. Section judges included **Jerry Ouellette, Ernie Plumb,** Vice Chair **Gary Buckley,** and **Phil Whitman.** The event was held at Stafford Tech in Rutland, Vt.

APRIL 6

Activity: The Green & White Mountains Section held a board of directors meeting at Members Choice Federal Credit Union in Rutland, Vt. Attending were Chair **Ray Henderson,** Vice Chair **Gary Buckley,** Secretary **Joe Tokarski,** Treasurer **Philip Witteman, Jim Reid, Ernie Plumb, John Steel, Jerry Ouellette,** and **Marc Shattuck**.

MAINE

MARCH 13, 14

Activity: The Section members met on March 13 to prepare for the SkillsUSA welding contest for the next day. Vice Chair **Tom Cormier** served as event chairman. The event took place at United Technology Center in Bangor, Maine. The students were tested using oxyfuel cutting, gas tungsten arc, flux core arc, and shielded metal arc welding procedures. Judges included Section Chair **Scott Lee**, Lincoln Electric representative **Adam Fallon,** and **Dick Gregiore**.

District 2

Director: Kenneth R. Stockton
Phone: (732) 787-0805

NEW JERSEY

MARCH 18

Speaker: **Robert F. Meade,** OD

Affiliation: Montclair State University and Morris County School of Technology

Topic: Avoiding welding-related eye injuries

Activity: The new slate of Section officers was approved. The Morris County School of Technology welding students and their instructor, **Herb Browne,** attended the program. Chairman **Steve DeFilipps** presented **Bob Wlazlowski** an appreciation award. The meeting was held at L'Affaire Restaurant in Mountainside, N.J.

District 3

Director: Alan J. Badeaux Sr.
Phone: (301) 753-1759

YORK-CENTRAL PA.

APRIL 3

Speaker: **Kevin Malley,** account representative

Affiliation: 3M Occupational Health & Environmental Safety

Topic: The hexavalent chromium standard

Bob Wlazlowski (far right) receives his appreciation award from New Jersey Section Chair Steve DeFillipps (far left) and Bob Petrone.

Activity: York-Central Section Chair **Dave Herr** welcomed the Section's Student Chapter members to the program.

York County School of Technology Student Chapter

April 3
Activity: The Student Chapter members toured the weld shop facilities of Herr & Sacco, Inc., a mechanical contractor in Landisville, Pa.

District 4

Director: Roy C. Lanier
Phone: (252) 321-4285

SOUTHWEST VIRGINIA

March 20
Speaker: **James Pike,** welding standard practice engineer
Affiliation: NASA Langley
Topic: New rocket *Orion*

District 5

Director: Steve Mattson
Phone: (904) 260-6040

NORTH CENTRAL FLORIDA

October 9
Speaker: **Tom Christ,** manufacturer's representative
Affiliation: All-State, Presto-O-Lite
Topic: Joining specialty metals
Activity: The program was held at Airgas in Orlando, Fla.

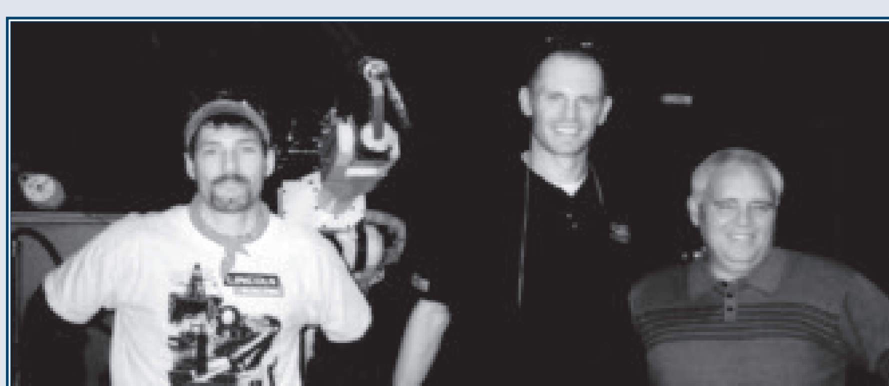
February 12
Activity: The North Central Florida Section members toured the Outokumpu Stainless Pipe Inc., facilities in Wildwood, Fla. The tour was led by **Paul Carpenter,** plant operations VP, and **Roy Harrison,** production manager.

Welding instructor Herb Browne (far left) is shown with his students at the New Jersey Section program.

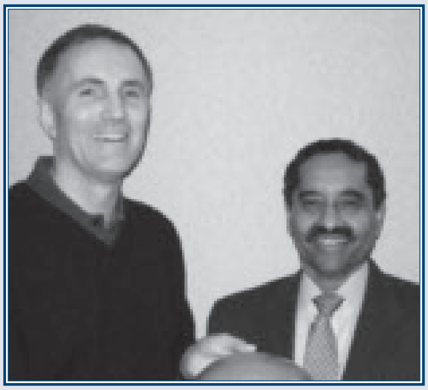
Shown at the Southwest Virginia Section program are (from left) Treasurer David Cash, Chair Ted Alberts, and speaker James Pike.

York-Central Pa. Chairman Dave Herr (left) is shown with speaker Kevin Malley.

York County School of Technology Student Chapter members are shown during their tour of Herr & Sacco.



Shown at the South Carolina Section program are (from left) Robert Harrison, speaker Jeremy Nawyn, and Chair Gale Mole.



Shown at the joint ASM-Columbus Section program are Treasurer John Lawmon (left) and speaker Shrikant P. Bhat.

Webster County Vo Tech welding students are shown at the Northeast Mississippi Section program held in November.

Dayton Section Chair Steve Whitney (left) welcomes speaker Jim Hannahs.

Speaker Harry Wehr (left) is shown with Chattanooga Section Chair Bill Brooks.

SOUTH CAROLINA

MARCH 20
Speaker: **Jeremy Nawyn,** technical sales representative
Affiliation: The Lincoln Electric Co.
Topic: Ultracore flux cored wire
Activity: Following the talk, the Section participated in welding demonstrations using the wire with CO_2 shielding gas and robotic welding with argon-CO_2.

District 6

Director: Neal A. Chapman
Phone: (315) 349-6960

District 7

Director: Don Howard
Phone: (814) 269-2895

COLUMBUS

MARCH 19
Speaker: **Shrikant P. Bhat,** manager, advanced engineering, automotive products
Affiliation: Arcelor Mittal Global R & D
Topic: The advancement of high-strength steels in automobile applications
Activity: This was a joint meeting with members of the local chapter of ASM International. The program was held at Arlington Banquets in Columbus, Ohio.

DAYTON

APRIL 8
Speaker: **James R. Hannahs,** Section secretary and treasurer
Affiliation: Welding engineer and educator (ret.)
Topic: Documents governing welding and qualification
Activity: This was a joint meeting with members of the Miami Valley Chapter of ASNT. The program was held at Chantrell's in Springboro, Ohio.

District 8

Director: Joe Livesay
Phone: (931) 484-7502

CHATTANOOGA

MARCH 11
Speaker: **Harry Wehr,** technical director
Affiliation: Arcos Industries
Topic: The impact of wire surface conditions on welding quality
Activity: **Rick Tidwell,** representing Arcos' sister company Select Arc, assisted Wehr with the discussion. The meeting was held at Chattanooga State College in Chattanooga, Tenn.

NORTHEAST MISSISSIPPI

NOVEMBER 15
Speaker: **Chris McCully,** technical representative
Affiliation: Motoman Robotics
Topic: Robotics in manufacturing
Activity: Following the talk, the attendees participated in demonstrations of industrial robots. This students' night program was held at East Mississippi Community College in Mayhew, Miss. In attendance were welding students from Webster County Vo Tech.

District 9

Director: George D. Fairbanks
Phone: (225) 473-6362

MOBILE

MARCH 13
Speaker: **Clay Byron,** district manager
Affiliation: Miller Electric Mfg. Co.
Topic: GMAW-pulse for welding aluminum
Activity: The program was held in Saucy Q Restaurant in Mobile, Ala.

NEW ORLEANS

MARCH 18
Speaker: **Steven Snyder**
Affiliation: STS Welding Consultation
Topic: AWS welding fabricator certification and audits
Activity: This students' night program was held at Industrial Welding Supply in Boomtown, La.

District 10

Director: Richard A. Harris
Phone: (440) 338-5921

District 11

Director: Eftihios Siradakis
Phone: (989) 894-4101

DETROIT

APRIL 14

Activity: The Section hosted the 15th annual District 11 Quiz the Experts event at Tony M's in Lansing, Mich. Competing were representatives from Ferris State University Student Chapter, and the Detroit, Saginaw Valley, Central Michigan, and Western Michigan Sections. The Central Michigan Section team took top honors.

NORTHWEST OHIO

JULY 20

Activity: The Section hosted its annual Don Leonhart Scholarship Golf Outing at South Toledo Golf Club in Toledo, Ohio. More than 20 teams competed. **Mike Rogers, Tony Duris,** and **Mark Scalise** organized the fund-raising event. The outing has been named in honor of the late **Don Leonhart** who organized the events in the past.

MARCH 24

Activity: The Northwest Ohio Section members toured Gillmor Ordnance Ltd., in Old Fort, Ohio. **C. Robert Gillmor** led the tour of the facility for casting, machining, and building replica canons, howitzers, and mortars for use in movies and documentaries. The facility also casts bells, belt buckles, and the carriage parts for the canons, and working models down to ⅛ scale.

District 12

Director: Sean P. Moran
Phone: (920) 954-3828

LAKESHORE

MARCH 13

Speaker: **David Ramseur,** senior manufacturing engineer

Affiliation: Manitowoc Cranes, Inc.

Topic: The life of Maj. Gen. Stephen Dodson Ramseur

Activity: The Section hosted its past chairmen's and ladies' night event at Machut's Supper Club in Two Rivers, Wis. Secretary Ramseur's talk described his ancestor's career at West Point and distinguished active duty roles in the Civil War.

RACINE-KENOSHA

MARCH 25

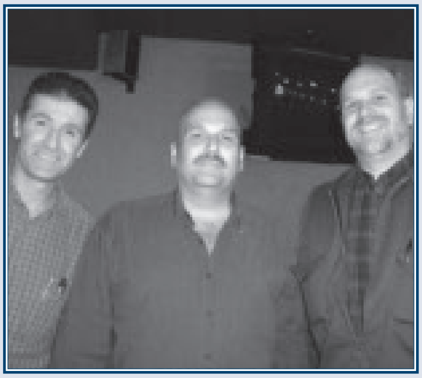
Activity: **Tim Kemen** led the Section members on a tour of the coal-fired Wisconsin Energy Power Plant in Pleasant Prairie, Wis.

District 13

Director: W. Richard Polanin
Phone: (309) 694-5404

Speaker Steven Snyder (left) is shown with Travis Moore, New Orleans Section chair.

Randy Henderson (left) is shown with speaker Clay Byron at the Mobile Section program.



The Detroit Section's Quiz the Experts team included (from left) Steve Slavick, Andy Klos, and Don Maatz.

Travis Moore (far right), New Orleans Section chair, presents a sponsor-appreciation plaque to representatives from Industrial Welding Supply.

Speaker Tim Kemen (right) is shown with Ken Karwowski, Racine-Kenosha Section vice chair.

Shown at the Lakeshore Section program are speaker and Secretary David Ramseur (left) and Chairman James Hoffman.

Racine-Kenosha Section members are shown during their tour of Wisconsin Energy.

Indiana Section members are shown during their tour of the Ivy Tech Community College welding lab.

Shown at the March Chicago Section program are (from left) Jim Greer, an AWS past president; Rick Polanin, District 13 director; Craig Tichelar, Section chair; Hank Sima, vice chair; Martin Vondra, treasurer; and Chuck Hubbard, a past chairman.

Shown at the April Chicago Section meeting are (from left) Chuck Hubbard, Pete Host, Hank Sima, Chair Craig Tichelar, Eric Krauss, and Cliff Iftimie.

Shown at the March Mid-Plains Section program are (from left) Jeff Purintun, Jeremy Kapple, Chuck McCarthy, Secretary Rex Cross, Chairman Dan Rucker, tour guide Steve Forbs, and Treasurer Duane Stevens.

CHICAGO

March 19
Speaker: **Gene Lawson,** AWS president
Affiliation: ESAB Welding & Cutting
Topic: A changing welding environment creates new opportunities
Activity: **Peter Host** received the District Educator Award from **Rick Polanin,** District 13 director.

April 2
Activity: The Chicago Section held a board meeting at Bohemian Crystal Restaurant in Chicago, Ill. In attendance were Chair **Craig Tichelar,** Vice Chair **Hank Sima, Chuck Hubbard, Pete Host,** and **Cliff Iftimie.**

District 14

Director: Tully C. Parker
Phone: (618) 667-7744

INDIANA

March 29
Activity: The Section members toured the welding lab at Ivy Tech Community College in Kokomo, Ind. **Roger King,** welding instructor, conducted the program and detailed the future plans for the welding program at the school. About 30 members attended the event.

TRI-RIVER

March 27
Speaker: **Earl Young,** quality control manager
Affiliation: Industrial Contractors, Inc.
Topic: Welding quality control standards used during power plant maintenance shut-downs
Activity: The meeting was held at Evansville Armature in Evansville, Ind.

District 15

Director: Mace V. Harris
Phone: (651) 287-3267

ARROWHEAD

March 26

Speaker: **Bob Schuster,** technical sales
Affiliation: Nelson Stud Welding, Inc.
Topic: Stud welding practices and standards
Activity: This Arrowhead Section program was held at Mesabi Range College in Eveleth, Minn.

District 16

Director: David Landon
Phone: (641) 621-7476

MID-PLAINS

FEBRUARY 8
Activity: The Section hosted its St. Valentine's meeting and party at Stubs Pub in Sumner, Neb. The Section donated $200 to the Brad Troyer Memorial Fund to support a welding scholarship for a graduate of North Platte or Hershey High School.

MARCH 13
Activity: The Section members toured Kaufman Trailers of Nebraska, Inc., in Beaver City, Neb., to study its production facilities. **Steve Forbs,** production manager, conducted the program.

NEBRASKA

APRIL 7
Activity: The Section held a students program at Papillion LaVista High School in Papillion, Neb. Welding instructor **Randy Stribley** made a presentation. The Section members used funds raised from various events to purchase equipment donated to the school's welding program. The equipment included two portable Lincoln GMA welding machines, spool guns, hoods, gloves, wire, and miscellaneous shop items.

Shown at the Nebraska Section program are from left (front) students Chris Dornbusch, Brain Wingel, and Andrew Kalvelage; (center) Nick Weidenbach and Jason Hill; and (back row) Bruce Gregory, Rick Hanny, Randy Stribley, and Scott Kneifi.

District 17

Director: J. J. Jones
Phone: (940) 368-3130

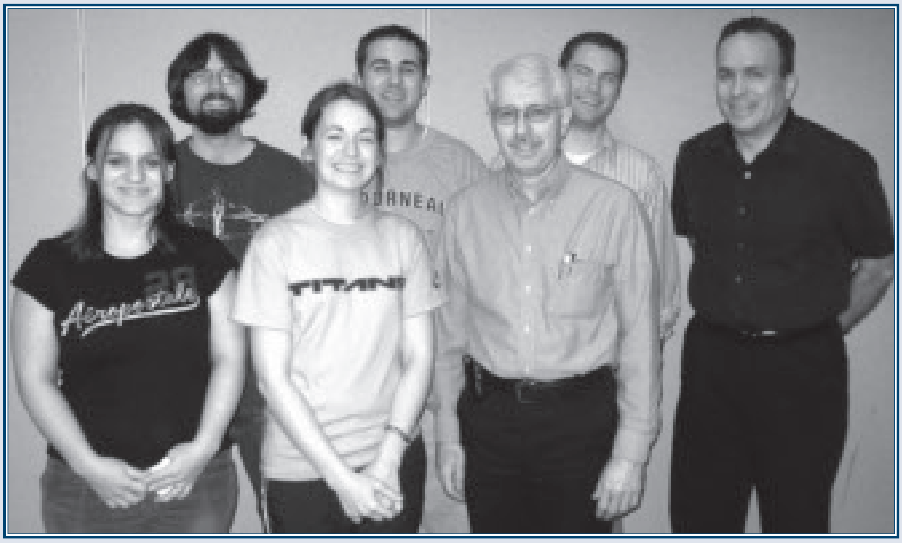
CENTRAL ARKANSAS

JANUARY 22
Speaker: **Bob Hlass,** Section secretary
Affiliation: The Lincoln Electric Co.
Topic: Ventilating welding stations to comply with hexavalent chromium standards
Activity: The program was held at Hot Springs Rehabilitation Center in Hot Springs, Ark.

FEBRUARY 23
Activity: The Central Arkansas Section members toured Plumbers and Pipefitters Local #155 in Little Rock, Ark. **Matt Fair,** business manager, presented a talk on UA welder certification, then led a tour of the facility.

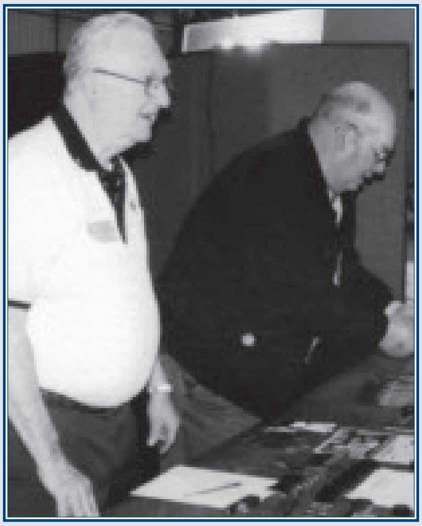
Shown at the February Central Arkansas Section program are (from left) Chairman Dennis Pickering, Gary Stubblefield, and presenter Matt Fair.

Steve Sigler (far left) is shown teaching San Antonio Section members and student welders the fine points of GMAW-P.



Shown at the LeTourneau University Student Chapter program are (from left) Anna Wolfgang, Dan Moers, Jerica Cadman, Nathaniel Horton, Dave Hebble, Richard Baumer, and Student Chapter Advisor Robert Warke.

Shown at the North Texas Section program are Chairman Robert Tessier (left) and speaker Lester Purdham.



Working the Tulsa Section welding information booth in April are Paul Morgan (left) and Jay Rufner.

LeTourneau University Student Chapter

MARCH 27
Speaker: **Dave Hebble,** senior sales applications engineer
Affiliation: ESAB Welding and Cutting Products
Topic: Weld fume safety solutions for cutting, gouging, and welding processes
Activity: A highlight of the evening was the recognition of LeTourneau University students who received AWS national scholarships. The recipients included **Kenneth Bean Jr., Reuben Brooks, Edward Funnell, Devin Hartshorn, Kenneth Martin III,** and **Anna Wolfgang.** The program was held at the university in Longview, Tex.

NORTH TEXAS

MARCH 18
Speaker: **Lester Purdham,** district manager
Affiliation: Thermadyne
Topic: Oxyfuel cutting and safety
Activity: Purdham distributed copies of the Victor cutting manual and discussed its key points. The program was held at Spring Creek Barbecue in Irving, Tex.

TULSA

MARCH 25
Speaker: **Kevin Ford,** regional manager
Affiliation: Plymovent Co., Houston, Tex.
Topic: Hexavalent chromium concerns
Activity: The Section members met at Furrs Buffet in Tulsa, Okla.

APRIL 9
Activity: The Tulsa Section sponsored a welding information booth at Tulsa Engineering Challenge Day held at the local technology center campus for students in the grades 7 through 12. Manning the booth were **Paul Morgan** and **Jay Rufner**.

Shown at the March Tulsa Section program are speaker Kevin Ford (left) and Jamie Pearson, program chairman.

Shown at the Colorado Section program are (from left) Chairman Jim Corbin, Jeff Klein, speaker Michelle Parrott, and Paul Hasty.

District 18

Director: John Bray
Phone: (281) 997-7273

HOUSTON

February 20
Speaker: **Billy Harrell**
Affiliation: Sam Houston State University
Topic: The agriculture mechanics diversified welding program
Activity: Ninety-seven people attended this students' night program held at Brady's Landing in Houston, Tex.

SAN ANTONIO

April 9
Speaker: **Steve Sigler,** technical sales representative
Affiliation: The Lincoln Electric Co.
Topic: Pulsed GMA welding of stainless steel and nickel alloys
Activity: Following the presentation, the attendees had a chance to experiment with the GMAW-P process. Floresville High School welding instructor **Clifton Rogers** and his students attended the event.

District 19

Director: Neil Shannon
Phone: (503) 201-5142

District 20

Director: William A. Komlos
Phone: (801) 560-2353

COLORADO

April 10
Speaker: **Michelle Parrott,** metallurgist and production engineer
Affiliation: Xcel Energy, Golden, Colo.
Topic: Failure analysis

San Francisco Section Vice Chair Liisa Pine poses with swordsmiths Jim Austin (left) and Jeff Pringle.

District 21

Director: Jack D. Compton
Phone: (661) 362-3218

District 22

Director: Dale Flood
Phone: (916) 933-5844

SAN FRANCISCO

April 2
Speakers: **Jim Austin,** Alchemy Metalworks; and **Jeff Pringle,** Stewart Dean Co.
Topic: Solid phase welding as it relates to swordsmithing
Activity: The program was held at Spenger's Restaurant in Berkeley, Calif.

Publicize Your Section's Activities

Send your Section Meeting/Event reports, photos, and upcoming calendar of meeting events for publication in Section News to Howard Woodward, e-mail *woodward@aws.org;* or FAX to (305) 443-7404. For more information, call (800/305) 443-9353, ext. 244.

Member-Get-A-Member Campaign

Listed are the members participating in the 2007–2008 AWS Member-Get-A-Member Campaign for the period between June 1, 2007, and May 31, 2008. For campaign rules and a prize list, see page 101 of this *Welding Journal.* Standings are as of 4/11/2008. If you have any questions regarding your member proposer points, call the Membership Department, (800) 443-9353, ext. 480.

Winner's Circle

Members who have sponsored 20 or more new Individual Members, per year, since June 1, 1999. The superscript indicates the number of times the member has achieved Winner's Circle status.

J. Compton, San Fernando Valley[7]
E. Ezell, Mobile[5]
J. Merzthal, Peru[2]
G. Taylor, Pascagoula[2]
B. Mikeska, Houston[1]
R. Peaslee, Detroit[1]
W. Shreve, Fox Valley[1]
M. Karagoulis, Detroit[1]
S. McGill, NE Tennessee[1]
L. Taylor, Pascagoula[1]
T. Weaver, Johnstown/Altoona[1]
G. Woomer, Johnstown/Altoona[1]
R. Wray, Nebraska[1]
M. Haggard, Inland Empire[1]

President's Guild

Members sponsoring 20 or more new Individual Members.

L. Taylor, Pascagoula — 135
E. Ezell, Mobile — 21

President's Roundtable

AWS Members sponsoring 9–19 new Individual Members.

J. Compton, San Fernando Valley — 14
J. Hope, Puget Sound — 12
J. Sanchez, Cuautitlan Izcalli — 9

President's Club

AWS Members sponsoring 3–8 new Individual Members.

R. Cook, Utah — 8
S. Christensen, Nebraska — 7
R. Ellenbecker, Fox Valley — 7
D. Wright, Kansas City — 7
A. Castro, South Florida — 6
J. Krall, Dayton — 5
V. Raloff, J.A.K. — 5
P. Johnson, Houston — 4
K. Kotter, Utah — 4
T. Lowe, Northwest Ohio — 4
L. Garner, Mobile — 3
C. Gilbert, East Texas — 3
P. Hanley, Peoria — 3
T. Nielsen, Pittsburgh — 3

President's Honor Roll

AWS Members sponsoring 1 or 2 new Individual Members. Only those sponsoring 2 AWS Individual Members are listed.

T. Alberts, Southwest Virginia
M. Beaton, North Texas
C. Bridwell, Ozark
D. Campbell, North Texas
D. Daugherty, Indiana
M. Enis, Arizona
R. Gaffney, Tulsa
W. Galvery Jr., Long Beach/Or. County
H. Jackson, L.A/Inland Empire
C. Johnson, Northern Plains
J. Johnson, Northern Plains
R. Key, San Antonio
J. Kozeniecki, Milwaukee
D. Landon, Iowa
S. Leighton, Louisville
J. Livesay, Nashville
J. McCarty, St. Louis
T. Moffitt, Tulsa
J. Nieto, Corpus Christi
R. Norris, Maine
R. Panter, Long Bch./Or. Cty.
F. Schmidt, Niagara Frontier
G. Sinkule, Northern Michigan
T. Snider, Mobile
A. Sumal, British Columbia
J. Truitt, San Diego
R. Wright, San Antonio
M. Yarmuch, Northern Alberta
P. Zammit, Spokane

Student Member Sponsors

Members sponsoring 3 or more new AWS Student Members.

S. Siviski, Maine — 45
D. Berger, New Orleans — 38
M. Reiter, Columbus — 36
G. Euliano, Northwestern Pa. — 34
R. Evans, Siouxland — 34
D. Nelson, Puget Sound — 34
T. Zablocki, Pittsburgh — 28
M. Anderson, Indiana — 26
N. Goncalo, Milwaukee — 21
R. Hutchinson, Long Bch./Or. Cty. — 20
G. Smith, Lehigh Valley — 20
J. Daugherty Louisville — 19
G. Seese, Johnstown-Altoona — 19
B. Yarrison, York-Central Pa. — 19
J. Kacir, Detroit — 18
C. Kipp, Lehigh Valley — 18
D. Ketler, Willamette Valley — 17
M. Arand, Louisville — 16
J. Ciaramitaro, N. Central Florida — 16
T. Bridigum, Northwest — 15
C. Donnell, Northwest Ohio — 15
T. Moore, New Orleans — 15
D. Roskiewich, Philadelphia — 15
R. Briddell, St. Louis — 14
H. Browne, New Jersey — 14
T. Geisler, Pittsburgh — 14
C. Overfelt, SW Virginia — 14
A. Stute, Madison-Beloit — 14
J. Compton, San Fernando Valley — 14
T. Geisler, Pittsburgh — 14
C. Overfelt, Southwest Virginia — 14
A. Stute, Madison-Beloit — 14
H. Hughes, Mahoning Valley — 13
D. Kowalski, Pittsburgh — 13
A. Wyatt, Holston Valley — 13
T. Buchanan, Mid-Ohio Valley — 12
J. McCarty, St. Louis — 12
R. Munns, Utah — 12
B. Suckow, Northern Plains — 12
D. Zabel, Southeast Nebraska — 12
M. Rotary, Detroit — 11
W. Harrris, Pascagoula — 10
D. Lynn, Ozark — 10
R. Tully, San Francisco — 10
D. Aragon, Puget Sound — 9
P. Bedel, Indiana — 9
D. Vranich, North Florida — 9
D. Williams, North Texas — 9
A. Badeaux, Washington D.C. — 8
W. Komlos, Utah — 8
M. Legel, Maine — 8
C. Schiner, Wyoming Section — 8
T. Smith, Utah — 8
J. Theberge, Boston — 8
J. Boyer, Lancaster — 7
L. Smerglia, Cleveland — 7
T. Strickland, Arizona — 7
W. Troutman, Cleveland — 7
J. Cox, Spokane — 6
B. Hallila, New Orleans — 6
S. McDaniel, Inland Empire — 6
E. Norman, Ozark — 6
R. Richwine, Indiana — 6
G. Rolla, L.A./Inland Empire
T. Shirk, Tidewater — 6
L. Taylor, Pascagoula — 6
B. Wenzel, San Francisco — 6
P. Carney Jr., Lehigh Valley — 5
W. Galvery Jr., Long Bch./Or. Cty. — 5
B. Hardin, San Francisco — 5
R. Hilty, Pittsburgh — 5
R. Olesky, Pittsburgh — 5
T. Parker, Wheeling — 5
S. Robeson, Cumerland Valley — 5
C. Yaeger, Northeastern Carolina — 5
J. Angelo, El Paso — 4
J. Craiger, Indiana — 4
G. Ellar, Detroit — 4
S. Hansen, Southeast Nebraska — 4
R. Leford Jr., Birmingham — 4
C. Rossi, Washington, DC — 4
N. Carlson, Idaho/Montana — 3
J. Crosby, Atlanta — 3
C. Daily, Puget Sound — 3
A. Kitchens, Olympic — 3
J. Geesey, Pittsburgh — 3
L. Gross, Milwaukee — 3
R. Purvis, Sacramento — 3
G. Saari, Inland Empire — 3
D. Saunders, Lakeshore — 3
R. Wahrman, Triangle — 3

Guide to AWS Services

550 NW LeJeune Rd., Miami, FL 33126
www.aws.org; phone (800/305) 443-9353; FAX (305) 443-7559
(Phone extensions are shown in parentheses.)

AWS PRESIDENT
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glawson@esab.com
ESAB Welding and Cutting
25108 Marguerite Pkwy. #165
Mission Viejo, CA 92692

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Dora Shade.. *dshade@aws.org* . . . .(235)

INT'L INSTITUTE of WELDING
Senior Coordinator
Sissibeth Lopez . . *sissi@aws.org* . . . .(319)
Provides liaison services with other national and international professional societies and standards organizations.

GOVERNMENT LIAISON SERVICES
Hugh K. Webster. . . *hwebster@wc-b.com*
Webster, Chamberlain & Bean, Washington, DC, (202) 466-2976; FAX (202) 835-0243. Identifies funding sources for welding education, research, and development. Monitors legislative and regulatory issues of importance to the industry.

Brazing and Soldering Manufacturers' Committee
Jeff Weber.. *jweber@aws.org* . . . .(246)

RWMA — Resistance Welding Manufacturing Alliance
Manager
Susan Hopkins.. *susan@aws.org* . . . .(295)

WEMCO — Welding Equipment Manufacturers Committee
Manager
Natalie Tapley.. *tapley@aws.org* . . . .(444)

CONVENTION and EXPOSITIONS
Associate Executive Director
Jeff Weber.. *jweber@aws.org* . . . .(246)

Corporate Director, Exhibition Sales
Joe Krall.. *krall@aws.org* . . . .(297)
Organizes the annual AWS Welding Show and Convention, regulates space assignments, registration items, and other Expo activities.

PUBLICATION SERVICES
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Welding Journal
Publisher/Editor
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National Sales Director
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Society and Section News Editor
Howard Woodward..*woodward@aws.org* .(244)

Welding Handbook
Welding Handbook Editor
Annette O'Brien.. *aobrien@aws.org* . . . . .(303)
Publishes the Society's monthly magazine, *Welding Journal*, which provides information on the state of the welding industry, its technology, and Society activities. Publishes *Inspection Trends*, the *Welding Handbook,* and books on general welding subjects.

MARKETING COMMUNICATIONS
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Webmaster
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Department Information . . . .(480)

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Director
Rhenda A. Mayo... *rhenda@aws.org* . . . . .(260)
Serves as a liaison between Section members and AWS headquarters. Informs members about AWS benefits and activities.

CERTIFICATION SERVICES
Department Information . . . .(273)

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John Filippi..jfilippi*@aws.org* . . . .(222)

Managing Director, Technical Operations
Peter Howe.. *phowe@aws.org* . . . .(309)
Manages and oversees the development, integrity, and technical content of all certification programs.

Director, Int'l Business & Certification Programs
Priti Jain.. *pjain@aws.org* . . . .(258)
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Director, Education Services Administration and Convention Operations
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Coordinates AWS awards and AWS Fellow and Counselor nominees.

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Int'l Standards Activities, American Council of the Int'l Institute of Welding (IIW)

Director, National Standards Activities
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Personnel and Facilities Qualification, Computerization of Welding Information

Manager, Safety and Health
Stephen P. Hedrick.. *steveh@aws.org* (305)
Metric Practice, Safety and Health, Joining of Plastics and Composites

Technical Publications
AWS publishes about 200 documents widely used throughout the welding industry.
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Staff Engineers/Standards Program Managers
Annette Alonso.. *aalonso@aws.org* . . . . . .(299)
Automotive Welding, Resistance Welding, Oxyfuel Gas Welding and Cutting, Definitions and Symbols, Sheet Metal Welding

Stephen Borrero.. *sborrero@aws.org* . . . . .(334)
Welding Iron Castings, Joining of Metals and Alloys, Brazing and Soldering, Brazing Filler Metals and Fluxes, Brazing Handbook, Soldering Handbook

Rakesh Gupta.. *gupta@aws.org* . . . .(301)
Filler Metals and Allied Materials, Int'l Filler Metals, Instrumentation for Welding, UNS Numbers Assignment

Brian McGrath . *bmcgrath@aws.org* . . . . .(311)
Methods of Inspection, Mechanical Testing of Welds, Welding in Marine Construction, Piping and Tubing, Robotic and Automatic Welding

Selvis Morales.....*smorales@aws.org* . . . . .(313)
Welding Qualification, Structural Welding

Matthew Rubin.....*mrubin@aws.org* . . . . . .(215)
Machinery and Equipment, Robotics Welding, Arc Welding and Cutting Processes

Reino Starks...*rstarks@aws.org* . . . .(304)
Welding in Sanitary Applications, High-Energy Beam Welding, Aircraft and Aerospace, Friction Welding, Railroad Welding, Thermal Spray

Note: *Official interpretations of AWS standards may be obtained only by sending a request in writing to the Managing Director, Technical Services. Oral opinions on AWS standards may be rendered. However, such opinions represent only the personal opinions of the particular individuals giving them. These individuals do not speak on behalf of AWS, nor do these oral opinions constitute official or unofficial opinions or interpretations of AWS. In addition, oral opinions are informal and should not be used as a substitute for an official interpretation.*

Nominees for National Office

Only Sustaining Members, Members, Honorary Members, Life Members, or Retired Members who have been members for a period of at least three years shall be eligible for election as a director or national officer.

It is the duty of the National Nominating Committee to nominate candidates for national office. The committee shall hold an open meeting, preferably at the Annual Meeting, at which members may appear to present and discuss the eligibility of all candidates.

To be considered a candidate for the positions of president, vice president, treasurer, or director-at-large, the following qualifications and conditions apply:

President: To be eligible to hold the office of president, an individual must have served as a vice president for at least one year.

Vice President: To be eligible to hold the office of vice president, an individual must have served at least one year as a director, other than executive director and secretary.

Treasurer: To be eligible to hold the office of treasurer, an individual must be a member of the Society, other than a Student Member, must be frequently available to the national office, and should be of executive status in business or industry with experience in financial affairs.

Director-at-large: To be eligible for election as a director-at-large, an individual shall previously have held office as chairman of a Section; as chairman or vice chairman of a standing, technical, or special committee of the Society; or as District director.

Interested persons should submit a letter stating which office they seek, including a statement of qualifications, their willingness and ability to serve if nominated and elected, and a biographical sketch.

E-mail the letter to Gricelda Manalich, *gricelda@aws.org,* c/o Gerald D. Uttrachi, chair, National Nominating Committee.

The next meeting of the National Nominating Committee is scheduled for October 2008. The terms of office for candidates nominated at this meeting will commence January 1, 2010.

Honorary Meritorious Awards

The Honorary-Meritorious Awards Committee makes recommendations for the nominees presented for Honorary Membership, National Meritorious Certificate, William Irrgang Memorial, and the George E. Willis Awards. These awards are presented during the FABTECH International & AWS Welding Show held each fall. The deadline for submissions is December 31 prior to the year of awards presentations. Send candidate materials to Wendy Sue Reeve, secretary, Honorary Meritorious Awards Committee, *wreeve@aws.org;* 550 NW LeJeune Rd., Miami, FL 33126. Descriptions of the awards follow.

William Irrgang Memorial Award is awarded each year to the individual who has done the most over the past five years to enhance the American Welding Society's goal of advancing the science and technology of welding.

This award consists of a $2500 honarium and a certificate. It is presented during the FABTECH International & AWS Welding Show held each fall. The award is administered by the American Welding Society and sponsored by The Lincoln Electric Co. to honor the late William Irrgang.

George E. Willis Award is awarded each year to an individual who promotes the advancement of welding internationally by fostering cooperative participation in areas such as technology transfer, standards rationalization, and promotion of industrial goodwill.

The award consists of a $2500 honarium and a certificate. It is presented during the FABTECH International & AWS Welding Show held each fall. The award is administered by the American Welding Society and sponsored by The Lincoln Electric Co. to honor George E. Willis.

Honorary Membership Award is presented to a person of acknowledged eminence in the welding profession, or who is accredited with exceptional accomplishments in the development of the welding art, upon whom the American Welding Society sees fit to confer an honorary distinction. Honorary Members have full rights of membership.

National Meritorious Certificate Award is given in recognition of the candidate's counsel, loyalty, and devotion to the affairs of the Society, assistance in promoting cordial relations with industry and other organizations, and for the contribution of time and effort on behalf of the Society.

International Meritorious Certificate Award is given in recognition of significant contributions to the welding industry for service to the international welding community in the broadest terms. The awardee is not required to be an AWS member. Multiple awards may be given. The award consists of a certificate and a one-year AWS membership.

AWS Publications Sales

Purchase AWS standards, books, and other publications from
World Engineering Xchange (WEX), Ltd.
orders@awspubs.com; www.awspubs.com
Toll-free (888) 935-3464 (U.S., Canada)
(305) 824-1177; FAX (305) 826-6195

Welding Journal Reprints

Copies of *Welding Journal* articles may be purchased from Ruben Lara.
(800/305) 443-9353, ext. 288; *rlara@aws.org*

Custom reprints of *Welding Journal* articles, in quantities of 100 or more, may be purchased from
FosteReprints
Toll-free (866) 879-9144, ext. 121
sales@fostereprints.com

AWS Foundation

The AWS Foundation, Inc., is a not-for-profit corporation established to provide support for educational and scientific endeavors of the American Welding Society. Information on gift-giving programs is available upon request.

Executive Director, AWS
Ray Shook, ext. 210, *rshook@aws.org*

Executive Director, Foundation
Sam Gentry, ext. 331, *sgentry@aws.org*

Corporate Director, SOS
Monica Pfarr, ext. 461, *mpfarr@aws.org*

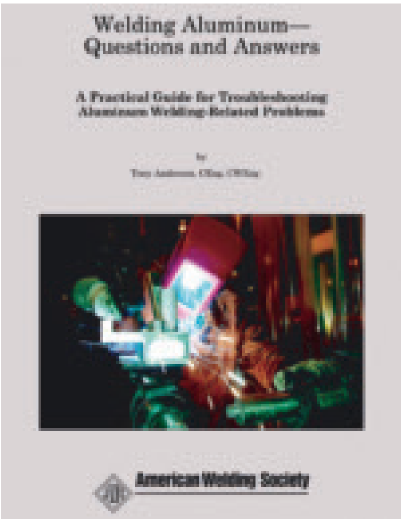
550 NW LeJeune Rd., Miami, FL 33126
(305) 445-6628; (800) 443-9353, ext. 293
general information:
(800) 443-9353, ext. 689; *vpinsky@aws.org*

AWS Mission Statement

The mission of the American Welding Society is to advance the science, technology, and application of welding and allied processes, including joining, brazing, soldering, cutting, and thermal spraying.

It is the intent of the American Welding Society to build AWS to the highest quality standards possible. The Society welcomes your suggestions. Please contact any staff member or AWS President Gene E. Lawson, as listed on the previous page.

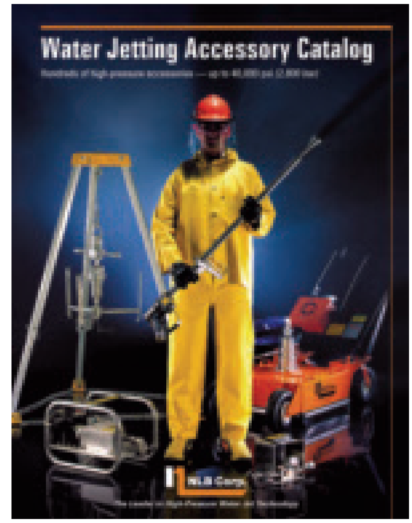
New Manual Troubleshoots Aluminum Welding



A first of its kind resource manual, *Welding Aluminum — Questions and Answers,* subtitled *A Practical Guide for Troubleshooting Aluminum Welding-Related Problems,* is authored by world-renowned aluminum welding expert Tony Anderson. It includes a comprehensive listing of frequently asked questions with answers, general information, guidelines, and feature articles on welding aluminum. Chapters discuss aluminum welding within several manufacturing industries, an overview of aluminum alloys and metallurgy, welding testing and discontinuities, processes and procedures, and codes and standards. The book also provides an overview of the history of aluminum welding and common welding processes. It is available in print and electronic formats. The book contains 192 pages, eight chapters, ten tables, and 77 figures. The list price is $124; $93 to AWS members.

World Engineering Exchange
www.awspubs.com
(888) 935-3464; (305) 824-1177

Catalog Features Waterjet Accessories



The company has introduced a new waterjet accessory catalog linked with an online quoting system to simplify selecting the right accessory for every application. Among the new accessories pictured are field-repairable lances and rotating nozzles rated to 40,000 lb/in.^{2}, rotary hose devices, and 3-D tank-cleaning heads. An expanded section pictures couplings and fittings with a variety of application photos and hook-up drawings. Included are all necessary specifications and ordering information with a comprehensive reference section that includes nozzle flow charts, thrust, and pressure-drop tables, and English/metric conversions. The online catalog is posted on the literature page of the Web site. Contact the company for a printed catalog.

NLB Corp.
www.nlbcorp.com
(248) 624-5555

Soldering Application Videos Posted on Internet

A new Web site displays soldering irons, solder pots, resistance soldering equipment, plus an extensive video library displaying use of the best tools and techniques for specific applications. The site has three search areas: type of user, type of application, and key word. Each search area provides information about applications and products, including videos and downloadable technical bulletins. Designed for assembly engineers, the site includes information to improve job performance and productivity, detailed narratives about soldering, troubleshooting tips, and maintenance.

American Beauty Soldering Tools
www.americanbeautytools.com
(800) 550-2510

— continued on page 110

Thermatool Welded Tube Used in the Georgia Dome!

THERMATOOL
An Inductotherm Group Company

Southland Tube Inc. of Birmingham, Alabama a leading supplier of welded steel pipe and hollow structural sections (HSS) was a major producer of structural tubing for the Georgia Dome in Atlanta.

Southland has been a Thermatool customer for twelve years. They recently added to their HSS production capacity with the installation of a new mill to produce up to 12.75 inch round and 10 inch square by up to ½ inch wall thickness. The new mill is equipped with a Thermatool 1200kw Solid State Induction Welder and per John Montgomery Jr., Vice President and General Manager, "The welder was commissioned in record time and it is producing the high quality welded products which Southland's customers demand."

For more information on how Thermatool can assist you in making a superior cost effective product, please contact us.

Thermatool Corp.
East Haven, CT 06512, U.S.A.
Tel: (203) 468-4100
E-mail: info@ttool.com
www.thermatool.com

Thermatool IHWT
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E-mail: info@ttool.co.uk
www.thermatool-europe.com

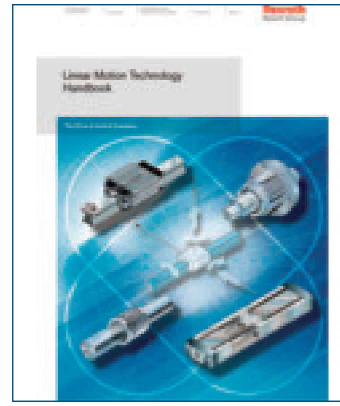
For Info go to www.aws.org/ad-index

INDUCTOTHERM GROUP

Leading Manufacturers of Melting, Thermal Processing & Production Systems for the Metals & Materials Industry Worldwide.

— continued from page 108

Linear Motion Technology Detailed in CD Handbook



A core element of the company's linear motion resource kit CD is the 350-page *Linear Motion Technology Handbook.* The text is an educational, engineering reference book on linear motion technology and its uses. It offers basic principles to practical applications, explaining all of the common types of linear motion guides, as well as ball screw drives and ready-to-install linear motion actuators and Cartesian systems. The book includes information about the structural design operating principles and characteristics of linear motion technology components. Topics such as rolling, contact, life expectancy, preload, rigidity, accuracy, and lubrication are discussed in detail. It also describes the structural design and technical characteristics of the manufacturer's linear bushings and shafts, profiled rail systems, ball screw assemblies, and ready-to-install linear motion actuators and Cartesian robots. The book may be ordered or downloaded from the Web site.

Bosch Rexroth Corp.
www.boschrexroth-us.com/brl
(800) 322-6724

Welding Sensors Featured in Catalog

The Welding Solutions catalog details the company's complete lines of sensors, cord sets, and accessories able to withstand the abrasion, physical impact, weld slag, spatter, and high-temperature environments created by resistive, gas metal arc, and gas tungsten arc welding cells. The company's weld-specific products deliver a variety of rugged solutions for many challenging applications, providing more options than before. The catalog may be ordered on the Web site.

TURCK
www.turck.com
(800) 544-7769

CALL FOR PAPERS

Abstract Deadline: July 15, 2008 **Manuscripts Due: October 15, 2008**

The American Welding Society® and ASM International® are again organizing the world-recognized International Brazing & Soldering Conference (IBSC). This four-day event will begin with **Short Courses** offered on Sunday, followed by a three-day **Technical Program** Monday-Wednesday. IBSC brings together scientists, engineers and technical personnel from around the globe involved in the research, development, and application of brazing and soldering. Parallel sessions allow us to present the latest advances in these joining technologies and will be organized to permit interaction between the two disciplines.

IBSC 2009 Program Organizers invite to submit your work for consideration of inclusion in the technical program. They are accepting 150-200-word abstracts describing original, previously unpublished work. The work may pertain to current research, actual or potential applications, or new developments. Whereas **commercialism must be avoided** to maintain the high level of technical quality and integrity of the IBSC conferences, the new brazing applications and case histories are most welcome.

The technical program will include a special ½ day session focused on practical and innovative applications of brazing and soldering. The **Tabletop Exhibit** will provide a forum for commercial presentations and demonstrations of state-of-the-art brazing and soldering materials, processes and equipment. Check our website for details. **The Poster Session** will allow yet another opportunity to present the interesting developments in brazing and soldering technologies.

A **Conference Proceedings** containing **only** full manuscripts of the accepted research papers will be published to capture these high-quality technical presentations for later reference. Presentations focused on practical applications of brazing and soldering will also be included in the conference proceedings.

Below are some of the topical areas covered at IBSC

Aircraft and Aerospace	Furnace / Vacuum Brazing	Power and Electrical Equipment
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This premiere event is truly one that anyone involved in the brazing and soldering community should plan to attend.

Mark your calendar now, and if you are interested in presenting your work at the conference, submit your abstract no later than July 15, 2008.

Thermacut Expands Sales Team

Dana Colson

Wade Chase

Tom Farley

Thermacut, Inc., Claremont, N.H., has appointed **Dana Colson, Wade Chase,** and **Tom Farley** to fill key sales posts. Colson, with the company for five years as a plasma product specialist, will serve as outside sales representative for distributors in the newly formed northern zone. Chase, previously managing director, has been appointed to the newly created position director of sales, North and South America. Farley, previously with TMF & Associates, has been named a manufacturer's representative in Indiana, Illinois, Wisconsin, western Ohio, southern Minnesota, northern Kentucky, and eastern sections of Iowa and Missouri.

Hobart Institute of Welding Technology Names Trustee

Charlie Ribardo Jr.

The board of directors of Hobart Institute of Welding Technology (HIWT), Troy, Ohio, has elected **Charlie L. Ribardo Jr.** to serve as a trustee. Ribardo, currently with BP America, Inc., Houston, Tex., has served for several years on the HIWT Program Advisory Council, and the Engineering Industrial Advisory Committee at Texas A&M University. A graduate of The Ohio State University and Texas A&M University, he has more than 17 years' experience in the fields of welding engineering, materials research, manufacturing, and management. He brings to the board extensive expertise in the areas of welding processes, design, metallurgy, and nondestructive evaluation.

Lincoln Appoints Global Automotive Director

David Park

The Lincoln Electric Co., Cleveland, Ohio, has appointed **David Park** global business segment director — automotive/transportation. Prior to joining the company, Park was manager of the Manufacturing Solutions Group, part of a Linde Gas operation acquired by Airgas last year.

Hypertherm Reapportions North American Divisions

Jeff Staton

David Taylor

Alan Hamilton

Tim Oney

Hypertherm, Hanover, N.H., has reapportioned its North American territory from two divisions into three regions. **Jeff Staton,** formerly the Western division manager, will head the newly created Northeastern U.S. and Canadian region. Two former district sales managers, **David Taylor** and **Alan Hamilton,** will lead the Central and Southeastern U.S. region, and the Western U.S. region, respectively. The company also announced the appointment of **Tim Oney** as national distribution manager. Oney formerly served ten years as district sales manager for the Kentucky market.

Head of Multiquip to Retire

Roger Euliss

Roger Euliss has announced his intention to retire from Multiquip, Inc., Carson, Calif., at the end of 2008 after 28 years of service. The new MQ organization will be headed by **Mike Howlett** who will become president of the MQ General Construction Equipment Group.

Industrial Scientific Fills Newly Created Post

Industrial Scientific Corp., Pittsburgh, Pa., a supplier of gas detection and monitoring instruments has named **Scott Lordo** to the newly created position of global director of product development. Prior to joining the company, Lordo worked for Cattron-Theimeg for 12 years, where he most recently served as director of program management.

CMW Names Operations Manager

Vincent Sanders

CMW Inc., Indianapolis, Ind., has named **Vincent Sanders** operations manager. Before joining the company, Sanders worked 12 years for O'Neal Steel where he most recently served as manager of process improvement.

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SUPPLEMENT TO THE *WELDING JOURNAL,* JUNE 2008
Sponsored by the American Welding Society and the Welding Research Council

Effect of GMAW Process and Material Conditions on DP 780 and TRIP 780 Welds

The effects of variables on microstructure and mechanical properties were explored for advanced high-strength steels

BY N. KAPUSTKA, C. CONRARDY, S. BABU, AND C. ALBRIGHT

ABSTRACT. The drive to reduce vehicle weight and improve crash performance has led automotive manufacturers to introduce higher-strength grades of advanced high-strength steels (AHSS). For these materials to be used effectively, the influence of material and process conditions on gas metal arc (GMA) weld properties must be understood. The objective of this work was to characterize the effects of material prestrain, cooling rate conditions (welding heat input and fixture heat sink), filler metal selection, dilution, and postbaking on the microstructure and mechanical properties of GMA welds on coated dual-phase (DP) and transformation-induced plasticity (TRIP) steels. The primary materials studied were DP 780 and TRIP 780; for comparison purposes a limited amount of work was conducted with DP 980. The DP steels showed varying degrees of heat-affected zone (HAZ) hardening and softening depending on the material grade, prestrain, and cooling rate condition. The relatively high aluminum content of the TRIP 780 allowed retained ferrite to be present in all regions of the HAZ, along with a continuous region of coarse ferrite along the weld interface. This resulted in the TRIP 780 having lower peak HAZ hardness than the DP 780. Fusion zone microstructure and hardness were found to be affected by the base metal chemistry, the cooling rate condition, and the filler metal composition. Filler metal strength did not affect the static or dynamic tensile properties of either the TRIP 780 lap or butt joint welds, or the DP 780 butt joint welds. All of the TRIP 780 and DP 780 butt joints failed in the soft HAZ. The results of the lap joint tests showed a greater variation in strength that is attributed to porosity at the root of the weld.

N. KAPUSTKA, C. CONRARDY, and S. BABU are with Edison Welding Institute, Columbus, Ohio. C. ALBRIGHT is with The Ohio State University, Columbus, Ohio.

Introduction

The use of AHSS has increased as a means of reducing vehicle weight through the use of thinner material gauges (Ref. 1). Future applications will likely require coated DP and TRIP steels with thicknesses of less than 2.0 mm (0.08 in.) and strength levels greater than 700 MPa (101.5 ksi). Gas metal arc welding (GMAW) is often employed where part geometry prevents the use of resistance spot welding (RSW) or when the design requires additional joint strength and stiffness.

To use AHSS effectively, it is important for designers and manufacturing engineers to understand the factors that may affect the performance of GMA-welded structures. This paper primarily explores the effects of common manufacturing variations on the microstructure and mechanical properties of coated DP 780 and TRIP 780. The effects of the following manufacturing variations were evaluated:

• **Material Prestrain**. Various degrees of strain may be imparted in the sheet metal during stamping or forming operations prior to welding.

• **Filler Metal Type**. Mild steel sheet applications typically employ common electrode compositions (e.g., ER70S) that are designed to produce weld metal having an ultimate tensile strength of at least 70 ksi (483 MPa). Higher-strength grades may be required to weld some AHSS grades in order to match the strength of the base metal.

• **Cooling Rate Conditions**. Weld cooling rates can be affected by the welding process parameters (i.e., welding heat input) as well as heat sinking from tooling or other adjacent materials.

• **Dilution**. Depending on the joint design and welding process parameters, the weld fusion zone alloy can consist of different fractions of base metal and filler metal.

• **Postbaking**. Components may be painted and baked after welding.

This work allows the relative importance of these factors on the weld microstructure and properties of DP 780 and TRIP 780 to be assessed. A limited amount of work was conducted with coated DP 980; the results of which are listed in table format for comparison purposes.

KEYWORDS

AHSS
Cooling Rate
DP Steels
Filler Metal
GMAW
Gas Metal Arc
TRIP Steels

Experimental Approach

Mechanized GMA welds were produced on coated steels under a range of conditions, including:

• **Material Grades**. Table 1 is a list of the steel grades that were evaluated, along with the nominal gauge thickness and coating type of each. Table 2 lists the chemical composition of each steel. The chemical compositions of the DP 780 and TRIP 780 steels were determined by inductively coupled plasma (ICP) analysis,

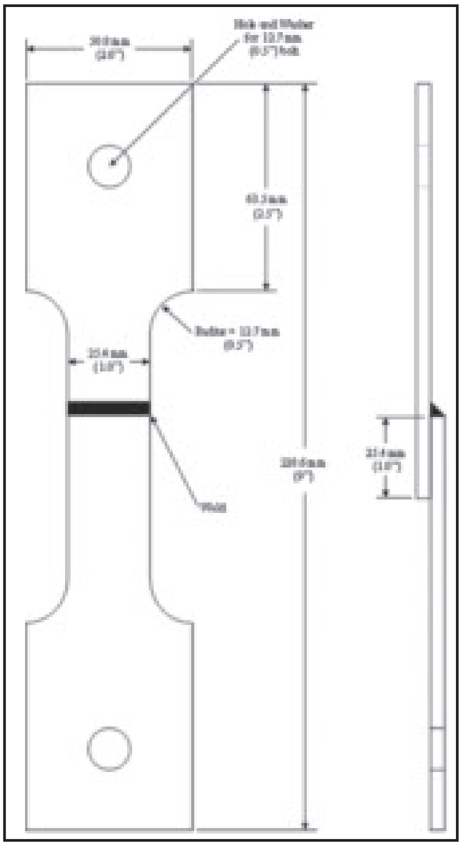

Fig. 1 — Reduced cross-sectional geometry of lap joint tensile specimens.

Table 2 — Base Metal Compositions

Element	TRIP 780	DP 780	DP 980
Carbon	0.17	0.13	0.112
Manganese	2.08	2.01	2.45
Silicon	0.023	<0.005	0.028
Phosphorous	0.011	0.016	0.013
Sulfur	<0.001	0.002	0.004
Copper	0.034	0.026	0.02
Nickel	0.021	0.015	0.01
Molybdenum	0.055	0.20	0.325
Chromium	0.094	0.23	0.24
Niobium	<0.001	<0.001	0.004
Vanadium	0.002	0.003	0.001
Titanium	0.010	0.002	0.003
Boron	<0.001	<0.001	0.0001
Aluminum	1.81	0.049	0.052
Nitrogen	0.0060	0.0096	—
Oxygen	0.0033	0.0078	—
Lead	<0.001	<0.001	—
Tungsten	0.002	<0.001	—
Zirconium	0.003	<0.001	—

Table 3 — Typical Welding and Heat Sink Conditions for Welds with Nominally High and Low Cooling Rates

Grade	Nominal Cooling Rate	Transfer Mode	Average Current (A)	Average Voltage (V)	Travel Speed (in./min)	Heat Sink	Heat Input (kJ/mm)
DP 780	High	SC	48.7	17.2	11.9	Copper	0.18
TRIP 780	High	SC	45	19.8	13.2	Copper	0.16
DP 780	Low	Spray	230	24.4	32	Air	0.40
TRIP 780	Low	Spray	237	24.8	45.1	Air	0.29

Table 1 — Base Materials Investigated

Grade	Coating	Thickness (mm)
DP 780	HDGA	1.54
DP 980	HDGA	1.60
TRIP 780	HDGA	1.35

Note: HDGA = Hot-dipped galvanized and annealed.

Table 4 — Test Matrix of Lap Welds for HAZ Characterization

Grade	Nominal Cooling Rate	Transfer Mode	Heat Sink	Heat Input (kJ/mm)
DP 780	High	SC	Copper	0.17
DP 780	Low	Spray	Air	0.41
TRIP 780	High	SC	Copper	0.16
TRIP 780	Low	Spray	Air	0.29

Note: Test matrix repeated for prestrained coupons.

while the composition of the DP 980 steel is that which was provided in the manufacturer's certification.

• **Joint Types**. Lap joint fillet welds were produced for HAZ characterization. Both lap joint fillet welds and square groove butt joint welds were produced for fusion zone and mechanical property characterization. As shown in Fig. 1, the lap joints had 25.4 mm (1.0 in.) of overlap. Lap joints were produced using 140- × 203-mm (5½- × 8-in.) coupons, while butt joints used 127- × 203-mm (5- × 8-in.) coupons.

• **Prestrain**. Two conditions were used: as-received and prestrained via roll reduction in thickness of approximately 8%.

• **Filler Metal**. Two filler metals were used: a nominally "low"-strength electrode (ER70S-6) and a nominally "high"-strength electrode (ER100S-G).

• **Heat Sink Effects**. Welds were produced at nominally high and low cooling rate conditions. High cooling rate was achieved with short-circuit transfer and a copper backing bar. Low cooling rate was achieved with spray transfer and no backing bar. Table 3 lists typical welding parameters and heat sink conditions used to produce welds with a nominally high or low cooling rate. Parameters were developed to achieve adequate fusion without excessive penetration (i.e., no melt-through on lap joints). For butt joint welds, the major acceptance criteria was full penetration, without excessive root reinforcement. The fixture (Fig. 2) had a ½-in.-deep × 1-in.-wide channel along the weld centerline. A copper bar was inserted into the channel for the high heat sink welds. For the no heat sink welds, the copper bar was removed. A computerized

Table 5 — Gleeble Test Conditions for HAZ Characterization

Sample	Peak Temperature (°C)	Heating Rate (°C/s)
1	500	25
2	1000	25
3	1000	0.16

data acquisition system was employed to measure the current, voltage, and time of each weld; travel speeds were determined by dividing the weld length by the weld time. The average theoretical heat input of each weld was calculated to provide an indication of the actual heat input. Because heat input calculations were determined for comparative purposes, a heat transfer efficiency of 1.0 was used.

• **Postbake**. Samples were evaluated

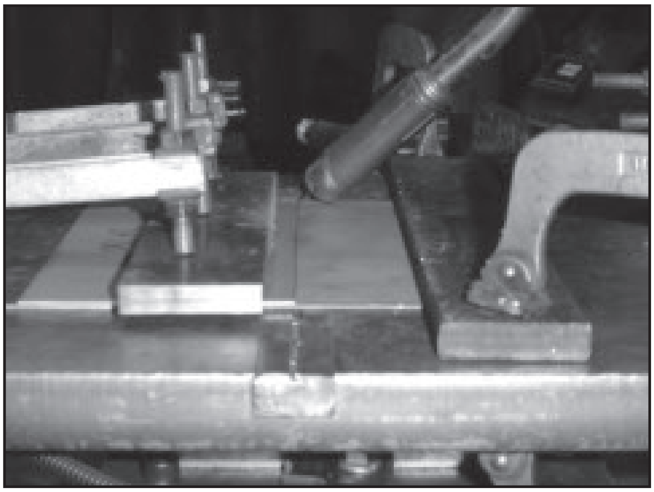

Fig. 2 — Fixture used to produce different heat sink conditions.

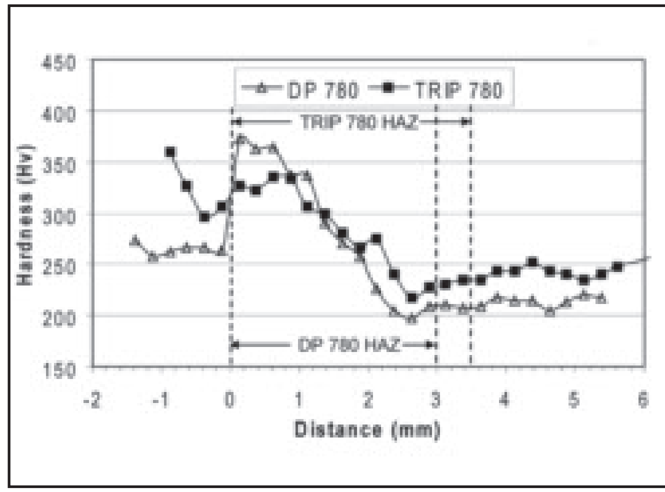

Fig. 3 — Hardness profiles of DP 780 and TRIP 780 lap welds produced with the nominally high cooling rate: no prestrain or postbaking.

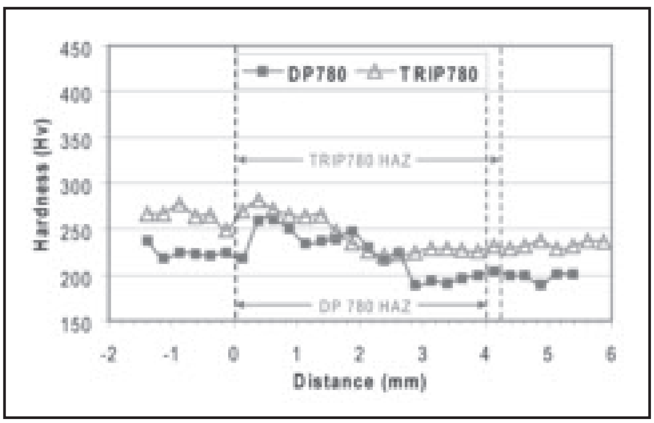

Fig. 4 — Hardness profiles of DP 780 and TRIP 780 lap welds produced with the nominally low cooling rate: no prestrain or postbaking.

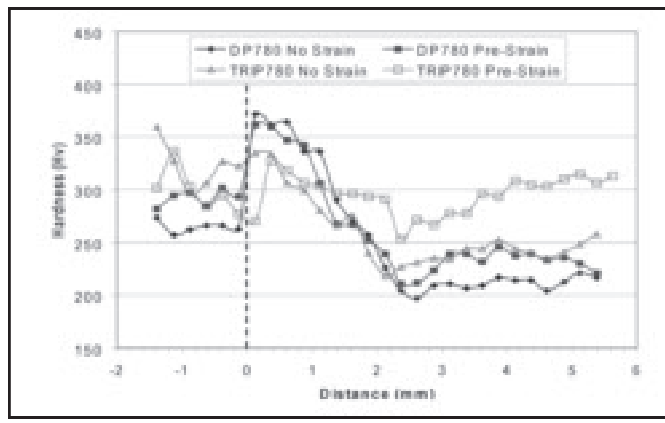

Fig. 5 — Hardness profiles of DP 780 and TRIP 780 lap welds produced both with and without prestrain for the high cooling rate condition.

both with and without postbaking. Postbaking consisted of placing welded specimens in a preheated oven, allowing the specimens to heat, holding the specimens at 170°C for 25 min., then removing from the oven and allowing to air cool.

The HAZ and fusion zone hardness profiles and microstructures of the GMA welds were characterized. Static and dynamic tensile properties of DP 780 and TRIP 780 were also evaluated and related to the microstructural observations. The weld evaluation approach is described below in three parts.

HAZ Characterization

The effects of grade, prestrain, cooling rate condition, and postbake on the HAZ microstructure and hardness profile were evaluated. Lap welds for HAZ evaluation were produced using ER70S-6 wire. Table 4 is the test matrix, which was applied for the lap joints both with and without prestrain. To ensure that steady-state conditions had been reached, metallographic cross sections were taken at least 3 in. from the start of the weld. One cross section was examined in the as-received condition, while another underwent a postbake treatment prior to metallographic preparation. Hardness traverses were taken along the centerline of the top sheet.

Gleeble testing was performed to relate the phase transformations that occur at different HAZ locations to the temperature at which the location was heated. Table 5 is the test matrix used during the Gleeble trials. 5- × 75-mm (0.020- × 2.95-in.) samples were heated at the rates listed and then cooled to room temperature at approximately 40°C/s. Each sample was

Table 6 — Test Matrix of Lap Welds for Fusion Zone Characterization

Steel Grade	Filler Metal	Nominal Cooling Rate	Transfer Mode	Heat Sink	Heat Input (kJ/mm)
DP 780	ER70S-6	High	SC	Copper	0.15
DP 780	ER70S-6	Low	Spray	Air	0.43
DP 780	ER100S-G	High	SC	Copper	0.19
DP 780	ER100S-G	Low	Spray	Air	0.41
TRIP 780	ER70S-6	High	SC	Copper	0.16
TRIP 780	ER70S-6	Low	Spray	Air	0.34
TRIP 780	ER100S-G	High	SC	Copper	0.19
TRIP 780	ER100S-G	Low	Spray	Air	0.29

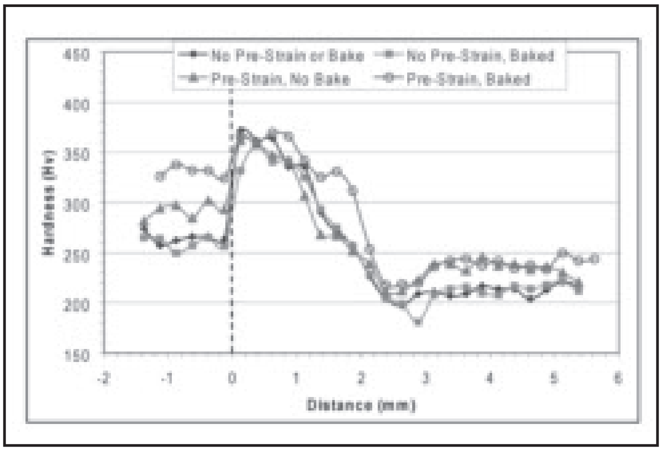

Fig. 6 — Hardness profiles of DP 780 lap welds with and without postbaking for both prestrained and not prestrained sheet. (Welds were produced with the nominally high cooling rate condition.)

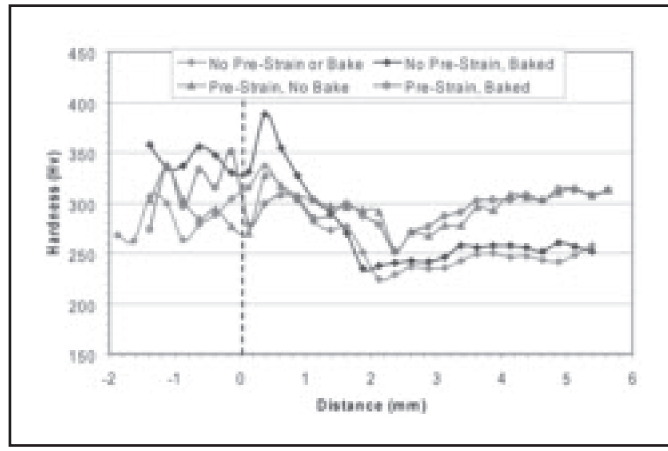

Fig. 7 — Hardness profiles of TRIP 780 lap welds with and without postbaking for both prestrained and not prestrained sheet. (Welds were produced with the nominally high cooling rate condition.)

then cross sectioned along its center (the location where the temperature reached that listed in Table 5) and prepared for metallographic examination and hardness testing.

Fusion Zone Characterization

The effects of filler metal selection, cooling rate condition, and dilution on the fusion zone microstructure and hardness were evaluated. The test matrices of the lap and butt joints are shown in Tables 6 and 7, respectively. DP 780 and TRIP 780 lap and butt joints were produced using both ER70S-6 and ER100S-G wire types. To ensure that steady-state conditions had been reached, metallographic cross sections were taken at least 3 in. from the start of the weld. For each specimen dilution of the filler metal by the base metal was approximated from the macrographs using imaging software. In addition, the weld metal chemistry of the high and low cooling rate TRIP 780 lap welds produced with the ER70S-6 wire was analyzed to verify the dilution estimates.

Table 7 — Test Matrix of Butt Joint Welds for Fusion Zone Characterization

Steel Grade	Filler Metal	Nominal Cooling Rate	Transfer Mode	Heat Sink	Heat Input (kJ/mm)
DP 780	ER70S-6	High	SC	Copper	0.20
DP 780	ER70S-6	Low	Spray	Air	0.17
DP 780	ER70S-6	High	SC	Copper	0.17
DP 780	ER70S-6	Low	Spray	Air	0.18
TRIP 780	ER70S-6	High	SC	Copper	0.20
TRIP 780	ER70S-6	Low	Spray	Air	0.18
TRIP 780	ER100S-G	High	SC	Copper	0.19
TRIP 780	ER100S-G	Low	Spray	Air	0.18

Table 8 — Test Matrix of Lap and Butt Joint Welds for Mechanical Property Characterization

Steel Grade	Filler Metal	Nominal Cooling Rate	Transfer Mode	Heat Sink	Joint Geometry	HI (kJ/mm)
DP 780	ER70S-6	High	SC	Copper	Butt	0.20
DP 780	ER70S-6	Low	Spray	Air	Butt	0.17
DP 780	ER100S-G	High	SC	Copper	Butt	0.17
DP 780	ER100S-G	Low	Spray	Air	Butt	0.18
TRIP 780	ER70S-6	High	SC	Copper	Lap	0.16
TRIP 780	ER70S-6	Low	Spray	Air	Lap	0.29
TRIP 780	ER100S-G	High	SC	Copper	Lap	0.18
TRIP 780	ER100S-G	Low	Spray	Air	Lap	0.29
TRIP 780	ER70S-6	High	SC	Copper	Butt	0.20
TRIP 780	ER70S-6	Low	Spray	Air	Butt	0.18
TRIP 780	ER100S-G	High	SC	Copper	Butt	0.19
TRIP 780	ER100S-G	Low	Spray	Air	Butt	0.18

Mechanical Property Characterization of DP 780 and TRIP 780

The static and dynamic tensile strength of lap and butt joints produced using TRIP 780, and butt joints produced using DP 780 were assessed. Table 8 is the welding matrix used in producing the mechanical test specimens. To achieve complete penetration and avoid melt-through, the calculated welding heat input of all butt joint welds was similar. Thus, cooling rate was affected primarily by the heat sink condition for the butt joint welds. For the TRIP 780 lap joints, a broader range of calculated welding heat input levels were used in combination with heat sinking to affect cooling rate.

For each welding condition listed in Table 8, three specimens underwent static tensile testing and three specimens underwent dynamic tensile testing. Weld metal reinforcement was machined from the surface of the butt joint welds so that the fusion zone thickness was similar to that of the base material. Coolant was used during machining to minimize metallurgical effects. All specimens were laser cut into the reduced cross-sectional geometry shown in Fig. 1. The butt and lap joint tensile specimens were similar; with the primary difference being the location of the weld. For the butt joints, the weld was in the middle of the specimen, while for the lap joints the overlapped region was in the middle of the specimen. To avoid slippage, 12.5-mm- (½-in.-) diameter holes were first placed 25 mm (1 in.) from the end of each specimen. These holes were then reinforced with 12.5-mm-diameter washers that were spot welded to the specimen. To minimize bending on the lap joint tensile

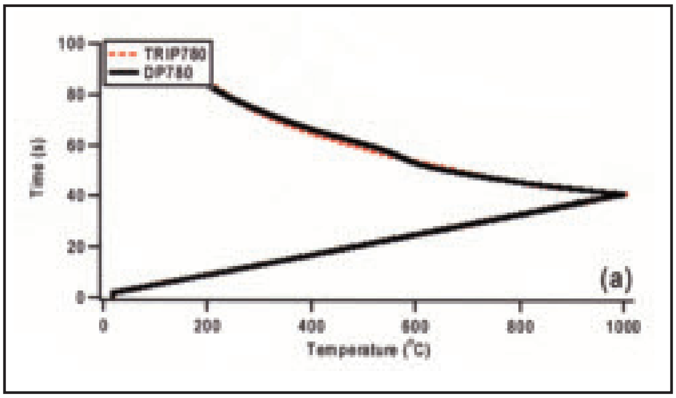

Fig. 8 — Comparison of measured temperature cycle from DP 780 and TRIP 780 steels during heating and cooling to 1000°C at 25°C/s. [It is important to note during cooling cycle no forced cooling was used to track the heat of transformation from austenite to ferrite. The DP 780 steels showed significant change in cooling rate as the transformation starts at ~600°C (solid arrow). No such change in cooling rate was observed in TRIP 780 steels.]

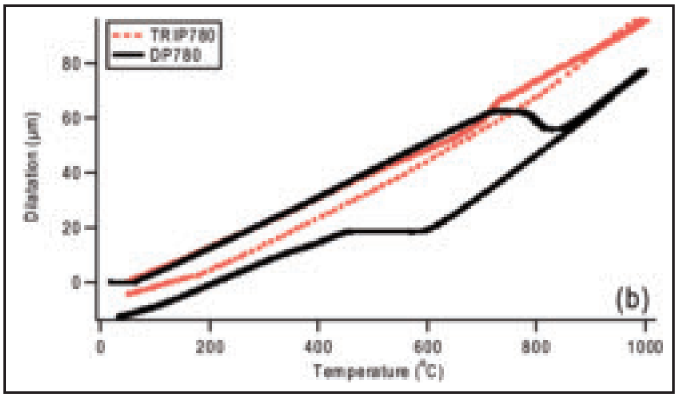

Fig. 9 — Measured dilation corresponding to the temperature cycle shown in Fig. 8. [DP 780 steel shows classical behavior: on heating austenite formation above 700°C and on cooling transformation from austenite to ferrite below 600°C (marked by solid arrow). It is interesting to note that the TRIP 780 steels show a small change in dilation on heating above 500°C and then no classical austenite to ferrite transformation.]

specimens, 12.5-mm-thick plates were placed on the surface opposite the washers during testing.

The static tensile specimens were tested at a rate of 50 mm/min (2.0 in./min). The dynamic tensile specimens were tested using two different weights and a constant drop height of 10 ft. Initially, a 58.5-lb weight was used. When it was realized that this weight was inadequate to break all specimens, a 106.7-lb weight was used. Analysis of the peak load vs. strain at peak load, and the peak load vs. elongation at peak load curves indicated that the different weights did not have a significant effect on dynamic tensile properties. For all tensile tests, peak load, energy at peak load, and elongation at peak load were recorded.

Results

The results of the HAZ characterization, fusion zone characterization, and mechanical property characterization are presented separately. The Discussion section of this paper then relates these results.

HAZ Characterization

Figures 3–6 show hardness profiles for welds made on DP 780 and TRIP 780 using ER70S-6 wire under a range of heat sink and prestrain conditions. The zero on the X-axis represents the fusion boundary location with HAZ to the right and fusion zone to the left. Note that the HAZ boundary was defined as the location in which the hardness in the HAZ reaches the average hardness of the base metal. The data presented in these figures are summarized in Table 9; data for DP 980 lap welds produced with ER70S-6 welding wire are also listed. Referring to Table 9, ΔH_{Pk} and ΔH_{Min} are the degrees of HAZ hardening and softening, respectively. The figures show various degrees of HAZ hardening and softening depending on material grade and other conditions. The highest hardness occurs in the near HAZ (adjacent to the fusion boundary), while the softest point is in the far HAZ. Compared to TRIP 780, DP 780 has a higher degree of hardening and a slightly lower degree of softening. The following provides additional description of the results in these figures:

• **Cooling Rate**. Figure 3 shows hardness profiles for welds produced with the nominally high cooling rate condition (i.e., combination of low heat input and heat sink). Figure 4 shows hardness profiles for

Table 9 — HAZ Characterization Data for Lap Welds Produced on DP 780, TRIP 780, and DP 980 Using ER70S-6 Welding Wire

Grade	Condition: Cooling Rate	Condition: Prestrain	Condition: Baking	H_{Pk} (Hv)	ΔH_{Pk} (%)	H_{Min} (Hv)	ΔH_{Min} (%)	Width (mm)
DP 780	High	No	No	372	80	197	–5	3.0
	Low	No	No	261	26	189	–9	4.0
	High	Yes	No	362	52	211	–11	3.2
	Low	Yes	No	294	24	207	–13	4.5
	High	No	Yes	357	72	181	–13	3.0
	Low	No	Yes	280	35	187	–10	4.0
	High	Yes	Yes	370	55	218	–8	3.2
	Low	Yes	Yes	311	31	210	–12	4.8
TRIP 780	High	No	No	334	34	218	–8	3.8
	Low	No	No	277	11	211	–11	4.2
	High	Yes	No	327	5	253	–18	4.2
	Low	Yes	No	282	–9	261	–16	5.0
	High	No	Yes	388	55	235	–6	3.5
	Low	No	Yes	302	21	220	–12	4.2
	High	Yes	Yes	308	–1	252	–19	4.2
	Low	Yes	Yes	300	–3	259	–16	5.0
DP 980	High	No	No	392	28	266	–13	3.5
	Low	No	No	344	12	250	–18	5.2
	High	Yes	No	402	15	274	–22	NA
	Low	Yes	No	381	9	252	–28	NA
	High	No	Yes	407	27	270	–16	3.2
	Low	No	Yes	362	17	258	–17	5.4
	High	Yes	Yes	400	14	291	–17	NA
	Low	Yes	Yes	383	9	284	–19	NA

H_{Pk} = Peak HAZ hardness $\Delta H_{Pk} = [(H_{Pk} - \text{Base Metal Hardness}) - 1] \times 100$
H_{Min} = Minimum HAZ hardness $\Delta H_{Min} = [(H_{Min} - \text{Base Metal Hardness}) - 1] \times 100$

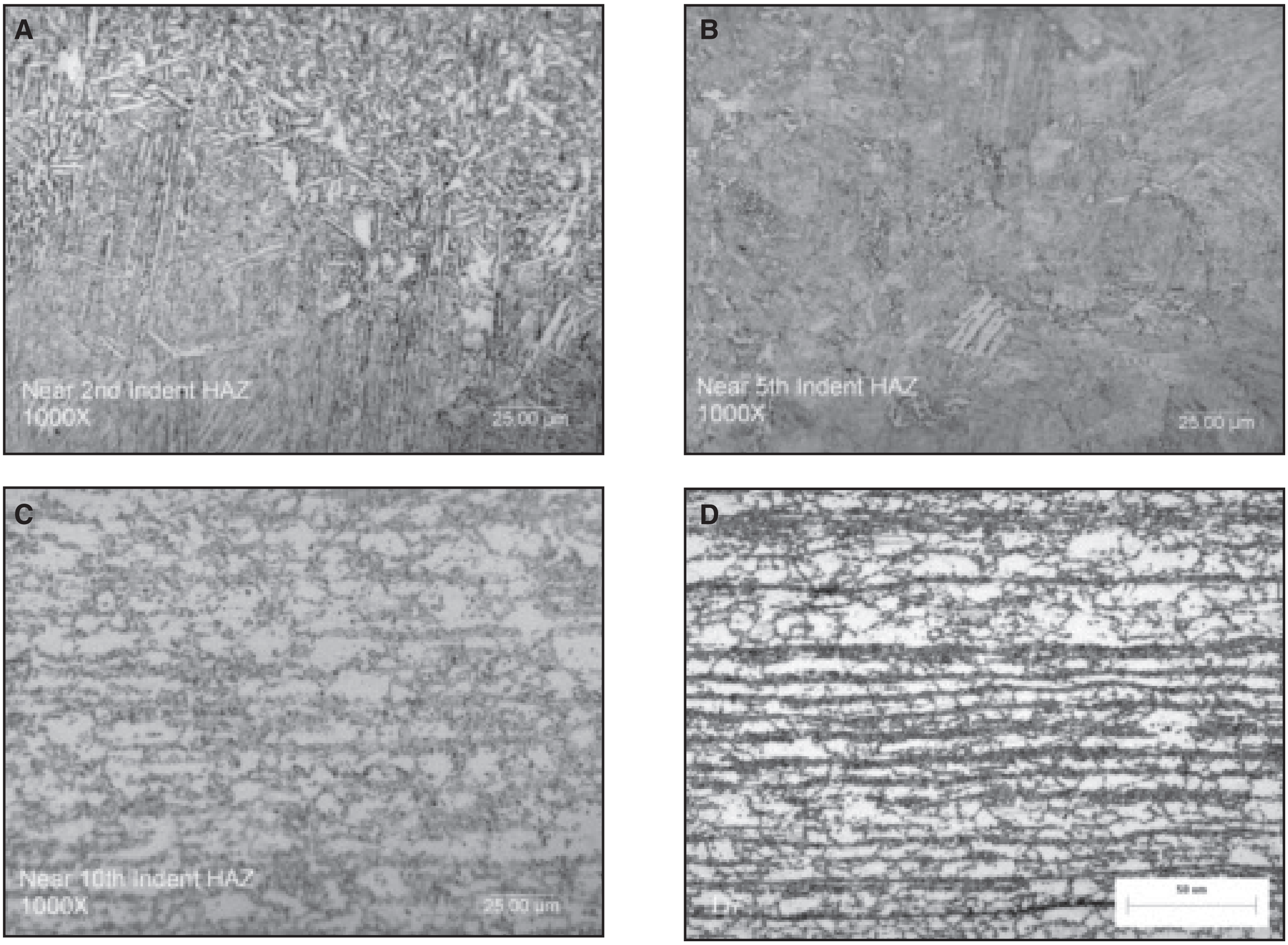

Fig. 10 — Micrographs of the DP 780 HAZ and base metal for a lap weld produced with the nominally high cooling rate condition (2% Nital etch). A — 2nd indent in HAZ (370 HV, 1000×); B — 5th indent in HAZ (340 HV, 1000×); C — 10th indent in HAZ (195 HV, 1000×); D — base metal (207 HV, 500×).

the DP 780 and TRIP 780 welded with the nominally low cooling rate (i.e., combination of high heat input and no heat sink). The plots show that cooling rate tends to have the largest effect on the DP steel, with the TRIP steel being somewhat less affected. Lower cooling rates tend to produce a wider HAZ (as identified from the hardness profile) with lower peak hardness. For example, the DP 780 peak hardness was about 80% higher than the base metal for the high cooling rate condition, and about 25% higher than the base metal for the low cooling rate condition. The lower cooling rate also tends to produce slightly more HAZ softening. The TRIP 780 showed about 11% reduction in hardness compared to the base metal.

• **Material Prestrain**. Figure 5 shows hardness profiles for DP 780 and TRIP 780 welds made both with and without prestrain for the high cooling rate condition. Prestrain has the largest effect on the TRIP base material, increasing the base metal hardness by about 25%. The hardness of the softest location of the TRIP 780 HAZ is also increased by prestrain; with the degree of softening being slightly increased (about 3–10%). The softest point in the TRIP 780 HAZ remains greater than the hardness of the as-received base metal. Prestraining increased the DP 780 base metal hardness by only about 10%. Prestraining did not affect the peak HAZ hardness for either material.

• **Postbake**. Figure 6 shows hardness profiles of DP 780 welds with and without postbaking for both prestrained and not prestrained sheet. Based on these data, postbaking did not appear to have a significant influence on the HAZ hardness profiles of the DP 780 material, regardless of prestrain condition. Figure 7 shows a

Table 10 — Fusion Zone Microstructure, Hardness, and Dilution of DP 780 Welds Produced with ER70S-6 Electrode

Heat Input (kJ/mm)	Nominal Cooling Rate	Heat Sink	Dilution (%)	Average Hardness	Microstructure
				Lap Welds	
0.15	High	Copper	21	269	Predominately AF with a small fraction of B
0.43	Low	Air	59	251	Predominately AF with a small fraction of B
				Butt Joint Welds	
0.20	High	Copper	46	309	Predominately AF with some B and M (very fine microstructure)
0.17	Low	Air	52	266	Mixture of B and AF

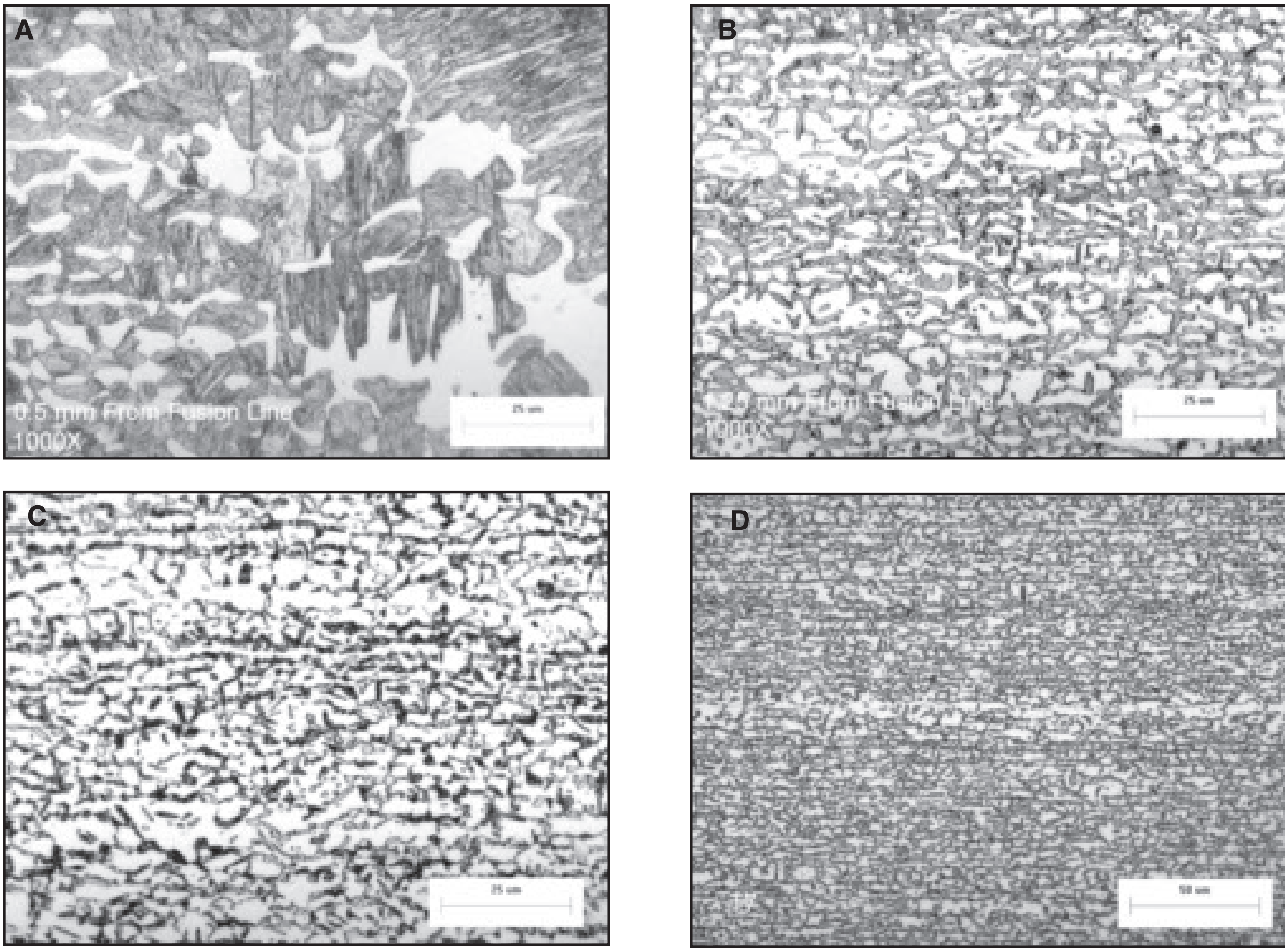

Fig. 11 — Micrographs of the TRIP 780 HAZ and base metal for a lap weld produced with the nominally high cooling rate condition (2% Nital etch). A — 2nd indent in HAZ (335 HV, 1000×); B — 5th indent in HAZ (275 HV, 1000×); C — 10th indent in HAZ (224 HV, 1000×); D — base metal (254 HV, 500×).

similar result for the TRIP 780 material.

Referring to Table 9, comparison of these two steels with DP 980 indicates that although DP 980 had the highest peak HAZ hardness, DP 780 had the highest degree of HAZ hardening. Furthermore, the DP 980 generally had a higher degree of HAZ softening compared to the DP 780 and TRIP 780 materials.

Figures 8 and 9 show Gleeble test results for the DP 780, and TRIP 780 steel heated to 1000°C at 25°C/s. Figure 8 is a plot of measured thermal cycles during heating and cooling of these steels. It is noteworthy that during these experiments, the heating rates were controlled precisely and the cooling rate was allowed to be modified by heat of transformation. The plots clearly show an abrupt change in the cooling curve slope (marked by arrow) for the DP 780 steels. Figure 9 shows the corresponding measured dilatation for the same samples. In DP 780, specimen expansion is nearly linear with increased temperature within the ranges of room temperature to 720°C and 860° to 1000°C. Upon heating through the temperature range of 720° to 860°C, the specimen width decreases and then begins to once again increase. This, along with the fact that the linear coefficient of thermal expansion (CTE) is lower in the range of 100° to 720°C than from 860° to 1000°C, suggests that the initial microstructure transformed to austenite between 720° and 860°C. Similar heating curves were observed for the DP 980 specimens that underwent similar thermal cycles and will be presented in future work. The measured dilation curve for TRIP 780 is significantly different than that which was observed for the DP materials. Upon heating to

Table 11 — Fusion Zone Microstructure, Hardness, and Dilution of DP 780 Welds Produced with ER100S-G Electrode

Heat Input (kJ/mm)	Nominal Cooling Rate	Heat Sink	Dilution (%)	Average Hardness	Microstructure
				Lap Welds	
0.19	High	Copper	38	326	Mixture of M and B
0.41	Low	Air	53	274	Predominately AF with a small fraction of B
				Butt Joint Welds	
0.17	High	Copper	46	317	Predominately AF, which is probably interweaved with M. Some WF
0.18	Low	Air	54	307	Predominately AF with some areas of B

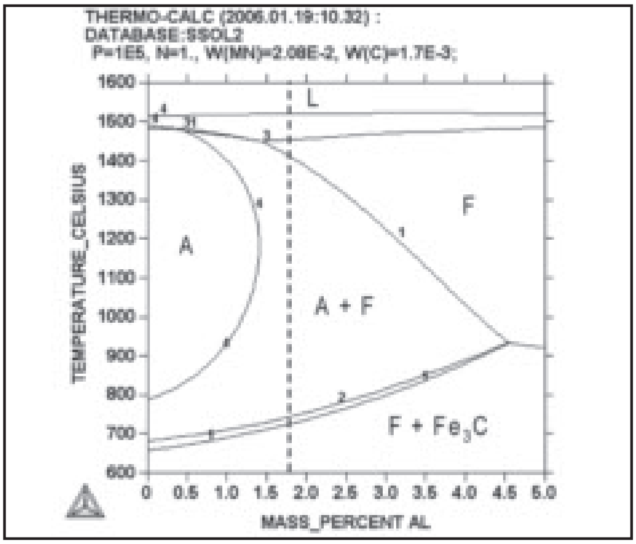

Fig. 12 — Equilibrium phase diagram of TRIP 780 calculated with Thermo-Calc™ software, chemical composition determined by ICP analysis.

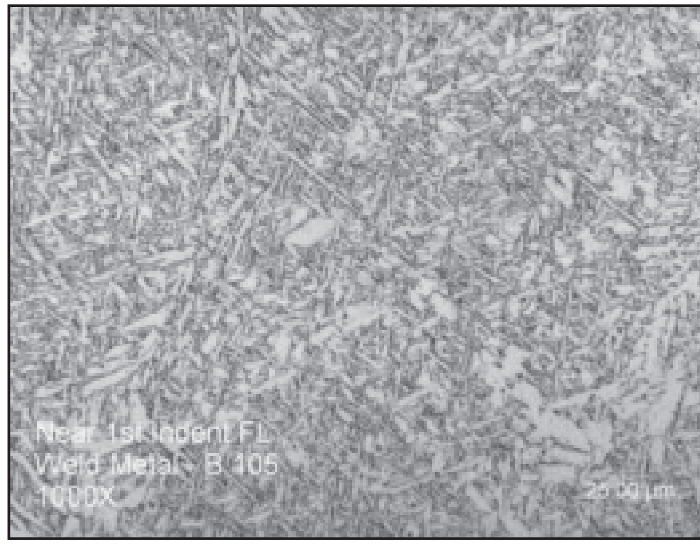

Fig. 13 — Weld metal microstructure of the DP 780/ER70S-6 lap weld produced at high cooling rate.

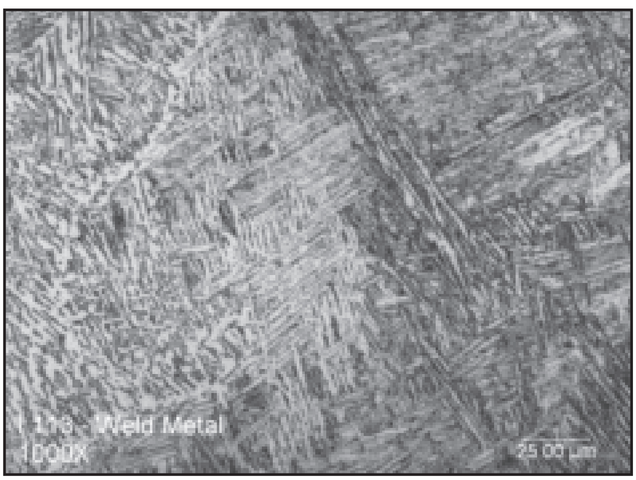

Fig. 14 — Weld metal microstructure of the TRIP 780/ER70S-6 lap weld produced at high cooling rate.

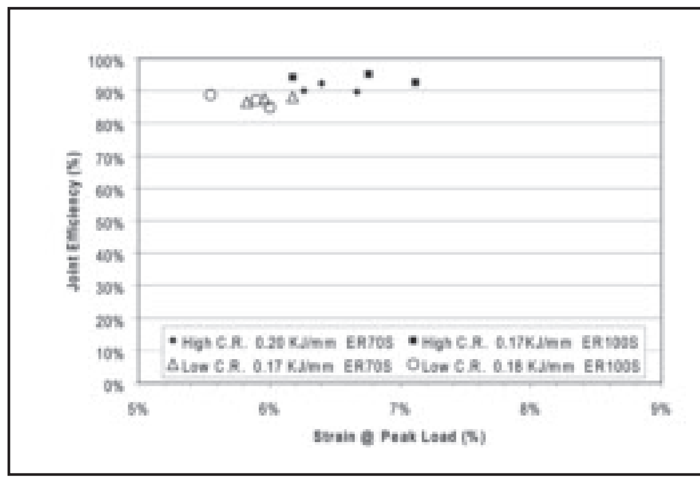

Fig. 15 — Static tensile test results of DP 780 butt joints.

1000°C, no large changes in the CTE were observed, which suggests that the TRIP 780 does not fully transform to austenite. The difference in transformation strains is attributed to increased ferrite stability in the TRIP 780. However, more work is necessary to understand these complex transformations at different heating and cooling rates.

To relate the hardness data to microstructures, micrographs were taken at various HAZ locations of the DP 780 and TRIP 780 welds. Figure 10 shows regions of the DP 780 HAZ and base metal of a high cooling rate weld. The top-left micrograph was taken near the location of peak HAZ hardness (370 HV). The bottom half of the image (where the hardness was measured) has a microstructure that consists of predominately martensite with some bainite. Moving farther away from the fusion boundary, the top-right micrograph shows a slightly softer (340 HV) region with a mixture of martensite and bainite. The bottom-left micrograph shown in Fig. 10 was taken near the minimum hardness (195 HV) location of the high cooling rate weld HAZ. As shown, the microstructure is indistinguishable from that of the base metal.

By comparison, the microstructure of the low cooling rate DP 780 weld (not shown) in the area of peak hardness (260 HV) consists of predominately bainite with some grain boundary ferrite. These data suggest that the significant increase in peak hardness in the high cooling rate weld near HAZ is due to the higher volume fraction of martensite.

Micrographs taken at various locations of the TRIP 780 high cooling rate weld HAZ are shown in Fig. 11. The top-left micrograph was taken near the point of peak HAZ hardness (335 HV) and has a microstructure that consists of a mixture of martensite and large ferrite grains. The top-right micrograph was taken farther from the fusion boundary in a softer HAZ region (275 HV) and has a mixture of large ferrite grains and degenerate martensite. Note that the term degenerate martensite is used to describe regions that appear to be martensite at optical microscopy levels, but may contain tempered martensite and/or bainite constituents (Ref. 2). Comparison of the top-left and top-right micrographs shown in Fig. 11 in-

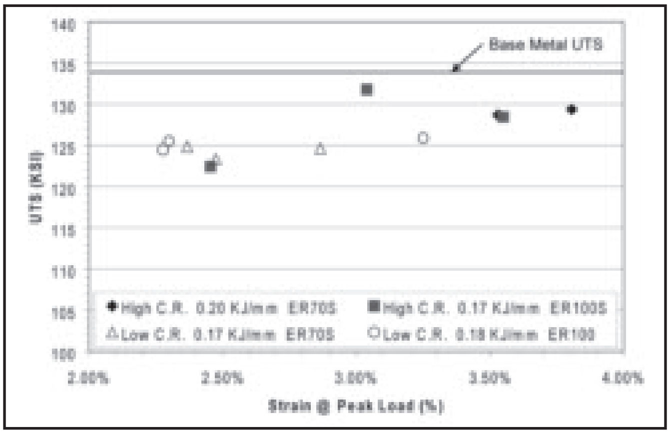

Fig. 16 — Dynamic tensile test results of DP 780 butt joints.

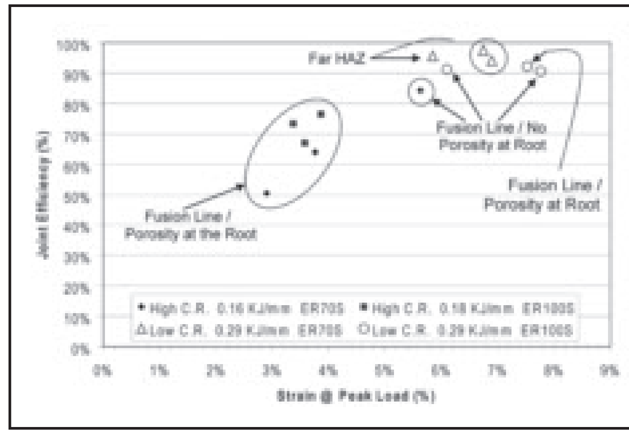

Fig. 17 — Static tensile test results of TRIP 780 lap joints.

dicates that the fraction of ferrite increases with distance from the point of peak HAZ hardness. The bottom-left micrograph is in the softened region and appears similar to that of the base metal, consisting of predominately ferrite with islands of degenerate martensite. The darker contrast of many of the degenerate martensite islands suggests tempering has occurred during the weld thermal cycle.

By comparison, the microstructure of the low cooling rate TRIP 780 weld HAZ (not shown) at the location of peak hardness (275 HV) consists predominately of ferrite grains separated by regions of a fine dispersion of degenerate martensite. Again, this suggests that the lower martensite content is responsible for the reduced peak hardness.

It should be noted that the weld interface of the TRIP 780 welds consists of a continuous band of ferrite grains. The ferrite grains are larger along the weld interface of the high cooling rate weld than along the weld interface of the low cooling rate weld. It was observed that for both cooling rate conditions the fraction of ferrite decreased from the weld interface to the location of peak HAZ hardness, and then increased as the point of minimum HAZ hardness was approached. Between the point of minimum HAZ hardness and the HAZ boundary (unaffected base metal), the area fraction of ferrite in the microstructure appears constant.

Additional analysis was done to better understand the TRIP 780 HAZ phase transformations. The composition of the TRIP 780 was determined by ICP analysis. The aluminum content was found to be 1.8%, which is about 1% higher than the nominal composition indicated by the manufacturer. Using this composition, the equilibrium phase diagram shown in Fig. 12 was determined using Thermo-Calc™ software (Ref. 3). As shown in Fig. 12, the TRIP 780 steel isn't expected to transform to 100% austenite on heating to higher temperature. In other words, ferrite is thermodynamically stable at all temperatures below the melting point with 1.8% aluminum. The phase diagram also shows that we would expect 100% austenite formation if the nominal composition of 0.8% aluminum was used.

Fusion Zone Characterization

Figures 3 and 4 show hardness profiles of DP 780 and TRIP 780 welded with ER70S-6 for the high and low cooling rate conditions, respectively. Tables 10–13 list the nominal cooling rate conditions, dilution, average hardness, and microstructure of DP 780 and TRIP 780 lap and butt joint welds produced with both the ER70S-6 and ER100S-G wires. For comparison purposes, similar data for DP 980 lap welds produced with ER70S-6 wire are listed in Table 14.

Figure 13 shows the weld metal microstructure of the DP 780/ER70S-6 lap weld produced with a high cooling rate, consisting predominately of acicular ferrite with a small fraction of bainite. As Table 10 indicates, lap joints produced at both high and low cooling rates had a similar microstructure, although the low cooling rate was found to have a somewhat softer and coarser microstructure. The butt joint welds produced with high cooling rate consisted of predominately acicular ferrite with some bainite and martensite. At low cooling rates the butt joint weld consisted of a mixture of acicular fer-

Table 12 — Fusion Zone Microstructure, Hardness, and Dilution of TRIP 780 Welds Produced with ER70S-6 Electrode

Heat Input (kJ/mm)	Nominal Cooling Rate	Heat Sink	Dilution (%)	Average Hardness	Microstructure
				Lap Welds	
0.16	High	Copper	37	271	Predominately B with a small fraction of AF
0.34	Low	Air	59	256	Predominately B with a small fraction of AF, (B has higher aspect ratio)
				Butt Joint Welds	
0.20	High	Copper	44	283	Predominately B, no AF
0.18	Low	Air	57	278	Predominately B with a small fraction of AF

Table 13 — Fusion Zone Microstructure, Hardness, and Dilution of TRIP 780 Welds Produced with ER100S-G Electrode

Heat Input (kJ/mm)	Nominal Cooling Rate	Heat Sink	Dilution (%)	Average Hardness	Microstructure
				Lap Welds	
0.19	High	Copper	31	369	Mixture of M and B
0.30	Low	Air	54	317	Predominately B with some AF
				Butt Joint Welds	
0.19	High	Copper	44	389	Most likely M
0.18	Low	Air	57	333	Predominately B with some M

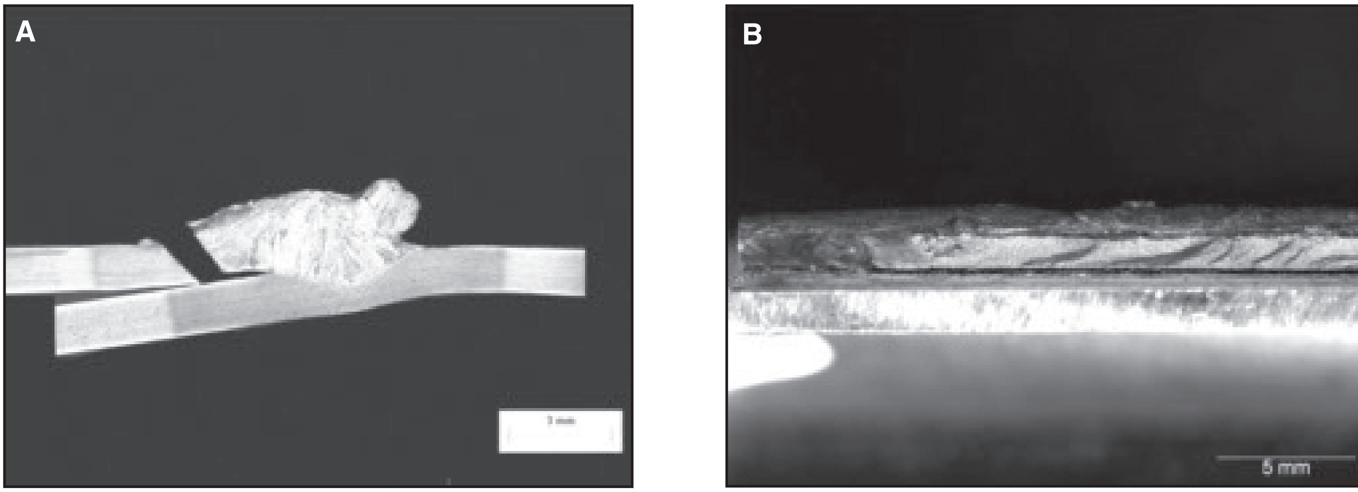

Fig. 18 — Fracture appearance of TRIP 780 low cooling rate lap joint produced with the ER100S-G wire. (Failure is along the weld interface of the top sheet.)

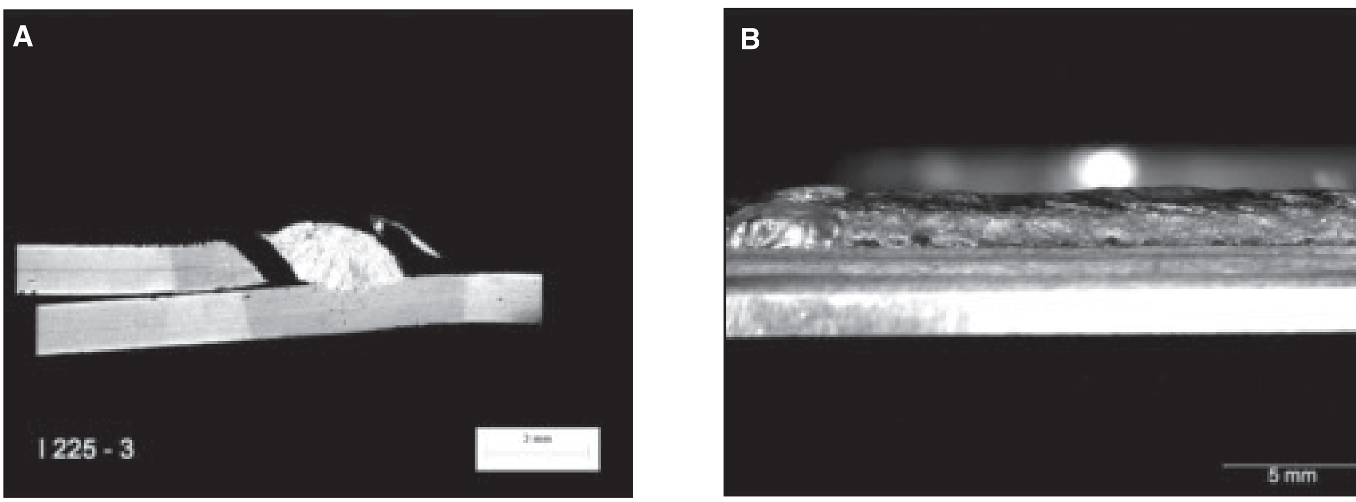

Fig. 19 — Fracture appearance of TRIP 780 high cooling rate lap joint produced with the ER100S-G wire. (Failure is along the weld interface of the top sheet, possibly initiating at porosity present at the root.)

Table 14 — Fusion Zone Microstructure, Hardness, and Dilution of DP 980 Lap Welds Produced with ER70S-6 Electrode

Heat Input (kJ/mm)	Nominal Cooling Rate	Heat Sink	Dilution (%)	Average Hardness	Microstructure
0.15	High	Copper	20	263	Predominately AF with a small fraction of B
0.44	Low	Air	59	253	Predominately AF with a small fraction of B

Table 15 — Carbon Equivalents, Aluminum, and Silicon Contents of Each Base Material

Material	CE	Aluminum (wt-%)	Silicon (wt%)
TRIP 780	0.53	1.81	0.023
DP 780	0.47	0.049	0.005
DP 980	0.49	0.052	0.028

Note: CE = C + A(C) * [Si/24 + Mn/6 + Cu/15 + Ni/20 + (Cr + Mo + Nb + V)/5 + 5*B]
A(C) = 0.75 + 0.25*tanh[20*(C – 0.12)]

rite and bainite. Table 11 indicates the cooling rate conditions and relates them to the average hardness, dilution, and microstructure of the DP 780 welds produced with the ER100S-G wire. The microstructure of the high cooling rate lap weld consisted of a mixture of martensite and bainite, while the low cooling rate lap weld consisted of predominately acicular ferrite with a small fraction of bainite. Butt joint welds were predominantly acicular ferrite with either martensite (for the high cooling rate welds) or bainite (for the low cooling rate welds). Thus, the fusion zone microstructure of the DP 780 was affected by filler metal type, joint design, dilution, and cooling rate.

Figure 14 shows the weld metal microstructure of the TRIP 780/ER70S-6 lap weld produced at a high cooling rate, consisting predominately of bainite with a small fraction of acicular ferrite. As Table 12 indicates, the fusion zone microstructure and hardness obtained for the TRIP 780 lap welds consists predominately of bainite with a small fraction of acicular ferrite. The microstructure of the butt joint welds consisted primarily of bainite, with the low cooling rate weld having a

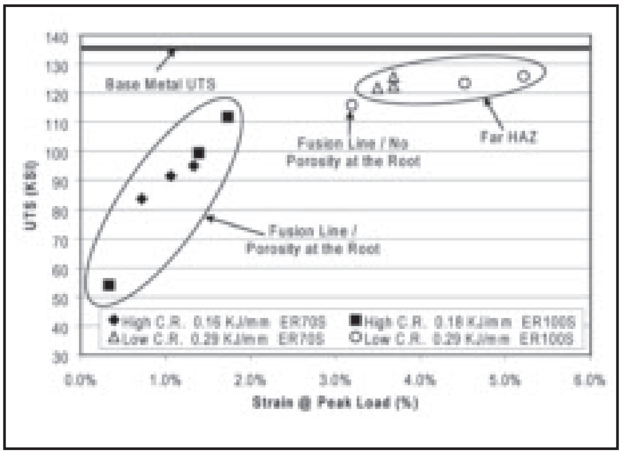

Fig. 20 — Dynamic tensile test results of TRIP 780 lap joints.

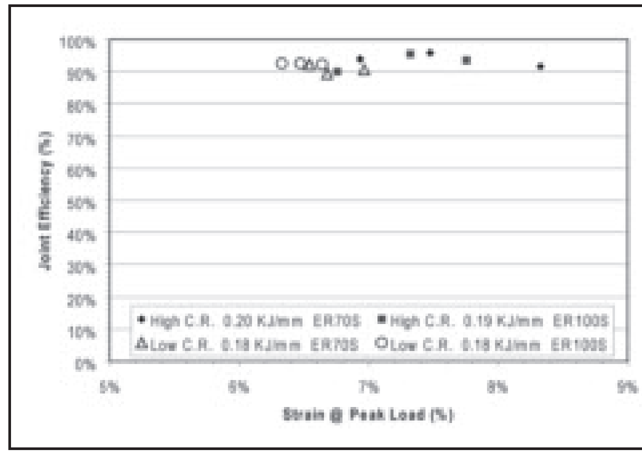

Fig. 21 — Static tensile test results of TRIP 780 butt joints.

small fraction of acicular ferrite. Table 13 lists the microstructure and hardness of the TRIP 780 welds produced with the ER100S-G wire. The fusion zone microstructure of the welds at high cooling rate consisted predominantly of martensite. These welds had significantly higher hardness than those produced at low cooling rate, which were predominantly bainite with some martensite or acicular ferrite.

Table 14 lists the microstructure, average hardness, and dilution of the DP 980 lap welds produced with a high and low cooling rate using ER70S-6 wire. The microstructure of both welds is primarily acicular ferrite with a small fraction of bainite. In this case, cooling rate did not have a large influence on microstructure or hardness. Referring to the HAZ characterization data listed in Table 9, the DP 980 weld fusion zone is softer than any point in the weld HAZ. This suggests that an undermatched strength condition may exist when DP 980 is welded with ER70S-6 wire. Depending on the loading condition, failure may be expected to occur through the softer weld metal. Comparing the fusion zone characterization data of the DP 780 and DP 980 lap joints (Table 10 and Table 14, respectively) indicates that the microstructures and hardness values obtained were very similar. Therefore, the base metal composition did not significantly affect the fusion zone microstructure for the DP steels.

Mechanical Property Characterization

The static tensile test results of the DP 780 butt joints are shown in Fig. 15. The results are expressed in terms of joint efficiency (i.e., weld ultimate tensile strength/measured base metal ultimate tensile strength) and the strain at peak load. All of these welds failed in the softened region of the far HAZ. As shown, the high cooling rate welds had joint efficiencies in excess of 90%; whereas the low cooling rate welds had joint efficiencies in the range of 85 to 90%. The high cooling rate welds also appear to have slightly greater strains at peak load. Filler metal strength did not have a distinguishable effect on the static tensile properties.

The dynamic tensile test results of the DP 780 butt joints are shown in Fig. 16. The results are presented in terms of ultimate tensile strength and the strain at peak load. All of these specimens failed in the softened region of the far HAZ. Ultimate tensile strengths ranged from 122 to 132 ksi (841 to 910 MPa), and strain at peak load ranged from 2.25% to less than 4.0%. Neither filler metal strength nor cooling rate condition had a distinguishable effect on the dynamic tensile properties of the DP 780 butt joints.

Figure 17 shows TRIP 780 lap joint static tensile results for different filler metal and cooling rate conditions. The data from Fig. 17 indicate the following:

- Joint efficiencies ranged from about 50% to about 98%. Strains at peak load ranged from less than 3% to nearly 8%.
- Specimen failure occurred either in the far HAZ (i.e., near the point of greatest softening) or at the weld fusion boundary.

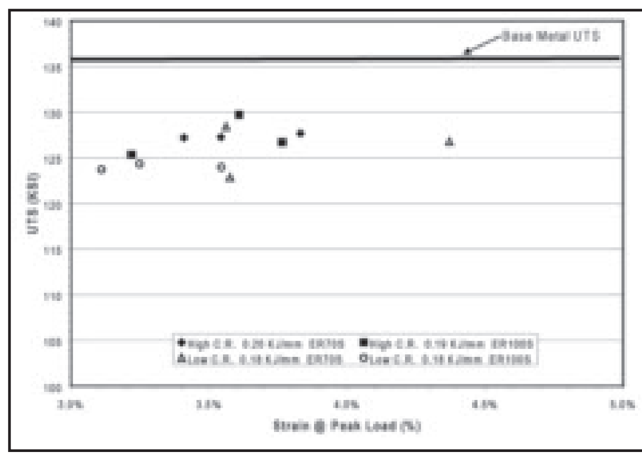

Fig. 22 — Dynamic tensile test results of TRIP 780 butt joints.

- Filler metal strength had no discernable effect on the weld tensile properties.
- Welds produced under high cooling rate conditions had a significantly lower joint efficiency and strain than the welds produced under low cooling rate conditions. This difference was primarily attributed to porosity in the welds produced with the high cooling rate conditions (using short-circuit transfer).

The low cooling rate lap welds produced with the ER70S-6 welding wire failed in the softened region of the HAZ. Figure 18 shows micrographs of a low cooling rate weld produced with the ER100S-G wire, which failed along the weld interface of the top sheet. The right side of the right micrograph reveals a very small amount of porosity to be present. However, two of the low cooling rate welds produced with the ER100S-G wire failed along the weld interface of the top sheet without observable porosity.

Five of the six high cooling rate welds have joint efficiencies in the range of 50 to 78%, and strains at peak load between 2.75 and 4%. Failure in these welds may have initiated at porosity present at the weld root, with failure along the fusion boundary of the top sheet. Figure 19 shows micrographs of one of these welds. The outlying high cooling rate weld (with about 85% joint efficiency and 5.75% strain at peak load) failed along the weld interface of the bottom sheet.

Figure 20 shows the TRIP 780 lap joint dynamic tensile results for different filler metal and cooling rate conditions. As shown, ultimate tensile strengths ranged from 54 to 126 ksi (372 to 867 MPa) and strain at peak load ranged from less than 1% to over 5%. Referring to Fig. 20, the high cooling rate TRIP 780 lap joints had lower strengths and strains at peak load. These welds failed along the weld interface presumably due to porosity present at the root. All of the low cooling rate TRIP 780 lap welds produced with the ER70S-6 wire failed in far HAZ of the bottom sheet. Of the low cooling rate TRIP 780 lap joints produced with the ER100S-G wire, two dynamic tensile specimens failed in the softened region of the far HAZ, and one failed along the weld interface of the top sheet without the presence of porosity at the weld root. Analysis of Fig. 20 indicates that filler metal strength did not have a distinguishable effect on the dynamic tensile test results of the TRIP 780 lap joints.

The static tensile test results of the TRIP 780 butt joints are shown in Fig. 21. All of these welds failed in the softened region of the far HAZ with joint efficiencies in excess of 89%. On average, high cooling rate welds had higher strains at peak load than the low cooling rate welds. As was the case with the DP 780 butt joint welds and the TRIP 780 lap welds, filler metal strength did not appear to influence the static tensile properties.

Figure 22 shows the dynamic tensile test results of the TRIP 780 butt joints. All of these specimens failed in the softened region of the far HAZ. The ultimate tensile strengths of the TRIP 780 butt joints ranged from 122 to 130 ksi (841 to 896 MPa), and strain at peak load was generally between 3 and 4%. Analysis of Fig. 21 indicates that neither filler metal strength nor cooling rate condition had a distinguishable effect on the dynamic tensile test results of the TRIP 780 butt joints. It should be noted that the low cooling rate TRIP 780 butt joints had dynamic tensile properties comparable to the TRIP 780 lap joints and the DP 780 butt joints. However, on average, the TRIP 780 butt joints had slightly higher strain at peak load compared to the DP 780 butt joints.

Discussion

The chemical compositions of DP 780 and DP 980 are similar, with the latter having a higher percentage of carbon and other hardenability alloying additions. The base metal microstructure of the DP steels consists of a ferrite matrix with degenerate martensite islands, with the DP 980 having a higher proportion of martensite. The results of this project indicate that the process variables investigated have similar effects on the DP 780 and DP 980 HAZ and weld metal microstructure. This is expected when one considers that the base metal microstructure and chemistry of the two steels are similar.

The base metal microstructure of TRIP steels consists of a ferrite matrix with islands of martensite, bainite, and retained austenite. The TRIP 780 investigated in this study contains a relatively high amount of aluminum (1.8 wt-%). Aluminum is a ferrite stabilizer and (when above approximately 0.8 wt-%) can allow ferrite to remain stable at temperatures approaching the melting point of the material (Refs. 1, 3). The results of this investigation verified that retained ferrite is present in all regions of the TRIP 780 HAZ.

Because the microstructures of the DP and TRIP steels are substantially different, the results for these steels are discussed separately.

DP 780 and DP 980 Steels

Hardness traverses indicate that the weld has regions of significant hardening and softening depending on the base metal grade, filler metal type, and cooling rate conditions (as determined by welding heat input and heat sinking). The location of greatest hardening is in the near HAZ (adjacent to the fusion boundary), where the far HAZ experienced softening.

For DP 780 welded with ER70S-6 wire, the softest location in the weld is the far HAZ. Gleeble test results indicate that the DP steels both fully transform to austenite upon heating to 1000°C. The minimum hardness location corresponds to the point in the HAZ where the temperature is near the minimum required to begin forming austenite (A_{C1} boundary). This softening is probably attributable to tempering of the degenerate martensite. Mechanical testing showed that this softened region limits the DP 780 weld strength, and that a higher-strength consumable did not provide static or dynamic tensile strength improvements. During static tensile testing, cooling rate had only a slight effect on the DP 780 butt joint efficiency; for the high cooling rate condition joint efficiencies exceeded 90%, while for the low cooling rate condition joint efficiencies ranged from 85 to 90%. During dynamic tensile testing, cooling rate did not have a distinguishable effect on the strength of the DP 780 butt joint welds.

The microstructure and peak hardness of the near HAZ were strongly influenced by both cooling rate and base metal composition. A predominately martensitic microstructure is present in the region of peak hardness (395 HV) in the DP 980 high cooling rate weld, while the DP 780 had a somewhat softer (375 HV) mixture of martensite and bainite. The peak hardness of the low cooling rate DP 780 weld (260 HV) is significantly less than that of the high cooling rate DP 780 weld (375 HV). This difference in hardness is probably a result of autotempering of the martensite during the slower cooling cycle. In other words, the slower cooling rates allow martensite formed in the near HAZ sufficient time at temperatures in which tempering can occur. The potential implications of the hardness increase in the near HAZ region are not well understood.

As previously mentioned, the microstructure of both DP 780 and DP 980 consists of a ferrite matrix with degenerate martensite islands. During cold rolling of these materials, the stress and strain distribution in the two structures is different (Refs. 4, 5). The strain tends to concentrate in the soft ferrite (Ref. 4). Because DP 980 has a lower fraction of ferrite than DP 780, it may have a higher dislocation density in the ferrite phase of its microstructure. Therefore, prestrain produces a larger increase in base metal hardness for the DP 980 steel than for the DP 780 steel.

Welding on prestrained DP 780 and DP 980 resulted in a wider HAZ and the minimum HAZ hardness being slightly greater than that of the welds without prestrain. In addition, it was observed that for each respective material the high cooling rate weldment had a slightly greater minimum HAZ hardness than the low cooling rate welds with nominally the same amount of prestrain. The differences in the HAZ of the welds produced with prestrain to those produced on the as-received base metal are attributable to the process of recovery. For both DP grades, the minimum HAZ hardness of the prestrained weld remains greater than that of the weld without prestrain, which is likely due to the weld thermal cycle in the far HAZ being insufficient for completion of the recovery process. Compared to DP 780, a greater reduction in base metal hardness occurs in the HAZ of prestained DP 980. This may be due to the higher dislocation density present in the ferrite phase of this material producing a larger driving force for recovery.

Based on the fusion zone data presented in the tables, weld metal microstructure and hardness appear to be predominately influenced by the cooling rate, rather than the DP grade. Welds on DP 780 produced using both wires tended to consist of predominately acicular ferrite with varying degrees of bainite and martensite. The welds on the DP 780 and DP 980 produced using the ER70S-6 wire had similar microstructures and hardness, and no correlation could be made between base metal dilution and microstructure. Analysis of the microstructure and the resulting fusion zone hardness indicates that dilution of the filler metal by the base metal does play a role in weld metal microstructure evolution, although the effect of dilution was more pronounced for the TRIP 780, which is discussed later.

When the DP 980 was welded with the ER70S-6 consumable, the lowest hardness occurred in the fusion zone. This suggests that a higher-strength electrode would be required to avoid undermatched weld metal strength and consequent failure through the fusion zone. Application of a higher-strength electrode may be required to shift the failure location to the softened region of the HAZ.

TRIP 780 Steel

The TRIP 780 welds had a continuous structure of ferrite grains along the fusion boundary. The presence of ferrite along the fusion boundary can be explained with the equilibrium phase diagram shown in Fig. 12. For TRIP 780, at temperatures near the liquidus, ferrite is the only thermodynamically stable phase.

For all locations within the TRIP 780 HAZ, the fraction of ferrite in the microstructure is greater for the welds produced with low cooling rate compared to high cooling rate. The microstructure of the low cooling rate weld at the point of peak HAZ hardness consists of predominately ferrite grains separated by regions of degenerate martensite. As previously noted, the term degenerate martensite is used to describe regions that appear to be martensite at optical microscopy levels, but may contain tempered martensite and/or bainite constituents. The microstructure in the high cooling rate weld at the location of peak HAZ hardness consists of a mixture of martensite and large ferrite grains. In both cases, the fraction of ferrite in the HAZ microstructure increases from the point of peak HAZ hardness to the location of minimum HAZ hardness. The microstructure of the high cooling rate weld has greater hardness at each HAZ location between the points of minimum and peak hardness.

The microstructure evolution in the HAZ of TRIP steels can be separated into two different regions. The regions that heated above the A_{C1} temperature (700°C) and the regions heated below the A_{C1} temperature.

Referring to Fig. 12, the regions heated above the A_{C1} do not entirely transform to austenite due to increased stability of ferrite. As a result, the regions heated above the A_{C1} will remain in a two-phase (austenite + ferrite) region throughout the heating cycle. Depending upon the peak temperature, the ferrite fraction may increase from the original level. This often resulted in a continuous necklace of ferrite along the weld interface of the welds produced on the TRIP 780 steel. Similar microstructural observations have been noted for multipass self-shielded gas metal arc welds (Refs. 6, 7). As the HAZ starts cooling, a small fraction of the austenite may be retained, but the larger fraction decomposes into either bainite or martensite. The rate of cooling will determine the nature of this microstructure mixture. This is supported by the HAZ microstructure of welds made with both the nominally high and low cooling rate conditions.

The regions heated below the A_{C1} (far HAZ) and cooled are expected to undergo subtle microstructural changes. As previously noted the base metal microstructure of TRIP steel consists of a ferrite matrix with islands of martensite, bainite, and retained austenite. Depending upon the peak temperature, the retained austenite may transform to martensite upon cooling; this can only be determined using transmission electron microscopy. At a given location of the far HAZ, the martensite formed from the retained austenite, as well as that present in the as-received base material, may undergo tempering. The degree of martensite tempering is dependent on the weld thermal cycle at the given location. Based on the measured hardness of the welds produced with both cooling rate conditions, lesser degrees of martensite tempering is expected in the welds made with the high cooling rate condition. The extent of softening appears to decrease with an increase in distance from the A_{C1} boundary.

Prestrain had a more pronounced effect on the TRIP 780 than was observed with the DP steels. During deformation of TRIP steels at ambient temperatures the retained (quasi-stable) austenite progressively transforms into martensite as the material is strained (Refs. 4, 8). Therefore, the increased base metal hardness is due to both the new martensite formed, and an increase in the dislocation density of the ferrite grains. For both cooling rate conditions, prestrain did not increase the peak HAZ hardness, but did increase the hardness in the region between the A_{C1} boundary and the peak HAZ hardness location. In addition, the minimum HAZ hardness of the welds made on the prestrained base metal remained greater than the hardness of the as-received base metal.

Welds produced on TRIP 780 with the ER70S-6 wire consisted primarily of bainite with a small fraction of acicular ferrite. Compared to the DP 780 welds, for each condition of joint geometry and cooling rate these welds tended to have slightly higher hardness. When the ER100S-G wire was used, the microstructure of the TRIP 780 welds tended to consist either of martensite and/or bainite. For this electrode/base material combination, acicular ferrite was only observed in the microstructure of the low cooling rate lap joint weld. Compared to the DP 780 welds produced with the ER100S-G wire, for each condition of joint geometry and cooling rate the TRIP 780 welds had significantly higher hardness.

The fusion zone hardness data suggest that base metal dilution has a greater effect on weld metal hardenability for TRIP 780 than for DP 780 or DP 980. Of the three materials, TRIP 780 appears to be the most heavily alloyed (Table 2). Table 15 lists the carbon equivalents of these materials, which were calculated using the formula proposed by Yurioka et al. (Ref. 9). As listed, TRIP 780 has the highest carbon equivalent. However, it is important to note that the carbon equivalency formula does not consider aluminum. In this regard, the major effect of dilution is attributed to higher carbon content in TRIP steels. As Kou reported, increasing the alloying content of weld metal increases its hardenability by pushing the nose of the continuous cooling transformation curves to longer times (Ref. 10). Thus, harder constituents such as bainite and martensite are more likely to form in the welds produced on TRIP 780.

A wide range of joint efficiencies (50 to 90%) and ultimate tensile strengths (54 to 128 ksi) were obtained for the TRIP 780 lap welds during static and dynamic testing, respectively. Failure was either along the weld interface or more commonly in the softened region of the HAZ. Five of the six TRIP 780 lap welds produced with high cooling rate conditions failed along the weld interface during static testing (presumably due to porosity at the weld root) at significantly lower strength and ductility than the welds produced with low cooling rate conditions. Notably, some of the welds failed along the weld interface without any indication that porosity was present at the weld root. As mentioned previously, the weld interface of the TRIP 780 welds contains a continuous region of large ferrite grains. This region most likely has lower strength than the surrounding weld metal and HAZ microstructure. The weld root and any porosity present near the root serve as stress concentrations. Fracture can initiate at these stress concentrations and propagate through the lower-strength ferrite grains along the weld interface. Butt joint welds that lacked such stress concentrations all failed in the softened region of the HAZ at joint efficiencies of over 90% (static testing) and ultimate tensile strengths between 122 and 130 ksi (dynamic testing). For the butt joints that underwent static tensile testing, higher cooling rate conditions tended to increase the joint efficiency slightly. However, cooling rate conditions did not have a distinguishable effect on joint strength during dynamic tensile testing.

For each condition of cooling rate and joint geometry, filler metal strength did not have a distinguishable effect on either joint strength or ductility. Filler metal strength may play a larger role in static strength for prestrained TRIP 780. Prestraining increased the hardness of the softest point in the HAZ, which may shift the failure to the fusion zone. It is possible, however, that the continuous ferrite band along the fusion boundary may be the point of failure on prestrained material, regardless of the filler metal strength. Additional work is needed to assess the effect of prestrain and the continuous ferrite band on weld tensile properties.

Summary and Conclusions

This work primarily investigated the effects of cooling rate (welding heat input and fixture heat-sinking), prestrain, filler metal selection, dilution, and postbaking on the microstructure and mechanical properties of GMA welds on coated DP 780 and TRIP 780 sheet metal lap joints and butt joints. A limited amount of testing was also conducted for DP 980 lap joints. The most significant conclusions are listed below.

1) The DP steels showed varying degrees of HAZ hardening and softening depending on the material grade, prestrain, and cooling rate condition. The relatively high aluminum content of the TRIP 780 steel allowed retained ferrite to be present in all regions of the HAZ, along with a continuous region of coarse ferrite along the weld interface. This resulted in the TRIP 780 having lower peak HAZ hardness than the DP 780.

2) Fusion zone microstructure and hardness were found to be affected by the base metal chemistry, the cooling rate condition, and the filler metal composition.

3) Filler metal strength did not affect the static or dynamic tensile properties of either the TRIP 780 lap or butt joint welds, or the DP 780 butt joint welds. All of the TRIP 780 and DP 780 butt joints failed in the soft HAZ. The results of the lap joint tests showed a greater variation in strength that is primarily attributed to porosity at the root of the weld.

4) Additional work is needed to relate HAZ and fusion zone microstructures, hardness profiles, and geometric discontinuities to fatigue, bend, impact, and crush performance. In particular, work is needed to evaluate the effect that the ferrite region along the fusion boundary has on the mechanical properties of TRIP 780 lap joints.

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A New Path Forward for Understanding Microstructural Evolution during Welding

In-situ X-ray probing of welds was developed using synchrotron radiation for the direct observation of phase transformations during welding

BY JOHN W. ELMER

ABSTRACT. Over the past century, the principal method for estimating the sequence of microstructural events that produce the final weld microstructure has been postweld microstructure analysis, and it's the interpretation of these microstructures that sets welding metallurgy apart from other related endeavors. In conjunction with heat flow analysis and thermodynamic principles, the postweld microstructural interpretation of grain sizes and shapes, second-phase particles, interphase boundaries, and composition gradients provide the framework for interpreting the events that lead to the final microstructure. However, without direct and confirming evidence of the actual phases that exist during welding, multiple interpretations for microstructural evolution of welds often occur. For this reason, methods for the direct observation of the phases and phase transformations that occur during welding was developed. This paper summarizes the 2007 Adams Lecture titled "A New Path for Understanding Microstructural Evolution during Welding Using Synchrotron Radiation," where real-time X-ray diffraction methods were presented as a means for the direct observation of phase transformations during welding.

A Brief History of Synchrotron Radiation

Synchrotron radiation is a form of electromagnetic radiation that is emitted by charged particles moving in a curved path. As the charged particles accelerate around the path, they emit energy tangent to the curved path with wavelengths that cover a broad spectral range extending from the infrared to hard X-ray portions of the electromagnetic spectrum (Refs. 1–3). These X-rays are often generated in facilities specifically designed to produce intense and highly collimated X-ray beams for the purpose of performing controlled scientific experiments. The power of synchrotron radiation is that it is both tunable in wavelength and intensity. These parameters are controllable and are related to the energy of the charged particle, the radius of the curved path, and the number of charged particles in the circulating beam. Synchrotron design takes advantage of these parameters by developing large storage rings targeted to perform specific types of experiments, for example soft or hard X-ray applications, that can be operated around the clock. The high intensity and broad spectrum of synchrotron radiation has enabled it to become one of the most important research tools for the study of matter in all its various forms, and can be used as a noncontact probe to determine the otherwise invisible structure of matter.

The roots of synchrotron radiation trace back to the invention of X-ray tubes in the late 1800s. The historical development of synchrotrons and X-rays is a fascinating one involving some of the great names in science and many Nobel prizes (Refs. 4, 5). The first Nobel Prize in Physics was given to W. Röntgen for the discovery of X-rays in 1901, which created an intense competition for further discoveries and new applications. Vacuum X-ray tubes were soon developed and optimized to generate higher-intensity X-ray beams for physics experiments. X-ray tubes gave way to cyclotrons as a means to create higher-energy electron interactions, and this eventually led to the discovery of synchrotron radiation in 1947 when visible light was observed emanating from a 70-MeV beam being used in a cyclotron experiment at General Electric's Schenectedy facility (Refs. 2, 3, 6). Within the next decade synchrotron radiation was being studied on larger and larger cyclotrons, and experiments were being performed using the synchrotron as a soft X-ray source. By the early 1960s, the first-generation synchrotrons were being built around the world with GeV energies to access the hard X-ray spectrum for solid-state technology research.

The earliest first-generation synchrotrons were called parasitic facilities because they were built as part of high-energy physics studies that were not devoted solely to the generation of synchrotron radiation (Ref. 1). However, the demand for access to synchrotron beam time was high and facilities were being proposed to be devoted to synchrotron radiation research. By the mid 1960s, the first storage rings were being built, which allowed electrons or positrons to be circled under high-vacuum conditions for extended periods. These storage rings permitted multiple beam lines to access high flux synchrotron radiation for many hours at a time. In 1974, the first storage ring in the multiple GeV range providing hard X-rays to a large community of users was built at the Stanford Linear Accelerator Center (SLAC), in Palo Alto, Calif. (Ref. 1). The 2.5-GeV SPEAR ring at SLAC included five experimental stations and was being used for more than just high energy physics experiments. However, SPEAR was still a parasitic ring at the time and didn't operate at optimum conditions for many of the types of experiments that synchrotron researchers were interested in.

The second-generation synchrotron storage rings were built in the late 1970s and early 1980s, and around that time

KEYWORDS

HAZ Formations
In-Situ Experiments
Microstructure Evolution
Phase Transformations
Real Time Observations
Synchrotron Radiation
Solidification Mode
X-Ray Diffraction

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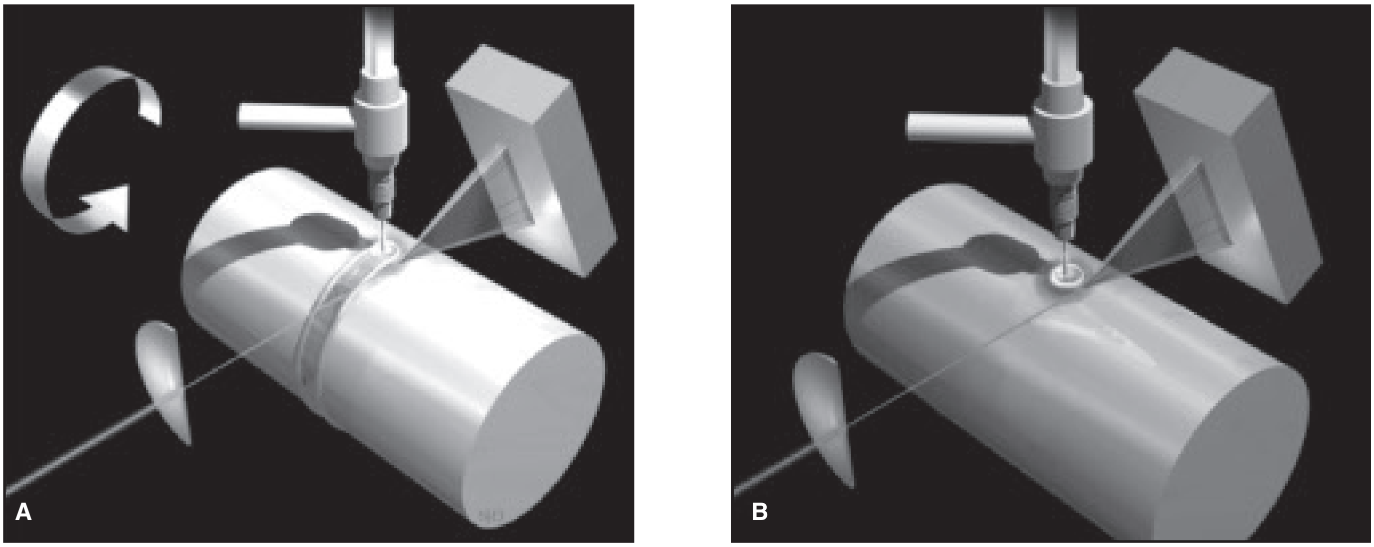


Fig. 1 — Illustrations of the following: A — SRXRD experimental setup where a steady-state weld is made by rotating the bar being welded beneath a stationary torch; B — TRXRD experimental setup where a transient GTA spot weld is made on top of a stationary bar. In both cases, the synchrotron beam (already focused and monochromatized) enters from the left and passes through a pinhole to provide spatial resolution. The X-ray detector is illustrated downstream of the weld to collect the diffracted beams.

some of the original first-generation sources were converted to second-generation sources (Refs. 1, 2). The second-generation storage rings were designed and dedicated to synchrotron radiation studies, and were finding an increasing number of applications. Whereas previous generation machines were largely used for physics research, the second generation sources were finding large numbers of users in more diverse fields such as chemistry, biology, geology, and engineering. High-flux experiments were possible on these beam lines using magnetic bending devices and other insertion devices (Refs. 1–3, 6, 7), allowing spatially resolved and time-resolved experiments to be performed at levels not possible using conventional X-ray sources.

As the demand for these types of experiments increased, it was clear that beam brightness was becoming as important, and sometimes more important, than beam flux. Brightness is a property of the beam defined as the number of photons emitted per second, per square millimeter, per square milliradian of opening angle within a given spectral bandwidth, usually 0.1% (Ref. 1). The brightness of the second-generation sources was increased, and at the same time beam wigglers and undulators (Refs. 1–3, 6, 7) were being developed that produced beams with even higher brightness. These beams were allowing developments to be made in the fields such as angular resolved photoemission for the study of electronic structure of solids and surfaces, extended X-ray absorption fine-structure spectroscopy (EXAFS) for measurement of local atomic structure, protein crystallography, X-ray lithography, and topography (Refs. 1–3, 6, 7).

The third-generation, and most recent, synchrotron sources are built as fully dedicated facilities with high brightness and high flux capabilities in mind. Smaller third-generation sources such as the Advanced Light Source (ALS) in Berkeley, Calif., were developed for VUV and soft X-ray production and have circumferences on the order of 200 m. Larger third-generation sources such as the Advanced Photon Source (APS), located at Argonne National Laboratory near Chicago, Ill., or the European Synchrotron Radiation Facility (ESRF), located in Grenoble, France, which have circumferences on the order of 1000 m, were developed primarily for the hard X-ray spectrum. These third-generation sources are distinguished from second-generation sources in that they have higher inherent brightness and were designed specifically for the insertion of beam-enhancing devices to further increase their flux and brightness. There are more than 20 of these third-generation sources in more than 10 countries throughout the world today (Ref. 1), with multiple thousands of users running experiments each year. Whereas the early synchrotron sources were only being used for high energy physics experiments, the access to the new third generation sources are available to all scientific and engineering endeavors. Many synchrotrons are user facilities that are open to all types of researchers, oftentimes through an open proposal competition process.

The Application of Synchrotron Radiation to Welding

A project was initiated at Lawrence Livermore National Laboratory (LLNL) in 1993 to investigate the feasibility of using synchrotron radiation as an *in-situ* probe to investigate phase transformations that occur during welding. Because of its intense and highly collimated X-ray beams, it was believed that atomic structure of welds could be probed in real time with sufficient temporal and spatial resolution to gather meaningful data about the phase transformations that occur during welding. This feasibility study led to three early publications that demonstrated that a spatially resolved X-ray beam produced at SSRL could be used for the *in-situ* identification of high-temperature phases in the heat-affected zone (HAZ) of welds (Refs. 8–10). Based on this early work, a program was initiated by the Department of Energy's Office of Basic Energy Science to study the kinetics of phase transformations during welding using *in-situ* synchrotron radiation as a real-time X-ray probe. This larger program was funded at LLNL from 1996 through 2004, where direct observations of welding-induced phase transformations were performed on many different metals and alloys at SSRL as is discussed in more detail later. From 2005 to the present, additional synchrotron-based work is being performed at APS where a weld simulation technique is used rather than direct welding to allow solid-state phase transformations to be studied under more controlled conditions. This paper provides an overview of the work that has been done to date at LLNL at both the SSRL and the APS synchrotron facilities.

Introduction

The need for *in-situ* observations of phase transformations during welding stems from the fact that very little unequivocal data are available about the phases that exist in the extreme conditions that surround welds. Experimental observations are hampered by the severe temperature gradients, high peak temperatures, and rapid thermal fluctuations that occur in the weld HAZ. Although the resulting effects of weld temperatures on weld microstructures are well known (Refs. 11–13), the lack of actual data acquired during welding has severely limited the validation of the theories and models that have been proposed for the evolution of weld microstructure. Unlike postweld metallographic observations, which are essentially postmortem examinations of the weldment, synchrotron observations allow the phase transformations to be directly observed in realtime with high spatial resolution for actual verification of the phases that exist.

In-situ synchrotron X-ray diffraction methods are direct, in that they can determine the actual phases that exist during welding. If a high-temperature phase is identified by its X-ray diffraction pattern, then it is certain that that phase was present. This fact is one of the principal distinctions between synchrotron observations and other methods for weld microstructure analysis. Conventional, indirect methods measure some property of the metal or alloy (length, resistivity, enthalpy) during simulated weld heating and cooling, but do not verify the presence or absence of a given phase as transformations occur. For example, high-temperature dilatometry or gleeble testing, measures the change in length of a sample during heating and cooling, but the phases that are really present can only be inferred from the results. Complex phase transformations and those involving substantial changes in composition due to chemical diffusion cloud the picture of what is really taking place. Similar complications arise when trying to interpret differential scanning calorimetry data (changes in enthalpy), or resistivity data (changes in electrical properties) during thermal cycling.

Although the heating cycle of the weld can be modeled and/or experimentally measured, the kinetics of each of the various phase transformations are difficult to determine and are rarely known under actual welding conditions. In the absence of these data, isothermal time-temperature-transformation (IT) and continuous-cooling-transformation (CCT) diagrams, which are available for many ferrous and nonferrous alloys (Refs. 14, 15), are sometimes used to approximate the behavior of phase transformations that occur during the nonisothermal cooling cycle of the HAZ (Ref. 12) if the thermal profile of the weld is known. Application of these diagrams for the prediction of weld behavior requires many assumptions in order to deal with the nonuniform temperature distribution of welds (Ref. 12). Furthermore, these diagrams represent the cooling but not the heating portions of the HAZ, and there is no generally accepted method for verifying how well these diagrams predict actual HAZ behavior. This lack of information has hindered both the efforts to develop comprehensive models for the prediction of the HAZ microstructure, and our basic understanding of microstructural evolution in welds.

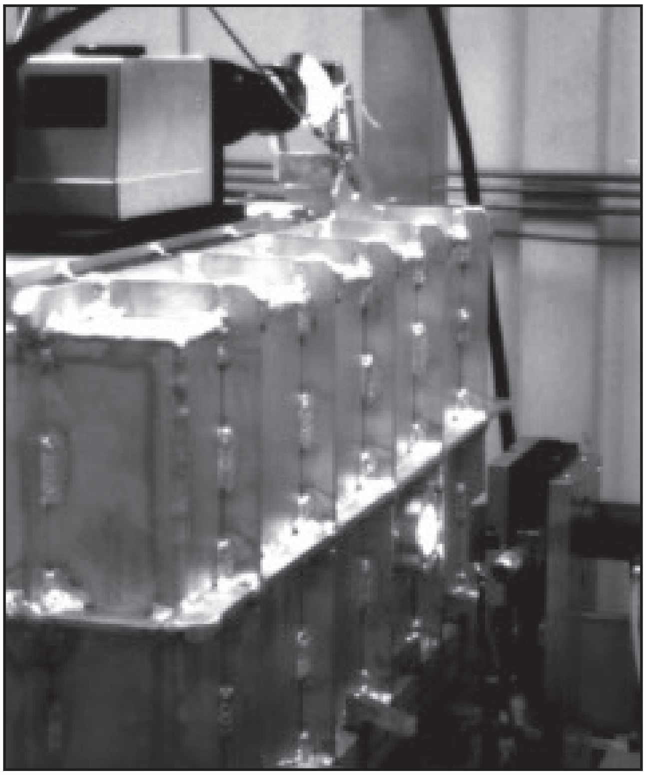


Fig. 2 — Photograph of an SRXRD experiment in progress in the experimental hutch at beam-line 10-2 at SSRL. An aluminum environmental chamber surrounds the weld and X-ray detector. The welding arc is visible as a blue glow seen through the same port where the synchrotron beam enters the side of the chamber. An infrared camera views the weld through a second port located on the top of the chamber.

Even if kinetic data were available, the temperature cycle of the weld has to be known in order to properly predict the effects of welding on microstructure. Since it is extremely difficult to get reliable experimental thermal data from welds, numerical modeling of the weld temperatures is now being used to determine the weld thermal cycles. These numerical models have advanced considerably (Refs. 16–22) over the analytic solutions to weld heat flow that were prominent two decades ago (Ref. 12). Numerical weld models are now being used by weld researchers to calculate the size and shape of the fusion zone with three-dimensional coupled thermal fluid codes for quasi-steady-state welds (Refs. 23, 24), as well as the more complicated transient welds (Refs. 25–27). The resulting calculations allow the spatial distribution of peak temperatures, heating rates, and cooling rates in the HAZ to be determined. However, without corresponding phase transformation kinetic data, microstructural evolution in the weld HAZ cannot be predicted.

Obtaining kinetic data about phase transformations in welds is complicated by the intense thermal conditions surrounding welds that interfere with all types of physical probes that are placed near them. Because of this, a noncontact probe was desired that could identify phases during welding with high spatial resolution and would not be damaged by the welding arc. Synchrotron radiation turned out to be ideal for this probe, and two synchrotron-based techniques were developed at Lawrence Livermore National Laboratory specifically aimed at gathering real-time phase transformation data from welds. These techniques are referred to as spatially resolved X-ray diffraction (SRXRD) and time-resolved X-ray diffraction (TRXRD). In addition, a weld simulation technique was developed for direct observations of phase transformations under controlled heating and cooling (CHC) conditions. These three techniques are new to welding and permit 1) the direct observation of the solidification mode of an alloy during welding, 2) the ability to discover, in real time, definitive sequence of phase transformations that lead to the final weld microstructure, and (3) the capability to generate quantitative kinetic data of phase transformations

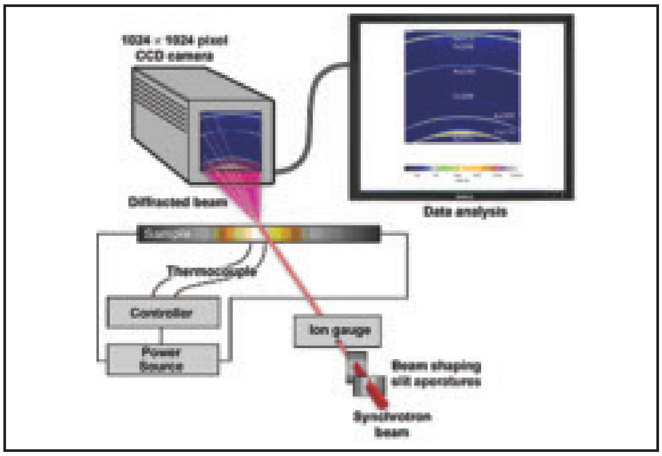


Fig. 3 — Schematic diagram of the X-ray setup used for in-situ observations of phase transformations under controlled heating and cooling (CHC) conditions. The synchrotron beam passes through vertical and horizontal slits for spatial resolution, and the sample is heated by a direct resistance method. An environmental chamber (not illustrated) surrounds the sample to prevent oxidation during the run.

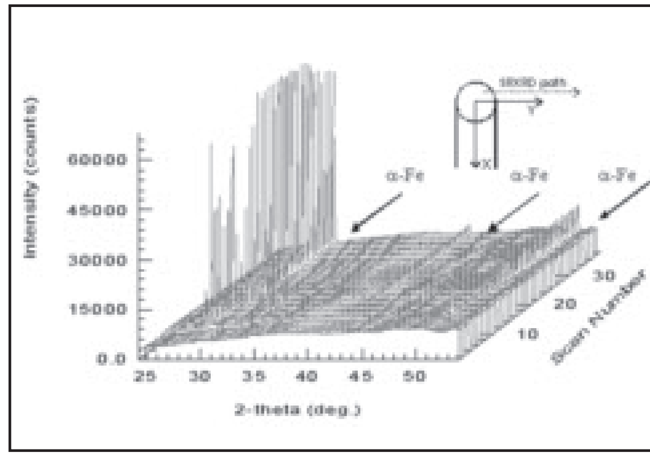


Fig. 4 — A typical complete SRXRD scan showing 37 diffraction patterns taken across the weld HAZ. The schematic drawing illustrates the scan path of the beam. Each successive diffraction pattern was taken at 0.25-mm steps along the y direction away from the weld centerline. The α-ferrite peaks are indicated, the remaining peaks correspond to those of γ-austenite.

through synthesis of *in-situ* data with the temperature history obtained through numerical heat transfer modeling. From these data, the kinetics of phase transformations that occur under the highly nonisothermal heating and cooling cycles produced during welding can be better understood. This paper presents an overview of each technique and some of the experimental highlights that each has produced.

In-Situ Synchrotron Experimental Methods and Modeling

Spatially Resolved X-Ray Diffraction (SRXRD)

The SRXRD technique was the first method developed at LLNL to observe phase transformations during welding, and is used to both identify and map phases that exist in the heat-affected zone (HAZ) of steady-state moving arc welds. In this method, X-ray diffraction patterns are acquired in real time at discrete locations in the weld HAZ (Refs. 28–36). This data can be further analyzed and modeled to understand the kinetics of phase transformations taking place (Refs. 37–45). Figure 1A shows a schematic illustration of the SRXRD technique, where a steady-state gas tungsten arc (GTA) weld is made by rotating a metal bar at a constant speed beneath the welding torch, while the spatially resolved synchrotron beam is used to probe the phase present in the weld HAZ (Refs. 28, 29).

All of the SRXRD experiments on welds were performed on the 31-pole wiggler beam line, BL 10-2 (Ref. 46) at SSRL with SPEAR (Stanford Positron-Electron Accumulation Ring) operating at an electron energy of 3.0 GeV and an injection current of ~100 mA. These experiments used a synchrotron beam that emerged from the wiggler and was focused by a toroidal mirror back to the source size of ~1 × 2 mm before being monochromatized using a double Si (111) crystal. After leaving the monochromator, the beam is spatially resolved by passing it through a tungsten pinhole with diameters 180 μm, 260 μm, or 540 μm to render a sub-millimeter beam on the sample at an incident angle of ~25 deg. The beam flux was measured to be ~10^{12} photons/s for a 260-μm pinhole (Refs. 34–36) after the SPEAR 3 upgrade at SSRL in 2002. A photon energy of 12.0 keV ($\lambda = 0.1033$ nm) was chosen for most experiments to maximize the number of Bragg peaks in a selected 2θ window of (25–55 deg), and to be far enough in energy above the Fe-edge to minimize the background contribution due to Fe K-fluorescence from steel samples (Fe K-edge at 7.112 keV) (Ref. 47).

The SRXRD patterns were recorded downstream of the weld using a 50-mm-long 2048 element position sensitive Si photodiode array detector. This detector, together with the associated data acquisition system was manufactured by Princeton Instruments, was used to store and display the real-time X-ray diffraction data. The array was mounted on a dual-stage Peltier effect thermoelectric cooler, which in turn was water cooled, and was placed approximately 100 mm behind the weld to cover the 2θ range from 25 to 55 deg.

Once the diffraction patterns were acquired, the integrated intensity of each peak was then measured using a sum of one or more Gaussian peak profile fitting functions (Ref. 48), and the results used to determine the semiquantitative volume fractions of the phases present as a function of welding time. This technique is summarized in detail in previous work (Refs. 49–52). In the Fe-based systems (steels, stainless steels) the 12-keV beam covers 2θ range that contains three ferrite peaks: bcc (110), bcc (200), and bcc (211); and three austenite peaks: fcc (111), fcc (200), and fcc (220). For titanium alloys (commercially pure and Ti-6Al-4V), this 2θ range encompasses three possible β-titanium peaks: bcc (110), bcc (200), and bcc (211); and 9 possible α-titanium (hcp) peaks (Ref. 49).

The SRXRD experiments were performed inside an environmentally controlled chamber as shown in Fig. 2, which is further confined inside a synchrotron radiation hutch. Prior to performing the experiment, the chamber was evacuated to 60 mTorr using a mechanical roughing pump and then backfilled with high-purity (99.999%) helium gas prior to running the experiment in order to deliver the X-ray beam with minimal attenuation to the sample and to prevent oxidation of the weld surface. Helium gas was flowed through the torch during welding to further prevent oxidation in the weld region and to cool the torch. An additional cross jet of helium gas was also directed at the X-ray beam impingement location to prevent metal vapors from depositing on the surface where X-ray diffraction was taking place. The chamber contains two 50-mm- diameter ports. The first port was sealed with a 0.125-mm-thick Mylar® window, which allowed the X-rays to enter the chamber. The second port was sealed with a KBr crystal and was used to video tape the weld using an infrared cam-

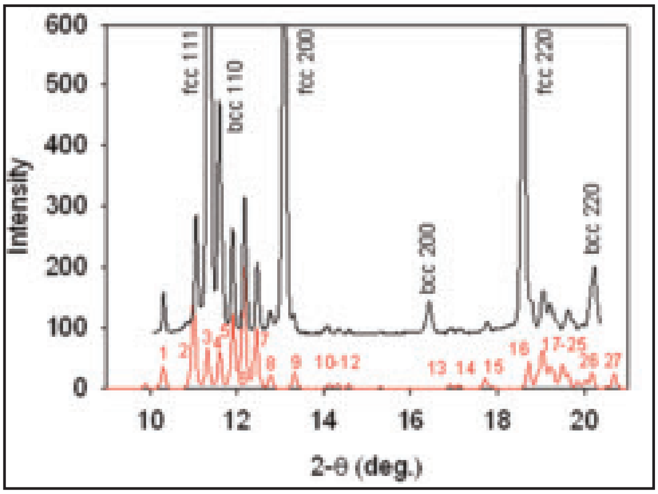


Fig. 5 — Room-temperature diffraction pattern of a duplex stainless steel alloy after heat treating to form sigma phase (black line) with the calculated diffraction pattern of the sigma phase (red line). Indexing numbers for the sigma phase correspond to the peaks summarized elsewhere (Ref. 59).

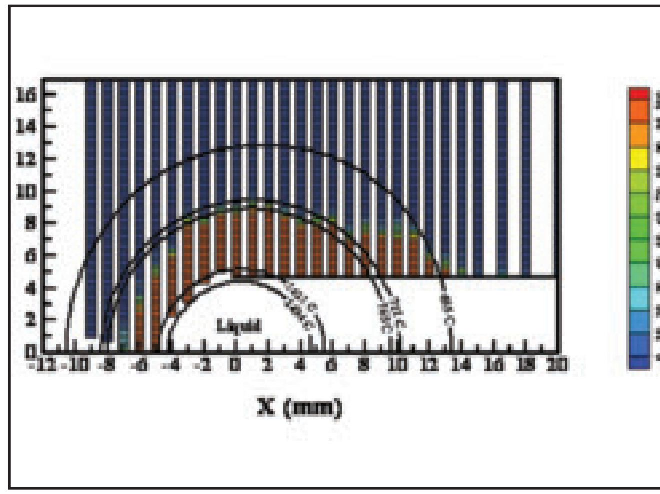


Fig. 6 — SRXRD semiquantitative map showing the volume fraction of austenite (red) in the 1045 steel HAZ. The scale indicates the amount of austenite (0–100%), and the calculated isotherms are shown for the liquidus, solidus, A3, A1, and bainite start temperatures.

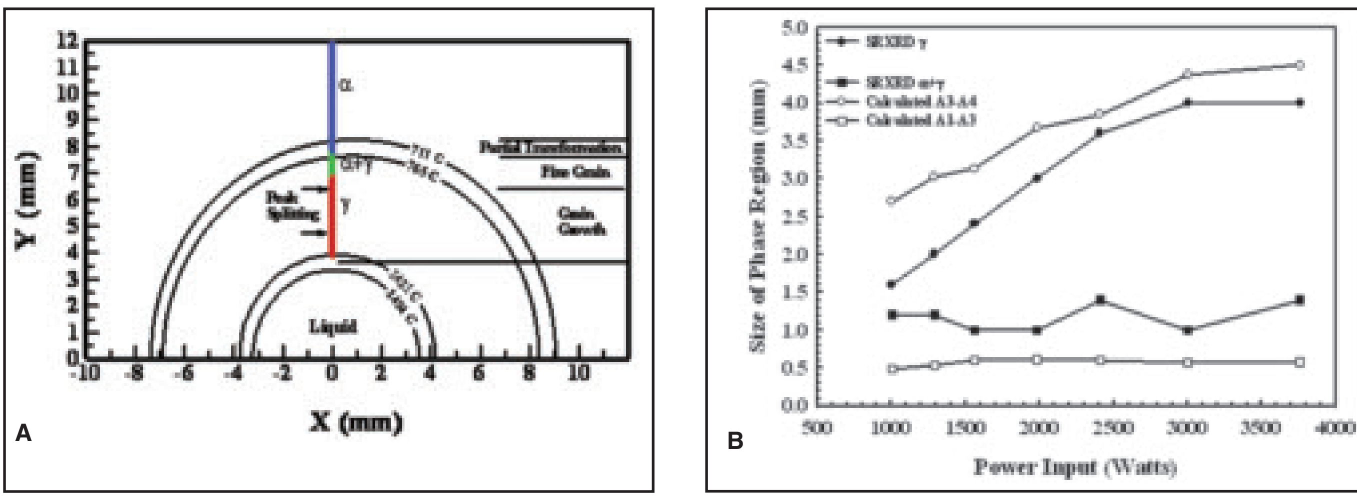


Fig. 7 — A — SRXRD experimental observations of the HAZ regions in 1045 steel compared to the calculated isotherms for a 1984 W GTA weld; and. B — SRXRD measured sizes of the HAZ phase regions, and calculated values based on the equilibrium transformation temperatures.

era (Inframetrics Inc. Model 600) with a 0.46-m focal length lens and a 40 × 25 mm field of view of the weld. This instrument provided real-time visual monitoring of the welding process.

The welding assembly was integrally mounted to a translation stage driven by a stepper motor with 10-μm precision and placed inside the environmental chamber. Spatial mapping of the phases in the HAZ was performed using the translation stage to manipulate the weld (welding torch and workpiece) with respect to the fixed synchrotron X-ray beam in order to probe discrete regions around the weld. A typical SRXRD run consisted of gathering 40 diffraction patterns, each spaced 250 μm apart (for a 260-μm pinhole), along a predetermined path to span a range of 10 mm through the HAZ in early experiments (Refs. 8–10, 28–33). Later, after SSRL had gone through the Spear 3 upgrade in 2002, the higher beam flux allowed shorter integration times of 4 s/point, which allowed scans of 80 points that spanned 20 mm through the HAZ (Refs. 34–36).

A software package was developed on a personal computer using LabView software to control the position of the weld with respect to the X-ray beam, to control the bar rotational speed (welding speed), and to trigger the data acquisition system on a second computer. Each SRXRD data point was taken while the beam was at a fixed location with respect to the welding electrode, and X-ray data were collected (integrated) for times between 4 and 10 s, while the bar rotated under the torch at a constant speed. The resulting data were presented as a series of X-ray diffraction patterns along a given X-ray scan direction perpendicular to and away from the centerline of the weld. After completing a run, the weld was allowed to cool to room temperature and the weld was repositioned to a new starting location with respect to the X-ray beam prior to taking the next series of SRXRD data. By repeating rows of X-ray diffraction data, equally spaced along the length of the weld, the phases in the entire HAZ region can be mapped.

Time Resolved X-Ray Diffraction (TRXRD)

The related TRXRD technique, illustrated in Fig. 1B, was developed to analyze transient arc welding conditions using rapid sampling X-ray diffraction for the observation of the phases that exist in the HAZ during rapid heating and cooling of

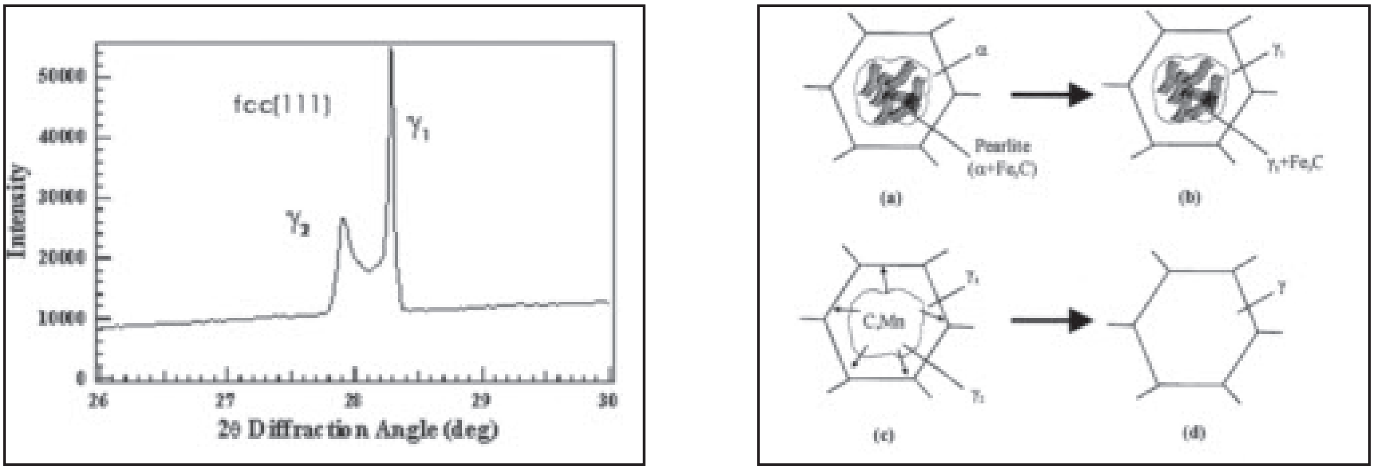


Fig. 8 — In-situ X-ray diffraction pattern showing splitting of the fcc(111) austenite peak (left). Schematic diagrams showing the progression of the α→γ transformation during heating of 1045 steel (right).

GTA spot welds in real time. The transient spot welds heat and cool much more rapidly than steady-state welds and require different data acquisition methods to achieve the high temporal resolution (50 to 100 ms) necessary to monitor them.

The TRXRD technique developed at LLNL was designed for this rapid data acquisition, and consists of both X-ray diffraction and GTA spot welding components. TRXRD is performed in the same experimental chamber as the SRXRD experiment, but uses a stationary bar rather than a rotating bar. During the experiments, a highly focused synchrotron X-ray beam was directed at a single predetermined location on a 102-mm-diameter cylindrical bar while a GTA spot weld was being made. The location where the X-ray impinges can include the molten metal in the weld pool fusion zone (FZ), which allows solidification to be monitored, or in the weld HAZ, which allows high-temperature solid-state transformations to be monitored. Additional details about the specific TRXRD welding experiments are included in previous work, (Refs. 49–56), and a summary of the experimental conditions and types of materials studied is shown in Table 1.

The TRXRD experiments were also performed using the same 31-pole wiggler beamline (10–2) at SSRL as the SRXRD experiments, and with the same photodiode X-ray detector. The synchrotron beam is spatially resolved by passing it through a tungsten pinhole with diameters up to 730 μm, to provide more signal than the SRXRD experiment, which is necessary to accommodate the shorter integration time per X-ray diffraction pattern. During each experiment, a stationary arc was maintained for a fixed amount of time, usually between 15 and 30 seconds to make the weld. After the arc was extinguished, the data acquisition continued taking data during cooling for a total of 60 s. These spot welds are approximately 10 mm in diameter, and the heating rates are calculated to be on the order of 100°C/s near the melting temperature of the alloy, while cooling rates are calculated to be on the order of 1000°C/s in the fusion zone (Ref. 25). These high cooling rates achieved in the TRXRD experiment are approximately 10-× faster than those achieved in the SRXRD experiment.

Controlled Heating and Cooling (CHC) Experiments

The SRXRD and TRXRD techniques described above are the only methods available for gathering real-time diffraction data on welds under real welding conditions. However, these techniques are difficult to perform in that they require welding equipment with sophisticated motion control and data acquisition systems to be set up on a synchrotron beam line. In addition, the weld temperatures, heating rates, and cooling rates, which are set by the weld parameters, are not directly controllable. Further, the rather large sample sizes are required to perform the experiments. Because of these constraints, a third synchrotron technique is employed that allows smaller samples to be used and controls the temperature during the experiment. This method uses direct resistance heating so that the sample can be

Table 1 — Overview of TRXRD Experimental Parameters

Materials System	Beam Energy (kV)	Beam Wavelength (nm)	Beam Size (μm)	Time Resolution (ms)
304L Stainless Steel	12.0	0.1033	730	50
	7.0	0.1771	730	50
Flux Cored Steel	12.0	0.1033	730	50
1005 C-Mn Steel	12.0	0.1033	730	50
	12.0	0.1033	260	100
1045 C-Mn Steel	12.0	0.1033	540	100
2205 Duplex Stainless Steel	12.0	0.1033	540	100
Ti-6Al-4V	12.0	0.1033	540	100

subjected to an arbitrary temperature profile. In addition, the X-ray diffraction patterns are measured with an areal detector for more accurate diffraction data. This technique has been used on many of the same materials as the SRXRD and TRXRD technique (Refs. 57–61), but also on new materials such as Cu-Au (Ref. 62), dual-phase sheet steels (Refs. 63, 64), and 9% Cr steels (Refs. 65–67). The drawbacks of this technique are that welding thermal cycles are only simulated and that melting/solidification phenomena cannot be observed. In addition, the present data collection rate is slow, so that rapid heating and cooling rates cannot be analyzed. Nevertheless, this method provides a very important complementary tool to SRXRD and TRXRD, and can be used to simulate heat treating as well as welding.

The *in-situ* CHC X-ray diffraction measurements were all performed on the UNICAT beam line BM-33-C at APS using a 30-keV X-ray beam from a ring current of 100 mA. This beam line was set up with a water-cooled Si (111) monochromator, and the beam was focused and sized to dimensions of 1 mm wide by 0.25 mm high using a dynamically bent Si crystal and collimator slits. The X-ray detector was manufactured by Roper Scientific (A99k401, RS/Photometrics). This X-ray detector uses 2 × 2-in. array of 1024 × 1024 pixels spaced 60 microns apart to capture the diffraction patterns produced on a scintillating screen connected to the CCD array using a fiber-optic bundle. The overall CHC experimental setup is schematically illustrated in Fig. 3, where the X-ray beam is spatially resolved to a square shape using vertical and horizontal slits, the beam flux is measured using an ion gauge detector, and the diffracted beams are recorded using the areal detector placed downstream from the diffraction point. The sample is surrounded by an environmental chamber (not shown) that is first evacuated and then backfilled with high-purity helium to minimize oxidation of the sample during high temperature runs. The X-rays enter and exit the chamber through kapton ports on the front and back side of the chamber. The CHC coupons measure 100 mm long by 4.75 mm wide by 2 mm thick, and are clamped into a water-cooled-copper fixture that allows high currents to be passed through them as indicated in Fig. 3. This direct resistance heating of the coupon method can heat most samples at several 100°C/s, while water-cooled-grips allowed the sample to be rapidly cooled at similar rates however, the present data acquisition system limits the rates to approximately 20°C/s in order to correlate the temperature to the diffraction pattern with sufficient accuracy. The temperature of the sample is monitored and recorded using type-S (Pt/Pt-10%Rh) thermocouples that are spot welded on the back side of the sample directly below the X-ray impingement point. A Eurotherm 818 temperature controller, a Eurotherm 425A power thyristor, and a Trindl RT300 transformer were used to control the AC current passing through the sample so that preprogrammed thermal cycles could be followed in a controlled manner. The heating power supply is capable of producing 300 A at 6 V and can heat steel samples up to temperatures as high as 1400°C.

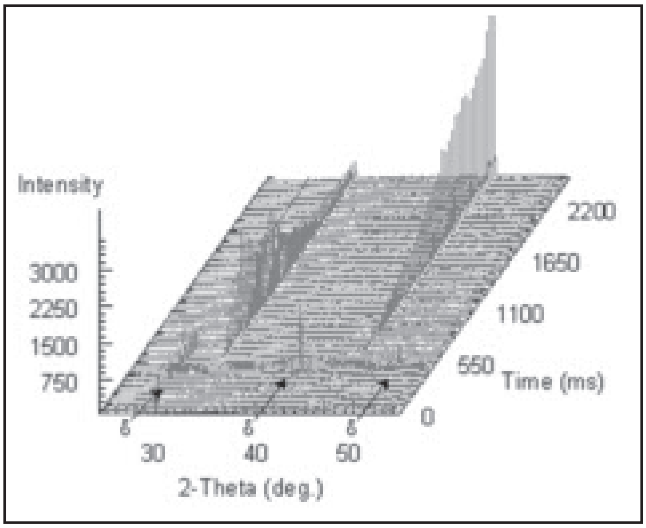


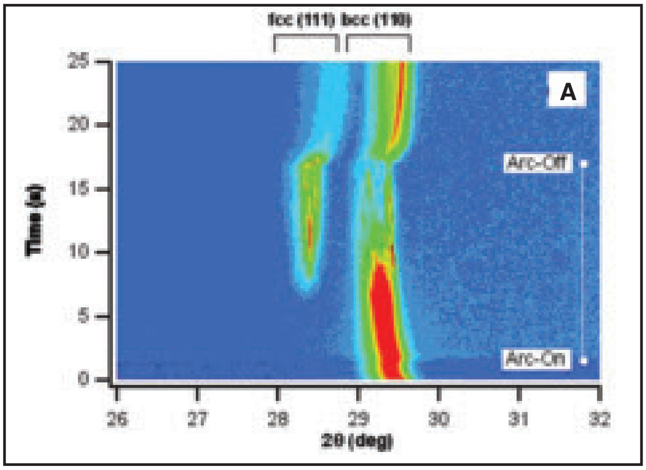
Fig. 9 — TRXRD patterns taken at 50-ms intervals during solidification of the AISI 304 stainless steel spot weld. The bcc peaks (denoted by →) are the first to appear as solely the δ-phase for the first 500 ms. Coexistence of the δ and γ phases is observed during the next 200 ms followed by the appearance of only fcc peaks of the γ-phase to room temperature.

While the sample is being heated, the X-ray beam impinges on the top surface of the sample at a 5-deg angle of incidence, and the diffracted beams are collected 330 mm downstream from the sample. The detector integrates the diffracted beams over a 1-s exposure time, and transfers these data to a computer to clear the detector for the next diffraction pattern. The transfer of data requires 2 s, thus it is possible to capture a complete diffraction pattern approximately every 3 s, but can be accelerated by about 1 s through a 2 × 2 binning of the pixels. An advantage of the 2-D detector is that statistically significant diffraction data can be collected for coarse-grained samples, which occurs by grain growth at elevated temperatures, as opposed to the narrow photodiode array detector used on the SRXRD and TRXRD experiments.

To calibrate the X-ray detector, the room-temperature lattice parameters of the base metal at room temperature are first measured using a conventional Cu K_α X-ray diffraction system. A room-temperature pattern is then collected on this same sample using the CCD array detector on the synchrotron radiation beam line. Five points are then selected along each of the Debye arcs of the diffraction pattern. Finally, the sample-detector distance, the position of the center of the arcs on the detector, and the magnitude and orientation of the detector tilt are varied to minimize the difference between the d spacing at the selected points as calculated from these detector patterns and that calculated from the lattice parameters. Using this calibration, the Debye arcs are converted into a 1-D plot showing diffracted beam intensity vs. d-spacing using Fit- 2-D software (Refs. 68, 69). This software integrates the diffracted beam intensity for each arc over the entire 2-D areal array, creating a conventional intensity vs. 2θ diffraction pattern. The lattice spacing, FWHM value, and integrated intensity of each peak were determined using an automated curve-fitting routine developed in Igor Pro®, Version 4.0 (Ref. 48), and these data provide semiquantitative information about the amounts of phases present in each diffraction pattern.

Thermal-Fluids Modeling

The *in-situ* synchrotron welding experiments gather information about phases as a function of weld position (SRXRD) or weld time (TRXRD), but not as a function of weld temperature. Since the direct measurement of weld temperatures is very difficult to perform, due to the steep thermal gradients and intense conditions that exist around the plasma formed by the welding arc, weld thermal cycles are calculated using a well-tested coupled thermal fluids model. This model was developed by the Pennsylvania State University, and utilizes a 3-D numerical heat transfer and fluid flow code that was created specifically for fusion welds (Ref. 23). In this model, the equations of conservation of mass, momentum, and energy in three-dimensional form are discretized using the power law scheme and numerically solved by the SIMPLER algorithm (Ref. 70). The model solves the equations to determine the size, shape, and thermal profiles around the weld pool in three dimensions. After obtaining the steady-state temperature field, the thermal cycle at any



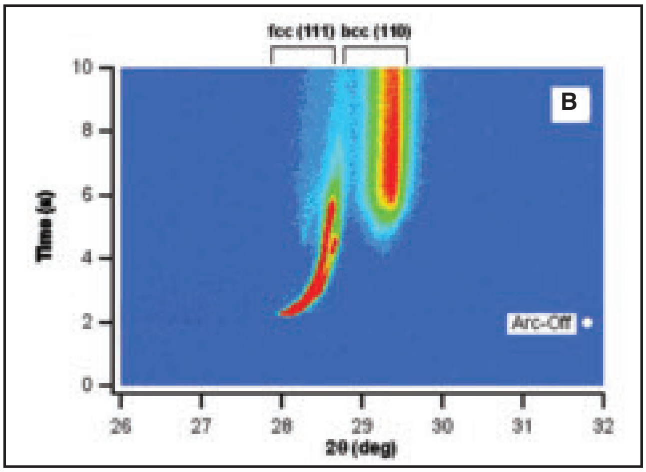


Fig. 10 — TRXRD diffraction data from — A — the HAZ region; and B — the FZ region of the high aluminum FCAW steel under rapid cooling spot weld conditions. The high-intensity diffraction data are represented by red, background intensity by blue. The arc-on and arc-off periods are shown. Data were recorded at 50-ms intervals.

given location (x,y,z) can be calculated using the following equation:

$$T(x,y,z,t_2)=\frac{T_S(\zeta_2,y,z)-T_S(\zeta_1,y,z)}{\zeta_2-\zeta_1}V_S(t_2-t_1)+T(x,y,z,t_1) \qquad (1)$$

where $T(x,y,z,t_2)$ and $T(x,y,z,t_1)$ are the temperatures at times t_2 and t_1, respectively, $T_s(\xi_2,y,z)$ and $T_s(\xi_1,y,z)$ are the steady-state temperatures at coordinates (ξ_2,y,z) and (ξ_1, y, z), respectively, V_s is the welding speed; and $(\xi_2 - \xi_1)$ is the length welded in time $(t_2 - t_1)$.

In the SRXRD experiments, the thermal profile is determined in the steady-state weld for quasi-steady-state welding conditions represented by Equation 1; however, for transient welds, the calculations are much more complicated due to the fact that a quasi steady state is never reached and the weld pool size must be recalculated at each time step. This problem has been solved by the Pennsylvania State University group, and the model has been used to analyze the TRXRD experiments by calculating the transient thermal profiles as a function of time and position for the spot welding condition, where the size of the liquid pool is constantly changing (Ref. 25). From these results of the thermal calculations, the temperature profiles can be determined for any point relative to the weld center, and then further used as input to kinetic models for analyzing the synchrotron data. Applications of the heat and fluid flow model for the steady-state welds used for SRXRD are discussed in references (Refs. 32–37), while those for transient welds used for TRXRD are discussed in references (Refs. 49–51).

Computational Thermodynamics Modeling

The equilibrium phases of an allotropic metal or alloy change with temperature, and because of this, the HAZ of a weld will contain different subregions that are undergoing different phase transformations during welding. Low-carbon steels, for example, undergo two solid- state phase transformations before melting, resulting in a large austenite region surrounded by a thin layer of delta ferrite adjacent to the weld pool on one side and ferrite on the other (Refs. 31, 37). Although the different HAZ subregions are suspected to exist, the exact size of these zones relative to the weld pool is not known without direct first-hand observations or through verified phase transformation modeling.

Once the weld temperatures have been calculated, then the first step at estimating the location of the different HAZ subregions is to calculate the equilibrium phase transformation temperature isotherms in the HAZ. *Thermocalc®* (Ref. 71) was used to calculate the phase equilibria and transformation temperatures for all of the alloys investigated, and when coupled with the results of the thermal fluids model of weld temperatures, the equilibrium phase boundaries in the HAZ could be determined. Kinetic departures from equilibrium distort these equilibrium boundaries, extending the low-temperature phases into higher-temperature regions on heating, and the reverse on cooling (Refs. 28, 33, 35–37). By measuring the locations of the actual phase boundaries in the weld HAZ and comparing them to the calculated equilibrium boundaries, deviations between the two can be determined. The phase transformation kinetics can then be extracted by these deviations from equilibrium.

Phase Transformation Modeling

Solid-state phase transformations in welds occur by different possible mechanisms. Some mechanisms, such as nucleation growth, involve diffusion (Refs. 11–13) and others, such as martensite, are based largely on displacement with little or no diffusion taking place (Refs. 11–13). In the majority of the SRXRD experiments, where heating and cooling rates were relatively low, the phase transformations take place by nucleation and growth mechanisms, and these were modeled by the Johnson-Mehl-Avrami (JMA) formulation. This approach can be represented by the following expression (Ref. 11):

$$f_e(t)=1-\exp\left\{-(kt)^n\right\} \qquad (2)$$

where $f_e(t)$ is the extent of the transformation at a given time t, n is the JMA exponent, and k is a rate constant given as:

$$k=k_0\exp\left(-\frac{Q}{RT}\right) \qquad (3)$$

where k_0 is a pre-exponential constant, Q is the activation energy of the transformation including the driving forces for both nucleation and growth, R is the gas constant, and T is the absolute temperature in K. Equation 2 was modified to derive the JMA-based expression applicable phase transformations occurring in the two-phase region of the HAZ, and discretized so that it could be integrated over the non-isothermal weld profile (Ref. 37). This modeling approach was combined with

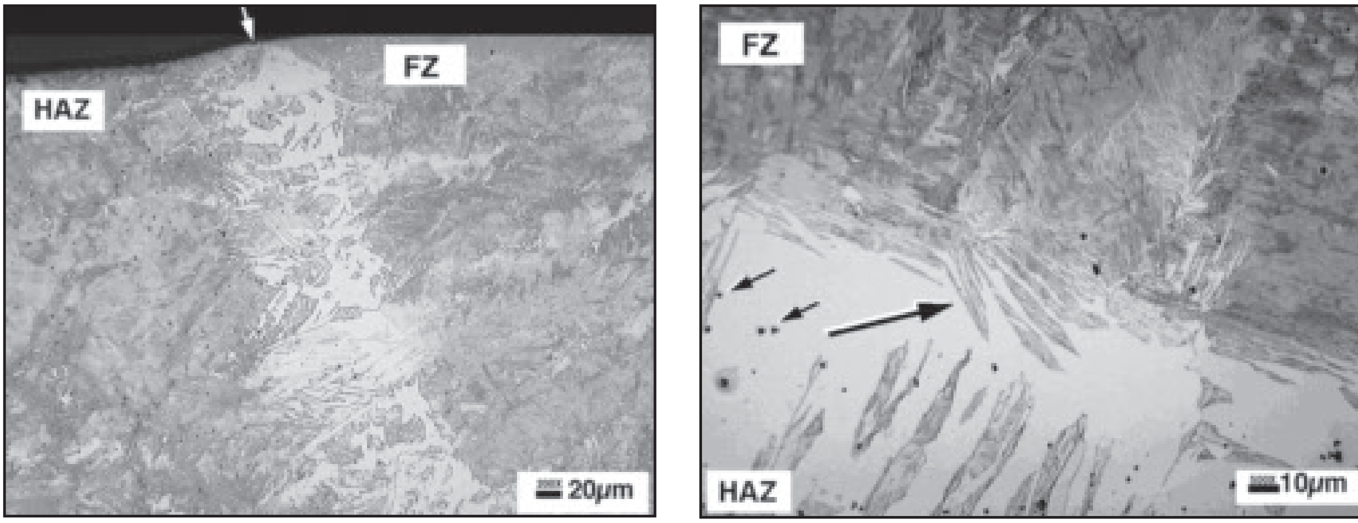


Fig. 11 — Micrographs of the HAZ-FZ boundary of the spot weld region in the FCAW alloy after TRXRD. The former δ ferrite (white etching phase) exists on both sides of the weld interface, before the change in solidification modes to austenite through the remainder of the fusion zone.

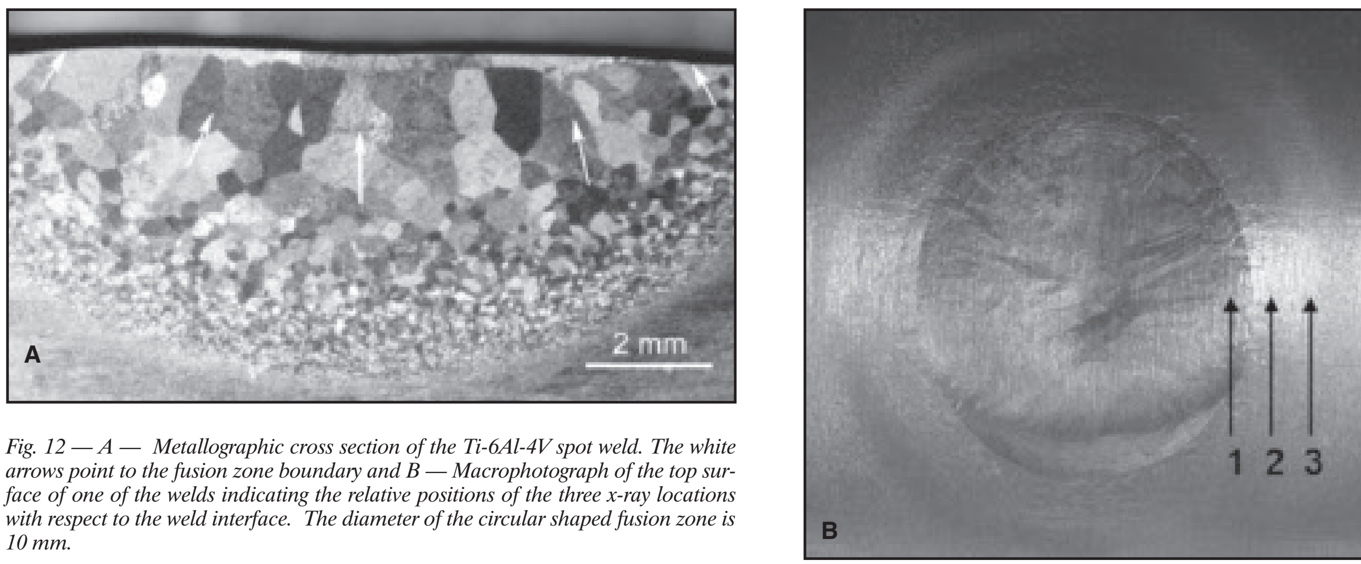


Fig. 12 — A — Metallographic cross section of the Ti-6Al-4V spot weld. The white arrows point to the fusion zone boundary and B — Macrophotograph of the top surface of one of the welds indicating the relative positions of the three x-ray locations with respect to the weld interface. The diameter of the circular shaped fusion zone is 10 mm.

the calculated thermal profiles and the SRXRD experimental data to determine the JMA parameters n and k_0 for the given value of Q using a graphical fitting routine applied to the SRXRD data (Refs. 37, 42, 43). Optimization of the JMA parameters from the limited amount of synchrotron data was later improved, using a parent centric recombination (PCX) based genetic algorithm (GA) to obtain optimized values of the JMA parameters (Ref. 38). The GA based determination of all three JMA equation parameters resulted in better agreement between the calculated and the experimentally determined phase fractions than was previously achieved, resulting in better predictability of the phase transformation rates (Ref. 38).

Additional models have been developed to analyze the synchrotron experimental results. These models include phase transformation mechanisms in nonuniform starting microstructures (Ref. 44), nonequilibrium weld solidification (Refs. 53, 54), bainite and martensite formation during rapid weld cooling (Ref. 50), 3-D grain growth in weld HAZs using Monte-Carlo methods (Refs. 39, 40), and microstructure evolution using phase field modeling techniques (Refs. 45, 63, 64). Details of each of these techniques can be found in the cited references.

Selected Results and Discussion

The three synchrotron-based techniques, SRXRD, TRXRD, and CHC, have been used to investigate phase transformations in commercially available steels, stainless steels, titanium alloys, a flux cored arc welding (FCAW) consumable, and a gold-copper diffusion couple. Table 2 summarizes the materials systems investigated and the different methods used on each. The results presented here highlight some of the findings for each technique, and demonstrate the capabilities that each possesses.

Spatially Resolved X-Ray Diffraction (SRXRD)

SRXRD X-Ray Diffraction Patterns and Analysis. During SRXRD, X-ray diffraction patterns are taken one at a time as the weld is moved relative to the synchrotron beam (Refs. 28, 31, 37). A typical sequence of diffraction patterns will contain 40–80 individual patterns, uniformly spaced across the HAZ of the weld. One such row of X-ray data is shown in Fig. 4 for 1005 steel, where there are three diffraction peaks for the bcc (ferrite) phase, and three diffraction peaks for the

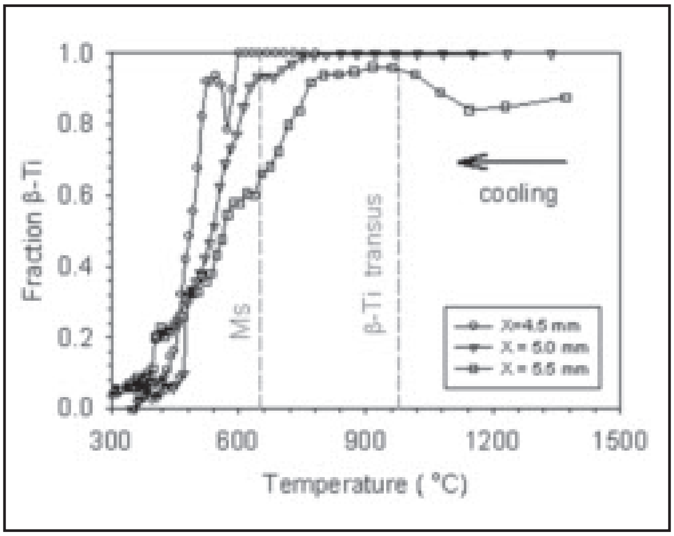


Fig. 13 — TRXRD results showing fraction β phase during the cooling cycle of the Ti-6Al-4V weld FZ and two HAZ locations plotted vs. the calculated weld temperature. The vertical dashed lines mark the calculated α/β transus, and the approximate Ms temperature for this alloy.

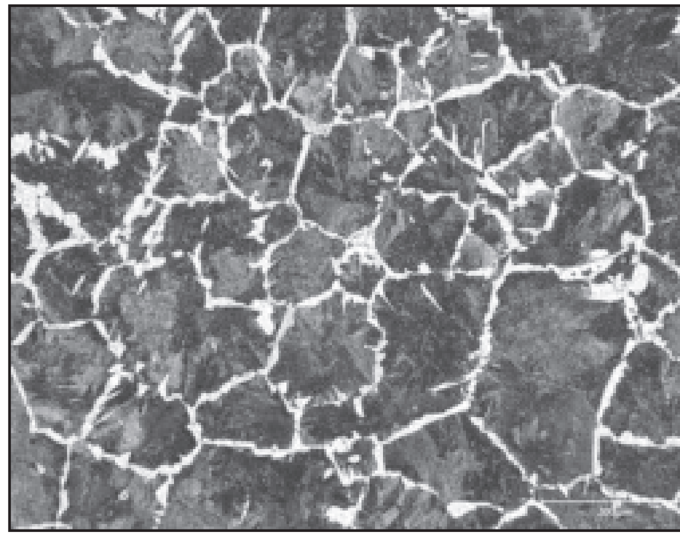


Fig. 14 — Base metal microstructure of the 1045 steel showing prior austenite grains and pearlite colonies inside the grains.

fcc (austenite) phase in the 2θ diffraction window. These data show the progression of phases from liquid to δ-ferrite to austenite to α-ferrite as the HAZ is probed from high temperatures in the fusion zone toward the base metal in real time. The X-ray diffraction peaks from each diffraction pattern were then analyzed using peak area based methods specifically in the two phase regions to estimate the relative volume fractions of α and γ at each location in the HAZ (Ref. 37). The resulting data provide semiquantitative information about the relative amounts of each phase that exist at the given location in the HAZ.

The diffraction patterns shown in Fig. 4 for the C-Mn steel are rather straightforward since there are only two phases, and each phase has a cubic symmetry. However, in other systems such as duplex stainless steels, lower symmetry phase such as sigma phase can form with more complicated diffraction patterns. Figure 5 shows one of these diffraction patterns where sigma phase coexists with both the fcc and bcc phases. Indexing the peaks of the sigma phase was performed with the aid of X-ray diffraction software (Ref. 72).

Once the X-ray diffraction patterns are indexed, additional analysis can be performed on them to determine the relative amounts of each phase in a given diffraction pattern, as detailed elsewhere (Ref. 37). In addition, the particular character of the diffraction peaks contains a wealth of information about the phases including annealing/recrystallization (Refs. 9, 28, 29, 31, 33, 51), oxide formation (Ref. 29), heterogenieties in the starting microstructure (Refs. 35, 36, 57), and diffusion that occurs during the transformation (Refs. 60–62). These effects are beyond the scope of this paper, but additional information is provided in the cited references.

Table 2 — Summary of the Synchrotron Techniques Used to Investigate Different Materials, and Phase Transformation Modeling Papers Based on or Verified by the Experimental Results(a)

	SRXRD	TRXRD	CHC	Phase Transformation Modeling
1005 Steel	31	55	57	37, 38, 41, 42, 43, 45
1045 Steel	34, 35, 36	50		
CP Titanium	8, 9, 10, 28, 29, 30			39, 40
Ti-6Al-4V	32	49	60, 61	
304 SS	8	52		
2205 Duplex SS	33	51	58, 59	44
FCAW		53, 54		
Cu-Au			62	
Dual-phase 600 steel			63, 64	63, 64
9% Cr Steel			65, 66, 67	

(a) The numbers in the table refer to the references cited in this paper.

Phase Mapping of 1045 Steel Weld

The rows of diffraction patterns acquired by SRXRD can be taken at different locations along the length of the weld by repositioning the welding torch to different starting locations relative to the X-ray beam (Refs. 31, 33, 36, 37). By doing this repeatedly, the X-ray diffraction data can be acquired and analyzed to produce a semiquantitative map of the phases and phase fractions that exist in the HAZ during welding. Figure 6 shows one of these maps for a GTA weld in AISI 1045 steel at power of 2.4 kW and a travel speed of 0.6 mm/s (Ref. 37). More than 20 rows of data were required to complete the phase map, which contained more than 800 individual diffraction patterns in the weld HAZ.

The phases identified by SRXRD in Fig. 6 are then superimposed with the calculated temperature isotherms from the coupled thermal fluids weld model discussed previously. For the 1045 steel, the HAZ contains the base metal ferrite (α) and the high-temperature austenite (γ) and a transition region where both phases coexist in-between. The locations of the α and γ phases are plotted with 250 μm precision perpendicular to the welding direction and 500 μm parallel to the welding direction. In this map, the shading indicates the γ fraction. The map shows a variation in γ from 0 to 100% over a narrow region approximately 1.0 to 1.6 mm wide that borders the rather large γ phase field that surrounds the weld pool.

The HAZ map shows that the γ phase field is wider on the trailing side of the weld than on the front side. It is also apparent that the completion of the α→γ phase transformation is shifted to higher temperatures on heating, while the γ→α phase transformation is shifted to lower temperatures on cooling relative to the calculated A3 temperature.

Analysis shows that superheating up to 250°C above the A3 temperature is required to completely transform the microstructure to γ on heating under these welding conditions, and that substantial undercooling below the A3 is required to initiate the transformation to α on cooling (Ref. 36). The lag required to complete the transformation to γ on heating is displaced further from the A3 isotherm at locations closer to the weld centerline where the heating rates are the highest, showing that the amount of superheating required for the α→γ transformation varies with the location and thus the heating rate. Furthermore, during cooling, the region closest to the fusion zone requires the highest undercooling prior to measurable amounts of austenite transformation. The significant undercooling below the A3 isotherm correlates with the formation of bainite, which results from the larger austenite grain sizes and higher cooling rates in this region of the weld (Ref. 37).

Effect of Weld Heat Input on HAZ Width

In addition to mapping weld phases at a given heat input, SRXRD can also be used to determine the maximum width of the different HAZ phase regions as a function of welding heat input. Variations in the size of the observed γ phase field in steels occur as a result of changes in the weld heat input, and these effects were studied in the 1045 steel using SRXRD for weld power levels between 1 and 4 kW and a travel speed of 0.6 mm/s (Ref. 35). The locations of the γ, α+γ, and α phase regions measured in the SRXRD scan made at a weld input power of 1984 W are shown Fig. 7A as an example, indicating that the high-temperature austenite field is nearly 3 mm wide under these conditions. The calculated isotherms for the liquidus, solidus, A3, and A1 temperatures, and the locations of the HAZ microstructural features observed in the postweld metallography are also shown (Ref. 35).

The widths of the γ and α+γ phase regions as measured by SRXRD are plotted in Fig. 7B (solid symbols) for the 1–4 kW range of weld powers. The austenite field is shown to increase from 1.5 to 4.0 mm over this range, while the mixed austenite plus ferrite region remains relatively constant between 1 and 1.5 mm. These values are compared with the calculated sizes of these phase regions based on thermodynamic considerations (open symbols). The variations between the calculated and experimental sizes of the γ-phase region differ over the range of powers investigated, and the differences are largest at the lower powers where the temperature gradients are highest. The size of the α+γ phase region remains fairly constant over the range of powers, but the measured width of the α+γ phase region is always larger than the calculated value due to the kinetics of the phase transformation that require higher than equilibrium temperatures to complete the transformation on heating.

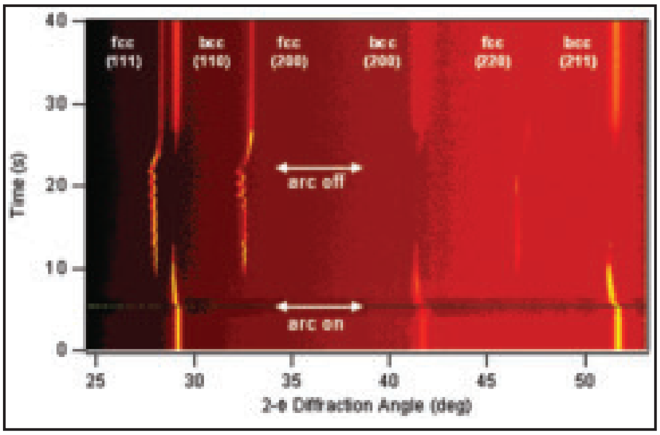


Fig. 15 — TRXRD results showing the changes in the diffraction peak locations as a function of welding time for the 1045 steel HAZ-+

Homogenization of Heterogeneous Starting Microstructures

In the 1045 steel welds, austenite was observed to form inhomogeneously on heating, which resulted in the creation of two distinct sets of X-ray diffraction peaks for all of the heat inputs investigated. The splitting of the austenite peaks occurs over a finite region of the austenite phase field as indicated by the two arrows in Fig. 7A for the 1984- W weld. Additional results are presented in Refs. 34, 35. When the austenite peaks split, a higher d-spacing (lower 2θ) austenite, γ_2, begins to form on the initial austenite, γ_1. Figure 8 shows one of these split peaks for the fcc(111) reflection at a location 5.2 mm from the weld centerline. The splitting is first observed near a calculated temperature of 884°C, which is approximately 100°C above the A3 temperature. The larger γ_2 lattice parameter is the result of higher concentrations of C and Mn in it. The primary source of these alloying elements is the undissolved cementite laths, which begin to dissolve into the austenite at elevated temperatures. Initially, the split between the γ_1 and γ_2 peaks is rather small, since γ_2 first begins to form from the γ_1 located within the pearlite colonies. With increasing temperatures, the amount of splitting increases as both C and Mn diffuse from the cementite into the γ_2 constituent. The amount of peak splitting reaches a maximum as the temperature approached 1250°C, which is assumed to correspond to the completion of cementite dissolution (Refs. 34, 35).

The peak splitting behavior and its disappearance at higher temperatures provides evidence of both the mechanism for the transformation of the base metal microstructure and the homogenization of the resulting austenite phase during welding. This austenitization mechanism is schematically shown in Fig. 8B, where in the initial stages, ferrite in the pearlite colonies and allotriomorphic ferrite regions that surround them in the base metal (a) is transformed into austenite, γ_1, (b). Because of the rapid heating cycles experienced in the weld HAZ, the cementite laths that are originally a part of the pearlite colonies do not completely dissolve before the ferrite in the microstructure is completely consumed above the A3 temperature. These cementite laths begin to dissolve with continued heating, introducing C and Mn into the austenite and causing a second, more highly alloyed austenite constituent, γ_2, to appear (c). As the heating continues, these alloying elements, which originated in the cementite laths, continue to diffuse into the less highly alloyed γ_1 constituent. At temperatures of approximately 1300°C and above, the chemical composition of the austenite becomes homogenized into one austenite phase, γ, (d).

Time Resolved X-Ray Diffraction (TRXRD)

Transient arc welds are commonly encountered in tack welding, stationary spot welds, and solidifying weld craters, and they behave differently than moving welds because the temperature profiles never reach a steady state. Because of their transient nature, the heating and cooling rates for these welds are often much higher than those observed in moving welds, potentially leading to the formation of nonequilibrium phases not observed under slower cooling conditions. One attribute of TRXRD is that it can reveal detailed insight about the microstructural evolution, starting from solidification all the way to room temperature, and can be done with time resolutions on a scale fast enough to

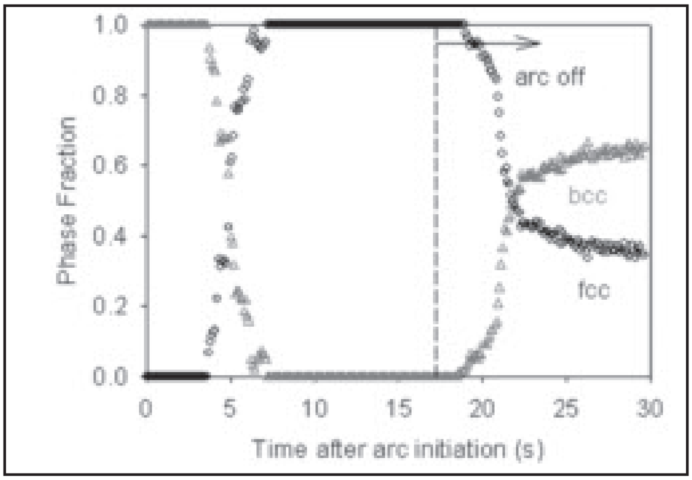


Fig. 16 — Analysis of the TRXRD diffraction patterns shown in Fig. 15 illustrating the relative fraction of the bcc and fcc phases as a function of arc welding time in 1045 steel.

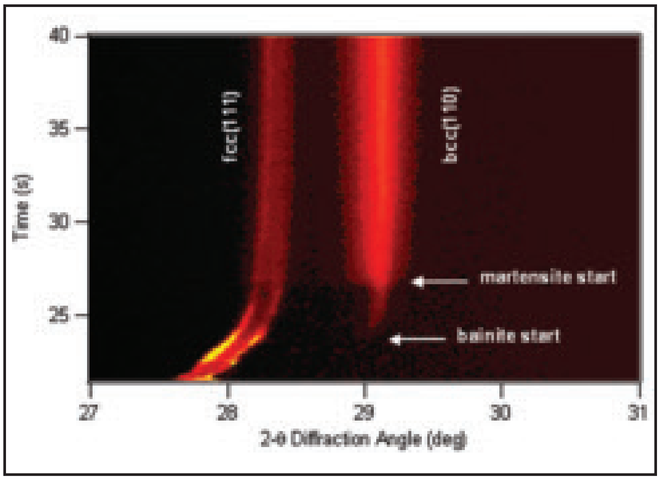


Fig. 17 — TRXRD results showing the fcc(111) and bcc(110) diffraction peaks during weld cooling. Martensite formation is accompanied by a rapid increase in peak width. Splitting of the austenite peaks continues during cooling due to insufficient time for homogenization of austenite in the TRXRD spot weld.

capture the formation of nonequilibrium phases. In the sections below, several results are presented for observations of the solidification mode and solid-state phase transformations that highlight TRXRD observations of nonequilibrium phase formation.

Primary Solidification Mode in 304 Stainless Steel

TRXRD was used to observe the dominant mode of solidification in an austenitic 304 stainless steel and the ensuing microstructural evolution during cooling (Ref. 52). Particular effort was made to verify the formation of δ-ferrite as the primary solidification phase from the melt anticipated based on previous work (Ref. 73), and to monitor the δ→γ phase transformation during rapid cooling. In the TRXRD experiment, the X-ray beam was positioned at a distance of 2 mm from the electrode, which was well within the fusion zone of the spot weld, allowing solidification to be monitored. The results from one experiment are shown in Fig. 9, where liquid formed quickly after the arc was struck, as indicated by an initial period of featureless diffraction (Ref. 52). The arc was extinguished and as the weld pool solidified, bcc δ-ferrite diffraction peaks were observed first. All three bcc peaks exist by themselves for a period of 500 ms (10 frames), although not all three peaks were observed together in any given frame due to the large grain size and grain rotation. Transformation of δ to γ began in the next frame with both δ and γ diffraction peaks appearing together. The δ peaks coexisted with γ peaks for 200 ms (four frames) during the transformation. Upon further cooling, only the γ peaks persisted in the remaining frames down to room temperature. The most significant finding of these TRXRD results is that δ-ferrite was verified as the first phase to solidify from the 304 stainless steel liquid weld pool. Although δ-ferrite solidification has been speculated, these results represent the first time that it has been observed.

Nonequilibrium Solidification of a FCAW Consumable

The TRXRD technique was used to determine the primary mode of solidification of a Fe-C-Al-Mn steel weld (Fe 0.23C-0.5Mn-1.7Al 0.28Si–0.02Ni–0.003Ti–0.006O–0.06 Nwt%). The steel was produced from a self-shielded flux cored arc welding (FCAW) electrode as a thick cladding over a solid steel bar (Refs. 53, 54). The high aluminum content of the FCAW electrode is intentionally added to deoxidize and denitride the weld because the flux cored welding process does not use gaseous shielding; however, residual aluminum is left in the weld deposit. Under conventional welding conditions, the added aluminum promotes formation of d-ferrite during solidification. The aluminum also stabilizes the d-ferrite at lower temperatures and prevents formation of 100% austenite during cooling. A small amount of austenite forms in the interdendritic regions, and decomposes to either bainite or pearlite depending upon the cooling rate. Thus, under low cooling rate conditions, the fusion zone inherits the high-temperature columnar d-ferrite microstructure that is present at room temperature and can adversely affect the mechanical properties of the weld.

Under rapid weld cooling of this same alloy, the final weld microstructure contains allotriomorphic ferrite, bainite, and martensite, similar to that expected to form from an austenitic microstructure (Refs. 53, 54). The absence of columnar δ-ferrite in these rapidly cooled welds could be explained theoretically using two paths of phase evolution. In the first path, the liquid transforms to 100% δ-ferrite before transforming to 100% austenite by a massive transformation. The massive austenite then transforms to a mixture of allotriomorphic ferrite, bainite, and martensite during subsequent cooling. In this second path, the liquid transforms to 100% austenite by non-equilibrium solidification and then transforms to a mixture of allotriomorphic ferrite, bainite and martensite during subsequent cooling. TRXRD was used to determine the correct microstructure evolution path.

Figure 10A shows the TRXRD results from the following: 1) the HAZ, and 2) FZ regions of the FCAW steel during welding (Refs. 53, 54). The TRXRD measurements in the HAZ provide evidence for the persistence of delta ferrite in the HAZ. In a second experiment, FCAW solidification was observed as shown in Fig. 10B. Here it is clear that the liquid (no diffraction peaks) continued to exist as the only phase for 0.2 s after the arc was extinguished. Austenite then formed as the first solid phase as indicated by the appearance of the fcc (111) peak. As cooling continued, the austenite peaks shifted toward higher 2θ values, indicating a decrease in the lattice spacing due to a drop in temperature. Approximately 3 s after the onset of solidification, ferrite began to form from the austenite, as indicated by the appearance of the

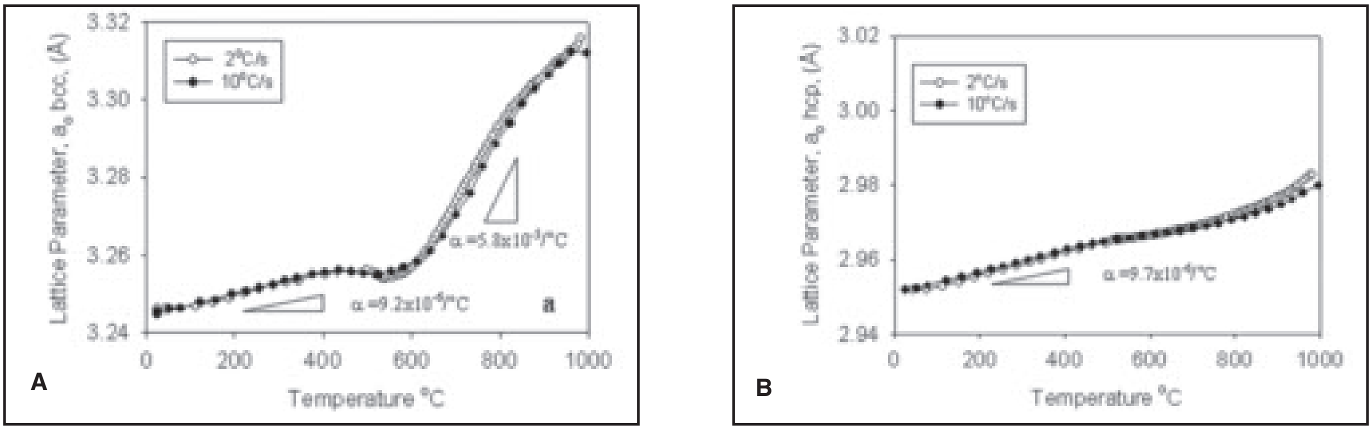


Fig. 18 — Lattice parameters alpha and beta phases in Ti-6Al-4V measured by in-situ X-ray diffraction as a function of temperature. A — The bcc (beta) phase; B — the hcp (alpha) phase during heating at two different rates. The indicated coefficients of thermal expansion, α, were calculated from the slopes of the curves.

bcc (110) peak. Upon further cooling, the ferrite peaks also shifted toward higher 2θ values as the temperature approached ambient conditions.

Primary austenite solidification for this high-aluminum FCAW alloy was verified through repeated experiments, in contrast to primary delta-ferrite solidification as predicted by thermodynamic calculations (Refs. 53, 54). The postweld microstructure of the FCA weld is shown in Fig. 11. The white etching region near the weld interface (marked by arrow) is identified as the δ-ferrite that formed in the HAZ at high temperature, which is further confirmation that the equilibrium ferrite mode of solidification can be replaced by nonequilibrium austenite even when the fusion boundary is surrounded by ferrite if the cooling rates are fast enough.

Martensite Formation during Cooling of Ti-6Al-4V

During solidification of Ti-6Al-4V, the fusion zone contains large columnar grains that solidify initially as β, and subsequently undergo a near complete transition to finely dispersed α or α′ phase (Ref. 49). Figure 12A shows the microstructure of a Ti-6-4 spot weld, where the HAZ/FZ boundary is revealed as a dark etching line that runs through the columnar grains, and is identified by the arrows. Large grains exist on both sides of the weld interface, indicating significant grain growth in the HAZ, which is important to note since grain size can influence the phase transformation kinetics. The TRXRD technique was used to evaluate the phase transformation kinetics of this alloy by observing the welds at the three different locations, indicated in Fig. 12B, where position 1 indicates the location in the FZ, and positions 2 and 3 indicate locations in the HAZ.

Analysis of the three TRXRD measurements was performed and the results are compiled in Fig. 13, which shows the fraction β during weld cooling of the Ti-6Al-4V in the FZ and two HAZ locations (Ref. 49). This figure shows that the β→α transformation begins at a different temperature for each point relative to the center of the weld. At the two HAZ locations (x = 5.0, x = 5.5 mm), the β→α/ά begins at nearly the same time and at temperatures between the beta transus and martensite start temperatures, where it is clear that there is ~100°C of undercooling below the β transus before the transformation begins. For the measurements made in the weld FZ (x = 4.5 mm), the transformation is first observed at 600°C, which corresponds to much larger undercoolings, approximately 375°C below the β transus, which is also below the calculated Ms temperature for this alloy (Ref. 49). Once initiated, the β→α transformation in the FZ occurs rapidly and nearly completely to α′ martensite in less than 2 s over a temperature range of approximately 200°C.

Bainite and Martensite Formation in Carbon Steels

The carbon content and cooling rate both have a profound influence on the microstructures that develop during welding of steels. This effect was studied using TRXRD to compare microstructural evolution in spot welds for 1045 and 1005 steels, having 0.45 and 0.05 wt-% carbon, respectively. The results showed different behaviors for the two steels in that a combination of bainite (nonlamellar ferrite plus Fe_3C) and martensite (interstitial carbon) was observed forming in the microstructure of the 1045 steel (Ref. 50), but these phases were not observed during welding of the 1005 steel under similar welding conditions (Ref. 55).

Figure 14 shows the base metal microstructure of the 1045 C-Mn steel. Ferrite outlines the prior austenite grain boundaries while pearlitic colonies dominate the microstructure inside these grains. In the TRXRD experiments, the X-ray beam was placed at a fixed location in the HAZ during heating and cooling to observe the phase transformations, and the resulting data from one experiment are shown in Fig. 15 (Ref. 50). In this figure the baseline diffraction data correspond to the three diffraction peaks of the bcc ferrite phase. After the arc is struck, these three peaks rapidly shift to lower 2θ values as the crystal lattice of the steel expands during heating. With continued heating, three new peaks appear, corresponding to the fcc austenite phase. All six peaks coexist for several seconds before the bcc peaks began to fade in intensity, leaving only the fcc diffraction peaks. The fcc peaks remained stable until the arc was extinguished at 17 s after arc initiation. The fcc peaks then rapidly shift to higher 2θ values as the lattice contracts with cooling. With an additional 1.5 s of cooling, the bcc peaks reappear, and increase in intensity as the weld cools. Analysis of these results is shown in Fig. 16 where relative fractions of the bcc and fcc phases present throughout the weld are plotted (Ref. 50).

A closer look at the diffraction patterns shows that the bcc (110) peak has a sudden increase in width at t = 26 s on cooling. Figure 17 shows this peak broadening where the wider bcc(110) peak exists throughout the remainder of the weld and increases in intensity as the weld cools. The sudden increase in the bcc(110) peak width during rapid cooling was not observed in similar experiments performed on the 1005 C-Mn steel (Ref. 55). The increase in peak width in the 1045 C-Mn steel is a consequence of its higher carbon content and the corresponding formation of body centered tetragonal (bct) martensite. The formation of martensite induces significant levels of strain and causes changes in the lattice parameters including the observed peak

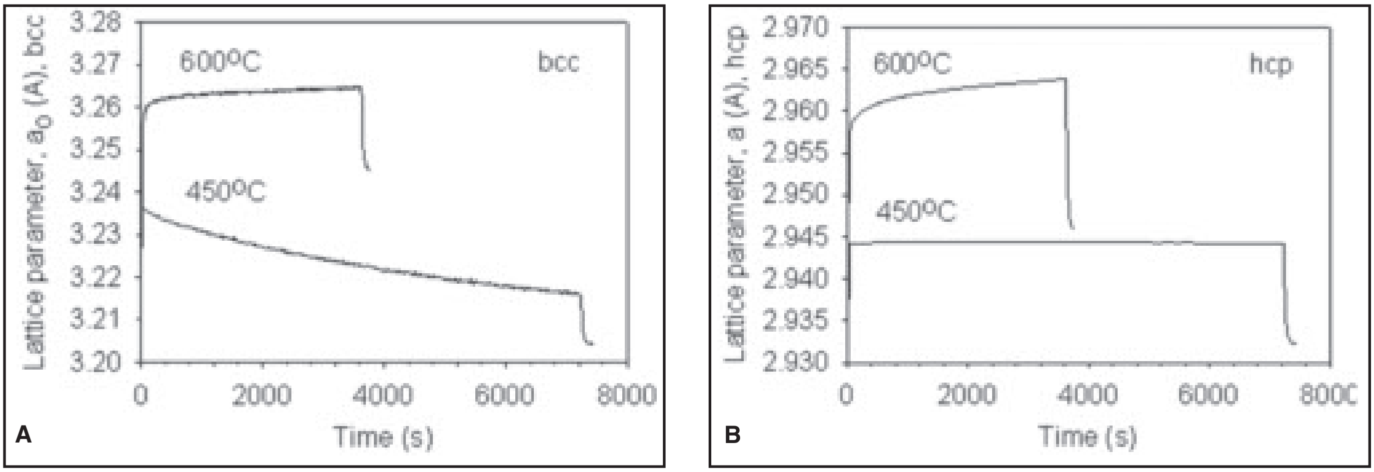


Fig. 19 — In-situ lattice parameters measured by CHC for Ti-6Al-4V as a function of isothermal hold time at 450° and 600°C for the following: A — the β phase; B — the α phase.

broadening. A simultaneous broadening of the austenite peaks was observed, which is consistent with the strain induced in it by the surrounding martensite. These results demonstrate both the differences in the phase transformation behavior of low and medium carbon steels, and how *in-situ* X-ray diffraction can be used to provide real-time observations of important phase transformations during the welding of steels.

Controlled Heating and Cooling (CHC)

The CHC method allows samples to be subjected to arbitrary thermal profiles to heat and cool them to any temperature up to their melting point. Because of its simplicity, the CHC method can be used to both simulate welding and perform heat treating of any metal that can be resistively heated. The heating method is similar to that of a Gleeble experimental setup, while at the same time providing *in-situ* X-ray diffraction of the phases that are forming. A number of different materials systems have been investigated using this technique (Refs. 57–67), and here we present two examples of the types of data that can be obtained.

Stress Relieving and Phase Transformations in Ti-6Al-4V

Two different phases coexist in Ti-6Al-4V at room temperature: the low temperature alpha phase, which has a hexagonal close-packed structure, and the high-temperature beta phase which has a body-centered cubic structure. At elevated temperatures during heat treating or welding, the alpha phase transforms to beta. During cooling the reverse transformation occurs, which creates stress gradients on the microstructural scale due to different thermal contraction rates of the two phases (Ref. 61). Through *in-situ* diffraction a surprising and unexplained dip in the beta lattice parameter occurred, as indicated in Fig. 18 (Ref. 61). The CHC method was used to examine the details of this lattice contraction dip on heating in more detail, and was particularly useful in that it can follow the individual lattice parameter developments of both the alpha and beta phases simultaneously (Ref. 61).

The CHC experiment was performed on Ti-6Al-4V alloy specimens that were machined from mill-annealed bar stock, which contained a small amount of beta phase distributed among and around the elongated grains of the alpha phase (Ref. 60, 61). Microprobe analysis was used to determine the compositions and amounts of the two phases, indicating an initial distribution of 87.9% alpha and 12.1% beta. The CHC diffraction measurements were carried out at the UNICAT beam line BM-33-C of the Advanced Photon Source, where 30 keV X-rays were passed through a silicon monochromator and focused to a beam 1 mm by 0.25 mm. Diffracted X-rays were collected with a CCD detector with the samples held at temperatures ranging from 400° to 650°C. Lattice expansion data were extracted from shifts in the Bragg peak positions as a function of time during ramping to and holding at the predetermined temperature (Ref. 60).

Figure 19 shows plots of the lattice parameters of both phases, and shows that they increase with temperature due to conventional thermal expansion during the first seconds of the experiment. Once the isothermal temperature is reached, the lattice parameter of the beta phase alone steadily decreased over a period of hours when held at 450°C (Ref. 60). In contrast, when the temperature was held at 600°C, the lattice parameter for the beta phase increased slowly over a comparable duration. The alpha phase, on the other hand, exhibited constant lattice parameter at 450°C and a slower increase at 600°C as shown in Fig. 19B. Other temperatures were investigated (Ref. 60), and the beta phase lattice parameter exhibited its largest contraction at 450°C before expanding again with temperature, while the alpha phase showed no such dip within experimental error (Ref. 60). Further results show that the time-dependent change in beta lattice parameter at temperatures below 550°C occurs mainly from relaxation of preexisting stress in the starting microstructure. Above 550°C, the change in the lattice parameter of beta is caused mainly by the alpha to beta phase change and the subsequent redistribution of vanadium from alpha to beta (Ref. 60).

Sigma Phase Formation in 2205 Duplex Stainless Steel

Duplex stainless steel (DSS) alloys are often processed to have nearly equal amounts of ferrite and austenite in the microstructure, which provides them with a desirable combination of strength, toughness, and corrosion resistance. However, when exposed to elevated temperatures between approximately 600° and 1000°C for sustained periods of time, several undesirable intermetallic phases can form (Refs. 58, 59). The σ phase is the most prominent of these intermetallic phases, and once formed, sigma is known to adversely affect the mechanical properties and corrosion resistance of DSS alloys. Figure 20 shows the microstructure of a DSS after elevated temperature heat treating at 850°C where abundant σ phase has formed. Here, the CHC technique was used to observe the formation of σ phase at different temperatures to determine the kinetics of its formation (Ref. 58), and to observe the dissolution of sigma at temperatures approaching 1000°C (Ref. 59).

An *in-situ* diffraction pattern taken of a DSS alloy after heat treating to form sigma phase was shown in Fig. 5 to illustrate the complex diffraction nature of the sigma phase. By taking diffraction patterns such as these repeatedly over the course of an elevated temperature cycle, the sigma phase formation can be observed and measured in real time. Figure 21 shows the results of the CHC X-ray diffraction data plotted for the initial 3700 s of a hold at 850°C. In this figure, the series of diffraction patterns are plotted with time along the y-axis, d-spacing along the X-axis, and the intensities of the diffraction peaks represented by different colors. The heating initiates at t = 0 s, and immediately all of the fcc and bcc diffraction peaks of the room-temperature microstructure shift to higher d-spacings due to the thermal expansion effect while the sample is being heated to 850°C. During holding, the intensity of the bcc peaks began to decrease while the intensity of the fcc peaks increase. At t = 81 s, the first sigma peak (411) appears, 40 s into the isothermal hold. With increased holding time, this peak intensifies and additional sigma peaks develop. Analysis shows that the sigma phase reached a maximum of 13.4% before beginning a thermal ramp to 1000°C at t = 1850 s. As the temperature ramps up the amount of sigma decreases, eventually reaching 0% at a temperature of 985°C. Sigma does not reappear again until the sample has been cooled back down and held at 850°C (Ref. 59).

A summary of the measured fractions of sigma, ferrite, and austenite is shown in Fig. 22, which also includes the temperature profile for this experiment. It is clear that sigma forms in increasing amounts until the temperature begins to ramp from 850° to 1000°C, reaching 0% at 985°C. This observed dissolution temperature for sigma is more than 100°C higher than predicted by thermodynamics (Ref. 59), and again is a measure of the kinetics of the phase transformation under a constant heating rate such as that produced during welding. The synchrotron data was modeled using a modified Johnson-Mehl-Avrami analysis (Refs. 58, 59), which provided kinetic data for sigma phase formation, and can be used to predict sigma phase formation under other welding and heat treating conditions.

Future Work and New Possibilities

SRXRD and TRXRD have proven to be unique and powerful tools to study microstructural evolution during welding, providing welding researchers with new capabilities. When combined with additional experiments such as *in-situ* CHC diffraction, and modeling of the results, a deeper understanding of the kinetics of phase transformations that occur during welding can be realized. As synchrotron-based investigations of welds gain more widespread use, they will provide the welding research community with the ability to quantitatively describe the kinetics of more complex phase transformations and improve the knowledge base for understanding welding in ways not possible using conventional methods.

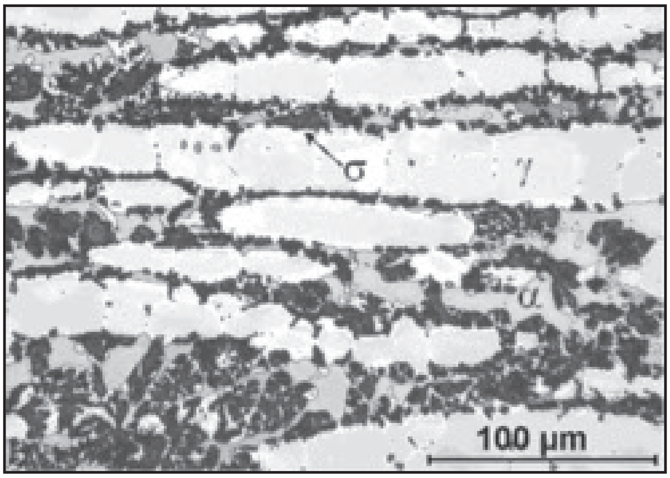


Fig. 20 — Optical micrograph showing the microstructure of the sample after the heat treating cycle. Ferrite, α, etches blue/purple in color, austenite, β, etches tan/white in color, and σ phase etches black/brown in color.

Looking into the future, these powerful synchrotron-based tools can be expanded to other areas of interest and different materials systems; however, the current SRXRD and TRXRD experimental setups are limited by two factors. First, the large size of the samples currently used for these experiments preclude investigations of potentially interesting materials systems of less common materials. Changes will be required to the experimental setup to allow different sample geometries, and thus a wider range of materials systems to be studied. This can easily be done for the TRXRD experiment where relatively small sample volumes are required. However, for the SRXRD experiment that requires a steady-state weld, different techniques will need to be developed. One method to reduce the SRXRD sample size is to acquire the data more rapidly. If the data can be acquired in a fraction of a second per data point, rather than the current 4–10 s per data point, then the total welding time, and thus the sample size, can be reduced accordingly. Methods where an entire row of data points can be acquired at one time using imaging plates (Ref. 74) could be developed further using digital imaging plate technology for example, which could rapidly speed up the SRXRD weld mapping process.

A second limiting factor to the existing setup is the speed and resolution of the X-ray detectors, which becomes even more important as higher data-sampling rates are desired. Even though the current silicon photodiode array detector used for SRXRD and TRXRD can capture X-ray diffraction patterns on the order of milliseconds, its linear geometry is only able to detect a small slice of the Debye circle, thus making the results susceptible to the effects of microstructural texturing and grain growth that occurs at high temperatures. Newer detection technologies are developing, and many already exist, which will allow for rapid X-ray detection with areal detectors such as the one used in the CHC diffraction experiments but with higher data-sampling rates. Some of these detectors are already incorporated into third-generation beam lines, and would provide increased ability to monitor welding-induced phase transformations at higher speeds.

If *in-situ* diffraction data are to be taken more rapidly or at higher spatial resolutions, then brighter beams will be required to produce the necessary intensity to accompany smaller integrated X-ray fluxes. Since the current SRXRD and TRXRD setups have not been optimized for brightness, there is plenty of room to grow without taxing existing synchrotron capabilities. For example, third-generation synchrotrons with undulators or more highly focused beams can utilize the full beam's power without having to pass the beam through a pinhole to provide the needed spatial resolution. This preserves all of the beam's intensity, and this effect alone will easily provide orders of magnitude increase to the X-ray photon flux in the weld region. These brighter beams also have higher inherent spatial resolution allowing smaller welds and smaller HAZs to be investigated. As bright as third-generation synchrotrons already are, the next generation of high-energy X-ray sources such as free electron lasers, will provide orders of magnitude brighter beams than those of current synchrotrons (Refs. 1, 3), but is doubtful that such bright beams will be required for *in-situ* welding experiments on anything other than welds with extremely small dimensions.

The future of *in-situ* observations of

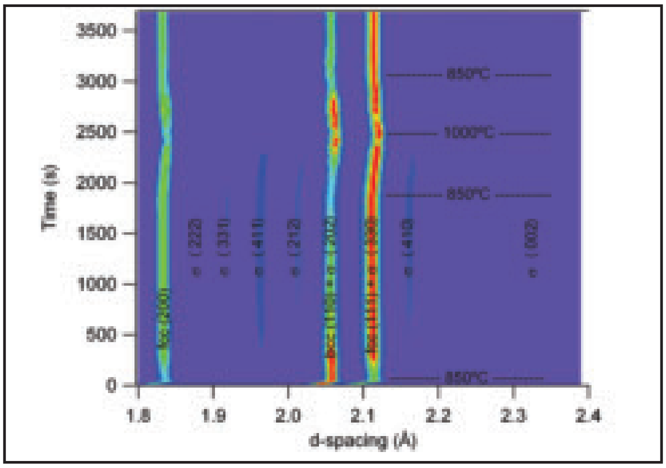


Fig. 21 — In-situ X-ray diffraction sequence up to 3700 s as detected by CHC of a duplex stainless steel alloy where the temperature was ramped to and from 1000°C, after an isothermal hold at 850°C. The sigma phase first appears at a time of 81 s.

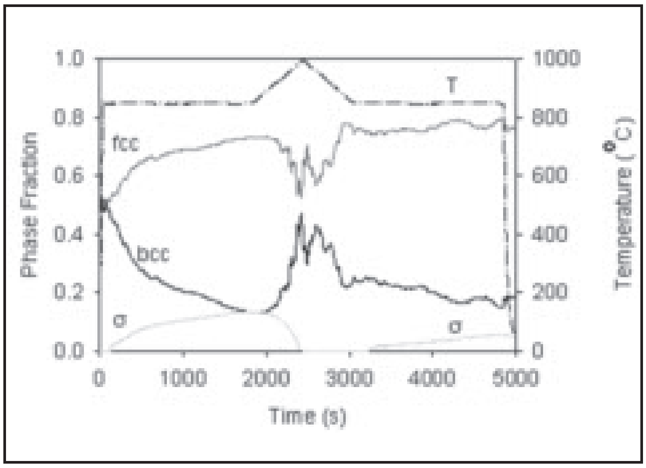


Fig. 22 — Measured fractions of ferrite (bcc), austenite (fcc), and sigma phases in a duplex stainless steel alloy as a function of time as determined by CHC. The temperature profile is indicated by the dashed line. Noise in the ferrite and austenite fractions appear at high temperatures when grain growth occurs and only a few grains satisfy the Bragg condition for diffraction. Both sigma phase formation at 850°C and its dissolution at temperatures approaching 1000°C are captured.

welds is one with a lot of growth potential, and will most likely involve some combination of all of the above effects including brighter synchrotron beams, faster X-ray detectors and new methods for rapidly detecting and mapping the phases that exist during welding. These advances will allow a wider range of welding techniques to be evaluated, for example, laser welding, resistance welding, and friction stir welding. In addition, weld simulation techniques like CHC diffraction can be augmented by incorporating mechanical stressing in addition to heating, so that true thermomechanical behavior of welds can be simulated and analyzed by *in-situ* X-ray diffraction. Furthermore, by incorporating more sophisticated and faster areal X-ray detectors into the experiments, residual stress analysis in real time will become a real possibility. Thinking outside of synchrotrons, the availability of higher flux neutron beams, such as the spallation neutron source at Oak Ridge National Laboratory, will be a big step forward to being able to perform real-time volumetric neutron diffraction and stress analysis on welds or simulated welds in real time, and there should be ample opportunity for new research in this field as well.

Acknowledgments

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344. Much of this work was supported by DOE, Office of Basic Energy Sciences, Division of Materials Science. Portions of this research were carried out at the Stanford Synchrotron Radiation Laboratory, a national user facility operated by Stanford University on behalf of the U.S. Department of Energy, Office of Basic Energy Sciences. The UNICAT facility at the Advanced Photon Source (APS) is supported by the U.S. DOE under Award No. DEFG02-91ER45439, through the Frederick Seitz Materials Research Laboratory at the University of Illinois at Urbana-Champaign, the Oak Ridge National Laboratory (U.S. DOE contract DE-AC05-00OR22725 with UT-Battelle LLC), the National Institute of Standards and Technology (U.S. Department of Commerce), and UOP LLC. The APS is supported by the U.S. DOE, Basic Energy Sciences, Office of Science under contract No. W-31-109-ENG-38. Additional portions of the research were performed by The Pennsylvania State University, under grant DE-FGO2-01ER45900. I would like to acknowledge the many collaborators who have worked with me over the past number of years to develop the synchrotron techniques for welding, particularly Professor Suresh Babu, Dr. Todd Palmer, Dr. Eliot Specht, Mr. Phil Waide, and Dr. Joe Wong. In addition, the modeling efforts provided by Professor T. DebRoy and his students at the Pennsylvania State University, Dr. X. He, Dr. Amit Kumar, Mr. Sarang Sista, Dr. Zhishang Yang, and Dr. Wei Zhang have added greatly to the analysis of the experimental results. I would like to also thank the postdoctoral researchers and PhD students at the time, Professor Michael Fröba, Dr. Peter Mayr, Professor Thorsten Ressler, and Dr. Richard Thissen, who have contributed to the analysis of the synchrotron data in many different and helpful ways.

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