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On the cover: The aircraft carrier USS George H. W. Bush (CVN 77) on builder’s trials, February 13, 2009. The ship, named after the nation’s 41st president, is the 10th and final Nimitz-class, nuclear-powered carrier built at Northrop Grumman Shipbuilding-Newport News. (Photo courtesy of Northrop Grumman Shipbuilding, by John Whalen, photographer.)
Are You Keeping Up to Date?

“Hey boss, there’s an AWS conference in May about welding purple widgets together, and I’d like to attend, just in case we start making those purple widgets.” This might seem bizarre, but as a supervisor, I’ve seen requests at least that foolish. Today, the pendulum may have swung the other way, as many managers have eliminated budgets for training of almost any kind. This can be threatening to the long-term health of the organization, as change is occurring faster and faster. There is real value in attending meetings where speakers talk about a subject that you need to know more about, and where you can share your concerns and ideas with the speaker and others in the group — and come away with ideas you can put to work immediately.

The AWS Conference Committee guides the selection of subjects for conferences that provide information to solve today’s design, materials, and manufacturing problems, and to highlight issues likely to surface soon. This is critical for those companies who must lower their costs in order to remain competitive, as well as those who are adding new products, introducing new materials, or changing their manufacturing processes. In today’s economy, the pressures to reduce costs can drive major design, materials, process, and methods changes. As manufacturing engineers and supervisors, our charter is to achieve these cost reductions while maintaining the quality and performance of our product, and keeping it safe to use.

The measure of performance for the Conference Program is the evaluation of attendees. In other words, did you learn something you needed to know and something you can put to use?

In recent years, AWS conferences have addressed special materials; nagging problems such as cracking, distortion, and other types of weld defects and failures; and newer welding processes such as lasers and hybrid GMAW-laser systems. The responses from attendees have been very positive, largely due to the efforts of Bob Irving, our consultant, who consistently finds the right speakers and organizes the programs to cover the critical areas of interest on the topics.

For 2011, we are planning to offer the following conferences. The dates for several events have not yet been set, but they will be announced shortly.

- 6th Shipbuilding Conference, Seattle, Wash., May 10
- Prevention of Weld Failures, New Orleans, La., June 14, 15
- 14th Aluminum Welding Conference, Fort Lauderdale, Fla., September 20, 21

The following four conferences will be held in conjunction with FABTECH in Chicago, Ill.

- National Welding Education Conference, Nov. 13
- ABCs of Welding Engineering Conference, Nov. 14
- 8th Weld Cracking Conference, Nov. 15
- Understanding Power Sources Conference, Nov. 16

Along with Bob Irving’s work developing conference programs and finding the best speakers, the AWS staff makes the myriad arrangements necessary to ensure that conferences come off effectively and efficiently.

A conference should be a stepping off point for you, i.e., it should stimulate your thinking and inspire you to dig deeper into the subject matter to cement this new or renewed knowledge. It is not an injection that will make you smarter in a day or two.

If you don’t see a topic here that interests you, please let us know. It’s our job to be responsive to your needs. We need your input to identify the areas where you need information to deal with current or anticipated challenges. Feel free to contact me at fsaenger@gmail.com or Selvis Morales at AWS headquarters; smorales@aws.org; (800) 443-9353, ext. 239.
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OSHA Issues Regulatory Agenda

The U.S. Occupational Safety and Health Administration (OSHA) has issued its most recent semiannual agenda regarding rules that it expects to act upon in some manner in the near future.

One new initiative is an Injury and Illness Prevention Program, which OSHA plans to initiate with stakeholder meetings beginning in June 2011. A major component of any final rule is expected to be significant employee participation.

Additional items on OSHA’s regulatory agenda include the following:
• A final rule modifying current safety standards for workers involved in electric power transmission and distribution, including new requirements for personal protective equipment;
• A final rule harmonizing the labeling of labels and data sheets for chemical substances to be consistent with global standards;
• A final confined spaces rule for the construction industry; and
• A final rule on the reporting of musculoskeletal injuries.

The entire agenda is available at www.dol.gov/regulations.

Research and Development Tax Credit Extended

Almost one year after it expired, the Research and Development (R&D) tax credit has been extended through the end of 2011. This extension was included in the recent tax legislation, the Tax Relief, Unemployment Insurance Reauthorization, and Job Creation Act and is retroactive to January 1, 2010. This is the 14th extension since the tax credit was first enacted in 1981. Generally speaking, a business may claim a research credit equal to 20% of the amount by which its qualified research expenses for a taxable year exceed its base amount for that year.

Nuclear Energy Supporters Look to Small Reactors

Many within the nuclear energy sector see small modular reactors (SMRs) as a possible growth area for the industry and something on which Congress may be able reach a compromise agreement. Recently, the National Association of Regulatory Utility Commissioners adopted a resolution urging federal support for SMRs, which are viewed as a lower cost alternative to larger nuclear plants, in terms of capital investment as well as security, waste disposal, and financing. Also, SMRs are seen as providing an opportunity for U.S. companies doing business overseas.

The existing fleet of 104 nuclear reactors within the United States are nearing the end of their current operating license periods.

America COMPETES Act Renewed

Congress has finally reached agreement on renewal of the America COMPETES Act, though on a smaller scale than initially envisioned. Originally enacted in 2007, this legislation was intended to implement certain recommendations of the National Academies in their report, Rising Above the Gathering Storm, including with respect to basic research and fostering entrepreneurship.

In late 2010, Rising Above the Gathering Storm, Revisited: Rapidly Approaching Category 5 was issued by the National Academies, which, among other recommendations, called for renewal of the COMPETES Act. Concerns over the federal deficit delayed the legislation and ultimately resulted in reduced spending ($43 billion instead of the originally proposed $84 billion), and a three-year renewal instead of five years. But the core of the COMPETES Act — staying on track to double the budgets of the National Science Foundation, Department of Energy Office of Science, and National Institute for Standards and Technology — is preserved.

EPA Postpones Major Regulations

The U.S. Environmental Protection Agency (EPA) is delaying issuance of two controversial regulations until well into 2011. Revised air quality standards for ground level ozone, which have been delayed at least twice before, would set the applicable standard as low as 60 parts per billion (ppb), instead of the current 75 ppb limit. The other regulation would sharply limit mercury and other hazardous air pollutants from boilers and solid waste incinerators.

IRS Issues Health Care Tax Credit Guidance

The Internal Revenue Service (IRS) has released Notice 2010-82, which provides final guidance for small employers eligible to claim the new small business health care tax credit for the 2010 tax year.

Included in the Affordable Care Act enacted last year, the small business health care tax credit is designed to encourage both small businesses and small tax-exempt organizations to offer health insurance coverage to their employees for the first time or maintain coverage they already have. The new guidance addresses small business questions about which firms qualify for the credit by clarifying that a broad range of employers meet the eligibility requirements, including small employers who cover their workers through insured multiemployer health and welfare plans, and employers who subsidize their employees’ health care costs through a broad range of contribution arrangements.

In general, the credit is available to small employers who pay at least half of the premiums for single health insurance coverage for their employees. It is specifically targeted to help small businesses and tax-exempt organizations who primarily employ moderate- and lower-income workers.

More information is available at the following link: www.irs.gov/newsroom/article/0, id=231928,00.html.

First Steps in New Export Control System

The White House is starting to take action to implement its planned revamping of export controls in an effort to boost U.S. exports. This includes launching the Export Control Reform Initiative Web page at www.export.gov, which includes a new tool to facilitate compliance with export control requirements by bringing together, for the first time, various screening lists maintained by multiple federal agencies. New draft exporting rules issued for public comment are also posted at this site.

Contact the AWS Washington Government Affairs Office at 1747 Pennsylvania Ave. NW, Washington, DC 20006; e-mail hwebster@we-st.com; FAX (202) 835-0243.
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Printed Electronics Research Facility to Be Established at University of Texas at El Paso

Texas Governor Rick Perry recently announced the state will invest $3 million through the Texas Emerging Technology Fund to help create new, integrated 3-D systems technologies through the Structural and Printed Emerging Technologies (SPEC) Center in The University of Texas at El Paso College of Engineering.

Industry partner Lockheed Martin Aeronautics will also contribute $3 million toward five-year operating costs of the new center, and The University of Texas System has pledged $3 million in construction and equipment funds, for a total of $9 million.

The center will use and build upon the existing rapid-prototyping or additive manufacturing equipment and research available in the college’s W. M. Keck Center for 3-D Innovation. The area housing the Keck Center will double in size to accommodate labs and equipment. The computer-driven systems will allow fabricating three-dimensional mechanical and electronic devices. Initially, it will focus on printed electronics, but will have the capability to produce devices of nearly all types, sizes, and materials.

The SPEC Center will be directed by Kenneth H. Church, an expert in the printed electronics field who holds a PhD in electrical engineering, and codirected by Professor of Mechanical Engineering Ryan Wicker, PhD, current director of the Keck Center.

Navy Metalworking Center Project Wins Technology Award

A Navy Metalworking Center (NMC) project received the 2010 Defense Manufacturing Technology Achievement Award for the development and commercialization of a weld shaver system that has wide applicability for military ships, Department of Defense (DoD) weapon systems, and commercial structures. The award, given by the DoD Joint Defense Manufacturing Technology Panel, was recently presented to the project team during the Defense Manufacturing Conference in Las Vegas, Nev.

“I’d like to commend Bruce Horn, Tim Freidhoff, and the entire project team for their accomplishments on this project. Their approach ensured success by working directly with shipyard personnel who knew first-hand the need for a solution and by incorporating their adjustments in multiple versions of the tool,” said Dr. Daniel Winterscheidt, NMC program director.

The Navy Metalworking Center led a project that developed a mechanized tool that removes 80% of the weld reinforcement at rates exceeding 20 ft/h and was implemented at Bath Iron Works in the construction of DDG 51 and DDG 1000. The tool will reduce the construction cost of DDG 1000 by $2.77 million.

U.S. Steel, Kobe Steel to Build Continuous Annealing Line

United States Steel Corp., Pittsburgh, Pa., and Kobe Steel, Ltd., Japan, have reached an agreement for their joint venture, PRO-TEC Coating Co., Leipsic, Ohio, to begin construction on a continuous annealing line at the facility. The project is expected to increase the joint venture’s ability to serve its automotive users. The capital investment for this project is approximately $400 million and is expected to create 500 temporary construction jobs as well as 80 full-time jobs once operating. Completion of the project will take an estimated 24 months.

With this addition, PRO-TEC will be able to produce cold-rolled advanced high-strength steels and ultrahigh-strength steels for certain automotive structural parts with an annual production capacity of 500,000 tons.

Vigor Industrial to Acquire Todd Shipyards

Todd Shipyards Corp., Seattle, Wash., and Vigor Industrial LLC, Portland, Ore., recently entered into a definitive agreement where Vigor will acquire Todd’s stock for $22.27 per share, or approximately $130 million. The transaction, structured as an all cash tender offer, is expected to close in the first quarter of this year. Todd’s management will remain intact and all contracts will remain in place.

“Todd is Puget Sound’s leading shipyard, and the combination of Vigor and Todd will create the largest and most capable marine services company in the Pacific Northwest,” said Frank Foti, Vigor’s president.
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.
**Arlington** Launched at Northrop Grumman’s Pascagoula Facility

Northrop Grumman Corp.’s Shipbuilding sector recently launched the company’s amphibious transport dock ship **Arlington** (LPD 24), the eighth ship of the USS **San Antonio** (LPD 17) class of ships being built at the Gulf Coast facilities.

“This is a top-quality warship and our shipbuilding team has done an outstanding job of meeting their commitments to one of the most important milestones in the life of any ship,” said Doug Lounsberry, LPD 17 program manager, Northrop Grumman Shipbuilding. “This ship was the most complete LPD to date at time of launch and the schedule was also the shortest time from keel laying to launch.”

Currently, the ship is 77% complete and includes upgrades from previous LPDs, including new water purification and operating systems. It’s named for the county in which the Pentagon is located and is one of three ships Northrop Grumman is building to honor the heroes and victims of the Sept. 11, 2001, terrorist attacks. Christening is tentatively scheduled for the spring.

LPD 24 is the third U.S. Navy ship to bear the name Arlington. The 11 ships of the LPD 17 class are an element of the Navy’s ability to project power ashore. Collectively, these ships functionally replace more than 41 ships, providing the Navy and Marine Corps with modern, sea-based platforms that are networked, survivable, and built to operate with 21st century platforms.

In addition, the LPD 17-class ships are 684 ft long, 105 ft wide, and displace approximately 25,000 tons. Their principal mission is to deploy the combat and support elements of Marine Expeditionary Units and Brigades. The ship can also carry up to 800 troops and has the capability of transporting and debarking air cushion or conventional landing craft and expeditionary fighting vehicles, augmented by helicopters or vertical take-off and landing aircraft.

**ThyssenKrupp Opens Alabama Plant**

Following a three-year construction period, the new steelmaking and processing plant of ThyssenKrupp Steel USA and ThyssenKrupp Stainless USA in Calvert, Ala., officially opened Dec. 10. Three thousand employees, customers, and guests from government and industry attended the event.

ThyssenKrupp has invested $5 billion in the complex with $3.6 billion for the carbon flat steel facilities and $1.4 billion for the stainless area. The plant may eventually have 2700 permanent employees.

Calvert was chosen for its logistics and direct access to the Gulf of Mexico for the supply of starting materials from ThyssenKrupp’s facilities in Brazil. The groundbreaking ceremony on the 14-sq-km site took place in November 2007.

For the production of carbon flat steel, the plant will be supplied with three million metric tons of slabs per year from Brazil. These will be shipped to the Port of Mobile, and from there, along the Tombigbee River to the plant’s own river terminal. The central element of the plant is a wide hot strip mill with a capacity of more than five million metric tons per year.

The hot strip mill will also be used by ThyssenKrupp Stainless USA. Stainless operations started last September with one cold rolling mill and an annual capacity of around 100,000 tons.

Starting material for ThyssenKrupp Stainless USA is currently
being supplied from the Group’s European plants. In the future, stainless steel slabs will be produced in an on-site melt shop in Calvert. Part of the stainless hot-rolled produced there will later be supplied to ThyssenKrupp Mexinox in San Luis Potosi, Mexico. Startup of the electric-arc furnace melt shop is planned for December 2012.

Ford’s Michigan Assembly to Build Electric, Hybrid, and Plug-In Vehicles

The company’s Michigan Assembly Plant is home to the new Ford Focus. Production of this car (seen above) is underway. The Focus Electric battery-operated vehicle goes into production late this year, followed by a new hybrid and plug-in hybrid in late 2012. (Photo courtesy of Ford Motor Co.)

Ford Motor Co.’s Michigan Assembly Plant completed a $550 million transformation that, according to the company, will make it the world’s first factory to build not only fuel-efficient gas-powered cars, but also three production versions of electric vehicles including battery electric, hybrid, and plug-in hybrid.

The plant is home to the new Ford Focus, which has started production. The Focus Electric zero-emission battery electric vehicle goes into production late this year followed by production of a new hybrid and plug-in hybrid in 2012.

On the outside, a 500-kW solar panel system will be installed to generate renewal energy for production of Ford’s new Focus and Focus Electric cars. Ten electric vehicle charging stations on the property will be used to recharge the electric trucks that transport parts between adjacent facilities.

Inside, new cars making the three-mile trip down the assembly line must pass dozens of quality inspections. A three-wet paint booth utilizes 66 paint robots with seven axes of movement to apply paint to the cars. In the body shop, 500 robots capable of 4000 welds per vehicle add to the plant’s flexibility. In addition, an internal communications system flashes updates and information to the plant’s 3200 employees via 163 monitor screens.

Hypertherm Earns OSHA STAR Status

Hypertherm, Hanover, N.H., has been selected as a STAR worksite by the Occupational Safety and Health Administration’s (OSHA) Voluntary Protection Program (VPP). Currently, less than 2200 worksites across the country have this designation.
The VPP recognizes organizations that have outstanding safety and health practices. Organizations must maintain injury and illness rates that are significantly below U.S. government averages for their industry. For 2010, Hypertherm’s rate is less than one incident per 100 full-time associates.

Organizations also have to demonstrate a disciplined system of hazard prevention and control, training programs, and worker involvement. The selection process includes a five-day on-site evaluation by five safety and health professionals.

**AT&F Steel Opens Hybrid Laser Arc Welding Facility**

AT&F Steel recently opened the doors of its newest welding center in Cleveland, Ohio. According to the company, this multimillion dollar hybrid laser arc welding facility is the largest in the United States.

Merging the advantages of gas metal arc welding with laser beam welding, the company’s hybrid laser arc welding procedure offers fabrication designers and engineers component design flexibility. Hybrid laser welds are uniform with less heat input and, combined with a welding speed of up to 250 in./min, this reduces the component distortion. The technology also allows lasers to be used to accommodate thick materials, and for gas metal arc welding to be applied without material deformation.

The facility can adapt to large-scale projects, with a working envelop of 14 x 60 ft, as well as customized components. From ship and bridge building to nuclear power and commercial construction, the company’s hybrid laser arc welding procedure is innovating component manufacturing.

“For critical applications where weight and straightness are key, this is the perfect technology. Hybrid laser welding will reduce production time and costs as well as produce the most consistent components,” said Michael Ripich, president.

**Industry Notes**

• LENOX® opened a new weld center in Mississauga, Ont., Canada, representing a $500,000 investment, to serve customers in Ontario, Quebec, and eastern Canada with factory welds on industrial metal-cutting band saw blades.

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**FANUC Robotics America**, Rochester Hills, Mich., recently sold its 100,000th robot in North and South America to [Schneider Packaging](#), Brewerton, N.Y.

**Lincoln Electric Holdings, Inc.**, Cleveland, Ohio, signed a definitive agreement to acquire [OOO Severstal-metiz](#) welding consumables, Russia, including manufacturing operations.

**Western Environmental Liner**, Tolleson, Ariz., added a heat welding machine to fabricate 4-13 ft wide plastic panels up to 220 ft long and weld several hundred thousand sq ft a day.

**Insteel Industries, Inc.**, is closing its leased facility in Houston, Tex., and moving manufacturing to its Dayton, Tex., plant. Also, the company is closing its facility in Wilmington, Del., and moving manufacturing to its Hazleton, Pa., plant.

**Graham Corp.**, Batavia, N.Y., acquired privately held [Energy Steel & Supply Co.](#), a code fabrication and specialty machining company dedicated to the nuclear power industry.

The [SEHO Academy](#) is expanding into the United States this year with soldering seminars in selective, wave, and reflow categories. For more details, e-mail academy@seho.de.

**The Worthington Cylinders** segment of Worthington Industries, Inc., Columbus, Ohio, entered an agreement to acquire a 60% interest in [Nitin Cylinders Ltd.](#), India.

**Jergens Industrial Supply** recently acquired the assets of [The George Whalley Co.](#)’s cutting tool and industrial supply division. Both companies are located in Cleveland, Ohio.

**RoboVent** has relocated its main office to Sterling Heights, Mich. This move will allow the company to better serve its existing markets as well as facilitate expanded product offerings.

**Lide Industries, LLC**, Mexia, Tex., became the 75th worldwide recipient of [The American Petroleum Institute](#)’s standardization certificate for 12F that encompasses shop welded storage tanks for production liquids.

**SIFCO Industries, Inc.**, Cleveland, Ohio, recently acquired the forging business and related assets from [T&W Forge, Inc.](#), Alliance, Ohio.

**The Laser Institute of America**, Orlando, Fla., introduced its free, online optical density calculator resource at www.laserinstitute.org/evaluator/od.php.

**E. J. Bartells** installed a [Jet Edge](#) waterjet cutting machine at its insulation, refractories, and HVAC fabrication facility in Spokane, Wash.

**Platte River Ventures**, Denver, Colo., acquired the outstanding stock of [Car-Ber Testing Services](#), Sarnia, Ont., Canada, a technical support provider to the petrochemical industry.

**Artech Welders Private Ltd.**, Pune, India, has launched its Web site at www.shearconnectorwelding.com.

**AuraPortal** recently announced the company, along with its customer, [ArcelorMittal Foundation](#), has been named the Silver Winners for the 2010 Global Awards for Excellence in Business Process Management and Workflow.
Characterizing a ‘Code’ Shop

Here’s an answer to what a “code” shop actually represents, a topic presented by Phil Evans, an AWS CWI, in a letter published in the December 2010 issue (page 20).

I’m a National Board commissioned Authorized Inspector working for an accredited Authorized Inspection Agency. I’ve also served in various inspector and supervisor roles over 36 years, plus still hold an active commission.

If a fabricator of boilers, pressure vessels, heating boilers, or piping systems has an ASME Code Certificate of Authorization, it would most likely be posted in a prominent place for visitors to see.

An ASME “code” shop has a Certificate of Authorization and a steel stamp that is used by the fabricator as long as the product complies with the rules of the fabricator’s own quality control program and that of the construction code. ASME Section(s) I, IV, and VIII Division 1 are construction codes. They are used for power boilers, heating boilers, and pressure vessels, respectively.

The fact that a manufacturer has a Certificate of Authorization means the shop has been audited by ASME to the aforementioned quality control program written description required by the codes named above. This audit focuses on compliance with the code as well as the manufacturer’s quality control program from order entry through design and fabrication to inspection and testing as required.

The ASME Certificate of Authorization is recognized worldwide. It’s renewable on a three-year cycle by virtue of an ASME joint review. The authorized inspector supervisor and authorized inspector are members of the team and headed up by a “team leader,” most likely a chief inspector of the state or a national board designee. Their responsibility is to complete an audit of the quality control program, including an actual demonstration of the certificate holder’s ability to produce a vessel that can, when completed, be stamped with the ASME Code Symbol. This stamp represents the product meets code requirements and has been inspected by a third-party authorized inspector, commissioned in that state, and holds a commission issued by the National Board of Boiler and Pressure Vessel Inspectors.

A purchaser of an ASME Code stamped boiler or pressure vessel is assured what they have purchased will meet the codes of any/all jurisdictions, municipalities, and international codes. The authorized inspector who certifies the manufacturer’s data report is to the best of his knowledge and belief a factual representation of the vessel described thereon.

Only the manufacturer can answer the question: Is it worth it?

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• Handle not only Welding, but also Torching/Cutting, and Grinding with Digi-Beret’s Multi-Modes
• You get 4 Sensors, not just 2, so your work continues even if some sensors get blocked
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For Info go to www.aws.org/ad-index
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, 2011. The Committee looks forward to receiving numerous Fellow nominations for 2012 consideration.

Sincerely,

Thomas M. Mustaleski
Chair, AWS Fellows Selection Committee
CLASS OF 2012
FELLOW NOMINATION FORM

DATE__________________NAME OF CANDIDATE__________________

AWS MEMBER NO.__________________YEARS OF AWS MEMBERSHIP__________________

HOME ADDRESS__________________________________________________________

CITY________________________________STATE________ZIP CODE________ PHONE____

PRESENT COMPANY/INSTITUTION AFFILIATION________________________________

TITLE/POSITION____________________________________________________________

BUSINESS ADDRESS__________________________________________________________

CITY________________________________STATE________ZIP CODE________ PHONE____

ACADEMIC BACKGROUND, AS APPLICABLE:

INSTITUTION______________________________________________________________

MAJOR & MINOR__________________________________________________________

DEGREES OR CERTIFICATES/YEAR____________________________________________

LICENSED PROFESSIONAL ENGINEER: YES____NO ______ STATE__________________

SIGNIFICANT WORK EXPERIENCE:

COMPANY/CITY/STATE______________________________________________

POSITION__________________YEARS__________________

COMPANY/CITY/STATE______________________________________________

POSITION__________________YEARS__________________

SUMMARIZE MAJOR CONTRIBUTIONS IN THESE POSITIONS:

________________________________________________________________________

________________________________________________________________________

IT IS MANDATORY THAT A CITATION (50 TO 100 WORDS, USE SEPARATE SHEET) INDICATING WHY THE NOMINEE SHOULD BE SELECTED AS AN AWS FELLOW ACCOMPANY NOMINATION PACKET. IF NOMINEE IS SELECTED, THIS STATEMENT MAY BE INCORPORATED WITHIN THE CITATION CERTIFICATE.

SEE GUIDELINES ON REVERSE SIDE

SUBMITTED BY: PROPOSER__________________AWS Member No.__________________

Print Name__________________

The Proposer will serve as the contact if the Selection Committee requires further information. Signatures on this nominating form, or supporting letters from each nominator, are required from four AWS members in addition to the Proposer. Signatures may be acquired by photocopying the original and transmitting to each nominating member. Once the signatures are secured, the total package should be submitted.

NOMINATING MEMBER:__________________NOMINATING MEMBER:__________________

Print Name__________________Print Name__________________

AWS Member No.__________________AWS Member No.__________________

NOMINATING MEMBER:__________________NOMINATING MEMBER:__________________

Print Name__________________Print Name__________________

AWS Member No.__________________AWS Member No.__________________

SUBMISSION DEADLINE July 1, 2011
DEFINITION AND HISTORY
The American Welding Society, in 1990, established the honor of Fellow of the Society to recognize members for
distinguished contributions to the field of welding science and technology, and for promoting and sustaining the professional
stature of the field. Election as a Fellow of the Society is based on the outstanding accomplishments and technical impact of the
individual. Such accomplishments will have advanced the science, technology and application of welding, as evidenced by:
* Sustained service and performance in the advancement of welding science and technology
* Publication of papers, articles and books which enhance knowledge of welding
* Innovative development of welding technology
* Society and chapter contributions
* Professional recognition

RULES
1. Candidates shall have 10 years of membership in AWS
2. Candidates shall be nominated by any five members of the Society
3. Nominations shall be submitted on the official form available from AWS Headquarters
4. Nominations must be submitted to AWS Headquarters no later than July 1 of the year prior to that in
   which the award is to be presented
5. Nominations will remain valid for three years
6. All information on nominees will be held in strict confidence
7. No more than two posthumous Fellows may be elected each year

NUMBER OF FELLOWS
Maximum of 10 Fellows selected each year.

AWS Fellow Application Guidelines

Nomination packages for AWS Fellow should clearly demonstrate the candidates outstanding contributions to the advancement
of welding science and technology. In order for the Fellows Selection Committee to fairly assess the candidates qualifications,
the nomination package must list and clearly describe the candidates specific technical accomplishments, how they contributed
to the advancement of welding technology, and that these contributions were sustained. Essential in demonstrating the candidates impact are the following (in approximate order of importance).

1. Description of significant technical advancements. This should be a brief summary of the candidates most
   significant contributions to the advancement of welding science and technology.
2. Publications of books, papers, articles or other significant scholarly works that demonstrate the contributions cited
   in (1). Where possible, papers and articles should be designated as to whether they were published in
   peer-reviewed journals.
3. Inventions and patents.
4. Professional recognition including awards and honors from AWS and other professional societies.
5. Meaningful participation in technical committees. Indicate the number of years served on these committees and
   any leadership roles (chair, vice-chair, subcommittee responsibilities, etc.).
6. Contributions to handbooks and standards.
7. Presentations made at technical conferences and section meetings.
8. Consultancy — particularly as it impacts technology advancement.
9. Leadership at the technical society or corporate level, particularly as it impacts advancement of welding technology.
10. Participation on organizing committees for technical programming.
11. Advocacy — support of the society and its technical advancement through institutional, political or other means.

Note: Application packages that do not support the candidate using the metrics listed above
will have a very low probability of success.

Supporting Letters
Letters of support from individuals knowledgeable of the candidate and his/her contributions are encouraged. These letters should address the metrics listed above and provide personal insight into the contributions and stature of the candidate. Letters of support that simply endorse the candidate will have little impact on the selection process.

Return completed Fellow nomination package to:

Wendy S. Reeve
American Welding Society
Senior Manager
Award Programs and Administrative Support
550 N.W. LeJeune Road
Miami, FL 33126

Telephone: 800-443-9353, extension 293

SUBMISSION DEADLINE: July 1, 2011
Marine Standards and Featured Publications
**Marine Welding Standards**

**D3.5−93R, Guide for Steel Hull Welding**  
Best practical methods to weld steel hulls for ships, barges, mobile offshore drilling units, and other marine vessels. Includes information on steel plates, shapes, castings, and forgings, their selection, and their weldability, 116 pages, 72 illustrations, 9 tables, (Reaffirmed 2000).  
D3.5 $85/$66

**NEW EDITION: D3.6M:2010, Underwater Welding Code**  
Covers the requirements for the underwater welding of structures or components in wet and dry environments at one-atmosphere and ambient atmospheres. Includes qualification and inspection requirements. 422 pages, 48 figures, 13 tables, 7 forms, (2011).  
D3.6 $100/$75

**D3.7:2004, Guide for Aluminum Hull Welding**  
Guidance on proven processes, techniques, and procedures for welding aluminum hulls and related ship structures. Applies chiefly to aluminum hulls over 30 ft. (9 m) long and made of sheet and plate 3/16 in. (4.8 mm) thick and greater. Sections on hull materials, construction preparation, welding equipment and processes, procedure and performance qualification, welding techniques, and safety. 86 pages, (2004).  
D3.7 $76/$57

**NEW PUBLICATION: D3.9:2010, Specification for Classification of Weld-Through Paint Primers**  
Specifies the classification requirements for weld-through paint primers for paint manufacturers, based on the maximum coating thickness and welding procedure used in testing. 20 pages, (2010).  
D3.9 $52/$39

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**Structural Steel Welding Standards**

**D1.1/D1.1M:2010, Structural Welding Code—Steel**  
For everyone involved in any phase of welding steel structures — engineers, detailers, fabricators, erectors, inspectors, etc. — the new D1.1 spells out the requirements for design, procedures, qualification, fabrication, inspection, and repair of pipe, plate, and structural shapes that are subject to either static or cyclic stresses. U.S. Customary and SI units of measurement. 570 pages, 21 annexes, 171 figures, 78 tables, (2010).  
D1.1 $495/$372

Covers arc welding of structural sheet/strip steels, including cold formed members, equal to or less than 3/16 in. (0.188 in./4.8 mm) nominal thickness and having a minimum specified yield point no greater than 80,000 psi (550 MPa). Applicable to welding of commonly used structural quality low-carbon hot rolled and cold rolled sheet and strip steel, with or without zinc coating (galvanized), to other structural sheet steel or to supporting structural steel members. Three weld types unique to sheet steel — arc spot, arc seam, and arc plug welds — are included. Includes sections on design, procedure and performance qualification, fabrication, inspection and stud welding as well as a commentary. 98 pages, 7 annexes, 44 figures, 11 tables, 3 forms (2008).  
D1.3 $120/$90

**NEW EDITION: D1.4/D1.4M:2011, Structural Welding Code—Reinforcing Steel**  
D1.4 $116/$87

**D1.5M/D1.5:2010, Bridge Welding Code**  
Get the facts and code requirements for bridge building with carbon and low-alloy construction steels. Chapters cover design of welded connections, workmanship, technique, procedure and performance qualification, inspection, and stud welding. Features the latest AASHTO revisions and nondestructive examination requirements, as well as a section providing a "Fracture Control Plan for Nonredundant Bridge Members." Revisions include:  
- Revised procedure, personnel, and test equipment inspection requirements  
- New materials and hybrid joint provisions  
- New guidance on electroslag and narrow-gap ESW  
- 72 illustrations, 9 tables, (Reaffirmed 2000).  
D1.5 $328/$246

**D1.6/D1.6M:2007, Structural Welding Code—Stainless Steel**  
Covers requirements for welding stainless steel structural steels. Chapters cover design of welded connections, workmanship, technique, procedure and performance qualification, inspection, and stud welding. Features the latest AASHTO revisions and nondestructive examination requirements, as well as a section providing a “Fracture Control Plan for Nonredundant Bridge Members.” Revisions include:  
- Revised procedure, personnel, and test equipment inspection requirements  
- New materials and hybrid joint provisions  
- New guidance on electroslag and narrow-gap ESW  
- 478 pages, 17 annexes, 90 figures, 43 tables, 9 forms, commentary (2010).  
D1.6 $328/$246

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**MONEY SAVING BUNDLES**

**Save 15% when you buy an AWS bundle.**

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assemblies/components (excluding pressure vessels or pressure piping) using metal arc welding, shielded metal arc welding, flux core arc welding, submerged arc welding, and stud welding. Allows prequalified Welding Procedure Specifications for the austenitic stainless steels based on considerable experience with the most widely used stainless steels. Sections include design, procedure and performance qualification, fabrication, inspection, and stud welding.


D1.6 $200/$150

D1.7 $108/$81

D1.8/D1.8M:2009, Structural Welding Code—Seismic Supplement

A supplement to D1.1, applicable to welded joints in seismic load resisting systems designed in accordance with the Seismic Provisions of AISC. Covers additional controls on detailing, materials, workmanship, testing, and inspection necessary to achieve adequate performance of welded steel structures under conditions of severe earthquake-induced inelastic straining. Commentary offers guidance on interpreting and applying this supplement. 124 pages, 9 annexes, commentary, 22 figures, 8 tables, (2009).

D1.8 $132/$99

**Own the Entire Library of AWS Welding Handbooks!**

These are the must-have references for engineers, structural designers, technologists, inspectors, welders, welding educators and others who need to understand this dynamic and evolving industry. Put all the facts at your fingertips and make sure you’re on the cutting edge with new and updated material. Here are five good reasons you should add these valuable editions to your library. The books represent:

• **The largest body of knowledge on welding available anywhere.**
• **Practical, hands-on information that you can put to immediate use.**
• **The most current information on best practices regarding safety, quality, and qualification issues.**
• **Unparalleled authority—chapters are written by leading scientists, engineers, educators, and other technical and scientific experts. Everything is peer-reviewed for accuracy and timeliness.**
• **The most valuable resource on welding on the market today, covering the entire spectrum of welding from science and technology, history, welding processes, and materials and applications.**

**Ninth Edition, Volume 1, Welding Science and Technology**

Presents the latest developments in the basic science and technology of welding, and general descriptions of processes, continues with chapters on the physics of welding and cutting; heat flow in welding; metallurgy; design; test methods; residual stress; welding symbols; tooling and positioning; monitoring and control; mecanization, automation, and robotic techniques; economics; weld quality; inspection; qualification and certification; welding codes and standards; and safe practices. 928 pages, 17 chapters, 2 appendices, 530 illustrations, 168 tables, hardbound. 8" x 10", (2001).

WHB-1.9 $192/$144


Presents comprehensive information on welding and related processes. Contains detailed information on arc welding power sources; shielded metal arc, gas tungsten arc, metal arc, flux core arc, submerged arc, and plasma arc welding processes. Includes chapters on electron beam, laser beam welding, oxy-fuel gas welding, brazing, soldering, oxygen cutting, and arc cutting and gouging. 736 pages, 15 chapters, 260 line drawings, 100 photographs, 148 tables, hardbound. 8" x 10", (2004).

WHB-2.9 $192/$144


Over 600 pages of comprehensive information on solid-state and other welding and cutting processes. The book includes chapters on resistance spot and seam welding, projection welding, flash and upset welding and high-frequency welding. In addition to a chapter on friction welding, a new chapter introduces friction stir welding. The most recent developments in beam technology are discussed in the greatly expanded chapters on laser beam welding and cutting and electron beam welding. A diverse array of processes are presented in chapters on the ultrasonic welding of metals, explosion welding, diffusion welding and diffusion brazing, adhesive bonding and thermal and cold spraying. The last chapter covers various other welding and cutting processes, including modernized water jet cutting. 669 pages, 15 chapters, 3 appendices, 438 illustrations, 59 tables, hardbound. 8" x 10", (2007).

WHB-3.9 $192/$144


Extensively revised and updated from the eighth edition, this comprehensive volume had more than 50 experts in materials and materials applications assure its accuracy and the currency of its content. It is a great reference source for engineers, educators, welding supervisors, and welders. Covers carbon and low-alloy steels; high-alloy steels; coated steels; tool and die steels; stainless and heat-resisting steels; clad and dissimilar metals; surfacing; cast iron; maintenance and repair welding; and underwater welding and cutting. Includes more than 500 tables, charts, and photos. 10 chapters, hardbound. 8" x 10", (2010).

WHB-4.9 $192/$144


Covers nonferrous metals, plastics, composites, and ceramics; specialized topics on maintenance and repair welding; underwater welding and cutting. Includes applications of the specific metals and processes, weldability, safety practices. Best copy available, 538 pages, 10 chapters, softbound. 8" x 10", (1996).

WHB-3.8 $160/$120

**GET FIVE VOLUMES OF THE CURRENT WELDING HANDBOOK SET AT SUBSTANTIAL SAVINGS**


WHB-ALL $762/$572

**GET THE TWO HANDBOOK VOLUMES ON PROCESSES AT SUBSTANTIAL SAVINGS**


WHB-PRC $288/$216

**DOWNLOAD SINGLE CHAPTERS**

Choose individual Welding Handbook chapters for PDF download, at an economical price.

SEE AWS PUBS.COM $20/$15

Lesser price shown is for AWS members. For a complete catalog, call 888-WELDING.
A2.4:2007, Standard Symbols for Welding, Brazing, and Nondestructive Examination
Establishes a method of specifying certain welding, brazing, and nondestructive examination information by means of symbols. Contains detailed information and examples for the construction and interpretation of these symbols. This system provides a means of specifying welding or brazing operations and nondestructive examination, as well as the examination method, frequency, and extent. 138 pages, (2007).

NEW EDITION: C7.2M:2010, Recommended Practices for Laser Beam Welding, Cutting, and Allied Processes
Covers common applications of the process, including drilling and transformation hardening. Describes equipment and procedures. Practical information, including figures and tables, should prove useful in determining capabilities in the processing of various materials. 144 pages, 85 figures, 8 tables, (2010).

Addresses which examination method—visual, liquid penetrant, magnetic particle, radiographic, ultrasonic, electromagnetic (eddy current), or leak testing—best detects various types of discontinuities. Note: Does not address acceptance criteria. 64 pages, 30 figures, 4 tables, (2009), fourth edition.

B1.11:2000, Guide for the Visual Examination of Welds
Provides guidance on visual examination of welds, including sections on prerequisites, fundamentals, surface conditions, and equipment. Sketches and color photographs illustrate common weld discontinuities. 48 pages, 3 annexes, 40 figures, (2000).

Covers all fusion welding processes and an exhaustive array of materials used in metal fabrication. Specifies requirements for the qualification of welding procedures, and for performance qualification of welders and welding operators for manual, semiautomatic, mechanized, and automatic welding, 298 pages, 43 figures, 25 tables, 5 forms (2009).

B4.0:2007, Standard Methods for Mechanical Testing of Welds
Describes the most common mechanical test methods applicable to welds and welded joints. Each test method gives details concerning specimen preparation, test parameters, testing procedures, and suggested report forms. Acceptance criteria are not included. Three new weldability tests (WIG, tough, and GROD) and resistance weld tests have been included in this new edition. (Note: Joint tests for brazements are covered in AWS C3.2M/C3.2 U.S. Customary Units, 152 pages, 97 figures, (2007).

$104/$78

B17.1:2001, Specification for Fusion Welding for Aerospace Applications
Specifies general welding requirements for welding aircraft and space hardware. Includes fusion welding of aluminum-based, nickel-based, iron-based, cobalt-based, magnesium-based, and titanium-based alloys and high energy beam welding processes. Includes sections on design of welded connections, personnel, and procedure qualification, fabrication, inspection, repair of existing structures and nonflight hardware acceptance. Additional requirements cover repair welding of existing hardware. 94 pages, 5 annexes, commentary, 47 figures, 14 tables, (2001).

$180/$120

B17.2:2008, Structural Welding Code—Aluminum

$200/$150

D1.2/D1.2M:2006, Sheet Metal Welding Code
Covers arc and braze welding requirements for nonstructural sheet metal fabrications using commonly welded metals available in sheet form up to and including 3 gauge, or 6.4 mm (0.250 in.). Applications of the code include heating, ventilating, and air conditioning systems, food processing equipment, architectural sheet metal, and other nonstructural sheet metal applications. Sections include procedure and performance qualification, workmanship, and inspection. Nonmandatory annexes provide useful information on materials and processes. Not applicable when negative or positive pressure exceeds 30 kPa (5 psi). 79 pages, 29 figures, 10 tables, (2006).

$72/$54

Specifies requirements for welding of all principal structural weldments and all primary welds used to manufacture cranes for industrial, mill, powerhouse, and nuclear facilities. Also applies to other overhead material-handling machinery and equipment that support and transport loads within the design rating, vertically or horizontally, during normal operations. Additionally, when agreed upon between the owner and manufacturer, it may apply to loading caused by abnormal operations or environmental events, such as seismic loading. All provisions apply equally to strengthening and repairing of existing overhead cranes and material handling equipment. Contains figures and tables with prequalified joint details, allowable stress ranges, stress categories, and nondestructive examination techniques. Does not apply to construction or crawler cranes or welding or repair of rails. 150 pages, 60 figures, 21 tables, (2005).

TWM $49.50

Preview and order any of these books and browse dozens of others at www.awspubs.com

Lesser price shown is for AWS members. For a complete catalog, call 888-WELDING.
Devasco designs, manufactures and tests cored wires and covered electrodes at its facility in Tomball, Texas. With research and development as a cornerstone, Devasco offers a variety of alloys within each metal group to satisfy your unique need. Devasco has over 830 different filler metals from hard surfacing to low alloy to stainless and continues to develop new products such as our HSLA electrodes that offer UTS levels from 120 ksi – 237 ksi. Devasco’s conscientious staff and incomparable quality program will assure your satisfaction with its products.
Q: Can you provide me a list of some textbooks that provide good information on aluminum and aluminum welding?

A: This question could easily promote a very subjective answer, but I will try to be as objective as possible. I have a number of books in my library that were recommended to me and some that I have recommended to others. I will list some of my favorites with a brief description of each and hope that this will help you decide which may be appropriate for your needs.

_Welding Aluminum: Theory and Practice (Fourth Edition)._ One of my favorites, this book from The Aluminum Association (www.aluminum.org) has to be one of the best overall practical guides to welding aluminum alloys that is still in print and up to date. It contains sections on basic aluminum welding metallurgy, the aluminum alloy temper designation system, metal preparation, weld design and performance, quality control, and information relative to all the common and most of the not-so-common welding processes used for aluminum. This publication has been around for many years, edited, revised, and expanded by Aluminum Association member companies represented on the Aluminum Association’s Technical Committee — Welding and Joining.

_The Welding of Aluminum and Its Alloys._ The book, by Gene Mathers, Woodhead Publishing Ltd., provides another very practical and thorough examination of aluminum welding. This publication is probably best described by the author in this extract from its preface: “When the difficulties of shop floor or site control are taken into account and the occasional vagaries of the welder and sometimes inadequate knowledge of the supervisory staff are added, the problems of the practicing shop floor engineer can appear overwhelming. I hope that some of this uncertainty can be dispelled in this book, which is aimed at those engineers with little or no knowledge of metallurgy and perhaps only the briefest acquaintance with the welding processes. It does not purport to be a metallurgical or process textbook and I make no apology for this. Having lectured fairly extensively on welding technology, I have come to realize that most engineers think of metals as being composed of a large number of small billiard balls held together by some form of glue. I have attempted to describe the metallurgical aspects of aluminum alloys in these terms. I have therefore kept the contents descriptive and qualitative and have avoided the use of mathematical expressions to describe the effect of welding. The book provides a basic understanding of the metallurgical principles involved in how alloys achieve their strength and how welding can affect these properties. I have included sections on metal storage and preparation prior to welding and have also described the more frequently encountered processes. There are recommendations on welding parameters that may be used as a starting point for the development of viable welding procedures. Also included are what I hope will be useful hints and tips to avoid some of the pitfalls of welding these sometimes problematic materials.”

.AWS Welding Handbook (Eighth Edition, Volume 3, Chapter 1). Another source of excellent information on aluminum welding can be found in a book that may be on your bookshelf. This chapter introduces this exciting new process, TIP TIG USA will be presenting a workshop at its facility in the Philadelphia Naval Yard on March 24, 2011. For info go to www.aws.org/ad-index

For detailed application information on the TIP TIG process, please visit www.tiptigusa.com
ter contains 117 pages of material devoted to aluminum welding, including as follows: arc, stud, electron beam, resistance, solid-state, and oxyfuel welding; brazing; soldering; adhesive bonding; joining aluminum to other metals; arc cutting; properties and performance of weldments; applications; and a supplementary reading list. Do not underestimate this collection of aluminum welding material as it is extensive and exceptionally well prepared.

**Aluminum and Aluminum Alloys.** The *ASM Specialty Handbook*, edited by J. R. Davis and prepared under the direction of the ASM International Handbook Committee, is a colossal 700+ pages of what you want to know about aluminum. It is not a “how to weld” book; in fact, welding comprises a fairly small but very comprehensive section of the publication. What this book does provide is a collection of information on aluminum that is extremely broad and very detailed. Its contents include alloy and temper designation systems, selection and applications of aluminum alloys, fabrication and finishing of aluminum alloys (forming, forging, extrusion, powder metallurgy processing, heat treating, machining, welding, brazing and soldering, adhesive bonding, cleaning, finishing, and coating). Also included is information on metallography, microstructures, and phase diagrams along with properties of aluminum alloys (corrosion behavior, tribological behavior, and properties of pure, wrought, and cast aluminum alloys). This is a terrific reference and source for research.

**Aluminum — Properties and Physical Metallurgy.** This ASM publication, edited by John E. Hatch, contains little information about welding; however, it provides an excellent insight into the metallurgy of aluminum alloys. It contains chapters on the properties of pure aluminum (both mechanical and physical), constitution of alloys (types of systems, microstructures, and phase diagrams), and microstructure of alloys (light, scanning electron, and transmission electron microscopy, plus quantitative metallography). Also covered is work hardening, recovery, recrystallization and grain growth, metallurgy of heat treatment, and general principles of precipitation hardening. Included is information on the effect of alloying elements and impurities on properties, corrosion behavior (general and crevice corrosion, stress-corrosion cracking, influence of microstructure on corrosion, and environmental factors), properties of commercial wrought and cast alloys, and aluminum powder and powder metallurgy products.

**Conclusion**

This is my cross section of favorite books on aluminum and aluminum welding. I have limited them to books that I believe are obtainable and not out of print. I appreciate that there are many others, some of which I have not had the pleasure of reading. There are others that are on my bookshelf and I often use like *Welding Aluminum* and *Welding Alcoa Aluminum*. Both are classics, but unfortunately, I believe them to be no longer in print. There are other specialty reference books like the *Aluminium Schlüssel — Key to Aluminium Alloys*, which is a listing of international aluminum alloys with cross references. This book can be extremely useful if you need to track down obscure aluminum alloys with designations other than American.

Other publications produced and supplied by The Aluminum Association include the following: *Aluminum Braze Handbook*, *Aluminum Design Manual*, *Aluminum Soldering Handbook*, *Aluminum Standards and Data*, *Aluminum Technology, Applications and Environment*, *Care of Aluminum*, *Designation for Aluminum Finishes*, *Forming and Machining of Aluminum*, *Guide for the Use of Aluminum with Food and Chemicals*, and *International Alloy Designations and Chemical Composition Limits*.

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**Acknowledgment**

The article “Control Costs by Avoiding Overwelding,” which was published in the December 2010 *Welding Journal*, neglected to acknowledge the contributions of Jack R. Barckhoff, Kenneth M. Kerluke, and Don L. Lynn. They are the authors of the *AWS Certified Supervisor Manual for Quality and Productivity Improvement* from which the article was excerpted. The manual has been copyrighted by the American Welding Society (AWS), and Barckhoff Welding Management holds and retains prior copyrights for much of its material.
Q: We brazed titanium Grade 5 tubing to a flange of the same alloy. The brazing filler metal was AWS BA1Si-4, and we also used the flux RL3 A16. Both braze foil and flux were placed inside the joint, and the parts to be brazed were heated with a propane torch as uniformly as possible. When setting up the process, we added a ring of aluminum filler made from ½-in. wire on top of the joint, because the filler inside the joint was apparently insufficient. Now the joint has a sound quality; however, a “halo” or nonuniform spreading of the braze alloy appeared around the joint area with a pattern that cannot be removed by polishing with sandpaper. The pattern looks like two concentric circles differently colored. The outline is almost black and has the irregular shape, while the inner circle has a typical “aluminum cast” color. Since we cannot remove the halo, we want to know: What is the nature of these two colored patterns?; and does this affect the strength of the titanium flange?

A: The spreading pattern you describe has appeared due to the effect called “reactive wetting.” It can be observed sometimes during brazing or soldering using such combinations of base and filler metals as nickel-plated copper printed circuit board (PCB) and tin-silver-copper solder, a superalloy and a braze of nickel-phosphorus, or nickel-chromium-phosphorus system, bronze and silver filler metals, titanium-aluminum-based brazing filler metals, and others — Fig. 1. In other words, if liquid filler metal or solder reacts with base metal with formation of reaction products (especially, intermetallic compounds), this “halo” pattern may appear. And it is understandable why you cannot remove it by polishing. Some reaction products (in your case, likely TiAl3 and TiAlSi intermetallic compounds) were formed at the interface between braze and base metal, and in order to remove them from the titanium surface, you have to remove the surface layer of titanium containing these intermetallics (supposedly, a layer several microns thick). Usually, manufacturers do not remove this layer because machining or abrasive treatment of brazed parts can damage the joint, and besides, the shape of parts is often not suitable for machining — for example, the PCBs mentioned previously.

Reactive wetting is a fairly sophisticated process that is accompanied by formation of different reaction products, mostly intermetallics, which have different reflective indexes (hence, different colors). These reaction products are formed during spreading of liquid braze or solder; therefore, we observe them as a number of concentric circles of a “halo” pattern of different colors — Fig. 1. A cross section of solidified braze filler or solder after reactive wetting is shown schematically in Fig. 2, where reactive product layers 2 and 3 are shaded in. Removal of peripheral circles would help only partially, because the same multilayer structure is formed at the interface, under the joint metal and fillet. If reactive wetting results in the formation of the halo pattern shown in Figs. 1 and 2, there is usually no reason to worry about the strength of the base metal. No evidence of decreasing the strength of the base metal has been found in practice. Moreover, I would consider the presence of such patterns after soldering as an indication of good wetting and the formation of quality joints, because wetting without the reaction of solder and substrate may lead to voids and other defects.

However, sometimes reactive wetting may accompany erosion of the base metal as shown in Fig. 3. This can happen when the substrate is overheated during brazing or soldering; and holding time is too long and the reaction of the solder with the base continues, resulting in local dissolution of the base metal.

At this stage of the process, motion of the spreading liquid is controlled by the solute concentration gradient of base metal in the liquid. In order to avoid erosion, one can cut the brazing/soldering time, but the best solution is to substitute the combination of base metal and solder for a low-reactive pair of materials. Application of “stop-off agents” is also used in the industry. Sprays of yttrium oxide or boron nitride fine powders are very effective as stop-off materials. These compounds are deposited, before brazing, on the surface around the joint and limit spreading of filler metal or solder.

Reactive wetting has been studied fairly well, especially during the last decade (Refs. 1–3). According to the model called “Reaction Product Control” (Ref. 2), both final contact angle and spreading kinetics are governed by interfacial reaction. Here, we can only abstract this sophisticated model, which is supported today by many experiments and discussed in detail. Soldier (or braze) spreading time in reactive systems is quite slow ($10^{-4}$ s) vs. nonreactive wetting times (less than $10^{-1}$ s), which means that spreading in reactive systems can be observed visually. As a consequence, slow spreading rate in reactive systems is not limited by viscous dissipation, but the rate of interfacial reaction at the front of spreading liquid metal. This rate is controlled by the slower of three successive phenomena participating in reactive wetting: a) diffusive transport, if reacting elements approach or recede from the spreading front; b) local reaction kinetics; and c) local dissolution of base metal in the liquid.

Generally, overall spreading kinetics involved with reactive wetting can be described as follows (Ref. 3): Global mass...
transport in liquid braze metal or solder is controlled by convective transport and the formation of intermetallics dominated at early and intermediate times. This results in the formation of horizontal layers along the solid-liquid interface. And diffusive mass transport dominates at the late stages of reactive spreading.

In your case of the Al-12Si and Ti reactive system, I can suggest the following kinetics of the process: When aluminum and silicon contents exceed the reactivity limit, thin continuous layers of TiAl₃, TiSi, or TiAlSi compounds are formed along the entire interface, enhancing the spreading of liquid brazing filler metal Al-12Si. The reaction changes the composition of the liquid filler metal as a function of spreading. When the aluminum and silicon contents in the liquid alloy become insufficient for formation of the previously mentioned intermetallics, no new TiAl₃, TiSi, or TiAlSi compounds are formed at the liquid/solid interface, and spreading stops.

References


Erratum

In the Oct. 2010 Brazing Q&A column, page 20, the volume ratio of oxide film to metal reads 1.214. It should read “1.214”.

This column is written alternately by TIM P. HIRTHE and ALEXANDER E. SHAPIRO. Both are members of the C3 Committee on Brazing and Soldering and several of its subcommittees, ASH Sub-committee on Filler Metals and Fluxes for Brazing, and the Brazing and Soldering Manufacturers Committee (BSMC). They are coauthors of the 5th edition of AWS Brazing Handbook.

Hirthe (timhirthe@aol.com) currently serves as a BSMC vice chair and owns his own consulting business.

Shapiro (ashapiro@titanium-brazing.com) is brazing products manager at Titanium Brazing, Inc., Columbus, Ohio.

Readers are requested to post their questions for use in this column on the Brazing Forum section of the BSMC Web site www.brazingandsoldering.com.

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New Steel Shows Promise for Navy Ships

HSLA-115, a higher-strength version of HSLA-100, has been shown to be suitable for critical naval ship structural applications and can be welded using existing consumables and procedures

BY PAUL J. KONKOL, KEVIN M. STEFANICK, AND GREGORY S. PIKE

Naval hull structures require high-strength alloy steels with excellent toughness and resistance to dynamic fracture. HY-80 and HY-100 steels were developed in the 1960s to meet these critical requirements in welded hulls. The HY series metallurgical system steels, however, compromise weldability. These steels contain a combination of carbon and medium alloy content for high strength, with tempering for toughness, but the minimum carbon content plus the alloying required for optimum strength and toughness adversely affect weldability. Hull construction with the HY steel systems is costly, since preheat and restrictive welding process conditions are required to prevent cracking in structural welds.

In the 1980s, the Navy worked with laboratories and steel producers to develop and certify HSLA-80, a low-carbon, Ni-Cr-Mo-Cu-Nb steel that obtains its strength through precipitation of nano-size e-Cu precipitates during age hardening (Ref. 1). The steel was an optimized version of a similar commercial grade made to ASTM A 710 (Ref. 2). Due to the need for improved performance for naval combatant applications, HSLA-80 has more stringent chemical composition, tensile, notch toughness, and quality assurance requirements than ASTM A 710 grade steels. HSLA-80 was certified for use on surface combatant ships in the 1980s (Ref. 3) and was produced to the material specification MIL-S-24645 (Ref. 4). The microstructure consists of low-carbon acicular or blocky ferrite with martensite-austenite (MA) constituents (Ref. 5), depending on the processing, plate thickness and heat treatment. HSLA-80 is more weldable than HY-80, with reduced preheat requirements using the same welding processes and consumables as HY-80.

About that same time, the increased need for topside weight reduction in surface ship designs led to the development and implementation of HSLA-100 as a cost-saving alternative to HY-100 steel (Ref. 6). HSLA-100 was developed by building on the metallurgy of the HSLA-80 system. The alloy design essentially consisted of increasing the Mn, Ni, Cu, and Mo content of HSLA-80 to raise the yield strength (YS) from 80 to 100 ksi minimum. Due to the increased hardenability, HSLA-100 consists primarily of tempered low-carbon bainite; because the carbon content remains low, the steel retains its good weldability. HSLA-100 was certified for use in surface combatant applications in 1989, and military specification MIL-S-24645A was issued in 1990 to include requirements for HSLA-100. MIL-S-24645A and other steels for critical naval applications are now governed by Appendix A of NAVSEA Technical Publication T9074-BD-GB-010/0300 (Ref. 7), referred to here as Tech Pub 300.

HSLA-115 Steel Development

The U.S. Navy identified a need for a new steel with YS higher than HSLA-100 with equivalent notch toughness in specific structural applications for weight reduction. Thus, the Navy Metalworking Center (NMC), operated by Concurrent Technologies Corp. for the Office of Naval Research Navy ManTech Program, led a project team to evaluate candidate compositions. The project team included Naval Sea Systems Command (NAVSEA), the Naval Surface Warfare Center - Carderock Division (NSWCD), Puget Sound Naval Shipyard and Intermediate Maintenance Facility (PSNSY), Navy Joining Center (NJIC), Northrop Grumman Shipbuilding - Newport News (NGSB-NN), ArcelorMittal Steel USA, and DDL Omni.

One option was to produce the rich chemistry thick-plate composition of HSLA-100 (Comp 3) in the underaged condition, which could result in YS up to 130 ksi or higher, with some acceptable reduction in notch toughness. (Comp 3 refers to Composition 3, an HSLA-100 grade richer in Ni, Mo, and Cu relative to Composition 2 (Comp 2).) ArcelorMittal USA indicated that HSLA-100 Comp 3
should be commercially producible to 115 ksi minimum YS in the thickness range of interest and the sizes needed. Under this NMC project, ArcelorMittal USA produced an initial HSLA-100 Comp 3 plate (Heat U7201) with special processing to achieve the higher YS while maintaining excellent notch toughness. The chemical compositions of this and other heats evaluated are shown in Table 1.

Explosion crack-starter and bulge testing of unwelded specially produced HSLA-100 Comp 3 steel plates of Heat U7201 with YS of 115—117.5 ksi provided very positive and encouraging results. Thus, the Navy directed the project team to produce and evaluate an optimized HSLA-100 Comp 3 steel for use at the higher strength level by extensive certification testing. This steel was designated HSLA-115 and had a specified YS range of 115—130 ksi vs. 100—120 ksi for HSLA-100. The composition is that of HSLA-100 Comp 3, but it is produced by special processing (continuous-cast slabs, low slab reheating temperature, double austenitizing, and aging at lower temperature) to achieve a 115—130 ksi YS with the ductility and notch toughness requirements specified for HSLA-100 Comp 5 (Ref. 7). ArcelorMittal USA produced a second heat of HSLA-115 (Heat D1267) for certification testing by the project team. The certification testing was successfully completed and approved by NAVSEA. A third heat (Heat D5889) was produced for the first-article vendor qualification. The chemical composition of these three heats is shown in Table 1. ArcelorMittal successfully met the requirements for the first-article qualification, and NAVSEA approved HSLA-115 for use in plate production in January 2009.

The Parameters of the Investigation

Fabrication of HSLA-100 is performed for the most part using welding consumables designed for welding HY-80 and HSLA-80; thus, a degree of strength undermatching exists in the weldments. For HSLA-115, the degree of strength undermatching could be even higher than in HSLA-100. This could affect such characteristics as hydrogen-assisted cracking (HAC) in the weld metal or heat-affected zone (HAZ), transverse weld tensile performance, static and dynamic fracture performance (such as explosion testing), and fatigue and stress corrosion cracking. For these reasons, NAVSEA determined that a material selection information (MSI) (Ref. 8) test plan be conducted to demonstrate the suitability of HSLA-115 for the intended structural applications. The MSI test plan included rigorous testing of the weld metal, HAZ, and weldments. Because HSLA-115 is not considered a new material, but rather a modification of HSLA-100, NAVSEA considered that in many cases only verification or confirmation testing was needed on HSLA-115 to demonstrate whether the new steel had performance equivalent to HSLA-100.

The project team prepared, and NAVSEA approved, a comprehensive list of task items in the MSI test plan, including the following:
- Weldment explosion testing both crack-starter and bulge
- Tensile properties of highly constrained undermatched weldments
- Weld and HAZ notch toughness and microhardness
- Verification of welding procedures and preheats approved for HSLA-100 applicable to HSLA-115

Additional task items such as weld mechanical properties and fracture toughness, HAZ stress corrosion, and weldment fatigue were also conducted; however, they are beyond the scope of this paper. NGSB-NN fabricated all weldments (except for HAZ toughness comparison) at their welding engineering laboratory. With the exception of welding procedures verification, testing was conducted by NSWCCD, NJC, and NMC.

Weldment Explosion Testing

The first step in the welding development effort was to determine whether HSLA-115 weldments would have sufficient dynamic fracture performance as measured by the explosion crack starter and bulge tests using the above welding processes and undermatched strength consumables. Otherwise, matching-strength consumables or restricted heat inputs would be necessary to attain higher weld metal strength. Near-matching-strength consumables, such as MIL-120S (Ref. 9), would adversely affect fabrication costs due to limited availability, the need for more extensive weld preheat and interpass temperature controls, the need for a postweld thermal soak, and limited range of allowable heat inputs.

The explosion test weldments were fabricated and tested in accordance with Appendix L (2149) of NAVSEA Tech Pub 300 (Ref. 7). A schematic of a typical crack
Fig. 1 — Schematic of explosion crack starter test specimen.

The starter specimen is shown in Fig. 1. In this test, brittle crack starter beads are deposited on the test weld and notched to induce cracking in the weld metal and weld HAZ. The specimen is then cooled to 0°F, placed over an open die and subjected to a series of explosive blasts. Each blast uses an appropriate charge weight and standoff distance to achieve approximately 3% thickness reduction per blast event. Bulge tests specimens are tested similarly, except that no crack starter welds are used.

In 2006, a series of explosion test weldments were fabricated at NGSB-NN in plates from HSLA-115 Heat U7201 (116 ksi nominal YS). Three sets of weldments, each containing two bulge and two crack starter weldments, consisted of the following:

- Submerged arc welding (SAW)/SAW (side 1/side 2) with MIL-100S electrode (Ref. 9), 55 kJ/in. heat input
- SAW/SAW with MIL-120S electrode, 55 kJ/in. heat input
- Flux cored arc welding (FCAW) overhead with MIL-101TM electrode, 55 kJ/in. heat input/SAW flat with MIL-100S electrode, 85 kJ/in. heat input.

The SAW at 55 kJ/in. maximum heat input was considered the lower limit that NGSB-NN would consider acceptable in terms of productivity. The SAW with MIL-120S was considered a fallback condition in the event that the MIL-100S and/or MIL-101TM weld metals resulted in excessive undermatching strength or otherwise failed the explosion test. The FCAW/SAW series was selected to replicate current shipyard practice for joining HSLA-100 plate. A weld prolong was cut from a weldment from each set and used by NMC for machining and testing of mechanical property specimens.

Puget Sound Naval Shipyard (PSNSY) conducted the explosion testing. Because the welds were undermatching in strength, NAVSEA established a minimum 10% thickness reduction for acceptance of the bulge tests vs. the 14% specified for HSLA-100 plate in Tech Pub 300 using matching strength weld metals. Both of the SAW/SAW sets passed explosion testing; however, one of the FCAW/SAW weldments failed.

The 2006 explosion test results showed that acceptable welding processes exist (SAW at 55 kJ/in. with either MIL-100S or MIL-120S) that could be used to certify the HSLA-115 weldment system. NAVSEA considered that if the SAW weldments passed explosion testing, verification of the shielded metal arc welding (SMAW) or gas metal arc welding (GMAW) processes would not be necessary. However, for optimum productivity, NGSB-NN would prefer to use SAW at higher heat input, and the FCAW still needed to be qualified for HSLA-115. Thus, in 2007, a second round of explosion tests was conducted on weldments made using the new HSLA-115 Heat D1267 (121 ksi nominal YS) with the following changes:

- FCAW/FCAW with MIL-101TM electrode, vertical position, 55 kJ/in. heat input to qualify the FCAW process separately.
- SAW/SAW with MIL-100S electrode, at 85 kJ/in. heat input to reflect optimum shipyard productivity.
- FCAW/SAW (FCAW overhead, MIL-101TM electrode/SAW flat, MIL-100S electrode, 85 kJ/in. heat input) was repeated.

### Tensile Behavior of Highly Constrained Undermatched Weldments

To ensure the suitability of welded HSLA-115 plate in service when joined using undermatched strength weld metals, highly constrained welded tensile specimens having a gauge width equal to five times the plate thickness (5T) were manufactured and tested at room temperature to determine whether the NAVSEA goal of a minimum of 10% elongation over a 10-in. gauge length would be met. This width-to-thickness ratio of 5:1 was chosen as a practical ratio that approximates an “infinite” plate and, thus, would represent the tensile behavior of undermatched welds in an actual structure.

A set of weldments was fabricated in 2008 in plates from HSLA-115 Heat D1267 (121 ksi nominal YS) using SAW at the higher 85 kJ/in. heat input to maximize the degree of weld YS undermatch.

These results were also compared with weldments fabricated in 2006 in plates from HSLA-115 Heat U7201 (116 ksi nominal YS) using the same parameters as for the 2006 explosion test series described above. Three 5T tensile specimens were made from each weldment. The direction of weld travel was perpendicular to the long axis of the specimen.

The specimens were machined using the full plate thickness, and the rolling direction of the base plate was perpendicular to the long axis of each specimen. One of the weld specimens had the weld reinforcement material machined away on both sides, while the other two specimens were left as-welded. No flattening operations were performed after welding. In order to compare the performance of weldments to the base material, three base material specimens (containing no weld) were also tested. The specimens were tested in tension using a large-capacity (1.2 x 10⁶ lb) machine.

### Weld and HAZ Charpy V-Notch Toughness and Microhardness

To further characterize the weldability of HSLA-115, the Charpy V-notch (CVN) impact toughness of the weld HAZ of HSLA-115 plate was measured and compared to the HAZ CVN toughness of the baseline HSLA-100 Comp 2 steel welded under similar conditions. Microhardness of the weld region was also characterized by conducting microhardness traverses % in. below the weld surface.

Weldments were fabricated by NMC in two materials: (a) HSLA-115 Heat D1267 (121 ksi YS) and (b) HSLA-100 Comp 2 Heat C6615 (113 ksi YS) plate. Weldments were made in both plates parallel to the plate rolling direction using the parameters in Table 2 and with a double bevel groove design to enable a nearly straight-sided HAZ.

Full-size CVN specimens were machined from the straight-side HAZ of each weldment and from the weld metal and base metal. The top surfaces of the CVNs were 10% below the plate surface. The CVN notch locations were at the weld centerline, 1 mm (0.04 in.) and 3 mm (0.12 in.) from the weld interface as measured from the longitudinal centerline of the CVN specimen and in the unaffected base metal at the same depth. The weld metal...
were made in the higher-carbon plate with minimal modification and those that with minimal modification. Thus, NGSB-NN proposed that many of its existing welding procedures currently approved for HSLA-100 could be used, with NAVSEA approval, for joining HSLA-115 with minimal modification. NGSB-NN and NAVSEA developed a weld crossqualification matrix that identified both the currently approved HSLA-100 welding procedures applicable to HSLA-115 with minimal modification and those that require additional preheat or higher minimum heat input for welding HSLA-115.

All welding was conducted by NGSB-NN. To provide worst-case conditions conducive to HAC, the fast-cooling rate welds were made in the higher-carbon plate (Heat D1267) re-heat treated to the upper YS range (128 ksi) and welded using strongbacks to provide very high restraint. These weldments were fabricated in an atmosphere-controlled room set at lower than 60°F ambient temperature and 80% or higher relative humidity to determine resistance to HAC in the weld metal or HAZ in adverse atmospheric conditions. After each pass, the weld was cooled to the interpass temperature, which was the same as the preheat temperature. These conditions are extremely conservative and rarely occur in the shipyard fabrication environment. These welding conditions were more conservative than those used to qualify the HSLA-100 welding procedures.

Most welds were made using 60°F preheat. However, due to evidence of HAC, certain welds were repeated using the 150°F/150°F or 275°F/300°F preheat/interpass temperature qualified for welding HY-100. All welds were examined nondestructively by visual (VT), magnetic particle (MT), and ultrasonic (UT) methods (Ref. 10). Additionally, the fast-cooling rate welds were examined by enhanced UT for evidence of transverse HAC.

Verification of attachment weld procedures was also conducted at NGSB-NN. The welds were made by fillet welding Grade DH-36 steel plates to HSLA-115 plates using consumables and procedures qualified for undermatched HSLA-100. After a 7- or 14-day delay, the welds were inspected by MT, the attachments were removed by cutting and grinding, and the HSLA-115 was inspected again by MT and enhanced UT. Again, most welds were made using a preheat/interpass temperature below 60°F, but some were made using the 150° or 200°F preheat/interpass temperature qualified for welding HY-100.

## Results and Discussion

### Weldment Explosion Testing

A typical test specimen after explosion testing is shown in Fig. 2. The acceptance criteria for explosion crack starter and bulge tests per Tech Pub 300 Appendix L follow.

**Crack starter test:** Two shots are required. For the first shot, no through-thickness cracks exist and no crack extends into the elastic (hold-down) region. For the second shot, no crack extends into the elastic hold-down region.

**Bulge test:** Multiple shots are conducted until the minimum specified thickness reduction is attained with no crack extending into the hold-down region. (For HSLA-115, the minimum thickness reduction of 10% specified by NAVSEA was used.) Through-thickness cracks are acceptable after the third shot.

The results of the 2006 explosion bulge and explosion crack starter tests are shown in Table 3. Note that the bulge tests met the more stringent 14% thickness reduction specified for HSLA-100 in addition to the 10% criterion imposed by NAVSEA for undermatched strength HSLA-115 weldments. The SAW weldments with MIL-100S electrode, deposited at 55
Undermatched Weldments

C.S. = crack starter test; Bulge = explosion bulge test

Table 3 — Results of 2006 Explosion Tests on HSLA-115 (Heat U7201) Undermatched Weldments

<table>
<thead>
<tr>
<th>Weld Combination</th>
<th>Weld Code</th>
<th>Test Type</th>
<th>Side A Thickness Reduction, %</th>
<th>Side B Thickness Reduction, %</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>SAW/SAW, 55 kJ/in., MIL-100S</td>
<td>308</td>
<td>C.S.</td>
<td>6.5</td>
<td>6.7</td>
<td>Pass</td>
</tr>
<tr>
<td>SAW/SAW, 55 kJ/in., MIL-100S</td>
<td>403</td>
<td>C.S.</td>
<td>3.9</td>
<td>6.5</td>
<td>Pass</td>
</tr>
<tr>
<td>SAW/SAW, 55 kJ/in., MIL-100S</td>
<td>309</td>
<td>Bulge</td>
<td>15.6</td>
<td>15.1</td>
<td>Pass</td>
</tr>
<tr>
<td>SAW/SAW, 55 kJ/in., MIL-100S</td>
<td>406</td>
<td>C.S.</td>
<td>2.2</td>
<td>2.2</td>
<td>Pass</td>
</tr>
<tr>
<td>SAW/SAW, 55 kJ/in., MIL-120S</td>
<td>508</td>
<td>C.S.</td>
<td>2.2</td>
<td>2.3</td>
<td>Pass</td>
</tr>
<tr>
<td>SAW/SAW, 55 kJ/in., MIL-120S</td>
<td>402</td>
<td>Bulge</td>
<td>14.6</td>
<td>15.4</td>
<td>Pass</td>
</tr>
<tr>
<td>SAW/SAW, 55 kJ/in., MIL-120S</td>
<td>405</td>
<td>Bulge</td>
<td>16.1</td>
<td>16.5</td>
<td>Pass</td>
</tr>
<tr>
<td>FCAW/SAW, 55 kJ/in.</td>
<td>407</td>
<td>Bulge</td>
<td>14.7</td>
<td>14.7</td>
<td>Pass</td>
</tr>
<tr>
<td>FCAW/SAW, 55 kJ/in., MIL-101TM/ MIL-100S</td>
<td>408</td>
<td>Bulge</td>
<td>15.4</td>
<td>16.2</td>
<td>Pass</td>
</tr>
</tbody>
</table>

Table 4 — Results of 2007 Explosion Tests on HSLA-115 (Heat D1267, 121 ksi YS) Undermatched Weldments

<table>
<thead>
<tr>
<th>Weld Combination</th>
<th>Weld Code</th>
<th>Test Type</th>
<th>Side A Thickness Reduction, %</th>
<th>Side B Thickness Reduction, %</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCAW/SAW, 55 kJ/in.</td>
<td>27-01</td>
<td>C.S.</td>
<td>7.64</td>
<td>6.64</td>
<td>Pass</td>
</tr>
<tr>
<td>FCAW, 55 kJ/in.</td>
<td>27-02a</td>
<td>Bulge</td>
<td>10.05</td>
<td>9.98</td>
<td>Pass</td>
</tr>
<tr>
<td>MIL-101TM</td>
<td>27-02b</td>
<td>Bulge</td>
<td>10.29</td>
<td>12.56</td>
<td>Pass</td>
</tr>
<tr>
<td>FCAW/SAW, 55 kJ/in.</td>
<td>27-06</td>
<td>C.S.</td>
<td>7.25</td>
<td>6.85</td>
<td>Pass</td>
</tr>
<tr>
<td>FCAW, 55 kJ/in.</td>
<td>27-07</td>
<td>C.S.</td>
<td>7.89</td>
<td>7.28</td>
<td>Pass</td>
</tr>
<tr>
<td>MIL-101TM/MIL-100S</td>
<td>27-05</td>
<td>Bulge</td>
<td>9.79</td>
<td>10.21</td>
<td>Pass</td>
</tr>
<tr>
<td>SAW/SAW, 85 kJ/in.</td>
<td>27-08</td>
<td>C.S.</td>
<td>6.59</td>
<td>8.10</td>
<td>Pass</td>
</tr>
<tr>
<td>SAW/SAW, 85 kJ/in.</td>
<td>27-09</td>
<td>C.S.</td>
<td>8.58</td>
<td>5.51</td>
<td>Pass</td>
</tr>
<tr>
<td>MIL-100S</td>
<td>27-10a</td>
<td>Bulge</td>
<td>9.95</td>
<td>9.30</td>
<td>Pass</td>
</tr>
<tr>
<td>MIL-100S</td>
<td>27-10b</td>
<td>Bulge</td>
<td>10.60</td>
<td>9.57</td>
<td>Pass</td>
</tr>
</tbody>
</table>

C.S. = crack starter test; Bulge = explosion bulge test

Fig. 3 — Typical fractured 5T weld specimen with weld reinforcement.

kJ/in., exhibited excellent bulge and crack starter performance. Only minor toe tears on the bulge tests and minor cracks on the crack-starter tests were observed. The SAW weldments fabricated with MIL-120S electrode deposited at 55 kJ/in. also exhibited excellent bulge and crack starter performance. Only minor toe tears on the bulge tests and minor cracks on the crack-starter tests were observed.

The FCAW/SAW weldments were tested with the FCAW side in tension. The bulge weldments passed. Crack-starter Weldment 401 passed, although it contained a through-thickness crack after the second shot. Weldment 409 failed on the first shot with a through-thickness crack that extended into the elastic hold-down region. The failure may have been associated with the unusually low CVN toughness observed in the FCAW side of the weld. The average CVN toughness measured in the FCAW side of the weld pro-longs was 37 ft-lb at 0°F and 16 ft-lb at -60°F. Additionally, the SAW side was deposited at 85 kJ/in. energy input, which is at the high end of the range used by NGSB-NN. In spite of this, the strength and CVN values for the SAW side were considered acceptable.

The 2007 explosion test results are summarized in Table 4. All weldments passed explosion testing. The improved performance of the FCAW/SAW weldments in the 2007 series also correlated with improved weld metal CVN values. Average CVN toughness measured in the FCAW side of the weld pro-longs was 66 ft-lb at 0°F and 36 ft-lb at -60°F. This second round of explosion testing gave confidence in recommending HSLA-115 steel for implementation for critical structural applications.

Highly Constrained Weldment (5T) Tensile Properties

Table 5 shows the results from the 2008 series wide-plate tensile testing. For comparison, the results from 5T testing on unwelded plate specimens and standard round ASTM E 8 tensile specimens from both plate and weld material are included. Table 6 shows the results from 5T tensile testing performed on HSLA-115 weldments from the 2006 test series. Note that the elongation for the 2006 5T specimens was measured over a 13-in. gauge length, while a 10-in. gauge length was used for the 2008 tests.

All of the 2008 test specimens achieved elongations in excess of the NAVSEA requirement of 10% in a 10-in. gauge length. In addition, the weld specimens tested with their weld reinforcements intact fractured away from the welds in the base plate area (Fig. 3) at strength levels slightly greater than the ultimate tensile strength of the base plate specimens. The weld specimen with the reinforcement machined away fractured in the weld metal (Fig. 4) and at strength level slightly greater than the ultimate tensile strength of the weld metal.
Similar results were obtained for the 2006 series of weldments that were made using FCAW and SAW at lower heat inputs. These results indicate that highly-constrained HSLA-115 weld joints can be made with undermatched-strength consumables with no significant reduction in the strength of the weldment.

HAZ CVN Weldment Testing

The mean CVN energy absorption of the SAW (85 kJ/in. energy input) weld metal, HAZ, and base metal of HSLA-115 and HSLA-100 Comp 2 at the specified temperatures is shown in Table 7. All HAZ and weld metal mean values met the specified minimum requirements for MIL-100s weld metal in Tech Pub 200 (Ref. 9). The base metal and HAZ values also met the specified minimum requirements for HSLA-100 plate.

The above weldments were also evaluated for microhardness. The hardness traverses, conducted % in. below the weld surface, are shown in Fig. 5 for HSLA-115 and Fig. 6 for HSLA-100 Comp 2.

The overall HAZ hardness of the HSLA-115 was consistently higher than for HSLA-100 Comp 2, with a maximum reading of 352 HV for HSLA-115 and 336 HV for HSLA-100 Comp 2. The higher HAZ hardness in HSLA-115 is to be expected due to the slightly higher carbon content of HSLA-115 Heat D1267 (0.06% C vs. 0.04-0.05% C for HSLA-100 Comp 2 Heat C6615) and higher hardenability (higher carbon equivalent due to increased Ni, Cu, and Mo contents). Because the specified chemical composition of HSLA-115 is the same as HSLA-100 Comp 3, the HAZ hardness should also be similar to that of Comp 3.

The main conclusions of this work are that in undermatched strength welds in HSLA-115, the weld metal is typically softer than the base metal, the highest hardness is found in the HAZ, and the maximum HAZ hardness of HSLA-115 is slightly greater than that of HSLA-100 Comp 2.

Verification of HSLA-100 Welding Procedures for HSLA-115

The minimum preheat and interpass temperatures and maximum heat inputs for welding HSLA-100 are specified in the applicable fabrication document. The requirements for a typical document are summarized in Table 8. However, NAVSEA may approve alternate welding procedures using higher heat inputs and lower preheat temperatures upon approval of the appropriate procedure qualification data. The alternate procedures are generally proprietary to each shipyard or fabricator and thus are not listed here.

NGSB-NN has a series of approved alternate welding procedures for HSLA-100 in which in certain cases the preheat temperatures can be reduced and the heat input can be raised. Thus, the verification test matrix was designed to determine
Table 7 — Mean CVN Toughness of MIL-100S SAW Weld Metal, HAZ, and Base Metal

<table>
<thead>
<tr>
<th>Test Temp, °F</th>
<th>Weld metal</th>
<th>1-mm HAZ</th>
<th>3-mm HAZ</th>
<th>Base metal</th>
<th>Tech Pub 200</th>
<th>Req’s: Weld Metal (Ref. 9)</th>
<th>Tech Pub 300</th>
<th>Req’s: Base Metal (Ref. 7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>70</td>
<td>98</td>
<td>149</td>
<td>137</td>
<td>60</td>
<td>60 (n/s)</td>
<td>80 (n/s)</td>
<td>80 (n/s)</td>
</tr>
<tr>
<td>-60</td>
<td>40</td>
<td>82</td>
<td>144</td>
<td>82</td>
<td>35</td>
<td>35 (n/s)</td>
<td>60</td>
<td>60 (n/s)</td>
</tr>
<tr>
<td>-120</td>
<td>1-mm HAZ</td>
<td>174</td>
<td>163</td>
<td>167</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>3-mm HAZ</td>
<td>105</td>
<td>162</td>
<td>102</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Base metal</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Impact Energy, ft-lb (Mean of 5 specimens)

n/s = not specified

Fig. 5 — Microhardness traverse of HSLA-115 SAW weldment.

Fig. 6 — Microhardness traverse of HSLA-100 Comp 2 SAW weldment.

Conclusions

1) HSLA-115 structural steel plate for critical naval applications has been developed and subject to a material selection information (MSI) process. The new steel has the same specified chemical composition and mechanical property requirements as HSLA-100 Comp 3 except that the yield strength range is 115–130 ksi instead of 100–120 ksi for HSLA-100. Additionally, it is produced by special processing consisting of continuous-cast slabs, low slab reheat temperature (resulting in a lower plate finishing temperature), double austenitizing, and water-quenching after tempering.

2) A domestic steel producer (Arcelor-Mittal USA) has produced plates from whether the alternate HSLA-100 procedures would be acceptable for HSLA-115.

A summary of acceptable welding procedures based on the present work and on existing approved HSLA-100 procedures is shown in Table 9. For most procedures, the preheat requirements approved for HSLA-100 (in most cases 60°F depending on welding process and plate thickness) can be used for HSLA-115, but for SMAW (butt joint and attachment welds), single-wire SAW butt joint welds, and FCAW attachment welds, a higher preheat (up to 150°F depending on plate thickness) approved for HY-100 must be used to prevent HAC. This may be due to the higher HSLA-115 base-metal strength relative to HSLA-100 that would impose higher residual stresses along the weld — a contributing factor for HAC. Transverse weld HAC was observed in several highly restrained HSLA-115 weldments in high humidity using a 60°F weld preheat/interpass temperature. HAC was confined primarily to the weld metal but was occasionally observed extending into the HAZ of HSLA-115, although the HAZ cracks were relatively minor (less than ½-in. long). Thus, the preheat limitations are mainly due to the HAC susceptibility of the welding consumables, which were originally designed for welding HY-80 steel.

The results of this work indicate that existing SMAW, GMAW, SAW, and FCAW consumables qualified for undermatched strength welds in HSLA-100 can be used to join HSLA-115 with minimal modification of welding procedures. The gas shielded welding processes, GMAW and GMAW-P, which are inherently low-hydrogen processes, can be used to weld HSLA-115 using the lower preheats approved for HSLA-100. The flux-containing welding processes, SMAW, SAW, and FCAW, may or may not require higher preheats depending on the heat input, thickness and weld joint type.
three heats of HSLA-115 that met the specified Navy requirements. ArcelorMittal USA has passed all first-article qualification testing and is certified to produce plates.

3) Explosion test weldments in HSLA-115 consisting of undermatched FCAW/FCAW using MIL-101TM electrode, undermatched SAW/SAW using MIL-100S electrode at 85 kJ/in. heat input, and undermatched combination FCAW/SAW weldments using MIL-101TM electrode overhead at 55 kJ/in. and MIL-100S electrode flat at 85 kJ/in. passed explosion crack starter and bulge testing.

4) Wide-plate transverse tensile specimens with a gauge region width-to-thickness ratio of 5:1 (or ST) in HSLA-115 undermatched weldments met the NAVSEA specified acceptance criterion of a minimum 10% elongation within a 10-in. gauge length.

5) Existing MIL-10718M SAW, MIL-1005 GMAW, MIL-1005 SAW, and MIL-101TM FCAW consumables previously qualified for undermatched strength welds in HSLA-100 can also be used to join HSLA-115.

6) In undermatched strength welds in HSLA-115 the weld metal was softer than the base metal. The highest hardness was found in the HAZ. The maximum HAZ hardness of HSLA-115 was slightly greater than that of HSLA-100 Comp 2.

7) The HAZ in HSLA-115 met the Tech Pub 200 requirements for Charpy V-notch toughness of the weld metal.

8) A matrix of recommended preheat/interpass temperatures to prevent HAC for a variety of welding processes and plate thicknesses was established. Most of the welding processes could be used with the 60°F preheat and interpass temperature currently approved for many HSLA-100 welding procedures, but other processes required procedures previously approved for HY-100.

9) HAC was observed in several highly restrained HSLA-115 weldments made under high humidity and low weld preheat/interpass temperatures. HAC was confined primarily to the weld metal and was governed by HAC crack sensitivity of the welding consumables.

Acknowledgments

This work was conducted by the Navy Metalworking Center, operated by Concurrent Technologies Corp. under Contract No. N00014-06-D-0048 to the Office of Naval Research as part of the U.S. Navy Manufacturing Technology Program. NMC is pleased to acknowledge the technical input provided by many contributing organizations, including the Naval Sea Systems Command, Naval Surface Warfare Center-Carderock Division, Navy Joining Center, ArcelorMittal USA, DDL Omni and Puget Sound Naval Shipyard.

References

Railcar wheels create stresses on the tracks that lead to degradation of the rail’s surface and the need for repairs. A semiautomatic welding process was developed to provide high-quality, lower-cost repairs to the running surfaces of railroad tracks.

The running of rolling stock wheels on rails creates high and complex stress patterns within the rail/wheel contact patch, leading to surface degradation. The wide range of track designs, wheel profiles, and types of traffic can result in a variety of surface defects that reduces the life of the rail. Defects such as squats (Fig. 1) and wheelburns occur even in the most modern and well-maintained railway networks and, as a broad general rule, every network develops one such defect each year, every two kilometers.

Replacement of such defects with a short rail section is expensive and not always desirable as it introduces two new discontinuities in the track in the form of two aluminothermic welds (exothermic reaction using aluminum as the reducing agent) that destroy the advantages obtained with long hot-rolled rail (up to 120 m). The alternative conventional technique for repairing such defects is the shielded metal arc welding (SMAW) process. Although many industries use SMAW, it is heavily reliant on the competence of the welder, time consuming, and prone to internal defects such as porosity that subsequently grow through fatigue, and if not detected by ultrasonic inspection, result in rail breaks.

Corus Rail France SA, which is part of the Tata Steel Group, recently developed a technique for the cost-effective repair of discrete defects on the tracks with a short rail section (up to 3 m). This process has been implemented on several European railways and has been used to successfully repair defects such as squats and wheelburns.

*Fig. 1 — A micrograph of a squat defect in rail. Squats are a type of local plastic deformation accumulated over many wheel passages. They start as small surface-breaking cracks. The impact force of squats is detrimental to both the tracks and the rolling stock.*

*Based on information provided by Corus Rail France SA (www.tatasteelrail.com), Saint Germain en Laye, France.*
running surface of rail. The key strength of this novel technique lies in replacing those aspects of the conventional SMAW process that often result in variability in the quality of the repair with automatic and more controlled operations. The developed semiautomatic process employs open arc welding with flux cored arc wire and relies on a low preheat temperature to control the metallurgical transformations within the heat-affected zone (HAZ). Given that the average cost to repair or replace a short segment of rail can run into several thousands of dollars and that the occurrence of wheel rail interface defects is likely to increase because of the expected increase in levels of traffic on most railways, the importance of the new process is easy to understand.

The process has been thoroughly tested, and a dedicated unit is currently being manufactured to undertake in-track demonstrations in several European networks including France and the United Kingdom.

The following factors contribute to the cost effectiveness and technical robustness of the newly developed process:

1. The move away from the conventional preheating temperature of 350°C to just 80°C has the advantage of faster repair, reduced depth of the HAZ, and a more robust microstructure.

2. The use of a standardized removal of the defect area through controlled milling has the advantage of reproducibility and removes the subjective judgment of the operator.

3. The use of a semiautomatic programed open arc welding process with flux cored arc wire ensures control of heat input and predictable operational times.

The quality of the weld-restored running surface from the developed process is ensured as the repair is extremely resistant to fatigue and has similar wear resistance to that of the standard Grade R260 rail with uniform hardness and microstructures across the weld-restored area.

The company’s new patented repair technique includes four steps.

Workers first remove the defect using a portable three-axis rail milling machine that clamps onto the sides of the rail — Fig. 2. The machine ensures consistent excavation of the identified defect — Fig. 3. This is a significant improvement over the use of manual grinding or flame scarfing, both of which do not give a consistent cavity shape or surface finish to facilitate automatic programmed welding.

Secondly, the adjacent area and the cavity are preheated with a conventional heat source. For Grade 260 rails, the prescribed temperature is between 60° and 80°C. The choice of this temperature is for the control of the microstructure in the HAZ, and the programmed square weave pattern of deposition of the subsequent/adjacent beads ensures that the microstructure in the HAZ is fine pearlite and free of any embrittling martensite. This preheat temperature is suitable for
the vast majority of high-carbon rail steels in use today, but it may need to be modified for steels that have different transformation characteristics such as low-carbon, carbide-free bainitic steels.

The third stage uses a semiautomatic weld repair machine, with an open arc welding process, a Network Rail (UK) approved TN3-0 welding consumable and prescribed welding parameters — Fig. 4. The positioning of the top layer is crucial to prevent the creation of a new HAZ. Most of the top weld layer is partially removed by profile grinding.

The fourth and last step consists of restoring and blending the transverse and longitudinal rail profile by grinding, using conventional rail grinders — Fig. 5.

A comparative evaluation of the existing SMAW technique and the new process was achieved by recording the thermal history of both processes using embedded thermocouples. Several key conclusions demonstrate the metallurgical robustness of the process:

• Despite the use of just 80°C preheat, the temperature in the HAZ after each deposited weld bead remains above 200°C, preventing any transformation to the martensitic microstructure. (The martensite start temperature is 160°C for Grade 260 rails.)

• The cooling rates in the developed process are almost identical to those in the conventional SMAW process for all deposition passes except the first. The faster rate of 5.2°C/s after the first weld bead is also half the critical rate for transformation to martensite.

• A crack-free weld deposit interface is apparent with a fully pearlitic microstructure, free from martensite and bainite.

• The hardness profile shows that the wear resistance of the bainitic weld deposit will be comparable to that of the Grade R260 base rail and ensure a good longitudinal profile.

The weld deposit was subjected to a bending fatigue test with an applied stress range equivalent to three times that expected in service. Five million cycles were successfully completed without any failure. The same deposit successfully endured a further 4.3 million cycles at an applied stress range equivalent to eight times that expected in service.
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BY JEFFREY NORUK

Your customer expects to receive a quality welded product on time. There are two ways for a supplier to achieve this — reactively or proactively. Reactively means not doing any preventative planning or analysis of what the true welding process capability is of each ship component welding system, be it man, machine, or robot.

The proactive approach means you design for manufacturing, employ capable processes, and work with intelligent systems that again can be man, machine, or robot based. An intelligent way to achieve a flexible adaptive welding system is to employ laser vision sensors for joint finding, joint tracking, and automated weld inspection. By doing this, you can avoid the biggest causes for poor welding productivity: excessive variability in the parts and fixturing. Laser vision gives an automated welding system “eyes” so if a joint is not within tolerance, the system can be programmed to not even start welding. Conversely, if the joint is within tolerance but still has too much variability for blind welding, laser vision sensing can compensate for this. Figure 1 shows some examples of successful robotic arc welding using intelligent laser vision sensing on ship subcomponents.

Per the American Welding Society, there is a hierarchy of welding automation starting with manual welding and moving up to “lights out” robotic work cells. Practically speaking, however, most welding automation falls into one of the categories shown in Fig. 2, which includes hard automation and flexible automation, and within these different approaches include articulated robots, portable robots, orbital welding machines, and seamers/manipulators. There is a place for all these approaches but they represent different levels of intelligence and capabilities.

Table 1 — Intelligent Processing and Proactive/Reactive Levels

<table>
<thead>
<tr>
<th>Levels of Intelligent Processing</th>
<th>Proactive/Reactive Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Manual welding</td>
<td>Could be both</td>
</tr>
<tr>
<td>Blind (no vision) machine or robot</td>
<td>Reactive</td>
</tr>
<tr>
<td>Automated prechecking of joint fitup</td>
<td>Proactive</td>
</tr>
<tr>
<td>Real-time joint tracking</td>
<td>Proactive. Adaptive correction</td>
</tr>
<tr>
<td>Real-time joint tracking w/adaptive control</td>
<td>Reactive but more accurate</td>
</tr>
<tr>
<td>Laser vision system inspection</td>
<td>Proactive. Continuous improvement</td>
</tr>
<tr>
<td>Weld inspection measurement system</td>
<td>Proactive. Prevent a bad weld</td>
</tr>
<tr>
<td>Closed-loop control of process</td>
<td>Proactive and reactive</td>
</tr>
<tr>
<td>Repair based on automated weld inspection</td>
<td></td>
</tr>
<tr>
<td>Feed-forward ID of parts not to weld</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 1 — Intelligent robot welding systems utilizing laser vision sensing.

JEFFREY NORUK (jnoruk@aol.com) is president, Servo Robot Corp., Milwaukee, Wis.
Automating Arc Welding Processes

Categories of Welding Automation Methods

Flexible Automation

Special Machines

Articulated Welding Robots

Portable Robots

Seamers Side Beam Welders Booms

Orbital Welding

Intelligent in-process control

Joint tracking

Joint building

Remote process control

How laser-vision ensures weld quality, minimizing waste and decreasing production costs

Figs. 2 — Levels of welding automation.

Fig. 3 — Intelligent in-process control.

Fig. 4 — WikiScan inspection system.

Fig. 5 — Overhead mounted robot system with laser vision tracking.

Many of the approaches listed in the table can utilize laser vision sensing to add both intelligence and the ability to proactively prevent weld problems. Figure 3 shows how this sensing can be used at different points in the welding sequence.

Let’s look at several specific applications for some of these systems starting with a manual portable weld inspection system called WikiScan.

Portable Weld Inspection System

Presently, there is a great deal of redundant and subjective inspection being done on all types of ship structures. It is not unusual to see 400% inspection, i.e., by the welder, a supervisor, a QC department inspector, and finally by the NAVSEA on-site inspector, of some welds. This results in wasted time and unnecessary repairs.

An improvement to this situation is now possible for many applications. It involves the solution shown in Fig. 4. The system consists of a portable hand-held laser vision inspection tool combined with a database management system. It provides objective weld feature measurements for consistent Go/No-Go decisions and SPC analysis tools for continuous improvement. It can also be used to achieve “precision welding” to reduce overwelding and the accompanying increased distortion and higher consumables costs.

Real-Time Joint Tracking and Adaptive Processing

Typical large welding manipulators consist of gantries or robots, welding equipment, and heavy-duty clamping devices. Maintaining the wire position correctly in the joint has been done historically by manual jogging of the wire or using a mechanical probe for joint following. More intelligent welding can be done using a laser vision joint tracker capable of the following: qualifying the weld joint is within tolerance, tracking the joint in real time, and adapting the weld process to optimize weld quality. Figures 5–7 show such systems in action, and Fig. 8 shows the type of adaptive processing that can be done on multipass welds.

Achieving precision welding results requires minimum overwelding at maximum travel speed. The traditional manual or mechanized methods will not work.

Laser Hybrid Welding Closed-Loop Control

The laser hybrid process, consisting of a high-power YAG laser and gas metal arc welding (GMAW) equipment, is beginning to make inroads into ship component manufacturing. One of its big advantages is more precise welding resulting in reduced distortion. To achieve optimum control and quality, one manufacturer has deployed a closed-loop control system that measures the weld shape just after the weld is solidified, then feeds this information back to give continuous corrections. The travel speed and the laser or GMAW parameters can be adjusted automatically as needed. Figure 9 presents an overview of this system.

Mobile Welding Robot

Traditional welding utilizes either
Fig. 6 — Standard stiffener welding system outfitted with laser vision sensors.

Fig. 7 — Real-time joint tracking system for automated panel splice welding.

Fig. 8 — Adaptive welding.

Fig. 9 — Real-time closed-loop controlled laser hybrid welding process.

Fig. 10 — A mobile welding robot (MWR).

manual, mechanized, or six-axis articulated robotic equipment. Figure 10 shows a mobile welding robot (MWR) system. The MWR provides a completely different approach that combines portability with the power of a full-size robot. This mobile welding robot can be brought to the component where the worker can weld in all positions even in tight areas not possible using large standard robots. The advantages of this portable robot, which can be used with or without intelligent laser vision for joint tracking and automated weld inspection, are as follows:

- The operator no longer needs to hold the torch nor be exposed to the fumes, which greatly improves on the ergonomics and minimizes the hazards associated with conventional methods.

- The portable robot can also be used for upstream operations like plasma cutting and gouging taking advantage of the programmability to more precisely and quickly prepare plates so the beveling is more exact, which will result in improved joint fitup.
Laser vision sensing can play an important role in all stages of the automated welding process.

- Allows the welder to be able to concentrate on the process and fine tune parameters as welding takes place.
- Provides first step up from manual or mechanized welding into full automation thus preparing people for future 6 axes robotic cells.
- Setup time for positioning the robot is small compared to traditional tractors that have to be located exactly along the joint because no intelligence is present.

Conclusion

Designing for manufacturing means taking into consideration the welding process to be used and its capability early in the planning stages of a project. In addition, design for automated processing and inspection should also be considered, which allows you to choose among the different intelligent automated welding and inspection systems discussed in this article. Laser vision sensing can play an important role in all stages of the automated welding process. This approach will give you a good chance of achieving a job done right the first time.
Welding repair on any metal requires finely tuned motor skills, good preparation, and a certain degree of application knowledge. However, requirements for welding stainless steel include additional knowledge and special preparation because of the complex metallurgical aspects related to alloying stainless.

Stainless steels contain a minimum of 10.5% chromium (Cr), which reacts with oxygen to form a passive oxide surface film that resists corrosive attack. The amount of chromium and the addition of other elements in each alloy adapt it to a wide variety of service conditions (Table 1). They also create different microcrystalline structures that impart different properties, such as those related to tempering, hardening, ductility, impact, creep, and brittleness.

Reviewing Five Classes of Stainless Steels

Stainless steels are frequently divided into the following classes:
- **Austenitic stainless steels** contain at least 16% chromium and 6% nickel. Grades include the most widely used grade, 304 (which is also called 18/8 because of its respective chromium and nickel content), and 316 (also known as marine or surgical grade stainless). Austenitic stainless steels exhibit excellent weldability, and 308L and 347 are often used for welding consumables (the L means low carbon). About 70% of all stainless applications use austenitic grades, including the kitchen sink and the dirty flatware in it.
- **Ferritic stainless steels** contain 10.5 to 18% chromium. They include 430 and 409, the latter of which is used for auto-

Welders can preserve the alloy’s properties as well as prevent common mistakes by following a good prerepair routine.
mobile exhausts. A 409 derivative, the proprietary Grade 3CR12, has improved weldability and lower cost. Applications for 3CR12 include mining, chemical and food processing equipment, appliances, and furnace and oven components.

• **Duplex stainless steels** are microstructures with a mix of austenite and ferrite that combine some of the properties of each class (such as relatively high strength and resistance to stress corrosion cracking) and have good weldability. Uses include petrochemical processing, pulp and paper manufacturing, and pollution control equipment.

• **Martensitic stainless steels** generally have a lower chromium and higher carbon content. Grades include those common for knives (440A, 440B, and 440C) because they offer increased hardness after heat treating. Other applications include fasteners, springs, and machine screws.

• **In precipitation-hardening martensitic stainless steels**, the most common grade is 630 or 17-4 PH (17% chromium and 4% nickel). These steels have good weldability and can be age hardened by a low temperature heat treatment that also avoids distortion. Applications include valves, valve stems, pump shafts, gears, balls, bushings, seats, fasteners, aircraft components, and processing equipment.

### Develop a Game Plan

The most important fact to remember when working with stainless steel is that the welding process can significantly alter the alloy's mechanical properties and cause a breakdown in the chromium oxide if precautions are not taken. Failure to treat stainless steel with the utmost respect can easily transform a profitable welding repair job to an expensive "you damaged it further, you just bought it" proposition. In extreme operating conditions, faulty weld repairs can have catastrophic consequences. As such, a good prerepair routine includes finding answers to the following questions:

1. Which specific stainless steel alloy is being repaired?
2. What are the specific service requirements of the weldment?
3. What welding codes apply?
4. Which welding procedures are acceptable?

Until definitive answers to these questions are obtained, do not attempt a weld repair. Good places to start looking for answers are welders, engineers, and experts within a processing plant, the base and filler metal providers, and specifying bodies such as AWS D1.6, *Structural Welding Code — Stainless Steel*, ASME Section IX — *Welding and Brazing Qualifications* (power piping and boiler codes), and API Standard 1104, *Welding of Pipelines and Related Facilities*, which also covers piping.

### Why GTAW?

The remainder of this article focuses on using the gas tungsten arc welding (GTAW) process for field repair, as well as provides some additional guidelines. Gas tungsten arc welding is the preferred process for a variety of reasons. First, the operator's control over heat input helps manage its effects on the alloy's metallurgical properties, as well as controls distortion (more on distortion control later). Second, the operator's control over the weld pool, weld bead placement, and weld bead size helps ensure 100% fusion and a weld free from voids, inclusions, or other defects. Control leads to better quality assurance in critical applications, such as high-pressure steam piping, as well as in sanitary applications such as food processing, where any void could promote bacteria growth. Even if gas metal arc welding is an acceptable procedure, the process is still prone to more flaws than a well-executed GTA weld.

Third is practicality, which encompasses several factors. Gas tungsten arc welding inverters provide the lightweight portability and primary power flexibility to locate the power source next to the work site. The GTAW process also provides the ability to weld in any position, enabling repair on components that would be impossible, inconvenient, or costly to move. A young mechanical contractor can
Table 1 — Select stainless steels types and their alloying elements using three-digit AISI number system.

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
<th>% Cr</th>
<th>% Ni</th>
<th>% C</th>
<th>% Mn</th>
<th>% Si</th>
<th>% P</th>
<th>% S</th>
<th>% N</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>304</td>
<td>Austenitic; includes classic “18/8” stainless</td>
<td>18-20</td>
<td>8-10.5</td>
<td>0.08</td>
<td>2</td>
<td>0.75</td>
<td>0.45</td>
<td>0.03</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>304L</td>
<td>Less carbon to improve weldability</td>
<td>18-20</td>
<td>8-12</td>
<td>0.03</td>
<td>2</td>
<td>0.75</td>
<td>0.45</td>
<td>0.03</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>308</td>
<td>Filler metal for 304</td>
<td>19-21</td>
<td>10-12</td>
<td>0.08</td>
<td>2</td>
<td>1</td>
<td>0.045</td>
<td>0.03</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>316</td>
<td>Second most common after 304; “surgical” or “marine” grade</td>
<td>16-18</td>
<td>10-14</td>
<td>0.08</td>
<td>2</td>
<td>0.75</td>
<td>0.045</td>
<td>0.03</td>
<td>0.1</td>
<td>2.0-3.0 Mo&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>316L</td>
<td>Low carbon; used for pressure vessels</td>
<td>16-18</td>
<td>10-14</td>
<td>0.03</td>
<td>2</td>
<td>0.75</td>
<td>0.045</td>
<td>0.03</td>
<td>0.1</td>
<td>2.0-3.0 Mo&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>347</td>
<td>Austenitic; common filler metal</td>
<td>17-19</td>
<td>9-13</td>
<td>0.08</td>
<td>2</td>
<td>0.75</td>
<td>0.045</td>
<td>0.03</td>
<td>-</td>
<td>Nb + Ta, 10 x C min, 1 max</td>
</tr>
<tr>
<td>416</td>
<td>Martensitic; wear-resistant, less corrosion resistance</td>
<td>12-14</td>
<td>-</td>
<td>0.15</td>
<td>1.25</td>
<td>1</td>
<td>0.06</td>
<td>0.15 min</td>
<td>-</td>
<td>0.060 Mo (optional)</td>
</tr>
<tr>
<td>440C</td>
<td>High-carbon cutlery steel retains edge</td>
<td>16-18</td>
<td>-</td>
<td>0.95-1.20</td>
<td>1</td>
<td>1</td>
<td>0.04</td>
<td>0.03</td>
<td>-</td>
<td>0.75 Mo</td>
</tr>
<tr>
<td>2205</td>
<td>Duplex Blends corrosion resistance and toughness, high strength</td>
<td>22</td>
<td>5</td>
<td>0.03</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>0.15</td>
<td>3 Mo</td>
</tr>
<tr>
<td>630</td>
<td>Most common precipitation-hardening grade.</td>
<td>15-17</td>
<td>3-5</td>
<td>0.07</td>
<td>1</td>
<td>1</td>
<td>0.04</td>
<td>0.03</td>
<td>-</td>
<td>Cu 3-5 Ta 0.015-0.45</td>
</tr>
</tbody>
</table>

1 — Molybdenum increases resistance to chloride corrosion compared to 304.

get started in the repair business with relatively little GTAW equipment, yet tackle a wide variety of repair tasks.

When it comes to torch options, GTAW torches enable access to tight spaces and awkward positions. Configurations include those with short back caps and short cups — Fig. 1. In addition, Weldcraft’s MicroTig™ torches feature light, short bodies allowing pen-like control. Their low-profile heads and head-angle options (such as 45, 60, 80, 90, and 180 deg) permit access into holes as small as ¼ in. diameter — Fig. 2. A clear gas cup further improves visibility — Fig. 3. Flexible necks that bend in all directions also ease operator strain when welding on difficult-to-access joints.

For welding included angles or for access to deep joints such as K or Y angles, using a GTAW torch with a gas lens and large cup permits extending the tungsten past the nozzle by up to 1 in. without sacrificing shielding gas coverage (see lead photo). Tungsten extension helps minimize weld pool and tungsten contamination that may result from long arcs, and it improves visibility of the arc and weld pool.

A gas lens is also helpful when welding alloys that are highly reactive to atmospheric contaminants or used in high-temperature applications, as poor gas coverage on these alloys can lead to porosity or welding challenges. The gas coverage provided by gas lenses also helps prevent atmospheric contamination and minimizes weld discontinuities. In fact, the author recommends using a gas lens for most GTAW applications because it reduces shielding gas turbulence and provides longer, undisturbed laminar flow of the shielding gas to the weld pool, which in turn promotes more consistent welding performance — Fig. 4. It is important to always have enough postflow shielding gas coverage; a rule of thumb to follow is 1 s per every 10 A of welding current.

**Stainless Challenges**

Compared to carbon steels, stainless steel alloys have poor thermal conductivity and high thermal expansion rates, both of which lead to welding challenges.

Poor thermal conductivity means that the heat of the welding arc dissipates very slowly. Excessive heat can permanently ruin stainless steel. Color is one indicator of excessive heat. Generally speaking, any grayish color means that the weld should be automatically rejected — Fig. 5. Good colors in stainless steel range from a straw or wheat shade to light blue — Fig. 6.

However, color is not always indicative of a good weld. If stainless steel reaches a temperature of 800°F to 1600°F and this temperature is maintained, the carbon in the steel may precipitate out and react with chromium to form chromium carbide at the grain boundaries, which in turn reduces the amount of chromium available to form the protective layer of chromium oxide.
Fig. 1 — The author’s torch kit features cups and back caps to meet a variety of applications, including the short cup and back cap shown in the foreground.

Fig. 2 — MicroTig™ torches allow GTAW repairs in difficult-to-access situations. A 1-in.-diameter stainless steel pipe is shown for size reference.

Fig. 3 — Clear gas cup options, in this case for a MicroTig™ torch, improve joint and weld pool visibility.

Fig. 4 — The colors and sheen of this tack weld, made with the tungsten extended more than ½ in., shows the results of good gas coverage.

Fig. 5 — The gray color to this weld is a clear indicator of excessive heat.

Fig. 6 — The straw and blue color on this stainless steel weld indicate acceptable heat input.

Corrosion may occur as a result. Keeping welds as small as structurally possible and shorter in length will help reduce heat input and the length of time at elevated temperatures. Increased travel speed will also have a positive effect.

To prevent corrosion in 300 Series stainless steels, some procedures call for choosing filler metals designed to prevent carbide precipitation, such as 347 (Cb added) or 321 (Ti added). Consult appropriate codes, welding procedures, and filler metal providers to find the most appropriate solution for a specific application.

**Preventing Warping**

Stainless steel is also known for its extreme tendency to warp, a result of its poor thermal conductivity (which causes uneven heating and cooling throughout the workpiece) and its high thermal expansion rate — Fig. 7. Conventional solutions to prevent warping include fixturing to hold components in place, using many more tack welds than would be used for a carbon steel application and distrib-
Fig. 7 — Heat input from this approximately 1-in. weld bead (which was made using the correct welding parameters) caused the warping shown here. Additional tack welding was required.

Fig. 8 — This simulated 3 x 5 in. patch repair, which might occur in a restaurant or food processing plant, demonstrates the number of tacks required prior to welding.

Fig. 9 — To prevent warping during the tack welding process, the author uses the edge of the gas cup to push down on the top plate.

Fig. 10 — The swoosh shape of this tack weld indicates the top-to-bottom movement used to carry molten metal from the top to bottom sheet.

Pulsing controls are relatively easy to set. While some settings may be ineffective, pulsing generally will not create new problems. Good starting points for most stainless and ferrous applications are listed below.

• Primary amperage: set as for conventional GTAW. (May need to be increased for some applications.)
• Frequency: 100 to 150 pulses per s.
• Peak time: 40 to 50% (and not higher than 60%).
• Background amperage: 20 to 25% of peak amperage.

The two variables that have the biggest effect on outcomes are peak and background amperages along with pulse frequency. Increasing frequency narrows and concentrates the arc cone, which in turn increases penetration and narrows bead width without increasing total heat input.

Conclusion

Food, agricultural, pharmaceutical, petroleum, chemical, power generation, marine, cutlery, mold making, furniture, architectural, mining, and other industries all have specific service conditions requirements for stainless steel. These include not just corrosion resistance, but corrosion resistance and improved strength at high and low temperatures, wear resistance, and other enhanced mechanical properties.

Much like the first rule of the physician’s code says, “First, do no harm,” the first rule of making a GTAW repair on stainless is to not make a bad situation worse. Sticking to the game plan and tactics outlined here can help those new to working with stainless steel gain experience, preserve the alloy’s special properties, and prevent many of the common mistakes that make stainless steel a challenge to weld.
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Remote Voltage Control Improves Shipyard’s Productivity

The iconic shipyard image is that of a massive, newly christened ship sliding down a steep bank into the water. By the time we see that image, the vessel is typically complete and the yard looks immaculate — no clutter and no equipment out of place. The daily reality of life in the shipyard, however, is much different. Ships in construction are multilevel mazes of planks and wooden ladders; steel skeletons of stiffeners and frames that must be navigated just to get to work; cords and cables that snake through every porthole and walkway.

It presents a welding environment
that’s unlike any other. Shipyard welders encounter almost every position and type of joint known. This requires the ability to adjust weld parameters on the fly. Unfortunately, this capability also requires the welder to walk all the way back to the power source — often hundreds of feet away — or use a remote control wire feeder that needs an extra control cable to run all the way back to the power source. These cables are expensive and prone to damage — a costly addition when you take into account the hundreds of welding arcs typically found in a shipyard.

Like many shipyards, Gunderson Marine, Portland, Ore. (Fig. 1), wrestled with the durability of cables and connections, the counterproductive time spent managing miles of cables spread throughout the yard, and process annoyances such as voltage readings at the feeder that didn’t account for the voltage drop across long stretches of cable. Gunderson addressed these problems by adding the new XMT Weld Cable Control (WCC) system from Miller Electric Mfg. Co. This technology transmits data across the weld cable, including voltage controls, and eliminates costly cords and the inefficiencies previously related to changing weld parameters — Fig. 2.

A Long Tradition

Gunderson Marine got its start in 1919 as Wire Wheel Sales and Service, a specialty fabricator that first worked on steel and wooden wheels before evolving to shipbuilding. The company’s skill and reputation grew through the years, and Gunderson has now launched more than 2000 marine vessels at its deep-water site in Portland. The bulk of its work is on ocean-going barges, including conventional deck barges, double-hull tank barges, railcar/deck barges, dump barges, and barges for aggregates and other heavy industrial products — Fig. 3. It also has a portion of its yard devoted to railcar fabrication.

The barges the company constructs typically range from 250 to 450 ft in length and are anywhere from 50 to 105 ft wide, although the company has built barges as long as 650 ft. The vessels are constructed of American Bureau of Shipping (ABS) steel grades (carbon steel) A through E, and 99% of the welding work performed on a ship’s hull and structure is flux cored arc welding.

“We build between six and eight vessels a year, depending on the size and complexity,” explained Walt Stokman, production coordinator, Gunderson Marine.

“The barges that we build are constructed out of various thicknesses. Most of our materials are between % and 1 in. thick. We do, however, work with some material that is as thin as % and % in., and as thick at 10 in. on some of our vessels.”

All of the vessels are inspected to ABS and Coast Guard standards. The ABS specifies that all welds in butt joints be welded to X-ray quality, and that all cross seams be tested by ultrasound near the joining of individual modules. The local ABS inspector also randomly selects certain joints for X-ray testing. Given the demanding specifications, cramped quarters of a ship’s hull, and the widely varied amount of joints and positions, Gunderson puts its welders through its own certification process.

“This is not booth welding, this is real-
Fig. 2 — The XMT Weld Cable Control system at work in a shipyard. Voltage settings are controlled at the feeder (pictured) by sending the commands directly through the weld cable.

Shipyard Welding

The shipyard relies on multiprocess welding inverter power sources because they are compact and require a relatively low power draw. A 450-A unit at 100% duty cycle is fairly typical in this application, and it gives them the capability to go up to 600 A, weld heavier material, and carbon arc gouge with up to a 1/4-in. carbon. The compact size allows the machines to be packed together on racks and plugged into a single outlet. Dozens of these racks, containing anywhere from four to eight power sources, are positioned in strategic locations throughout the shipyard. Each power source is matched with a suitcase-style wire feeder typically capable of holding a 12-in. spool of wire.

“Our employees like suitcase-style feeders because it is easy to move the feeder from location to location within the barge,” Stokman said. “The wire is also covered, so we don’t have to worry about elements such as dirt and moisture getting on the wire. Having the wire covered also ensures there are no arcing problems, such as when an exposed spool of wire arcs out on the framing inside of the barge and you have a bird’s nest.”

It is the connection between the power source and the wire feeder that has presented the greatest inefficiency in the past. In addition to the regular welding cable that stretches out to the point of use, an additional control cable that connected the wire feeder to the power source was required to manually adjust voltage levels at the feeder. Gunderson tries to keep the distance between its power sources and feeders no longer than 75 ft, but it’s not uncommon to see distances anywhere from 100 to 300 ft in other shipyards. The cost and handling of these cords is substantial. The control cable also provided one more piece of clutter to trip over or get tangled around equipment.

“We were looking for a way to make our welders more efficient,” Stokman said. “In order to change voltage, our welders have to walk all the way back to the power source or use a remote feeder connected back to the power source by a weld cable and the separate control cable.

“We were looking for a way to make our welders more efficient,” Stokman said. “In order to change voltage, our
welders currently have to leave the area, they have to get out of their gear, then move from the location they are working at inside the vessel to the outside of the vessel. In the time it takes to adjust their machine and work their way back, they may run into a coworker and talk for a few minutes. It’s approximately five to ten minutes anytime an employee goes to adjust the machine. With the welders being able to stay in their work location and change voltage right there, we can anticipate that they’ll be able to weld at least an additional half hour per shift each day.

“Our welders are now able to start at point A, work toward point B, and adjust their settings for the different applications as they move from point to point. Previously, the welders would pick all of the horizontal welds and weld out two or three sections of those, then take off their gear and leave the vessel to change their settings, then come back and take care of all the verticals. This made it easy for welders to skip areas because they were constantly jumping around. A welder is now able to weld everything as he goes.”

How It Works

The WCC technology is available two ways: either built into the power source (Miller’s Dimension™ NT power source) or as a separate control box that connects to the power source (as with the XMT inverters) — Fig. 4. The system uses advanced digital serial communication technology to send voltage commands from the wire feeder to the control over the welding cable — the same cable that carries the welding current from the power source to the feeder. This is critical as it gives welders remote control of both wire speed and voltage, which together are adjusted to compensate for changes in material and joint thickness.

Although the ability to transfer this type of command directly from a wire feeder to a power source over a weld cable was previously available, it relied upon pulse width modulation. This limited the amount and variability of data that could be transmitted, hence the need for a separate control cable. The new technology relies on phase shift keyed modulation, which substantially increases the amount of data transferrable across the weld cable. The information communicated to the power source may include welding power source output command information (amperage/voltage), welding circuit on/off information (power source output contactor control), and power source state control (constant voltage/constant current).

While a seemingly simple concept, this improvement is valuable for three reasons: improved productivity, improved safety, and reduced costs. Welders will spend more time with the arc on instead of walking back and forth to the power source.

Added Safety and Quality

Keeping the operator in the work area minimizes exposure to the elements and hazards (climbing ladders, tripping) of the job site, and eliminating the control cable reduces a major source of cost and downtime due to repair.

“An additional benefit that we anticipate from this technology is safety,” Stokman said. “With welders being able to stay at their station, they no longer have to traverse across frames, across stiffeners, through holes, through scaffolding, up ladders. Workers are able to minimize their traveling within the vessel.”

There is also a quality control benefit to the technology: the ability to read actual voltage levels on the feeder’s digital meter when welding great distances from the power source.

Simply put, the voltage at the output terminals of the power source (where the
weld cable is connected to the power source) may be significantly more than the voltage across the weld cable at the wire feeder. Accordingly, this technology enables an operator to modify the command signal that is sent back to the welding power supply via the weld cable, so that the losses experienced across the weld cables are properly compensated. The end result is that the voltage at the weld stays at the level the user desires. The level is displayed on the digital meter, so the operator always knows the accurate voltage level.

“It allows the supervisor to check the welding parameters right at the location,” he said. “The supervisor can see the position that the employee is welding in and that the parameters are set at the optimum settings that we have developed.”

The new feeders also feature a built-in meter that tracks arc on-time, which allows supervisors to monitor the productivity of their welders throughout the day. While a seemingly simple addition, having these data helps the company understand its workload and properly bill/estimate its work.

Overall, Stokman sees the new technology fitting in with Gunderson Marine’s mission — providing the highest quality ship fabrication and doing it in a manner that keeps the company’s welders safer.

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JOM-16. Intl Conf. on the Joining of Materials and ICEW-7, Int'l Conf. on Education in Welding. May 10–13. Sankt Helene Centre, Tisvildeleje, Denmark. Contact JOM Institute, Gilleleje, Denmark. Phone +45 48 35 54 58; jom_aws@post10.tele.dk.

AWS WELDMEX. May 11–13, Cintermex, Monterrey, Mexico. Colocated with FABTECH Mexico and MetalForm Mexico. See the latest welding and cutting products, thermal spray, metal finishing and safety equipment, metalforming products, tool and die, metal stamping, forming and assembly, and a variety of bending and fabrication products, including laser and plasma cutting, coil processing, roll forming, plate and structural fabricating, saws and cut-off machines, tooling, press brakes, shears, punching, and tube and pipe equipment. Visit www.awsweldmex.com.


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♦ FABTECH. Nov. 13–16. McCormick Place, Chicago, Ill. This exhibition is the largest event in North America dedicated to showcasing the full spectrum of metal forming, fabricating, tube and pipe, welding equipment, and myriad manufacturing technologies. Contact American Welding Society, (800/305) 443-9353, ext. 264; or visit www.fabtechexpo.com or www.aws.org.


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

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Educational Opportunities


Certified Welding Supervisor Preparation with Exam. Two-week-long classes beginning March 21, Sept. 1. Hobart Institute of Welding Technology, Troy, Ohio. Call (800) 332-9448; visit www.welding.org; e-mail hiwt@welding.org.


Art Using Welding Technology Classes and Workshops. Miami, Fla. With artist and sculptor Sandra Garcia-Pardo. Meet the artist at www.sandragarciaart.com; or call (786) 547-8681.

ASM Intl Courses. Numerous classes on welding, corrosion, failure analysis, metallography, heat treating, etc., presented in Materials Park, Ohio, online, webinars, on-site, videos, and DVDs. Visit www.asminternational.org, search for “courses.”


Basics of Nonferrous Surface Preparation. Online course, six hours includes exam. Offered on the 15th of every month during 2011 by The Society for Protective Coatings. Register online at www.spc.org/training.

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

CWI/CWE Course and Exam. Troy, Ohio. This is a two-week preparation and exam program. For schedule, call Hobart Institute of Welding Technology (800) 332-9448, or 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. Call Welder Training & Testing Institute (800) 223-9884, info@wtti.edu; or visit www.wtti.edu.

CWI Preparatory and Visual Weld Inspection Courses. Classes presented in Pascagoula, Miss., Houston, Tex., and Houma and Sulphur, La. Call Real Educational Services, Inc. (800) 489-2890, info@realeducational.com.
Consumables: Care and Optimization. Free online e-courses presenting the basics of plasma consumables, designed for plasma operators, distributor sales and service personnel, etc. Visit www.hyperthermcuttinginstitute.com.

Crane and Hoist Training. Safety courses and operator training for users of overhead cranes and hoists. For schedules, contact Konecranes Training Institute, Springfield, Ohio; call (262) 821-4001; or visit www.konecranesamericas.com.


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

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


For info go to www.aws.org/ad-index
CWS exams are also given at all CWI exam sites.

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<tr>
<th>LOCATION</th>
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<td>Spokane, WA</td>
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9-Year Recertification Seminar for CWI/SCWI
For current CWIs and SCWs needing to meet education requirements without taking the exam. The exam can be taken at any site listed under Certified Welding Inspector.

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<td>Miami, FL</td>
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Certified Radiographic Interpreter (CRI)

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

Certified Welding Sales Representative (CWSR)

<table>
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<tr>
<td>Miami, FL</td>
<td>Aug. 24–26</td>
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CWSR exams will also be given at CWI exam sites.

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.

Certified Robotic Arc Welding (CRAW)

<table>
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<tr>
<th>WEEK OF</th>
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<th>CONTACT</th>
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<tr>
<td>Feb. 7</td>
<td>ABB, Inc., Auburn Hills, MI</td>
<td>(248) 391–8421</td>
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<tr>
<td>Feb. 14</td>
<td>Genesis–Systems, Davenport, IA</td>
<td>(563) 445–5688</td>
</tr>
<tr>
<td>Feb. 28</td>
<td>Lincoln Electric Co., Cleveland, OH</td>
<td>(216) 383–8542</td>
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<tr>
<td>March 7</td>
<td>Wolf Robotics, Ft. Collins, CO</td>
<td>(970) 225–7736</td>
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<td>April 25</td>
<td>Wolf Robotics, Ft. Collins, CO</td>
<td>(970) 225–7736</td>
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<td>May 2</td>
<td>ABB, Inc., Auburn Hills, MI</td>
<td>(248) 391–8421</td>
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<td>May 23</td>
<td>Genesis–Systems, Davenport, IA</td>
<td>(563) 445–5688</td>
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<td>Aug. 1</td>
<td>Wolf Robotics, Ft. Collins, CO</td>
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<td>ABB, Inc., Auburn Hills, MI</td>
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International CWI Courses and Exams
Please visit www.aws.org/certification/inter_contact.html

Important: This schedule is subject to change without notice. Please verify your event dates with the Certification Dept. and confirm your course status before making your travel plans. For information, visit www.aws.org/certification, or call (800)305) 443-9353, ext. 273, for Certification; or ext. 455 for Seminars. Apply early to avoid paying the Fast Track fee.
Industry Leaders Recognized at FABTECH

Paul Konkol and Richard Smith have been inducted as AWS Fellows; and David Beneteau, David Fink, Gene Franke, Kenneth Kuk, Richard Seif, Dale Stager, and Mike Weller inducted as AWS Counselors.

Fellow Paul Konkol is cited for his research in high-strength steels and welding consumables used for U.S. Navy submarine hulls, structures, and line pipe. His papers have been published in the Welding Journal for six decades.

Fellow Richard Smith is noted for his research into solving industrial issues involving stress corrosion cracking, degradation of stainless steel, and nickel-alloy systems used in electric power equipment.

Counselor David M. Beneteau was noted for his leadership in the Resistance Welding Manufacturing Alliance (RWMA) and Detroit Section activities.

Counselor David Fink was cited for his welding consumables research performed at The Lincoln Electric Co., and leadership in preparing domestic and international welding-related standards.

Counselor Gene L. Franke was named for his work with high-strength steel welding procedures and welding consumables, fume mitigation, and failure analysis.

Counselor Kenneth Kuk was cited for his leadership and being the driving force in developing the welding engineering technology degree program at Ferris State University during his 25-year tenure.

Counselor Richard J. Seif was noted for his achievements in global marketing of welding products during his 37 years with The Lincoln Electric Co., where he serves as a senior vice president.

Counselor Dale Stager was cited for his expertise in flux core electrode production, work at Hobart Brothers, and the founding of Tri-Mark and Select-Arc.

Counselor Michael L. Weller was cited for his achievements as president of Miller Electric Mfg. Co. and North American Welding for Illinois Tool Works (ITW), and managing its several divisions.
Comf or t A. Adams Lecture Award
Welding, Key Technology in the Power Generation Industry

Horst Cerjak served as head of the Intitute for Materials Science and Welding at Graz University of Technology, Austria, from 1982 until 2008. He received his PhD at the Technical University, Hannover, Germany. In 1967, he joined Siemens AG Nuclear Power, in Erlangen, Germany, where he became general manager, materials and welding. He has written 350 scientific papers and 14 books in the fields of nuclear materials, weldability, modeling approaches, and creep-resistant steels. He is the founder and chairman of the IIW international seminars “Numerical Analysis of Weldability.” Cerjak has received the IIW Sossenheimer Software Innovation Award, IIW Yoshiaki Arata Award, Dr.-Wolfgang-Houska Price Award for research, and the AWS Adams Memorial Membership Award.

Hai-Lung Tsai received his PhD in mechanical engineering from the University of California, Berkeley, in 1984. After working at General Motors Research Laboratory, he joined the Missouri University of Science and Technology in 1986 where he currently is a professor of mechanical engineering. Tsai’s research focuses on mathematical modeling of transport phenomena, heat transfer, and fluid flow in various manufacturing processes, including casting, gas metal arc welding (GMAW), laser beam welding, and laser-GMAW hybrid welding. Recently, his research has been extended to ultrafast laser-material interactions and micro devices for sensing and detection. Tsai has published more than 200 technical papers and holds six patents. He has received many awards from Missouri S&T for his outstanding teaching acumen, as well as the Marcus A. Grossmann Young Author Award from ASM International, and the Distinguished Scholar Award from the Midwest Chinese-American Science and Technology Assn. Tsai serves as a Guest Professor of Xi’an Jiaotong University and Central South University in China, and is the Changjiang Distinguished Chair Professor at Beijing Institute of Technology, China.

Howard E. Adkins Memorial Instructor Membership Award

Jeffrey N. Carney is an associate professor and coordinator of the Ferris State University (FSU) welding program, an AWS member for 28 years, and the advisor for the FSU Student Chapter. He joined the university as an assistant professor in 1996, and earned his MS there in 1999. He first studied welding in high school in Royal Oak, Mich. His first job was part time at Door-Man Manufacturing working in the welding shop. Upon completion of high school, he continued working at the company as a welder and fitter. In 1983, he entered FSU where he received a welding engineering technology degree. From 1987 to 1994, he worked for Welding & Engineering Products and Robotic Production Technology in Madison Heights, Mich., as a welding engineer. From 1994 to 1996, Carney served as automotive center manager for ABB Flexible Automation in Auburn Hills, Mich.

Gary L. Gammill developed his welding skills during four years of vocational training in high school. He received a bachelor’s degree from Mississippi State University. Following 20 years in industry, he became a welding instructor at East Mississippi Community College where he has been teaching for the past nine years. Gammill currently serves as treasurer of the AWS Northeast Mississippi Section, District 8 deputy director, and District 8 Scholarship Committee chairman. He is an AWS Certified Welding Inspector (CWI) and Certified Welding Educator (CWE), an ASNT Level I and Level II in ultrasonic testing; and a National Center for Construction Education and Research Certified Instructor. In 2009, he received the Mississippi Manufacturing Association Award for Excellence in Vocational Education.

A. F. Davis Silver Medal Award
Machine Design

Development of a Multiline Laser Vision Sensor for Joint Tracking in Welding
K. Sung, Hae Woo Lee, Y. S. Choi, and Selun Rhee

Structure Design
Control of Longitudinal Bending Distortion of Built-Up Beams by High-Frequency Induction Heating

Dalton E. Hamilton Memorial CWI of the Year Award
Since 1993, Dennis Wright has been the plant manager and welding supervisor at Zephyr Products, Inc., Leavensworth, Kan. He is an AWS Certified Welding Inspector (CWI) and a Certified Welding Educator. He has held officer positions in the AWS Kansas City Section, and serves on National SkillsUSA and the Johnson County Community College Advisory Board for welding. He owns Wright Welding Technologies, providing welding procedures, welder qualifications, and welding inspections. He holds Level 2 MT and PT certifications. Wright has published articles in Welding Journal and Welding Design and Fabrication, and contributed to the AWS Welding Handbook. He worked in welding during his 8½-years tour in the U.S. Navy. Following discharge, he joined Allis Chalmers as a welding supervisor. From 1988 to 1993, he was employed with Libby Corp, where he was in charge of its three welding shops.

W. H. Hobart Memorial Award
A CCT Diagram for an Offshore Pipeline Steel of X70 Type

Gary Gammill

Morten I. Oeensien received his PhD in physical metallurgy from the Norwegian University of Science and Technology. His interests are in casting, welding, and heat treatment of steel and iron. Currently, he is research manager at SINTEF Materials and Chemistry in Oslo, Norway. He has authored 65 technical papers and publications and holds two patents.

Mohammed M’Hamdi received his PhD from the Institute National Polytechnique de Lorraine, France, in 1998. He joined SINTEC in 1999 where he currently is a senior research scientist, and
also serves as an adjunct professor at the Norwegian University for Science and Technology in Trondheim, Norway. His research concerns modeling of aluminum casting processes, steel welding, and silicon crystals for photovoltaic applications.

Asbjørn Mo received his PhD in hydrodynamics from the University of Oslo. He joined SINTEF Materials Technology, Oslo, Norway, where he was research director from 1998 to 2004 and principal scientist from 2004 to 2008. He also served as an adjunct professor at the University of Oslo from 1999 to 2008. In 2008, he joined the Research Council of Norway Division of Science and is currently director, Physical Sciences and Technology. His interests are mathematical modeling of metal solidification processes, mushy-zone phenomena, and thermally induced deformation. He has published more than 75 journal, conference papers, and book chapters with various university teams.

Honorary Membership Award
Earl C. Lipphardt, an AWS member since 1978, is affiliated with the northwestern Pennsylvania Section. He served as AWS treasurer 2001–2009, an AWS Foundation trustee, District 10 director, and a director-at-large. Currently, Lipphardt owns an H&R Block franchise with offices in Girard, Albion, and Edinboro, Pa. From 1954 to 1961, he worked as the foundry crew leader and warehouse supervisor at McGean Chemical Co., then became a sales consultant for Copper & Brass Sales Co. in Cleveland, Ohio. From 1964 to 1979, he was manager of inside sales for the Orrweld Division of William M. Orr Co. In 1979, he joined Findley Welding Supply, Inc., in Erie, Pa. Prior to his retirement in 1999, he was an outside supervisor, design consultant, and sales representative for General Electric.

Int'l Meritorious Certificate Award
Christian Ahrens, chairman of the AWS Germany Section, is managing director for Foreign Business at Gesellschaft für Schweisstechnik International (GSI), Düsseldorf, Germany. From 1976 to 1984, he was employed by Krupp Industrietechnik in the Bridge Design Department, then moved to SLV Duisburg Branch of GSI where he served as head of the Education and Training Department. Later he served as vice managing director from 1984 to 2009.

He is a member of the International Institute of Welding (IIW) and International Authorization Board (IAB). Since 2000, he has served as chairman of the IAB Working Group A, Education, Training, and Qualification; and as chairman of Subgroup WGA#2A/2B developing guidelines for International Welding Engineer (IWE), International Welding Technologist (IWT), International Welding Specialist (IWS), and International Welding Practitioner (IWP). Additionally, he is a member of IAB Group B, Implementation, Authorization, and Certification. From 1997 to 2009 he served as a peer assessor in the IAB quality system, and as a lead assessor since 2009. Since 1992, he has been active on IIW Commission XIV, Education. From 1995 to 2000, he served as chairman, IIW Commission VII — Authorization, Examination, and Qualification. Ahrens is a member of the German Welding Society (DVS). He served two terms as chairman of the Main Examination Board from 1992 to 2000, and three terms as chairman of the Regional (Rhinelan) Examination Board from 1988 to 2000. He continues to chair the Education Committee for Germany for IWE, IWT, IWS, and IWP.

As head of the Education and Training Department of the German Welding Institute Duisburg (SLV Duisburg), he was responsible for the SLV to receive the IIW 2006 André Leroy Prize for the computer-based training program CBT IWE. Part 1, for the best multimedia document and the 2007 German Training Export Award from the German Federal Ministry of Education and Research for the most internationalization concept. He received his degree in civil engineering from RWTH Aachen University.

Stephen Liu, an AWS Fellow and Distinguished Member, is a professor of metallurgy and materials engineering at the Colorado School of Mines (CSM) where he earned his PhD in metallurgical engineering. Before joining the faculty in 1987, Liu was a research metallurgist at Aesica, a manufacturer of specialty steels in Brazil, and an assistant professor in industrial and manufacturing engineering at Pennsylvania State University. He has conducted collaborative research with colleagues worldwide, made presentations at numerous international conferences, and published hundreds of papers. Liu has served four terms as chairman of the ASME Ocean, Offshore and Arctic Engineering Division, and ten years as editor-in-chief of the ASME Journal of Offshore Mechanics and Arctic Engineering. He currently chairs the AWS Technical Papers Committee and is a member of the Chapter Council of ASM International. He has received numerous AWS honors, including the Comfort A. Adams Lecture Award, Honorary Membership Award, McKay-Helm Award, Robert L. Peaslee Brazing Award, Charles H. Jennings Award, Adams Memorial Membership Award, District Meritorious Award, and the Plummer Educational Lecture in 1998. He was elected an ASME Fellow in 1999 and an ASM Fellow in 2001. Liu has received the ASME Special Achievement Award, ASME-OMAE Special Achievement Award, and the SAE Teetor Educational Award. Liu is a professional member of the Institute of Materials and a Chartered Professional Engineer registered with the Engineering Council, UK. He also holds memberships in ASM International, The Metallurgical and Materials Society, American Society of Mechanical Engineers, and the Japan Welding Society.

Thomas M. Mustaleski Jr. is an AWS Fellow, Life Member, and Distinguished Member. He served two terms as an AWS director-at-large, three terms as vice president, and president (2003–2004). He also served as an officer of the Milwaukee and Northeast Tennessee Sections, and chaired the Northeast Tennessee Section for several terms. He chairs the American Council of the International Institute of Welding (IIW), is a member of the Technical Management Board, and served as chair of the Select Committee on Welding for Aircraft and Aerospace Applications for seven years. He has served as the U.S. Delegate to IIW Commission V, Delegate to Commission IV, and as lead U.S. representative to SC AIR. He has led several technically based committees of the Society. He received...
the William Irgang Memorial Award, Honorary Membership Award, R. D. Thomas Memorial Award, and Davis Silver Medal. Mustaleski received his degree in metallurgical engineering from Rensselaer Polytechnic Institute with graduate work in metallurgical engineering at the University of Wisconsin—Milwaukee, and the University of Tennessee. He is retired from BWXT Y12 LLC, Oak Ridge, Tenn., where he worked from 1974 until 2006. There he served as a staff member and group leader in the Technology Development Organization where he was involved in welding metallurgy and process and procedure development.

H. Glenn Ziegenfuss is a senior auditor for the American National Standards Institute (ANSI). From 1973 until 1984, he was a manager in the welding engineering group at the Bettis Atomic Power Laboratory of the Westinghouse Electric Corp., involved with automatic welding operations for U.S. Navy nuclear submarines and aircraft carriers. Later, he served on the American Welding Society staff for 13 years, first as technical director and then as associate executive director, technical. Ziegenfuss then became executive director of the Standards Engineering Society (SES), and the standards officer for the International Institute of Welding (IIW). Ziegenfuss received his PhD in solid-state science from The Pennsylvania State University. He led a People-to-People delegation on pressure vessels and pressure piping to China in 1997. He is a past chair of the ANSI Executive Standards Council, Standards Publishers Advisory Board, Standards and Technical Activities Committee of the Council of Engineering and Scientific Society Executives, AWS South Florida Section, and the South Florida Chapter of ASM International. He has received the AWS-sponsored George E. Willis Award and the ANSI-sponsored George S. Wham Leadership Medal.

William Irgang Memorial Award
Wayne Thomas joined The Welding Institute (TWI) in 1983, where he held positions as senior welding engineer, section leader, and principal research engineer. Currently semiretired, he works part time as a consultant. He received his PhD in materials research at Bolton University Centre, UK. Thomas joined Baldwins Ltd. in 1959 as a craft apprentice then progressed to a boilermaker and fabricator. In 1964, he joined B.S.C. Machynys Works, where he gained extensive shop floor experience in production processes and nondestructive weld inspection. Later, he was promoted to planning engineer and project leader. From 1974 to 1983, he served as planning engineer and estimator for the Fabrication and Welding Departments. Thomas has received the Sir William J. Larke Medal, and the Japanese Welding Society Welding Process Technology Award for the invention and development of the friction stir welding method, Samuel Wylie Miller Memorial Medal, Comfort A. Adams Lecture Award, the International Institute of Welding Evgeny Poton Medal, and the Society of Manufacturing Engineers Award.

Charles H. Jennings Memorial Award
Al-to-Mg Friction Stir Welding: Effect of Positions of Al and Mg with Respect to the Welding Tool
Vahid Firouzdor is a research associate in the Department of Engineering Physics at the University of Wisconsin-Madison, involved with welding metallurgy, corrosion science, and coating technology. Firouzdor received his master’s degree from Sharif University of Technology, Tehran, Iran, and his PhD at the University of Wisconsin-Madison last year. He has received the AWS International Student Scholarship Award, and the District 12 Scholarship Award. He is a co-holder of a patent on friction stir welding, has given numerous conference presentations, and published a number of journal papers and conference proceedings.

Sindo Kou, an AWS Fellow, received his PhD in materials science and engineering from Massachusetts Institute of Technology. He worked at General Motors Research Laboratory, and at Carnegie-Mellon University as an associate professor, and as a professor at the University of Wisconsin from 1985 to the present. He has authored two books: Welding Metallurgy, and Transport Phenomena and Materials Processing, both published by Wiley, New York. Kou received the John Chipman Award from Iron and Steel Society, Adams Memorial Fellowship Award,IME Fellow status, Chancellors’ Award for Distinguished Teaching from the University of Wisconsin, Benjamin Smith Reynolds Award for Excellence in Teaching from the College of Engineering, University of Wisconsin, Charles H. Jennings Memorial Award, AWS Warren F. Savage Memorial Award, William Spraragen Memorial Award, and the Alumnus Award from the University of Wisconsin-Milwaukee.

McKay-Helm Award
Heat Transfer and Fluid Flow during Electron Beam Welding of 304L Stainless Steel Alloy
Rohit Rai is a senior research and development engineer at Hawthorne & York International, an engineering consulting company in Phoenix, Az. His area of research is the development of new materials with improved properties based on molecular dynamics simulations. Rai received his PhD in materials science and engineering from Pennsylvania State University in 2008. His thesis focused on modeling of heat and fluid transport in high-energy-beam keyhole mode welding process.

Todd A. Palmer received a master’s of business administration and a PhD in materials science and engineering at Pennsylvania State University. Since 2007, he has worked at the university’s Applied Research Laboratory as a research assistant, and an assistant professor in the Department of Materials Science and Engineering. Previously, he was a metallurgist at Lawrence Livermore National Laboratory, Livermore, Calif. He is chair of the C7B Subcommittee on Electron Beam Welding and Cutting, vice chair of the C7 Committee on High Energy Beam Welding and Cutting, and a member of the Welding Research and Development Committee. He is also a member of the peer review panel for the Welding Journal Research Supplement, the editorial board for Science and Technology of Welding and Joining, and a key reader for Metallurgical and Materials Transactions. Palmer has received the A. F. Davis Silver Medal Award, Koichi Masubuchi Award, and William Spraragen Memorial Award, Geoffrey Belton Award of The Iron and Steel So-
The Science and Technology of Welding and Joining using electron and laser beams, with postdoctoral work at Imperial College, London, and Massachusetts Institute of Technology before joining Pennsylvania State University, where he currently is a professor. He has published four edited books and authored 130 technical papers on topics relating to in-situ observations of welds using synchrotron radiation, materials joining, metallurgy, high solidification, high-energy-density beam-material interactions, electron beam diagnostics, soldering, explosive welding, and phase transformations. He is a Fellow of ASM International, a registered Professional Engineer, and holds 12 U.S. patents. He has received the Comfort A. Adam's Lecture Award, William Irgang Award, William Spraragen Award, Prof. Masubuchi-Shinsho Corporation Award, A. F. Davis Silver Medal Award, Warren F. Savage Memorial Award, and Samuel Wylie Miller Memorial Medal Award. He currently serves on several AWS and ASM International committees, is on the editorial review boards for *Welding Journal*, *Metallurgical and Materials Transactions A*, and *The Science and Technology of Welding and Joining*. Elmer also serves as an adjunct professor to the Pennsylvania State University.

Tarasankar DebRoy, an AWS Fellow and Honorary Member, received his PhD from Indian Institute of Science, Bangalore, with postdoctoral work at Imperial College, London, and Massachusetts Institute of Technology before joining Pennsylvania State where he currently is a professor. He has published four edited books and 280 papers on computational materials processing. He serves as chair of the AWS Research and Development Committee, is a founding editor of *Science and Technology of Welding and Joining*, and is a Principal Reviewer for *Welding Journal*. DebRoy, a Fellow of ASM International, has received the Yoshiaki Arata Award of IIW, Kenneth Easterling Best Paper Award of the University of Graz and IIW, Comfort A. Adams Lecture Award, and the Faculty Scholar Medal from Penn State University.

**Prof. Koichi Masubuchi Award**

Wei Zhang received his PhD in materials science and engineering from Pennsylvania State University. He worked at Edisson Welding Institute for five years as an application engineer and an engineer team leader. In the fall of 2008, he joined the Materials Joining Group at the Oak Ridge National Laboratory as a research staff member. Zhang studies computational weld modeling to provide a comprehensive understanding of heat transfer, fluid flow, microstructure evolution, residual stresses, and distortion during welding. His recent projects involve fracture toughness and fatigue life testing of pipeline steel welds in high-pressure hydrogen environment, prediction and measurement of weld residual stresses in dissimilar metal welds used in pressurized water reactor piping system, nondestructive evaluation of spot weld quality in automotive structures using infrared thermography, and applications of modeling and neutron diffraction in renewable energy systems such as wind, hydro, solar, and energy storage. He has published about 50 peer-reviewed papers. Zhang is a coinventor of EWI's E-WeldPredictor. He has received the Henri Granjon Prize from the International Institute of Welding and the William Spraragen Memorial Award from the American Welding Society.

**Samuel Wylie Miller Memorial Medal Award**

Damian J. Kotecki, an AWS Fellow and a past AWS president, is president of Damian Kotecki Welding Consultants, Inc., Cleveland, Ohio. In 2007 he retired from The Lincoln Electric Co. where he worked for 18 years, most recently as technical director for stainless and high-alloy product development. Previously, he was director of research at Teledyne McKay. He has chaired the AWS Technical Activities Committee; AS Committee on Filler Metals and Allied Materials; the Welding Research Council Subcommittees on Welding Stainless Steels, and Hardfacing and Wear; and the International Institute of Welding (IIW) Commission II. He is a member of the IIW Working Group on Standardization and ISO TC44 Subcommittee 3. He recently served as an AWS vice president and currently serves as treasurer. Kotecki earned his PhD in mechanical engineering from the University of Wisconsin-Madison. He is a coauthor of the text, *Welding Metallurgy and Weldability of Stainless Steels*, holds several patents, and has published numerous technical papers. Since 1999, Kotecki has authored the Stainless Q&A column published in the *Welding Journal*.

**National Meritorious Award**

**Posthumous recognition**

Joseph H. Dillhoff III served as president of OKI Bering, a family-owned company, for nearly 17 years. He participated on the AWS Finance Committee and was a member of the Welding Equipment Manufacturers Committee (WEMCO), an AWS standing committee, AWS Publications, Expositions, Marketing Committee (PEMCO); and served as a board member of Gases and Welding Distributors Association (GAWDA). Dillhoff served on the President's Advisory Board of Xavier University and as a mentor for Williams College of Business. He received his master's in business administration from Xavier University.

Robert L. Richwine, an AWS Distinguished Member and District 14 director, is active in the Indiana Section. He is a graduate of Delco Remy-GMC Apprentice Program, and Ivy Tech State College, Ball State University, Hobart Institute of Welding Technology, Lincoln Electric Welding School, and others. He began his career with the Delco Remy Division of GM in 1965. After completing a pipefitter steamfitter apprenticeship in 1977, he taught apprentice classes at the Anderson Area Vocation-Technical School, and later taught welding at the
Delco Remy Technical Training Center where he worked for eleven years then retired in 1997. Richwine has earned numerous AWS awards, including District Educator, District Meritorious, District Dalton E. Hamilton Memorial CWI of the Year, District Private Sector Educator, and the District Director Award. Other awards include Ivy Tech Technology Division Advisor of the Year, and the Midwest Team Welding Tournament’s Clifford Hunt Award. The state of Kentucky named him to the Honorable Order of Kentucky Colonels in 1998.

**Plummer Memorial Education Lecture Award**

**Welding Education: Encouraging a Continued Posture for Learning**

*R. Bruce Madigan*, an AWS member for more than 27 years, is an associate professor at Montana Tech at the University of Montana. He is an AWS Section officer and participates in numerous AWS activities including the Education, Scholarship, Welding Handbook, and Technical Papers Committees. Madigan learned to weld in junior high school then honed his welding skills with courses taken at Hobart Institute of Welding Technology. After welding in steelmaking support shops in Cleveland, Ohio, he attended The Ohio State University where he obtained his MS degree in welding engineering. He was a research engineer with Edison Welding Institute before moving to Colorado to work at the National Institute of Standards and Technology. While working at NIST, he obtained his PhD in metallurgical and materials engineering from the Colorado School of Mines. After he left NIST, he worked as a welding engineering consultant.

**Warren F. Savage Memorial Award**

**Ductility-Dip Cracking Susceptibility of Nickel-Based Welding Metals**

*Part 2 — Microstructural Characterization*

*Nathan E. Nissley* received his BS in welding engineering and mechanical engineering from LeTourneau University where he worked on hydrogen cracking of bridge weathering steels and served as a chapter committee member for the AWS Welding Handbook. He received his PhD in welding engineering from The Ohio State University where his research focused on the mechanism of ductility dip cracking in stainless steels and nickel-based welding consumables. He developed a Gleeble-based strain-to-fracture test that he later used to research the ductility dip cracking. Since 2006, Nissley has worked for ExxonMobil Upstream Research Co., Houston, Tex., where he served as a materials specialist and laboratory manager. His research has focused on developing robust solutions for joining high-strength steels and other materials, simulation testing, and failure analysis. He was awarded the Glenn J. Gibson Graduate Fellowship and the Praxair International Scholarships.

**John C. Lippold**, an AWS Fellow and a Fellow of ASM International, received his PhD in materials engineering from Rensselaer Polytechnic Institute. He worked seven years at Sandia National Laboratories, Livermore, Calif., as a member of the technical staff, specializing in the areas of stainless steel and high-alloy weldability. From 1985 to 1995, Lippold served as materials department leader and manager of research at Edison Welding Institute. In 1995, he joined the welding engineering faculty at The Ohio State University. He coauthored the texts, *Welding Metallurgy and Weldability of Stainless Steels and Welding Metallurgy and Weldability of Nickel-Base Alloys*. Lippold has received the Charles H. Jennings Memorial Award, William Spraragen Memorial Award, Warren F. Savage Memorial Award, A. F. Davis Silver Medal Award, Warren F. Savage Memorial Award, Prof. Koichi Masubuchi Award, and the William Irgang Award. Lippold received the National Science Foundation Presidential Early Career Award for Scientists and Engineers from Lehigh University where he is the R. D. Stout Distinguished Professor. He is also associate director of Lehigh’s Energy Research Center and holds a joint appointment in the Mechanical Engineering Department. His research interests include processing-microstructure-property relations in solidification and joining of materials, laser-engineered net shaping, and alloy development. He has published about 140 papers, edited four books, and holds one U.S. patent. DuPont received the Adams Memorial Membership Award, Charles H. Jennings Memorial Award, William Spraragen Memorial Award, McKay-Helm Award, A. F. Davis Silver Medal Award, Warren F. Savage Memorial Award, Prof. Koichi Masubuchi Award, and the William Irgang Award. DuPont received the National Science Foundation Presidential Early Career Award for Scientists and Engineers from President Clinton, and the Lehigh University College of Engineering Teaching Excellence Award. DuPont is a Principal Peer Reviewer for the *Welding Journal*, a reviewer for the *Journal of Materials Engineering and Performance*, and serves on the editorial board of *Science & Technology of Welding and Joining*. He is a past chair of the ASM International Committee on Fusion Welding, and past vice chairman of the ASM Committee on Joining. He is a member on several AWS committees including Awards, Research & Development, Handbook, Conference, and Technical Papers. He serves on the Edison Welding Institute Navy Joining Center Technical Advisory Board.

*John DuPont*, an AWS Fellow and a Fellow of ASM International, earned his PhD in materials science and engineering from Lehigh University where he is the R. D. Stout Distinguished Professor. He is also associate director of Lehigh’s Energy Research Center and holds a joint appointment in the Mechanical Engineering Department. His research interests include processing-microstructure-property relations in solidification and joining of materials, laser-engineered net shaping, and alloy development. He has published about 140 papers, edited four books, and holds one U.S. patent. DuPont received the Adams Memorial Membership Award, Charles H. Jennings Memorial Award, William Spraragen Memorial Award, McKay-Helm Award, A. F. Davis Silver Medal Award, Warren F. Savage Memorial Award, Prof. Koichi Masubuchi Award, and the William Irgang Award. DuPont received the National Science Foundation Presidential Early Career Award for Scientists and Engineers from President Clinton, and the Lehigh University College of Engineering Teaching Excellence Award. DuPont is a Principal Peer Reviewer for the *Welding Journal*, a reviewer for the *Journal of Materials Engineering and Performance*, and serves on the editorial board of *Science & Technology of Welding and Joining*. He is a past chair of the ASM International Committee on Fusion Welding, and past vice chairman of the ASM Committee on Joining. He is a member on several AWS committees including Awards, Research & Development, Handbook, Conference, and Technical Papers. He serves on the Edison Welding Institute Navy Joining Center Technical Advisory Board.
E. Willis, the award, administered by AWS, is given each year to contributions of time and effort on behalf of the Society. It includes a $2500 honorarium and a certificate. To enhance the Society's goal of advancing the science and technology and its allied processes, which have been recognized as significant contributions to the progress of welding engineering and related fields. In 1977, he joined Oak Ridge National Laboratory and has retired as a Corporate Fellow of UT-Battelle, and Group Leader of the Materials Joining Group in the Materials Science and Technology Division. He is a Fellow of The Minerals, Metals, and Materials Society, American Association for the Advancement of Science, and ASM International. He is editor-in-chief of Science and Technology of Welding and Joining published by the Institute of Materials, London. David has received the UT-Battelle Director's and Distinguished Engineer Awards; Warren F. Savage Memorial Award; McKay-Helm Award; University of Pittsburgh Distinguished Alumnus Award; William Irrgang Memorial Award; TMS Champion H. Mathewson Award; AWS Honorary Membership Award, Charles H. Jennings Memorial Award; and the Lincoln Gold Medal Award.

Honorary Meritorious Awards

The Honorary Meritorious Awards Committee makes recommendations for the nominees presented to receive the Honorary Membership, National Meritorious Certificate, William Irrgang Memorial, and the George E. Willis Awards. These honors are presented during FABTECH each fall. The deadline for submissions is December 31 prior to the year of the awards presentations. Send candidate materials to Wendy Sue Reeve, committee secretary, wreeve@aws.org; or mail to her at 550 NW LeJeune Rd, Miami, FL 33126. The descriptions of these awards follow.

William Irrgang Memorial Award

Sponsored by The Lincoln Electric Co. in honor of William Irrgang, the award, administered by AWS, is given each year to the individual who has done the most over the past five years to enhance the Society’s goal of advancing the science and technology of welding. It includes a $2500 honorarium and a certificate.

National Meritorious Certificate Award

This certificate award recognizes the recipient's counsel, loyalty, and dedication to AWS affairs, assistance in promoting cordial relations with industry and other organizations, and for contributions of time and effort on behalf of the Society.

George E. Willis Award

Sponsored by The Lincoln Electric Co. in honor of George E. Willis, the award, administered by AWS, is given each year to an individual who promoted the advancement of welding technology and its allied processes, which have been recognized as significant contributions to the progress of welding engineering and related fields. In 1977, he joined Oak Ridge National Laboratory and has retired as a Corporate Fellow of UT-Battelle, and Group Leader of the Materials Joining Group in the Materials Science and Technology Division. He is a Fellow of The Minerals, Metals, and Materials Society, American Association for the Advancement of Science, and ASM International. He is editor-in-chief of Science and Technology of Welding and Joining published by the Institute of Materials, London. David has received the UT-Battelle Director's and Distinguished Engineer Awards; Warren F. Savage Memorial Award; McKay-Helm Award; University of Pittsburgh Distinguished Alumnus Award; William Irrgang Memorial Award; TMS Champion H. Mathewson Award; AWS Honorary Membership Award, Charles H. Jennings Memorial Award; and the Lincoln Gold Medal Award.
D14B Subcommittee Meets at FABTECH

The D14B Subcommittee on Welded Joint Design in Machinery and Equipment members met at FABTECH to review their documents. Shown are (from left) Alma Olsen, Ron Leemans, Rob Larsen, Chair and District 16 Director David Landon, Secretary Matt Rubin, Bernard Banzhaf, Michael Sebergandio, and Bob Warke.

Erratum
Specification for Welding Procedure and Performance Qualification

The following erratum has been identified and will be incorporated into the next reprinting of this document.

Page 35 — 5.6.1.1(11) — Delete reference to Table 5.9 so that sentence reads: “Tables 5.6, 5.7, and 5.8.”

Official Interpretation
D1.8/D1.8M:2009
Structural Welding Code — Seismic Supplement

Subject: Yield Strength and Filler Metal Qualification
Code Edition: D1.8:2009
Code Provision: Table A.2
AWS Log: D1.8-09-II1
Inquiry: For WPS Qualification, must Yield Strength (0.2% offset) be used to comply with the requirements for Yield Strength in the D1.8 code?
Response: Yes.

ISO Draft Standard for Public Review

Copies of this standard are available for review through your national standards body, which in the United States is ANSI, 25 W. 43rd St., 4th Floor, New York, NY, 10036; (212) 642-4900. Any comments regarding ISO documents should be sent to your national standards body.

Technical Committee Meetings

All AWS technical committee meetings are open to the public. To attend a meeting, call the staff secretary, (305) 443-9353, at the extension listed.

Feb. 24, C1 Committee on Resistance Welding. Palm Beach Gardens, Fla. Call A. M. Alonso, ext. 299.
Feb. 25, J1 Committee on Resistance Welding Equipment. Palm Beach Gardens, Fla. Call A. M. Alonso, ext. 299.
March 8, 9, C3 Committee and Subcommittees on Brazing and Soldering. Santa Fe, N.Mex. Call S. Borrero, ext. 334.
March 15–18, D1 Committee on Structural Welding. Houston, Tex. Call J. L. Gayler, ext. 472.
March 24, A5T Subcommittee on Filler Metal Procurement Guidelines. Orlando, Fla. Call R. Gupta, ext. 301.

How to Order Journal Article Reprints and AWS Publications

For custom reprints of Welding Journal articles in quantities of 100 or more, or electronic posting of articles, contact Rhonda Brown, Foster Printing Services, rhondab@fosterprinting.com; (866) 879-9144, ext. 194; www.marketingreprints.com.
For individual copies of Welding Journal articles, contact Edalia Suarez, suarez@aws.org, or Ruben Lara, rlara@aws.org.
Order AWS standards, books, and other publications from WEX (World Engineering Xchange), www.awspubs.com; call toll-free in the United States (888) 935-3464; elsewhere call (305) 826-6192; or FAX (305) 826-6195.
Membership Service Awards Presented at FABTECH

The Life Member certificate is presented for 35 years of service to the American Welding Society. This year’s awardees are (in alphabetical order) Richard Arn, William Briody, David Edmonds, Gene Franke, Bruce Hallila, Loren Hendrickson, Rodolfo Hernandez, Jerry Hope, Robert Jackson Jr., Dennis Klingman, James Koster, David McQuaid, Duane Miller, Curtis Opdahl, John Stoll, Roger Swain, Robert Turpin, and Richard Watson.

The Gold Membership awardees are (from left) Fritz Saenger Jr., Ron Pierce, Wayne Engeron, Samuel Deboer, and Lawrence Lyon. Not shown is Carl Helder. The award is presented for fifty years of service to the American Welding Society.

The Silver Member awardees are (from left) Eric Young, Duane Stevens, William Monti, Jorge Merzthal, Janusz Lekki, Hee Kim, Steve Fyffe, Richard Cook, Johnny Combs, and Tony Anderson. Not shown are Thomas Burns, James Horvath, Daryl Duncan, and Carl Cross. The award is presented for twenty-five years of service to the American Welding Society.

Robby Fadjaray (center), director, Indonesian Welding Association, visited AWS recently to discuss certification opportunities in Indonesia. Shown with him are Cassie Burrell, AWS deputy executive director; and Ray Shook, AWS executive director.
AWS Foundation Recognizes the Houston and Albuquerque Sections

Left photo: Recognizing the establishment of the Ron VanArsdale Named Scholarship by the Houston Section are (from left) John Stoll, Derek Stelly, and Gerald Uttrachi, chairman, AWS Foundation board of trustees, and a past AWS president. Right photo: Albuquerque Section Chair Pierrette Gorman and Tom Lienert (far right), an AWS director-at-large, present scholarship donations to Sam Gentry, executive director, AWS Foundation. The event took place at the Section Appreciation Luncheon during FABTECH last November.

Member-Get-A-Member Campaign

Listed below are the Dec. 22, 2010, standings of the members participating in the 2010-2011 Member-Get-A-Member Campaign. For complete campaign rules and prize list, see page 83 of this Welding Journal, or visit www.aws.org/mgm.

Winner’s Circle
AWS Members who have sponsored 20 or more new Individual Members, per year, since June 1, 1999. The superscript denotes the number of years the member earned Winner’s Circle status, if more than once.

| J. Compton, San Fernando Valley | 7 |
| E. Ezell, Mobile | 2 |
| J. Merzthal, Peru | 2 |
| G. Taylor, Pascagoula | 2 |
| L. Taylor, Pascagoula | 2 |
| B. Chin, Auburn | 2 |
| S. Esders, Detroit | 2 |
| M. Haggard, Inland Empire | 2 |
| M. Karagoulis, Detroit | 2 |
| S. McGill, NE Tennessee | 2 |
| B. Mikeska, Houston | 2 |
| W. Shreve, Fox Valley | 2 |
| T. Weaver, Johnson/Altoona | 2 |
| G. Woomer, Johnson/Altoona | 2 |
| R. Wray, Nebraska | 2 |

President’s Roundtable
Sponsored 9-19 new members
G. Kirk, Pittsburgh — 17

President’s Club
Sponsored 3-8 new members
M. Pelegrino, Chicago — 8
M. Tryon, Utah — 8
E. Ezell, Mobile — 7
R. Dawson, Western Carolina — 4
J. Hope, Puget Sound — 4
J. Hopwood, Iowa — 4
D. Steyer, Niagara Frontier — 4
G. Bish, Atlanta — 3
H. Cable, Pittsburgh — 3
C. Crompton, Florida West Coast — 3
J. Dolan, New Jersey — 3
R. Ellenbecker, Fox Valley — 3
M. Haggard, Inland Empire — 3
W. Sartin, Long Bch/Or. Cty — 3
G. Seese, Johnstown-Altoona — 3
W. Sturje, New York — 3

Student Sponsors
Sponsored 3+ Student Members
M. Pelegrino, Chicago — 69
G. Bish, Atlanta — 45
G. Seese, Johnstown-Altoona — 36
D. Saunders, Lakeshore — 31
M. Anderson, Indiana — 27
D. Berger, New Orleans — 27
J. Carney, W. Michigan — 25
G. Gamml, NE Mississippi — 25
S. Siviski, Maine — 22
A. Reis, Pittsburgh — 21
V. Facchino, Lehigh Valley — 20
M. Haggard, Spokane — 20
A. Baughman, Stark Central — 19
G. Smith, Lehigh Valley — 19
E. Norman, Ozark — 18
T. Buchanan, Mid-Ohio Valley — 17
K. Cox, Palm Beach — 17
S. Robeson, Cumberland Valley — 17
D. Schnalzer, Lehigh Valley — 17
H. Hughes, Mahoning Valley — 16
T. Shirk, Tidewater — 15

President’s Honor Roll
Sponsored 2 new members
M. Allen, Charlotte
D. Berger, New Orleans
R. Fuller, Florida W Coast
G. Hamilton, Houston
J. Hill, Nebraska
A. Holt, St. Louis
J. Kline, Northern New York
A. Laabs, Lakeshore
T. Palmer, Columbia
W. Wall, Auburn
S. Witkowski, Houston
D. Wright, Kansas City

K. Karwoski, Milwaukee — 14
C. Schiner, Wyoming — 14
M. Arand, Louisville — 13
W. Davis, Syracuse — 13
C. Donnell, NW Ohio — 13
R. Boyer, Nevada — 12
J. Daughtery, Louisville — 12
J. Goodson, New Orleans — 12
G. Kirk, Pittsburgh — 11
R. Wahrman, Triangle — 11
J. Boyer, Lancaster — 9
J. Ciaramitaro, N. Central Florida — 9
S. Ulrich, St. Louis — 9
A. Badeaux, Washington, D.C. — 8
C. Kipp, Lehigh Valley — 8
T. Moore, New Orleans — 8
W. Wilson, New Orleans — 8
R. Hutchinson, Long Bch/Or. Cty — 7
D. Kottler, Willamette Valley — 7
J. Kline, Northern New York — 7
G. Siepert, Kansas — 7
D. Wright, Kansas City — 7
T. Palmer, Columbia — 6
D. Zabel, Southeast Nebraska — 6
D. Kowalski, Pittsburgh — 5
B. Suckow, Northern Plains — 5
B. Benyon, Drake Well — 4
W. Galvery, Long Bch/Or. Cty — 4
A. Holt, St. Louis — 4
S. Mackenzie, Northern Michigan — 4
J. Meyer, San Francisco — 4
C. Warren, N. Central Florida — 4
S. Colton, Arizona — 3
J. Gerdin, Northwest — 3
T. Green, Central Arkansas — 3
R. Hilty, Pittsburgh — 3
S. Miner, San Francisco — 3
G. Rolla, LA/Inland Empire — 3
J. Seitzer, York-Central Pa. — 3
T. Smeltzer, San Francisco — 3
B. Sullivan, Mobile — 3
B. Wenzel, Sacramento — 3
District 1

Thomas Ferri, director
(508) 527-1884
thomas_ferri@thermadyne.com

BOSTON
DECEMBER 6
Activity: The Section members toured Quincy High School, featuring its new smoke-free metal-fabrication and welding shop. Airgas process specialist Burt Riendeau and Dave Schaffer provided a discussion and demonstration of welding gases. Welding instructor Dennis Thibault and his students hosted the event and served the dinner in the President’s Café. Andrea Burke received the Section CWI of the Year Award from Tom Ferri, District 1 director.

District 2

Harland W. Thompson, director
(631) 546-2903
harland.w.thompson@us.ul.com

PHILADELPHIA
NOVEMBER 10
Speaker: Ben Schiavone
Affiliation: Schiavone Electronic Labs
Topic: How NDT technology has evolved in NASCAR race shops

District 3

Michael Wiswesser, director
(610) 820-9551
mike@welderinstitute.com

Career Inst. of Technology Student Chapter
NOVEMBER 23
Activity: The incoming day and evening welding technology students demonstrated their skills using the plate shear and oxy-fuel welding on a number of projects. Supervising the event was Chris Kipp, an AWS Certified Welding Inspector and Certified Welding Educator. The program was held at the Career Institute of Technology (CTT) weld shop in Easton, Pa.

Ben Schiavone was the featured speaker at the Philadelphia Section program.
Chris Kipp coached the students at the November CIT Student Chapter program.

Juan David Schuch, a freshman in the CIT welding technology class, learns how to use welding equipment safely.

Underwater welder Chris Gabel (left) receives a speaker gift from Jim Henry, York-Central Pa. Section chair, at the November program.

Reading Section members and guests are shown at the November program.

Shown working at the Southwest Virginia Section weld-off program are instructor Mark Gilbert (left) and judge Ted Alberts.

Reading
November 18
Speakers: Alan Harrison, Arc Machines; and Stu Struck, Pandjiris, Inc.
Topic: Positioners and welding automation
Activity: Following the talks, Harrison demonstrated orbital welding machine operations from programming to the finished welds. The meeting was held in the Reading-Muhlenberg Career and Technology Center welding lab in Reading, Pa.

York-Central Pa.
October 7
Activity: The Section members toured the recently remodeled welding lab at Harrisburg Area Community College. Welding instructor John Ganoe led the program.

November 4
Speaker: Chris Gabel, owner
Affiliation: Ocean Eye, Inc.
Topic: Underwater welding and job opportunities available in the area
Activity: This York-Central Pennsylvania Section program was held at Heritage Hills Country Club in York, Pa.

District 4
Roy C. Lanier, director
(252) 321-4285
rlanier@email.pittcc.edu

Southwest Virginia
October 14
Activity: Greg McQuaid of Lincoln Electric demonstrated the VRTEX™ 360 virtual reality arc welding training solution equipment for members of the Section at Virginia Western Community College in Roanoke, Va. The 30 attendees had a hands-on opportunity to experiment with the technology.

November 11
Activity: The Southwest Virginia Section members supervised a high school weld-off contest at New River Community College in Dublin, Va. The participating schools included Floyd County, Giles County, and Patrick Henry High School. Ted Alberts, an AWS Certified Welding Inspector, judged the entries. Welding instructor Mark Gilbert oversaw the event.

Tidewater
November 11
Activity: The Section members met at Peking International Buffet for dinner and a presentation by staff members of Sea Solutions Dive Services titled Underwater Construction Academy. The talks discussed how the students are trained to weld underwater and perform cutting and construction underwater.
District 5
Steve Mattson, director
(904) 260-6040
steve.mattson@yahoo.com

District 6
Kenneth Phy, director
(315) 218-5297
kenneth.phy@gmail.com

NORTHERN NEW YORK
DECEMBER 7
Activity: The Section members toured the Modern Welding School, Inc., facilities in East Worcester, N.Y. Jeff Daubert, vice president, discussed the school’s history dating back to 1936, its courses, and present interactions with local industries. Section Chair Dave Parker presented Daubert with a clock he designed and built.

District 7
Don Howard, director
(814) 269-2895
howard@ctc.com

PITTSBURGH
NOVEMBER 2
Activity: Several Section members participated in the events held at the FABTECH show in Atlanta. Manning a booth was Dave McQuaid, an incoming AWS Director-at-large and incoming chair of the AWS D1.5 Bridge Welding Committee.

NOVEMBER 18
Speakers: Pete Bernarding and John Adams
Affiliation: TesTex, Inc.
Topic: Nondestructive testing of welds using a balanced field electromagnetic technique
Activity: The Pittsburgh Section members joined members of the local chapter of ASNT at Twelve Oaks Mansion in Mars, Pa., to learn about the TesTex, Inc., proprietary weld examination method.

District 8
Joe Livesay, director
(931) 484-7502, ext. 143
joe.livesay@ttcc.edu

CHATTANOOGA
NOVEMBER 30
Speaker: Richard Beldyk
Affiliation: Alstom Power Co.
Topic: Six Sigma and use of flowcharts
Activity: The event was held at Komatsu America Corp., in Chattanooga, Tenn.

District 9
George Fairbanks Jr., director
(225) 473-6362
fits@bellsouth.net

ACADIANA-BATON ROUGE
NOVEMBER 18
Activity: The two Sections met at Code Inspection & Testing South in Lafayette, La.,

Jeff Daubert (left) receives a speaker gift from Dave Parker, Northern New York Section chair, in December.

Dave McQuaid is shown working a booth at the FABTECH show in Atlanta.

Speaker John Adams (left) is shown with Brad King, Pittsburgh Section chair, Nov. 18.

Shown at the Nov. 18 Pittsburgh Section program are George Maksin (left) from ASNT, and speaker Pete Bernarding.

Pittsburgh Section members are shown at the November meeting.

NORTEAST MISSISSIPPI
DECEMBER 10
Activity: The Section hosted its Christmas party event at Pap’s Place in Ackerman, Miss.

District 9
George Fairbanks Jr., director
(225) 473-6362
fits@bellsouth.net

ACADIANA-BATON ROUGE
NOVEMBER 18
Activity: The two Sections met at Code Inspection & Testing South in Lafayette, La.,

Richard Beldyk discussed Six Sigma techniques at the Chattanooga Section program.
Shown at the NE Mississippi Section Christmas program are from left (top photo) Craig Johnson, Gary Gammill, Sue and Steve Latham, and Sam and Wanda Gray; (center photo) Ethel and Jerry Ruggles, Jerry and Betty Mordecai, and Teresa Gammill; (bottom photo) Dorothy and Vice Chair George Smith with Heather and Dan James.

Shown at the joint Acadiana-Baton Rouge Sections’ program are (from left) speaker Robert Hardy, sponsors Connie and Curt Benoit, District 9 Director George Fairbanks, Acadiana Section Chair Mike Skiles, and speakers Gilbert Torres and Daniel Lacomb.

Baton Rouge Section Chair David Rayborn (left) and Publicity Chair Markkevin Spencer are shown at the joint Acadiana-Baton Rouge Sections’ event.

sponsored by Connie and Curt Benoit, for a program on pipe manufacture. The presenters, Daniel Lacomb, from Stupp Corp., discussed welding processes; Gilbert Torres, from Apex NDT Training, outlined the welder training courses available locally; and Robert Hardy, from Virtual Media Integration, demonstrated an X-ray imaging system at the joint Acadiana-Baton Rouge Sections’ event.

BIRMINGHAM
November 4
Activity: Section members and students and welding instructors from the Welding, Industrial Maintenance, and Drafting and Design programs at Lawson State Community College traveled to Atlanta, Ga., to explore the exhibits at FABTECH.

NEW ORLEANS
November 13
Activity: The Section hosted its sixth annual student welding competition at New Orleans Pipe Trades in Metairie, La. The participants included 45 beginners and 5 advanced welders. Working the event were Aldo Duron, Ironworkers Local 58; Paul Deslatte, Chris Fernandez, and Jimmy Goodson, welding instructors; Chairman D. J. Berger; and judges Travis Moore, Tony DeMarco, and Bruce Hallila. Top scorers in the beginners contest were Brian Moody, Dustin Rodrigue, Titus Turner, Craigton Smith, and David Haar. The advanced category participants were Jontrell Jeffery, Matthew Blackwell, Eroll Laviere, David Shields, and Bryan Abadie.

November 13
Speaker: David Hernandez, senior manager, education development
Affiliation: American Welding Society
Topic: The AWS SENSE welder training
Activity: This New Orleans Section meeting was sponsored by Louisiana Technical College, represented by Cynthia Posky, director. John Bruskotter, 2010 AWS president, attended the program.
Win Great Prizes in the 2010-2011 AWS Member-Get-A-Member Campaign*

ABOUT: AWS is looking for individuals to become part of an exclusive group of AWS Members who get involved and win. Give back to your profession, strengthen AWS and win great limited-edition prizes by participating in the 2010-2011 Member-Get-A-Member Campaign. By recruiting new members to AWS, you're adding to the resources necessary to expand your benefits as an AWS Member. Year round, you’ll have the opportunity to recruit new members and be eligible to win special contests and prizes. Referrals are our most successful member recruitment tool. Our Members know first-hand how useful AWS Membership is, and with your help, AWS will continue to be the leading organization in the materials joining industry.

PRIZE CATEGORIES

resident’s Honor Roll: Recruit 2 new Individual Members and receive an AWS Sportpack bag.

resident’s Club: Recruit 3-8 new individual Members and receive an AWS hat and an AWS Sportpack bag.

resident’s Roundtable: Recruit 1-19 new Individual Members and receive an AWS polo or denim shirt, hat and an AWS Sportpack bag.

resident’s Guild: Recruit 20 or more new Individual Members and receive an AWS Messenger Bag, an AWS polo or denim shirt, a one-year free AWS Membership, the "Shelton Sitter Member Proposer Award" certificate and membership in the Winner’s Circle.

Winner’s Circle: All members who recruit 20 or more new Individual Members will receive annual recognition in the Welding Journal and will be honored at the FABTECH Show.

SPECIAL PRIZES

Participants will also be eligible to win prizes in specialized categories. Prizes will be awarded at the close of the campaign (June 2011).

Sponsor of the Year: The individual who sponsors the greatest number of new Individual Members during the campaign will receive a plaque, a trip to the 2011 FABTECH Show, and recognition at the AWS Awards Luncheon at the Show.

Student Sponsor Prize: AWS Members who sponsor two or more Student Members will receive an AWS Sportpack bag. The AWS Member who sponsors the most Student Members will receive a free, one-year AWS Membership, an AWS polo shirt, hat and an AWS Sportpack bag.

International Sponsor Prize: Any member residing outside the United States, Canada and Mexico who sponsors the most new Individual Members will receive a complimentary AWS Membership renewal.

LUCK OF THE DRAW

For every new member you sponsor, your name is entered into a quarterly drawing. The more new members you sponsor, the greater your chances of winning. Prizes will be awarded in November 2010, as well as in February and June 2011.

Prizes Include:
★ Complimentary AWS Membership renewal
★ AWS t-shirt
★ AWS hat

SUPER SECTION CHALLENGE

The AWS Section in each District that achieves the highest net percentage increase in new Individual Members before the June 2011 deadline will receive special recognition in the Welding Journal.

The AWS Sections with the highest numerical increase and greatest net percentage increase in new Individual Members will each receive the Neitzel Membership Award.

The 2010-2011 MGM Campaign runs from June 1, 2010 to May 31, 2011.
AWS MEMBERSHIP APPLICATION

4 Easy Ways to Join or Renew:
- Mail this form, along with your payment, to AWS
- Call the Membership Department at (800) 443-9353, ext. 480
- Fax this completed form to (305) 443-5647
- Join or renew on our website <www.aws.org/membership>

Mr.  Ms.  Mrs.  Dr.  Please print & Duplicate this page as needed

Last Name
First Name
M.I.
Title

Were you ever an AWS Member?  □ YES  □ NO
If "YES," give year ______ and Member # ______

Primary Phone ( ) Secondary Phone ( )

FAX ( )

Did you learn of the Society through an AWS Member?  □ YES  □ NO

From time to time, AWS sends out informational emails about programs we offer, new Member benefits, savings opportunities and changes to our website. If you would prefer not to receive these emails, please check here □

ADDRESS

Company (if applicable)
Address
Address Con’t.

City_ State/Province_ Zip/Postal Code_ Country_ 

PROFILE DATA

Who pays your dues?  □ Company  □ Self-paid  □ Sex: □ Male  □ Female
Education level:  □ High school diploma  □ Associate’s  □ Bachelor’s  □ Master’s  □ Doctoral

PAYMENT INFORMATION (Required)

ONE-YEAR AWS INDIVIDUAL MEMBERSHIP...

TWO-YEAR AWS INDIVIDUAL MEMBERSHIP...

New Member:  □ YES  □ NO  If "YES," give one-time initiation fee of $12 ______

International Members add $50 for optional hard copy of Welding Journal (note: digital delivery of WJ is standard)++*

Individual Members add $25 for book selection (up to a $192 value)++*

(Notes: Book Selection applies to new Individual Members only. Book selections on upper-right corner)

TOTAL PAYMENT ______

NEW MEMBER

DOMESTIC (Canada & Mexico incl.)...

INTERNATIONAL...

TOTAL PAYMENT ______

AWS STUDENT MEMBERSHIP+++... Get a popular welding publication for only $25 ($192 value)

Domestic (Canada & Mexico incl.)...

International...

TOTAL PAYMENT ______

NOTE: Dues include $18.70 for Welding Journal subscription and $4.00 for the AWS Foundation.

BOOK/CD-ROM SELECTION

(Pay Only $25... up to a $192 value)

NOTE: Only New Individual Members are eligible for this selection. Be sure to add $25 to your total payment.

FROM TIME TO TIME, AWS SENDS OUT INFORMATIONAL EMAILS ABOUT PROGRAMS WE OFFER, NEW MEMBER BENEFITS, SAVINGS OPPORTUNITIES AND CHANGES TO OUR WEBSITE. IF YOU WOULD PREFER NOT TO RECEIVE THESE EMAILS, PLEASE CHECK HERE □

New Member  Renewal

A free local Section Membership is included with all AWS Memberships. Section Affiliation Preference (if known):

Type of Business (Check ONE only)

A □ Contract construction
B □ Chemicals & allied products
C □ Petroleum & coal industries
D □ Primary metals industries
E □ Fabricated metal products
F □ Machinery except elect. (incl. gas welding)
G □ Electrical equip, supplies, electrodes
H □ Transportation equip. — air, aerospace
I □ Transportation equip. — marine
J □ Transportation equip. — railroad
K □ Utilities
L □ Welding distributors & retail trade
M □ Misc. repair services (incl. welding shops)
O □ Educational Services (univ., libraries, schools)
P □ Engineering & architectural services (incl. assns.)
Q □ Misc. business services (incl. commercial labs)
R □ Government (federal, state, local)
S □ Other

Job Classification (Check ONE only)

01 □ President, owner, partner, officer
02 □ Manager, director, superintendent (or assistant)
03 □ Sales
04 □ Purchasing
05 □ Engineer — welding
20 □ Engineer — design
21 □ Engineer — manufacturing
06 □ Engineer — other
10 □ Architect designer
12 □ Metallurgist
13 □ Research & development
22 □ Quality control
07 □ Inspector, tester
08 □ Supervisor, foreman
14 □ Technician
09 □ Welder, welding or cutting operator
11 □ Consultant
15 □ Educator
16 □ Librarian
17 □ Student
18 □ Customer Service
19 □ Other

Technical Interests (Check all that apply)

A □ Ferrous metals
B □ Aluminum
C □ Nonferrous metals except aluminum
D □ Advanced materials/Intermetallics
E □ Ceramics
F □ High energy beam processes
G □ Arc welding
H □ Brazing and soldering
J □ Resistance welding
K □ Thermal spraying
L □ Cutting
M □ NDT
N □ Safety and health
O □ Bending and shearing
P □ Roll forming
Q □ Stamping and punching
R □ Aerospace
S □ Automotive
T □ Machining
U □ Marine
V □ Pressure vessels and tanks
W □ Sheet metal
X □ Structures
Z □ Automation
1 □ Robotics
2 □ Computerization of Welding

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American Welding Society
550 N.W. LeJeune Rd
Miami, FL 33126
Telephone (800) 443-9353
FAX (305) 443-5647
Visit our website: www.aws.org

*FLSA... Get a popular welding publication for only $25 ($192 value)

**Please... Get a popular welding publication for only $25 ($192 value)

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Member Services Revised 8/2/10
Birmingham Section members and Lawson State Community College students and instructors are shown at the entrance to FABTECH.

New Orleans Section Chair D. J. Berger (left) is shown with speaker David Hernandez (center) and John Bruskotter, 2010 AWS president.

Shown at the New Orleans Section beginners welding contest are from left (standing) Aldo Duron, Paul Deslatte, Brian Moody, Craigton Smith, David Haar, Chris Fernandez, Jimmy Goodson, Dustin Rodriguez, and Chair D. J. Berger; (front row) Travis Moore, Tony DeMarco, and Titus Turner.

New Orleans Section participants in the advanced welding contest are from left (back row) Bruce Hallila, Jontrell Jeffery, Matthew Blackwell, Chris Fernandez, Jimmy Goodson, Bryan Abadie, and Chair D. J. Berger; (front row) Tony DeMarco and Erroll Laviere.

**District 10**

Richard A. Harris, director
(440) 338-5921
richaharris@windstream.net

**DRAKE WELL**

**DECEMBER 14**

Activity: The Section held a social meeting in Cranberry, Pa. Eric Speer, a recipient of a District 10 scholarship, reported on his achievements at Penn College. The Section donated $100 to the Pittsburgh Section for its weld-off contest. Attending were Chair Mike Owens, Treasurer Ward Kiser, and Travis Crate, secretary.
Shown at the Drake Well Section meeting are (from left) Chair Mike Owens, speaker Eric Speer, Treasurer Ward Kiser, and Secretary Travis Crate.

Host Don Maatz (right) had the privilege of introducing the mystery guest of honor at the Detroit Section’s party.

Milwaukee Section past chairs met at the December meeting. From left are Roger Edge, Dennis Orlinski, Richard Nowicki, Craig Wentzel, John Albanese, John Hinrichs, Joseph Campbell, Gail Beyer II, and Mike Kersey with John Bruskotter, 2010 AWS president.

Robert Bruss received his Silver Member certificate from Karen Gilgenbach, Milwaukee Section chair, in December.

Detroit Section members are shown at the holiday party.

District 11
Robert P. Wilcox, director
(734) 721-8272
rmwilcox@wowway.com

DESTROY
December 9
Activity: The Section hosted its annual holiday party at Club Venetian in Madison Heights, Mich., for 80 attendees. Featured were a silent auction, 50/50 draw, and buffet-style dinner. Don Maatz, RoMan Engineering, served as host for the evening. Sponsors contributing to the Section include KUKA, Obara, CenterLine, MJM Sales, ATI, Denganhsa, Fusion Welding Solutions, RoMan Engineering, ARO, Syndevo, and Industrial Control Repair.

District 12
Daniel J. Roland, director
(715) 735-9341, ext. 6421
daniel.roland@us.fincantieri.com

MILWAUKEE
November 18
Activity: The Section members met at Bucyrus International in South Milwaukee, Wis., for a tour of the facility. The presenters included Dan Barich, director of manufacturing; Wayne Chmiel, vice president of product line shovels; Dave Wagner, manufacturing engineering manager; and Steve Behrendt, product manager, shovels. Discussed were the history of the company, recent acquisitions, and changes to the company’s lean manufacturing program. The facility, recently purchased by Caterpillar Corp., produces equipment for surface and underground mining operations. About 135 people attended the event.

DECEMBER 16
Speaker: John Bruskotter, 2010 AWS president
Affiliation: Bruskotter Consulting Services
Topic: Fabrication and operations of offshore drilling rigs
Activity: The Milwaukee Section held its past chairmen’s night, dinner, and spirits tasting event at Great Lakes Distillery LLC in Milwaukee, Wis. In attendance were past chairs Roger Edge, Dennis Orlinski, Richard Nowicki, Craig Wentzel, John Albanese, John Hinrichs, Joseph Campbell, Gail Beyer II, Mike Kersey, and present Chair Karen Gilgenbach. Robert Bruss received his Silver Member certificate for 25 years of service to the Society.

RACINE-KENOSHA
November 17
Activity: The Section members and students from Gateway Technical College convened to tour the American Champion Aircraft Corp. facilities in Rochester, Wis. The privately owned company produces light acrobatic and utility aircraft. Jerry Mehlhaff, president, and Mick Theobald, supervisor, conducted the event.
Racine-Kenosha Section members and Gateway Technical College students toured American Champion Aircraft in November.

Shown at the Chicago Section outing are (from left) Stu Cleven, Cliff Ifiimic, Ralph Daein, ASNT Treasurer Jennifer Anaya, Ray Moresen, Bob Zimny, Craig Tichelar, and Hank Sima.

District 13

W. Richard Polanin, director
(309) 694-5404
rpolanin@icc.edu

CHICAGO

DECEMBER 3

Activity: The Section members joined members of the local chapter of ASNT for an outing at Chicago Zoological Society.

PEORIA-

ICC Student Chapter

NOVEMBER 16

Speaker: Kerwin Brown, welding instructor
Affiliation: ICC and Metamora H.S.
Topic: Progressing from welder to inspector to college welding instructor
Activity: This Peoria Section and Illinois Central College Student Chapter meeting was held at Lariat Club in Peoria, Ill.

District 14

Robert L. Richwine, director
(765) 378-5378
bobrichwine@aol.com

INDIANA

OCTOBER 17

Speakers: Greg Early, Chris Cumberworth
Topic: New line of welding equipment
Activity: This meeting was held at Walker Career Center in Indianapolis, Inc. Following the talks, the presenters demonstrated the new equipment.

LEXINGTON

NOVEMBER 18

Speaker: Tom Nygen, sales representative
Affiliation: Hypertherm
Topic: Plasma arc welding
Activity: Anthony Newsome and Thomas

Chris Cumberworth addressed the Indiana Section members in October.

Shown at the Lexington Section program are (from left) Chair Tim Pinson, Anthony Newsome, Thomas Alley, and Scott Stringer, welding instructor.

Peoria Section Chair Phil England (left) is shown with speaker Kerwin Brown.
Joe Clasen discussed phased array ultrasonics at the Kansas Section program.

Alley were each presented a $500 Woodrow Scott Memorial Scholarship award to further their welding educations. Attending this Lexington Section program was welding instructor Scott Stringer.

The Kansas Section members are shown at the November program.

ST. LOUIS
OCTOBER 21
Activity: The Sheet Metal Workers Local 36 sponsored this oxyfuel safety training seminar, represented by Ed Kasper and Billy Crow. Each received a sponsor appreciation gift from Chair Victor Shorkey. The seminar was presented by Kevin Showers from Thermadyne Corp.

KANSAS
NOVEMBER 11
Speaker: Joe Clasen, NDT instructor
Affiliation: Cowley Community College
Topic: Phased array ultrasonics and laser shearography
Activity: The meeting was held at Cowley Community College in Mulvane, Kan.

NEBRASKA
NOVEMBER 18
Speaker: John Bruskotter, 2010 AWS president
Affiliation: Bruskotter Consulting Services
Topic: Fabrication and operations of offshore drilling rigs
Activity: John Kirke received the Section and District Educator of the Year Awards, Scott Blankman received the Section and District CWI of the Year Awards. Rick
Nebraska Section awardees are (from left) John Kirke, Rick Hanny, and Scott Blankman.

Hanny received the Section and District Meritorious Service Awards and an appreciation plaque for serving as Section chair. Olsson & Associates was acknowledged for its services to the Nebraska Section.

**District 17**

J. Jones, director  
(940) 368-3130  
jones@thermadyne.com

**TULSA**

**NOVEMBER 18**

Activity: The Section members toured Valmont Industries in Tulsa, Okla., to study the manufacture of electric transmission towers. Tony Schuler, manufacturing manager, conducted the program, assisted by Richard Schiller, a welding specialist; and Drew Hammond, safety manager.

**District 18**

John Bray, director  
(281) 997-7273  
sales@affiliatedmachinery.com

**SAN ANTONIO**

**NOVEMBER 9**

Activity: The Section’s student night program attracted about 70 students from two Student Chapters to the hands-on welding and cutting event held at St. Philips College in San Antonio, Tex. The speaker was John Bray, District 18 director, who addressed the students on the importance of considering a career in welding. Rob Tessier from Airgas Southwest, Clifton Rogers, Floresville H.S. welding instructor, and Howard Thomas, Section technical representative, assisted the students with the exercises.

**District 19**

Neil Shannon, director  
(503) 201-5142  
neilshnn@msn.com

**SPOKANE**

**NOVEMBER 17**

Speaker: Bud Kersey  
Affiliation: Moldex-Metric, Inc.

**District 20**

William A. Komlos, director  
(801) 560-2353  
bkoz@arctechllc.com

**COLORADO**

**NOVEMBER 11**

Activity: The Section members met at the Lincoln Electric Co., facility in Englewood, Colo., for a talk and demonstration of the VRTEX™ 360 virtual reality arc welding training solution. Dave Fullen, district manager, made the presentation.

Chuck Buck discussed the manufacture of quality knife blades for the Spokane Section members.
**Dean Mitchell (left), Colorado Section chair, tries his virtual reality welding skills coached by Lincoln representative Dave Fallen.**

**Butte College students attended the Sacramento Section program.**

**Speaker John DeHaan is shown with Liisa Pine, San Francisco Section chair.**

**IDAHO/MONTANA**

**DECEMBER 9**

Speaker: **Darren Pape**, operations manager  
Affiliation: Wolf Robotics LLC  
Topic: Improving welding and manufacturing tasks with robotics  
Activity: The program was held at Front Range Community College in Fort Collins, Colo. Following the talk, the attendees toured the college’s welding department.

**District 21**

Nanette Samanich, director  
(702) 429-5017  
nan07@aol.com

**District 22**

Dale Flood, director  
(916) 288-6100, ext. 172  
d.flood@tritool.com

**SACRAMENTO**  
**SEPTEMBER 28**  
Activity: The Section held a business meeting at American River College in Sacramento, Calif. Attending were Matt Wysocki, Mark Feuerbach, Mark Reese, Melvin Johnson, Bruce Tanner, David Kilburn, Jerry Wentland, Chair Ken Morris, Rob Purvis, and Dale Flood, District 22 director.

**NOVEMBER 17**

Speaker: **Sylvio Modena**  
Topic: Advancements in gas tungsten arc welding  
Activity: The Sacramento Section hosted this well-attended event at American River College in Sacramento, Calif. Students from Butte College, Chico, Calif., attended the program.

**SAN FRANCISCO**

**DECEMBER 1**

Speaker: **John D. DeHaan**  
Affiliation: Fire-Ex Forensics, inc.  
Topic: Fire and arson investigations  
Activity: The Section hosted this special holiday program at Spenger’s Restaurant in Berkeley, Calif.
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Submit Nominations for the M.I.T. Award

The deadline for submitting nominations for the 2012 Prof. Koichi Masubuchi Award is Nov. 2, 2011. Sponsored by the Dept. of Ocean Engineering at Massachusetts Institute of Technology (M.I.T.), this award, includes a $5000 honorarium. It 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.

Nominations should include the candidate’s experience, publications, honors, and awards, and at least three letters of recommendation from fellow researchers. E-mail your nomination package to Todd A. Palmer, assistant professor, The Pennsylvania State University, tapl03@psu.edu.

Contribute Your Knowledge to These Technical Committees

Marine Construction
The D3 Committee for Welding in Marine Construction to contribute to the development of D3.5, Guide for Steel Hull Welding; D3.6, Specification for Underwater Welding; D3.7, Guide for Aluminum Hull Welding; and D3.9, Specification for Classification of Weld-Through Paint Primers. Contact B. McGrath, bmcgrath@aws.org, ext. 311.

Mechanical Testing of Welds
The B4 Committee for Mechanical Testing of Welds to contribute to B4.0, Standard Methods for Mechanical Testing of Welds. Contact B. McGrath, bmcgrath@aws.org, ext. 311.

Surfacing Industrial Mill Rolls

Magnesium Alloy Filler Metals
ASL Subcommittee on Magnesium Alloy Filler Metals to assist in the updating of AWS A5.19-92 (R2006), Specification for Magnesium Alloy Welding Electrodes and Rods. Contact R. Gupta, gupta@aws.org, ext. 301.

Robotic and Automatic Welding

Thermal Spraying

Labeling and Safe Practices
SH4 Subcommittee on Labeling and Safe Practices to update AWS F2.2, Lens Shade Selector; AWS F4.1, Safe Practices for the Preparation of Containers and Piping for Welding and Cutting; and the AWS Safety and Health Fact Sheets. S. Hedrick, steveh@aws.org, ext. 305.
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Staff extensions are shown in parentheses.

AWS PRESIDENT
John L. Mendoza
johnlmendoza@att.net
Lone Star Welding
3319 Kashmir, San Antonio, TX 78223

ADMINISTRATION
Ray W. Shook, rbshook@aws.org ..........(210)
Deputy Executive Director
Cassie R. Burrell, cburrell@aws.org .... (253)
Sr. Associate Executive Director
Jeff Weber, jweber@aws.org ..........(246)
Associate Executive Director Accounting
Gesana Villegas, gvillegas@aws.org .... (252)
Executive Assistant for Board Services
Gricelda Manalich, gricelda@aws.org ......(294)

Administrative Services
Jim Lankford, jmlankford@aws.org ......(214)
IT Network Director
Armando Campana, acampana@aws.org ... (296)
Director of IT Operations
Natalia Swan, nswan@aws.org ..........(245)

Human Resources
Hidal Nunez, hidal@aws.org ..........(287)
Director of IT Operations
Natalia Swan, nswan@aws.org ..........(245)

Director, Compensation and Benefits
Luis Hernandez, luisa@aws.org ..........(266)
Director, Human Resources
Dora A. Shada, dshada@aws.org ..........(235)

INT’L INSTITUTE of WELDING
Sr. Coordinator
Sissibeth Lopez, sissibeth@aws.org ......(319)
Liaison services with other national and international societies and standards organizations.

GOVERNMENT LIAISON SERVICES
Hugh K. Webster, hwebster@vc.com ..... (201)
Webster, Chamberlain & Bean, Washington, D.C., (202) 785-9500; FAX (202) 835-0243, Monitors federal issues of importance to the industry.

CONVENTION and EXPOSITIONS
Jeff Weber, jweber@aws.org ..........(246)
Corporate Director, Exhibition Sales
Joe Kral, jkral@aws.org ......(297)
Organizes annual AWS welding show, convention, space assignments, and other expo activities.

Director, Convention and Meeting Services
Selvis Morales, smorales@aws.org ......(239)

Brazing and Soldering Manufacturers’ Committee
Jeff Weber, jweber@aws.org ..........(246)

GAWDA — Gases and Welding Distributors Association
Executive Director
John Ospina, jospina@aws.org ..........(462)
Operations Manager
Natalia Alexis, nalexis@aws.org ......(401)

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Manager
Susan Hopkins, susan@aws.org ......(295)

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Natalie Tapley, natalie@aws.org ......(444)

PUBLICATION SERVICES
Department Information ..........(275)
Managing Director
Andrew Cullison, cullison@aws.org ......(249)

Welding Journal
Publisher
Andrew Cullison, cullison@aws.org ......(249)

Mary Ruth Johnsen, mjohansen@aws.org ......(238)

National Sales Director
Rob Saltzstein, rlsaltz@aws.org ......(243)

Society and Section News Editor
Howard Woodward, woodward@aws.org ......(244)

Welding Handbook
Editor
Annette O’Brien, oobrien@aws.org ......(303)

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Public Relations Manager
Cindy Weih, cweih@aws.org ......(416)
Webmaster
Jose Salgado, jsalgado@aws.org ......(456)
Section Web Editor
Henry Chinea, hchinea@aws.org ......(452)

MEMBER SERVICES
Department Information ..........(480)
Deputy Executive Director
Cassie R. Burrell, cburrell@aws.org ......(253)

Rhenda A. Kenny, rhenda@aws.org ......(260)
Serves as a liaison between Section members and AWS headquarters.

CERTIFICATION SERVICES
Department Information ..........(273)
Director, Certification Operations
Terry Perez, tperez@aws.org ......(470)
Oversees application processing, renewals, and exam scoring.

Director, Int’l Business & Certification Programs
Pritil Jain, pjain@aws.org ......(228)
Directs all int’l business and certification programs.
Is responsible for oversight of all agencies handling AWS certification programs.

Director, Certification Programs
Linda Henderson, lhenderson@aws.org ......(296)
Oversees the development of new certification programs, as well as AWS-Accredited Test Facilities, and AWS Certified Welding Fabricators.

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Martica Ventura, mventura@aws.org ......(224)
Sr. Manager, Education Development
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Wendy S. Reeves, wreeves@aws.org ......(293)
Coordinates AWS awards and AWS Fellow and Counselor nominees.

TECHNICAL SERVICES
Department Information ..........(340)
Managing Director
Andrew R. Davis, adavis@aws.org ......(466)

Society and Standards Activities
Manager, National Standards Activities
John L. Gayler, jgayler@aws.org ......(472)
Personnel and Facilities Qualification, Computerization of Welding Information, Thermal Spray, and Friction Welding, Welding Qualification

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Metric Practices, Safety and Health, Joining of Plastics and Composites, Welding Iron Castings, Welding in Sanitary Applications

Sr. Manager, Technical Publications
Rosalinda O’Neill, ronell@aws.org ......(451)
AWS publishes about 200 documents widely used throughout the welding industry.

Sr. Engineer
Rakesh Gupta, rgupta@aws.org ......(301)
Filler Metals and Alloys, Int’l Filler Metals, UNS Numbers Assignment

Staff Engineers/Standards Program Managers
Annette Alonso, aadono@aws.org ......(299)
Automotive and Railroad Welding, Resistance Welding, Oxyfuel Gas Welding and Cutting, Definitions and Symbols, Sheet Metal Welding

Stephen Borraro, sborraro@aws.org ......(334)

Brian McGrath, bmcgrath@aws.org ......(311)
Methods of Inspection, Mechanical Testing of Welds, Welding in Marine Construction, Piping and Tubing

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Plasma Beveling Technology Offers Precise Plate Weld Preparation

In a recent cooperative experiment between Canadian and Australian companies, engineers ran two tests of precision plate weld preparation attaching a new three-axis (ACZ) plasma bevel head to a conventional XY plate profiler to create a synchronous five-axis plasma profiler. The core question was whether the new-generation plasma torches combined with the latest many axis controls were capable of producing multi-face beveled edges of sufficient accuracy for practical weld preparation.

Numerically controlled (NC) plate beveling machines have been in the marketplace for 30 years. However, their population is less than 0.5% of the approximately 200,000 machines worldwide. Therefore, plate weld preparation remains as it has always been, a shop problem, and almost all plate steel is square cut except for shipbuilding and, lately, for windtowers. So despite massive advances in welding technology over the years, the required weld preparation is still a semi-manual process: slow, dirty, demanding, costly, and requiring skilled operators. With an aging workforce, this is a serious problem for maintaining core capacities in heavy engineering.

The quest was whether we could precision cut K bevels in weld-ready parts with an NC plasma torch to an accuracy of ± 1 mm. To do this, three passes were used — Fig. 1.

Many specific innovations were also being tested including a distance measuring laser for torch height, three digital servos inside a pantograph bevel head, and a series of mathematical modules to calculate positions and compensations in real time. The pantograph design eliminates errors from torch rotation. The patent-pending plate scanning device removes height errors from traditional arc voltage height control.

Numerical control plate profilers have only two axes, X and Y. Beveling machines add torch tilt (A), the plane of torch tilt (C), and there is usually a torch tilt Z axis. While this looks like five axes, in almost all machines the C is kept square to the XY path in a method called tangential following so it is a dependent axis. In a legacy concept from the 1980s, torch height or Z is not programmable but driven by an independent torch height control. Lastly, the torch-tilt axis is generally not able to be interpolated with the XY axes. So most existing beveling machines have only 2½ simultaneous interpolated axes, which is very limiting, and you cannot get bevels into the inside corners or notches. To create sharp outside corners, this means large loops are required, which waste plate and make three-pass weld preparation impossible.

In contrast, in the two tests conducted, five simultaneous axes were used: X, Y, A, C, and Z. The complex and coupled tilt and twist axes in the pantograph design were derived with real-time computation from the programmed axes A and C.

A further critical restriction in most existing machines is that torch tilt is generally limited to 45 deg. This is actually a severe limitation, which can leave as much as half the material removal to be finished by hand. For example, to create sharp corners without loops, the torch needed to tilt much further for the large groove angles in Test 2.

The test can be seen on www.youtube.com/user/FastCAMServ ice/. Much of the software technology is invisible in the video and beyond the scope of this article. A new entirely mathematical approach was developed to generate torch position, varying feed, and kerf and torch angles both in the generation of the NC and in the control itself. This was based on the assumption that the modern plasma arc could be modeled as a cylinder with diameter dependent only on effective material thickness and feed rate. Finally, and unlike other systems, no empirically derived tables were used for the many offsets involved.

The two tests required similar K bevels on small parts about 300 x 200 x 25 mm thick. The 5-mm-deep weld face was vertical in the first test and rolling in the second, simulating the developed edge of an oblique cut through a pipe. Grooves were at a constant 30 deg relative to the weld root face angle.

In each test, the bottom pass was cut first, then the center pass, and finally the top pass to minimize the effect of previous cuts. To achieve the sharp corners in Test 1, there are stationary points where only the two rotary axes A and C move with no XY movement. Industry opinion was that this would not work. The quality of the cut was also quite unknown as the feed rate varies along the length of the arc itself. Other sections require four simultaneous axis movements X-Y and A-C. The torch tilt had to increase smoothly from 30 to 39.2 deg and return while moving and cutting. Z movement over these distances is tiny.

In the earliest tests, it was unknown whether the V-shaped scrap between the first and second passes would drop and block the third pass, the part move between passes, the corners melt away, and the arc stay cutting when the machine was not actually moving. Even successful crossing of existing cut paths was unknown let alone part tolerances and quality. Dross was a concern as was the path of the plasma beam when additional pathways were available for the plasma stream. Splitting and curvature of the beam were possibilities.

Close examination of the finished parts indicated very acceptable quality, straight cuts, and size and edge profiles within tolerances at cuts up to 55 deg.

The Bevel Editor. Not shown in the videos is that the three-pass NC programs were created from the CAM file without explicit NC programming. In the patent-pending concept, 3D CAM parts are completely defined by a welding professional including all weld preparation.
The CAM files remain 2-D in nature with parameterization on each geometric entity to enable the recreation of the 3-D part. The files at this point are independent of the cutting process.

To create these files, a separate piece of software called Bevel Editor is needed. It is the intention of FastCAM, Inc., to make Bevel Editor free to welding professionals.

At the production site, the files are nested onto a plate for a specific machine and cutting technology. It is only then that part geometry is translated into multiple passes on the top of the plate. The machine-specific NC code is generated automatically with all the compensations, offsets, passes, and corners in place. With this approach, there is also no practical difference between nesting and cutting weld-ready parts and traditional square cut parts allowing a smooth transition to the new technologies.

The angle D is the local dihedral angle relevant to welding the upper groove. The default is 90 deg, which is common for an orthogonal T joint. For butt joints, the equivalent or notional supporting element face is simply the bisector of the butt joint and the groove angles and root opening can be halved. Note that such direct NC programming systems as exist require D = 90 deg at all times, which severely restricts their usefulness.

D is an intrinsic property of the assembly before weld preparation. It is not directly a welding parameter. Rather, it can be defined with no knowledge of what joint technology will ultimately be applied. While it is seldom defined on individual part drawings, it should always be derivable from the assembly.

The remaining parameters G, A1, R1, A3, and R3 are all weld prep parameters and can be varied to define single and double bevel or V grooves, with or without a finite root face depth. This is equally relevant for complete-joint-penetration (CJP) and partial-joint-penetration (PJP) applications.

Plan Dimensions. If the weld root face is not vertical (D other than 90 deg), a critical issue is how the plan view part drawing has been dimensioned. With weld preparation, the parts are now 3-D. The common choices with our categorization are shown in Fig. 3.

- **Z#0** is the most common in practice. When parts are square cut on all edges, it guarantees sufficient material for weld prep to be applied using secondary processing techniques.
- **Z#1** is the exact converse of Z#0 and has the advantage that parts can be assembled prior to any secondary processing, provided that secondary processing can be undertaken in-situ.
- **Z#2** is most commonly applied to parts that are developed by triangulation.
- **Z#1** is often encountered at butt joints between parts of unequal thickness.

Z#0 has become a de facto standard, and many NC systems require that all parts be redrawn. Then, NC controls have to project the movements to the top surface and attempt to solve the path discontinuity problems. In our approach, there is no need to redraw parts. It is only necessary to categorize the dimensioning method used, and no change is required in shop detailing practices.

**Varying Bevel Editor.** Curved plate work is based on the same principles but is typically more complex. Given the large angle variation, the type of weld preparation can actually often vary along a single edge.

In Test 2, the initial CAM file was created with software that defined the shape of the edge by its X, Y values plus the dihedral angle D at each vertex, and Z# for the edge. Had these data been supplied via a file from a general design system, the Z# and D would need to be determined and D entered manually at a sufficient number of points along the edge to satisfactorily represent the rolling dihedral edge. Bevel Editor is changed to a spreadsheet-style format for this purpose, and will calculate all intermediate D values in a vertex table using edge-length based linear interpolation.

Additional Software. The type of weld chosen is based on many factors including access, equipment, skills, time, location, and, ultimately, cost, which can vary greatly. Within Bevel Editor, Weld Prep Wizard (WPW) provides a rational decision framework for specifying and then costing a variety of preapproved weld preparations for a particular joint detail.

The logic is based on a tabulation of permissible weld prep details for ranges of dihedral angle. It can include a fabricator’s own WPS library details plus prequalified details from any number of welding standards including AWS D1.1, Structural Welding Code — Steel. A simple costing model is used.

The WPW decision framework covers the following stages:
- **Position:** All, flat, horizontal, vertical, overhead — per side.
- **Joint arrangement:** T; butt, corner bevel, corner V
- **Joint type:** Complete penetration groove, partial penetration groove, or fillet
- **Welding process:** Shielded metal arc, submerged arc, flux cored arc welding, etc. (definable in costing model)
- **Backing:** Usage, location, removal requirement
- **Access:** Top, bottom, both
- **Position:** All, flat, horizontal, vertical, overhead — per side.

Given all applicable data, WPW presents all viable options in a table ranked by cost.

One characteristic of such joints is potential for an extreme range of dihedral angles. The CJP provisions of AWS D1.1 can be summarized in chart form as shown in Fig. 4.

Large tubular members are normally developed inside-up ready for forming, so the external local dihedral angle for welding, Ψ, translates to a beveling dihedral angle D = 180 − Ψ, while the groove angle, Φ, equates with the parameter A1 at the underside of the plate.

The diagram plots an envelope of the range of groove angles prequalified for a given local dihedral angle, which are actually
defined vice versa in AWS D1.1:2008 Table 3.6. The zones labeled A...D correspond with the detail diagrams drawn in AWS D1.1 Figs. 3.8-3.10. The dashed lines represent the effects of tilt limits. The importance of a 60-deg tilt limit is the dihedral can go as low as 60 with a much reduced groove angle of 30.

The left area plots prequalified ranges of root openings for various groove angles. The table in red represents data from the fabricator’s WPS library, which is plotted in red on the diagrams above the table for ready reference. This diagram is for complete joint penetration.

Once the choices are made, the WPW fills the vertex table with weld prep parameters for every dihedral angle D, the parameters being interpolated from the tabulated data in the relevant chart.

Information Transfer. Five-axis NC milling has had the ability to transfer 3-D parts electronically for immediate and accurate manufacture for some years, a simplicity that has been denied plate fabricators because of their additional requirement to nest parts onto flat plate. FastCAM’s patent-pending invention achieves a similar facility for parts with weld preparation. The key concept is that the CAM file remains a 2-D file for the purpose of nesting but contains parametric description of the finished 3-D part. These parts then can be nested in a modified, but largely conventional, nesting system and mixed freely with square-cut parts and with precise clearances.

What’s Next

With the availability of the new technology, the authors expect to see a rapid change to precision weld preparation instead of just square cutting of plate. The technology adds little cost, but offers opportunities for cost savings and gains in productivity. The benefits take on greater significance because of the expected reductions in skilled shop labor. Very quickly, whether in house or through service centers, fabricators will demand weld-ready parts not raw shapes. These experiments have shown that precision automatic weld preparation is now possible on plate without the need for hand grinding.

MATTHEW J. FAGAN (matthew.fagan@fastcam.com.au) is president and MIKE MCCORMICK is senior engineer, FastCAM, Inc., Melbourne, Victoria, Australia.
Start thinking about who you will nominate for the 2011 Image of Welding Awards recognizing exemplary dedication to promoting the image of welding.
Paper Discusses Protecting Eyes in the Workplace

The eight-page, well-illustrated, full-color paper, Eye Safety At-a-Glance: Protecting Your Vision at Work, details specific job categories, the main hazards encountered in each, and the protective eyewear recommended. The categories specified are welding, electrical work, plumbing, manufacturing, health care, laboratory, and janitorial work. One section details what to do and what not to do when an eye injury occurs and before professional medical care can be received. The introduction provides a wealth of facts and statistics related to workplace vision mishaps and the workers most exposed to injurious situations. The page on prevention details the various eye-protection products on the market and compares the characteristics of glass, plastic, and polycarbonate lenses. The document can be downloaded as a PDF from the Web site shown.

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The 20-page, full-color, well-illustrated Navy Metalworking Center 2010 Annual Report, Advanced Metalworking Solutions for Naval Systems that Go in Harm’s Way, illustrates and details a number of the center’s accomplishments in the development
and transition of advanced metalworking and manufacturing technologies during the year. A few of the projects described are a mechanized tool for weld joint fac- ing and backgouging, clean steel casting practices, near-net-shape casting, electron beam direct manufacturing, an optimized laser peening process, exothermic welding and insulation processes for splicing power cables, uses for new HSLA steels, laser coating-removal processes, and many others.

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For info go to www.aws.org/ad-index
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, 2011. The committee looks forward to receiving these nominations for 2012 consideration.

Sincerely,

Alfred F. Fleury
Chair, Counselor Selection Committee
CLASS OF 2012
COUNSELOR NOMINATION FORM

DATE ____________________ NAME OF CANDIDATE ____________________

AWS MEMBER NO. ____________________ YEARS OF AWS MEMBERSHIP ________________

HOME ADDRESS

CITY ____________________ STATE ____________________ ZIP CODE ____________________ PHONE ____________________

PRESENT COMPANY/INSTITUTION AFFILIATION

TITLE/POSITION

BUSINESS ADDRESS

CITY ____________________ STATE ____________________ ZIP CODE ____________________ PHONE ____________________

ACADEMIC BACKGROUND, AS APPLICABLE:

INSTITUTION

MAJOR & MINOR

DEGREES OR CERTIFICATES/YEAR

LICENSED PROFESSIONAL ENGINEER: YES ______ NO ______ STATE ________________

SIGNIFICANT WORK EXPERIENCE:

COMPANY/CITY/STATE

POSITION ____________________ YEARS

COMPANY/CITY/STATE

POSITION ____________________ YEARS

SUMMARIZE MAJOR CONTRIBUTIONS IN THESE POSITIONS:

______________________________________________

______________________________________________

______________________________________________

IT IS MANDATORY THAT A CITATION (50 TO 100 WORDS, USE SEPARATE SHEET) INDICATING WHY THE NOMINEE SHOULD BE SELECTED AS AN AWS COUNSELOR ACCOMPANY THE NOMINATION PACKET. IF NOMINEE IS SELECTED, THIS STATEMENT MAY BE INCORPORATED WITHIN THE CITATION CERTIFICATE.

**MOST IMPORTANT**

The Counselor Selection Committee criteria are strongly based on and extracted from the categories identified below. All information and support material provided by the candidate's Counselor Proposer, Nominating Members and peers are considered.

SUBMITTED BY:

PROPOSER

AWS Member No. ____________________

The proposer will serve as the contact if the Selection Committee requires further information. The proposer is encouraged to include a detailed biography of the candidate and letters of recommendation from individuals describing the specific accomplishments of the candidate. Signatures on this nominating form, or supporting letters from each nominator, are required from four AWS members in addition to the proposer. Signatures may be acquired by photocopying the original and transmitting to each nominating member. Once the signatures are secured, the total package should be submitted.

NOMINATING MEMBER: ____________________ Print Name ____________________

AWS Member No. ____________________

NOMINATING MEMBER: ____________________ Print Name ____________________

AWS Member No. ____________________

NOMINATING MEMBER: ____________________ Print Name ____________________

AWS Member No. ____________________

NOMINATING MEMBER: ____________________ Print Name ____________________

AWS Member No. ____________________

NOMINATING MEMBER: ____________________ Print Name ____________________

AWS Member No. ____________________

SUBMISSION DEADLINE JULY 1, 2011
Nomination of AWS Counselor

I. HISTORY AND BACKGROUND

In 1999, 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 such as AWS, IIW, WRC, SkillsUSA, NEMA, NSRP SP7 or other similar groups.)
- Leadership of or within an organization that has made 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 employees in industry activities such as AWS, IIW, WRC, SkillsUSA, NEMA, NSRP SP7 or other similar groups.)

II. RULES

A. Candidates for Counselor shall have at least 10 years of membership in AWS.
B. Each candidate for Counselor shall be nominated by at least five members of the Society.
C. Nominations shall be submitted on the official form available from AWS headquarters.
D. Nominations must be submitted to AWS headquarters no later than July 1 of the year prior to that in which the award is to be presented.
E. Nominations shall remain valid for three years.
F. All information on nominees will be held in strict confidence.
G. Candidates who have been elected as Fellows of AWS shall not be eligible for election as Counselors. Candidates may not be nominated for both of these awards at the same time.

III. NUMBER OF COUNSELORS TO BE SELECTED

Maximum of 10 Counselors selected each year.

Return completed Counselor nomination package to:

Wendy S. Reeve
American Welding Society
Senior Manager
Award Programs and Administrative Support
550 N.W. LeJeune Road
Miami, FL 33126
Telephone: 800-443-9353, extension 293

SUBMISSION DEADLINE: July 1, 2011
Want to Find Your Next Great Lead? Head to Monterrey!

Join AWS in Mexico as an exhibitor at Weldmex 2011!

May 11-13, 2011

As an AWS Weldmex exhibitor you’ll meet with eager buyers in the following industries:
- Aerospace
- Agriculture
- Contract Manufacturing
- Construction
- Heavy Equipment
- And more!

Take advantage of this great opportunity to meet with industry professionals and showcase your company’s products or services!

For AWS Weldmex exhibitor information, visit www.awsweldmex.com or call (305) 443-9353 ext 297
CenterLine® Appoints Account Manager

CenterLine (Wind-sor) Ltd., Windsor, Ont., Canada, has named Joe Ruggiero corporate account manager responsible for the company’s commodity supply commitments and standard component product sales to Ford Motor Co. operations throughout North America. Ruggiero joins the company with 15 years of experience managing welding commodity programs in the automotive industry. For the past ten years, he operated JEC Distributors, a welding component commodity distribution company.

Aluminum Association Announces Staff Changes

The Aluminum Association, Arlington, Va., has announced that Robert R. Strieter, vice president, health, environment & safety, will retire, effective March 1. The position will be filled at that time by Chuck Johnson, currently serving as director of environment, health & safety. Strieter has been with the association since 1994. Previously, he worked for the American Petroleum Institute. Johnson has served the association since 1999 in occupational health and safety, community and consumer protection, and international regulation activities.

President Named at BLACOH™ Fluid Control

BLACOH™ Fluid Control, Inc., Riverside, Calif., has appointed Andrew Yeghnazar president. The move is part of the company’s plan to expand its presence in global markets. Gary Cornell will continue as chairman and CEO, together with coowner and CFO Diana Vise. Yeghnazar has 20 years of experience in industrial manufacturing and global markets. Most recently, he served as vice president of global business development for RathGibson, a manufacturer of specialty tubing and piping.

LTI Names Lab Manager

Laboratory Testing, Inc., Hatfield, Pa., has announced the promotion of Lee Dilks to manager of its chemistry and metallography labs. The two laboratories are part of the company’s Destructive Testing Dept. for performing a wide range of materials testing and failure analysis services. Dilks, with the company for 23 years, most recently served as chemistry supervisor.

Speedline Technologies Names Mexico Manager

Speedline Technologies, Franklin, Mass., has named Roberto Fregoso sales manager based in Jalisco, Mexico. His responsibilities include sales and customer support for Electrovert soldering and cleaning systems, Camalot dispensing systems, MPM printers, and Accel cleaning systems. Fregoso previously held positions in surface mount technology production and engineering with both original equipment and contract manufacturers.

Wolf Robotics Names Eastern Canada Manager

Wolf Robotics, Fort Collins, Colo., has appointed Kevin McWhirter regional manager for eastern Canada, including the provinces of Ontario, Quebec, New Brunswick, and Nova Scotia. Based in the Belwood, Ont., area, McWhirter, with 15 years of experience in the welding industry, will manage sales of robotic welding and cutting systems and custom engineered solutions for metal fabrication customers.

MBMA Executive Committee Named

At last there’s a D1 for strengthening and repairing existing structures

Since the first D1 standard in 1928, the AWS D1 structural welding series has provided a consensus of the finest minds in the industry on the most reliable approaches to welding new structures.

Now there is a D1 that provides the same guidance for repair, corrective issues, and strengthening of existing steel structures. AWS D1.7/D1.7M, *Guide for Strengthening and Repairing Existing Structures*, is invaluable to the engineer who is obligated under D1.1 Clause 8 to plan for projects that involve strengthening and repairing.

Preview and order your AWS D1.7 by visiting www.awspubs.com, or call 888-WELDING for information on all of AWS’s structural welding codes.

American Welding Society

Founded in 1919 to advance the science, technology and application of welding and allied joining and cutting processes, including brazing, soldering and thermal spraying.
In 2011, WEMCO and RWMA will once again co-locate their annual meetings.

On February 24-26, 2011 WEMCO and RWMA will host their independent meetings and work groups at the PGA National Resort and Spa, in Palm Beach Gardens, Fla. Both committees have agreed to collaborate on a very relevant theme — "Opportunities in the Energy Sector." Join us as we gain insight on this topic from first-class business speakers, key industry leaders, enlightening presentations, and dynamic business forums.

The cost to attend this 3-day annual event is:
WEMCO and RWMA Members: $675
WEMCO and RWMA Spouses: $285

Negotiated rate at the PGA National Resort and Spa:
WEMCO and RWMA have negotiated a rate of $179 per night for all attendees. However, rooms are limited—first-come, first-served!

Register Today!
For more information on WEMCO and RWMA or to register for the annual meetings contact:
Susan Hopkins at susan@aws.org or 800-443-9353, ext. 295

This Year’s Theme:
“OPPORTUNITIES IN THE ENERGY SECTOR”

With the country’s continued demand for oil and natural gas, America has started to ask:

Is there a better way?
Absolutely. The United States is now focusing on natural, nuclear and renewable energy as alternatives. The nuclear energy sector is a key player in the energy industry. Old, unfinished plants are now being completed, and new ones are being built. In addition, energy sources such as sun, wind and tide are gaining strength. Next on many of our minds was:

“How will this affect the welding industry tomorrow?”
With the economy focusing on “green” jobs and technology, the employment outlook is bright for workers possessing skills in various welding processes. Competent and experienced welders, as well as welding equipment/products manufacturers will be critical to the creation of the green infrastructure in the coming years.

Will your company be a part of this new movement?
It is inevitable that this is the direction of the future. Countries such as Israel and Brazil are already making significant developments in this field. Now it’s time for WEMCO and RWMA to enlighten their members as well.
Why Preheat?

Understanding the benefits of preheating can help you produce crack-free welded joints under a wide variety of conditions.

One of the most troublesome features of the welding process is the danger of cracks developing in the weld metal or in the adjacent base metal.

What causes cracks in welds? What factors result in conditions that favor weld cracking? What, if any, are the means of preventing cracks from occurring? In considering these questions, we must remember that welding usually involves greater and more violent changes of temperature than other fabricating processes. Some of the complicated metallurgical factors involved in the welding operation are not fully understood as yet. Nevertheless, we can supply satisfactory answers to many of these questions, and the purpose of this article is to review some of the knowledge and experience that enables us to produce satisfactory crack-free weld joints under a wide variety of conditions.

There are two areas in a welded joint that may crack as a result of the welding operation. The first is a portion of the heat-affected zone (HAZ) adjacent to the weld. The second area that may crack under certain conditions is the weld metal itself. However, the weld metal used for most purposes has so low a carbon content that it does not change its properties as markedly as the base metal even under the most rapid rate of cooling likely to occur in welding. Therefore, the weld metal itself is less prone to cracking than the HAZ.

In view of this, we usually concern ourselves primarily with the base metal in the immediate vicinity of the weld. It is the metal closest to the weld that cools most rapidly, and in many cases, undergoes important changes in the structure and properties of the metal, as shown in Fig. 1.

Fig. 1 — A single-pass groove weld in a butt joint showing the following three zones: A — Weld metal; B — HAZ, C — base metal. (Illustration courtesy of the Hobart Institute of Welding Technology, Troy, Ohio.)
Preheating before welding is a well-recognized preventative measure against cracking. In fact, it was used for many years before scientific reasons were advanced to explain its function in preventing cracks. The importance of preheating is shown by the fact that recommendations for preheating are written into modern welding specifications wherever there is the slightest risk of a weld defect being present.

However, it is less generally recognized that preheating also contributes other useful effects. This article reviews briefly the fundamental principles involved in preheating, describes some of the beneficial effects of preheating, and outlines several procedures commonly used for preheating.

Preheating has been defined as “raising the temperature of metal above the temperature of the surroundings before welding.” Sometimes the entire part is preheated, which is termed the general preheat, or only the vicinity of the weld is heated, which is called local preheat.

**Effects of Preheating**

There are five principal reasons for preheating. They are as follows:

1. Eliminates or lessens the danger of crack formation.
2. Minimizes hard zones adjacent to the weld.
3. Minimizes shrinkage stresses.
4. Lessens distortion.
5. Enhances diffusion of hydrogen from steel.

Preheating, therefore, increases the ability of a welded joint to withstand service conditions. In fact, preheating may actually be viewed as a heat-treating operation.

How does preheating accomplish these beneficial results? In order to answer this question, it is necessary to consider several important metallurgical principles.

The making of any weld involves two metallurgical processes. First, the melting of the edges of the joint and of the electrode material, followed by solidification, which forms a single integral weld structure. Second, the heating and subsequent cooling of the base metal adjacent to the weld.

The heat generated during welding will have two separate effects on the welded joint. Depending on metal composition, temperature reached, and cooling rate, there will be a specific effect on the metal’s microstructure, which will in turn determine such properties as strength, toughness, ductility, and corrosion resistance. We will call these the metallurgical effects.

Second, heat will cause distortion and shrinkage stresses in the weld joint, this being dependent on the shape and geometry of the joint, the degree of restraint, heating and cooling rates, and time at maximum temperature. We will call these the mechanical effects. These two effects actually occur simultaneously and are interdependent, but they are separated in this discussion for convenience and to make it simpler to understand. The welded joint, although actually a single integral structure, may be considered to consist of three distinct zones that merge into one another: the weld metal, the HAZ, and the base metal.

**Metallurgical Effects**

Figure 1 represents a single-pass groove weld in a butt joint and shows the three zones that make up the weld. Weld metal A is the portion that has been in a molten state and consists of a mixture of the deposited electrode material, and plate material, which has been melted during welding.

The HAZ, shown as B, is that area which, although not melted during the welding operation, has been heated to temperatures sufficiently high to change its original microstructural properties.

The plate or base material C is the area that has not been affected by the weld thermal cycle. Figure 1 also indicates the approximate maximum temperatures reached in each zone while the weld was being made. The temperatures and structures shown indicate that the thermal cycle of the welding operation subjects the metal to a heat treatment that considerably alters its structure and properties.

In order to understand the effects on steel structures of temperature changes that accompany the welding operation, let us consider the following example. A typical welding grade of steel, 0.25% carbon for example, if heated to a temperature above 1525°F, becomes a solid solution of carbon in iron and has a face-centered crystal structure, called austenite. On slow cooling, the austenite remains unchanged until a temperature of about 1500°F is reached. At this point, austenite begins to break down and form a new phase. This new phase is almost pure iron with a body-centered structure called ferrite. This process continues until a temperature of 1350°F is reached. At 1350°F, the remaining austenite transforms to another phase called pearlite. Thus, on slow cooling to room temperature, steel will be composed of a ferrite-pearlite structure that is soft and ductile. However, the cooling rates in welds are usually not slow but quite rapid. Drastic
cooking of steel results in formation of a hard and brittle structure called martensite. Thus, instead of soft and ductile pearlite, we get hard martensite, which due to its low ductility has poor ability to withstand welding stresses. It is the formation of this brittle structure in the base metal that causes much weld cracking. (A summary of the physical changes that occur in steels and cast iron at various temperatures can be found in the Basic Guide to Ferrous Metallurgy, which can be downloaded at www.tempil.com.)

This metallurgical knowledge helps to interpret some of the typical structures that may be found in the HAZ of a welded joint, which are shown in Fig. 2.

As we examine Fig. 2, it is apparent that Zone 1 has been coarsened by the welding process and consists of a needle-like martensitic structure. Zone 2 has been refined by the heat incident to the welding operation, and Zone 3 is a transition zone. Figure 2 also shows the typical normalized structure of the original unaffected base metal.

The principal danger of cracking is found in Zone 1, which consists principally of coarsened martensite. The brittle martensite present gave rise to a crack that in all probability will eventually extend farther under the influence of welding stresses.

**Mechanical Effects**

The factors just described comprise the metallurgical effects of the welding operation. The mechanical effects of the heating and cooling cycles during welding result in sudden and highly nonuniform expansion and contraction. These will set up stresses that cause the welded joint to deform continually during and after the welding cycle. In general, a metal will crack if stresses exceed its ability to deform. Thus, a weld joint composed of a material that possesses sufficient ductility, such as ferrite and pearlite, will deform without cracking while a weld that contains a brittle structure such as martensite may react to thermal stresses by cracking. This illustrates the interdependence of the metallurgical and mechanical considerations stated previously.

**Stees and Cracking**

With this background, the five factors that determine the ability of steel to be welded without cracking can be listed as follows:

1. The steel's composition
2. Rate of heating
3. Maximum temperature attained and length of time at temperature
4. Rate of cooling
5. Hydrogen entrapment.

The chemical composition of steel has an important bearing on the hardness and brittleness of the weld joint for several reasons. First, because higher carbon content promotes the formation of martensite, and second, because the final hardness or martensite itself depends on the carbon content of the steel. The effect of carbon content on hardness of steel subjected to welding is shown in Fig. 3. This, of course, is the reason why steels with a high carbon content are not considered easily weldable. Certain alloying elements such as molybdenum, manganese, vanadium, and chromium also have a distinct hardening effect, promoting the formation of the crack-inducing martensite. The higher the carbon and alloy content of steel the more readily it will harden in the heated zone, and therefore, the slower the cooling rate will have to be in order to prevent cracking.

**Thermal Factors**

The final three factors that determine the ability of steel to be welded without cracking are of a thermal nature. The great and violent changes in temperature involved in welding can be illustrated by temperature changes of a point in the weld HAZ. A typical time-temperature curve is shown in Fig. 4. Within the first second after welding, this point rapidly reaches a very high temperature of approximately 2450°F, and then drops in the next few seconds to temperatures below 500°F.

The rate of heating is important for two reasons. First, rapid heating may result in high thermal stresses, and second, rapid heating will cause a high cooling rate thus promoting the formation of brittle martensite. The rate of heating will determine the steepness of the rising portion of the curve in Fig. 4, and it will vary with the welding process or, more specifically, with the method used for generating heat at the weld joint such as an electric arc or oxyfuel gas welding torch. For example, the electric arc provides a faster rate of heating than oxyfuel because the arc is a more intense heat source, and is in more intimate contact with the metal. The maximum temperature and the time at temperature are important because they determine the amount of austenite that will be formed and thus the amount of change in microstructure that will take place.

Besides being influenced by the weld-
ing process employed, the maximum temperature attained and the time at temperature are also dependent on factors such as the time and speed of welding, arc current, arc voltage, and the welding sequence. In other words, the maximum temperature reached depends upon the heat input of a welding electrode. A 3/32-in.-diameter electrode used at 400 A and 40 V will result in higher maximum temperature of a joint in the HAZ than a 1/16-in. electrode used with 150 A and 20 V. A higher temperature will also be obtained at any location in the HAZ if the speed of travel was 6 instead of 12 in./min, other factors being equal. The use of a stringer bead or weave technique, the number of layers, and the time between succeeding weld beads all play an important part in determining the maximum temperature attained.

Of the five factors we discussed that determine a steel’s weldability without cracking, the rate of cooling has the greatest influence on the structures of the HAZ. As shown previously, the cooling rate will determine the final structure of the transformation products that result from the welding operation.

If austenite is cooled slowly, the transformation products will be soft and ductile. If the transformation from austenite is rapid, the final products will be brittle and may crack if stressed. As welding is a quick process, the cooling rates are quite rapid and portions of the HAZ are likely to consist of this brittle constituent. Thus, the cooling rate determines the hardness and brittleness in the HAZ, and by controlling the cooling rate it is possible to create welding conditions that will prevent this brittle structure from forming, and prevent cracks. The rate of cooling is dependent on the mass and geometry of the piece to be welded, the temperature gradient between the weld joint and the base metal and the total heat input.

**Hydrogen Embrittlement**

Some authorities believe that cracks in welds are due to hydrogen introduced into the base metal from the coatings of welding electrodes. As hydrogen is more soluble in molten than in solid steel, it will seek to escape from the supersaturated solution as metal cools down to room temperature. If the escaping hydrogen is trapped within a discontinuity in the metal, and if such entrapment occurs within a hardened area, cracking may result.

Two practices are commonly utilized to prevent formation of cracks in welded joints: preheating and postheating. Preheating is used to prevent cracks during and immediately after the welding operation, and postheating to ensure crack-free welds before the metal enters service and also to ensure satisfactory metallurgical properties to withstand service conditions. Preheating acts to prevent cracks in several ways. First, it reduces the thermal gradient between base and weld metals. For example, a drop of only 200°F occurs if a weld is preheated to 800°F, as compared to the 2730°F drop from 2800°F to 70°F for a weld made at room temperature. This reduces the cooling rate preventing the formation of brittle martensite and causing metallurgical transformations to take place that produce softer and more ductile constituents.

Thus, preheating reduces the hardness of the HAZ and the tendency to cracking.

As steel is less heat conductive at higher temperatures, preheating causes slower withdrawal of heat from the welded joint. This further lowers the cooling rate with correspondingly beneficial effects.

Preheating has been found to be helpful in eliminating hydrogen entrainment in the base material. Many fabricating procedures recommend preheating even in conjunction with low-hydrogen-type electrodes. Although the arc atmospheres of the so-called hydrogen-free electrodes contain very small amounts of hydrogen — even traces of this element are sometimes sufficient to cause cracking in the embrittled HAZ.

**Benefits**

The useful effects of preheating can be summarized as follows: Hard martensitic zones occur in weld joints as a result of rapid cooling rates. These hard zones are likely to crack during or after the welding operation. The shrinkage stresses due to cooling augmented by the volume changes of steel during phase transitions may exceed the capacity of the hard zone to deform and thereby crack it. This may be aided by the presence of hydrogen, which has an embrittling effect on steel.

Preheating prevents weld cracking in three ways: It minimizes formation of the brittle martensite, it causes austenite to transform very slowly to martensite, and it increases the diffusion and escape rate of hydrogen.

The foregoing is summarized in practical terms as follows:
Preheating need is increased if the welded piece

1. Has larger mass
2. Is at lower temperature
3. Is in an environment of lower temperature
4. Is welded with smaller-diameter electrodes
5. Is welded at greater linear speed
6. Has complicated shape and design
7. Has large variation in size of adjacent parts
8. Has higher carbon content
9. Has higher manganese content
10. Has higher alloy content
11. Has greater air-hardening capacity.

A variety of methods can be used for preheating\(^1\). The most popular ones involve the use of gas torches and other types of burners, heat-treating furnaces, electrical strip heaters, low-frequency induction heating, and brick furnaces utilizing charcoal or coke as fuel. The choice of a particular method depends, of course, on many factors such as the preheating temperature and length of preheating time required, size and shape of piece being welded, whether production is of a batch or continuous type, and so forth. In many shops, heat-treating furnaces, such as shown in Fig. 5, are utilized for preheating. These are particularly advantageous in mass production work, and are sometimes combined with other methods of preheating in order to save labor and fuel. For example, castings preheated in the continuous annealing furnaces shown in Fig. 5 are removed to the casting repair area where multiple, specially shaped jet heating torches are used to maintain the preheat temperatures that were attained in the furnaces.

Measurement devices such as Tempilstik temperature indicators may be used to establish preheat temperatures as shown in Fig. 6.

Another widely employed method utilizes low-frequency induction heating and is particularly useful where close temperature control is required. Figure 7 shows the use of induction heating in preheating of alloy steel piping prior to welding.

Preheating before welding is now widely accepted as a desirable fabrication procedure. Both ferrous and nonferrous metal producers state recommended preheating temperatures for welding their materials. Prescribed preheating temperatures and procedures are today included in the majority of fabrication specifications. While preheating methods and temperatures will depend on factors such as metal composition and mass, fabrication methods, and service conditions, there is agreement that preheating before welding provides insurance against cracks.\^2

1. A table titled Preheat Temperatures for Metal and Alloys is available at www.tempil.com or by calling (800) 757-8301.

\[^1\] This text is not complete and seems to be cut off. It is likely that there is more information following these points.

\[^2\] This text is not complete and seems to be cut off. It is likely that there is more information following these points.
Get the information you need quicker than ever before. The AWS Welding Buyers Guide allows online searchers to easily locate products and services unique to the welding industry, without the clutter of a general Internet search engine.

Save valuable time, visit awsweldingbuyersguide.com!

**BENEFITS FOR CONSUMERS:** When leaders in the industry are looking for products and services, they turn to awsweldingbuyersguide.com to quickly get to the right source. Users can easily locate products and services unique to our industry with keyword-driven or category-specific searches. The AWS Welding Buyers Guide gives welding professionals a faster and easier way to find great vendors.

**BENEFITS FOR COMPANIES:** Purchasing a listing in the AWS Welding Buyers Guide will ensure that your company’s brand and message are easily accessible to the buyers who matter most to you. The AWS Guide includes Request for Information (RFI) functionality. This feature allows users to contact participating suppliers with a click of their mouse. Additionally, the guide includes a product showcase that allows you to highlight specific products and special offers on the front page of the guide. Visit the site to post your listing today!
Students Prove Themselves Auto Innovators

A group of middle- and high-school students have developed easily assembled vehicles that can be shipped as a kit to help bring affordable transportation to developing countries.

For the past four years, a group of students from Chelsea Middle School and Calera High School in Calera, Ala., have outscored college engineering students in a contest to build a basic utility vehicle (BUV).

The Institute for Affordable Transportation (IAT) sponsors the contest, held each year in Indianapolis, Ind. The organization’s primary mission is to develop an inexpensive vehicle that can be marketed in developing countries. The vehicles are judged on categories such as cost of production, obstacle course performance, and endurance. The Chelsea Middle School eighth grade Career Discovery class placed first in the open class in 2007 and took both first- and second-place honors in the 2008 competition — Fig. 1. In 2009, Calera High School’s Principles of Engineering class, which includes students from grades eight through twelve, not only placed first in its category, but also received the highest score of the competition and won the “Most Innovative” award. The 2010 team repeated the school’s success by placing first in the open class — Fig. 2. That team defeated such universities as Purdue, Cincinnati, John Brown, and Trine. Overall, Calera’s score was second only to the State University of New York.

Instructor Brian Copes leads the group. Copes began his career as a car-

Based on information provided by Brian Copes (b2copes@shelbyed.k12.al.us), AWS District 9 Director George Fairbanks, and SKY.

Videos of the project can be viewed by visiting www.youtube.com and then searching for children changing the world or Chelsea Middle School BUV.

Todd Killingsworth, father of Calera High School student T. J. Killingsworth, is shown driving the school’s entry in the Institute for Affordable Transportation’s 2010 basic utility vehicle competition.
Fig. 1 — The 2008 Career Discovery class from Chelsea Middle School pose with their winning vehicle. The middle-school students beat engineering students from a number of universities and took both first- and second-place honors. Shown (from left) are Garrett Grater, Shannon Foster, Josh Franklin, Dillon Champion, Instructor Brian Copes, Ryan Sims, Trevor Hughes, Jay Shaddix, Zane Zito, Corey Moore, and Alex Touchton.

Copes decided to model his classroom after such popular Discovery Channel television series as Monster Garage and MTV’s Pimp My Ride. “Essentially I rolled in a 1997 EZ-GO golf cart and challenged my students to transform it into a mud-loving monster,” Copes recalled. “Like the TV series, the students had to videotape their project to document their work.”

Initially, Copes said, members of the education community could not believe eighth graders could complete so extensive a project. However, because the project was so successful the first year, Copes decided it warranted refinement. He challenged the students to not just modify an existing cart, but to build one from the ground up.

“The students fabricated a cart frame using threaded water pipe and fittings. This allowed the vehicle to be broken down and shipped to foreign countries in a relatively small container and be reassembled with simple hand tools,” he said.

For the first three and a half years, Copes taught seventh and eighth grade at Chelsea Middle School. The county school system built a new high school in Calera that incorporated grades 7–12. Copes was transferred to this new facility where he currently teaches engineering-related classes to grades 7–12.

Copes likens the students to modern-day Henry Fords. “Essentially the students have invented a vehicle that will allow a person in remote locations around the world to assemble a vehicle similar to a John Deere Gator with simple hand tools, allowing them to get their goods and services to and from the marketplace,” he said.

“Through this project my students learned many skills such as teamwork, mechanics, engineering, welding, design, Internet technology and research, and problem solving. Not only are the students learning valuable Science, Technology, Engineering, and Mathematic (STEM) skills, but they are performing community service as they give of their time and talents to people who they will probably never meet. Through this project, these students learned they could radically change the lives of people around the world.”

Community Involvement

When the BUV project first began, the school partnered with Auburn University’s School of Industrial Design and the University of Alabama Birmingham’s School of Mechanical Engineering to educate the middle school students in engineering and design techniques and to help ensure the students had a successful learning experience.

The business and industrial communi-
ties have been enthusiastic about the project, and currently, more than 150 local, national, and international businesses and other organizations participate. These include The Lincoln Electric Co., Consolidated Pipe, O’Neal Steel, Jefferson State Community College’s Manufacturing program, Motion Industries, Pinson Valley Heat Treating, and Cawaco Resource, Conservation, and Development Council. Tuff Torq Corp. and Yanmar Corp. help sponsor the IAT competition and donate, respectively, drive trains and 10-hp diesel engines to the participating schools. In addition, Copes said his program’s advisory board has “evolved to the next level. The board has formed a 501(c)(3) organization to help organize and spread activities such as this to schools and students around the country.” The new not-for-profit organization, which received its recognition from the U.S. Internal Revenue Service in December 2010, has been named SKY, which stands for Skilled Knowledgeable Youth. SKY’s slogan is “children changing the world.”

The program passes on the help it has received by donating the completed vehicles to the Institute of Affordable Transportation for use as research and design teaching tools. The vehicles will be sent to missionaries in developing countries for testing.

AWS Section Participation

While Copes provides his students with some basic welding instruction in shielded metal arc (SMA), gas metal arc (GMA), and gas tungsten arc welding (GTAW), he has received invaluable welding help from the local Birmingham AWS Section. Chair James Cooley and other Section members have donated their time to teach the students welding skills and built and donated a trailer to haul the cars to Indiana for the competition — Fig. 3.

The Lincoln Electric Co. has donated SMAW, GMAW, and GTAW machines, as well as a plasma arc cutting machine to the Calera High School SKY program. Though the ultimate goal of these vehicles is simplicity of design, the students are encouraged to reduce the amount of complex fabricated parts and components, making the vehicle more serviceable in remote locations.

The students use these valuable welding/fabrication skills as they develop new dependable parts and features to be used on their BUV.

Although construction of the vehicles involves a lot of welding, Copes maintains that “this is not your average welding class, but an engineering class that is part of the STEM curriculum. Through this project, the students learn basic welding techniques as they develop complex parts, jigs, and fixtures for their vehicle.”

What’s Next

Several other organizations are now partnering with SKY to set up a mini factory assembly line at Calera High School. Tuff Torq has sent engineers from its facilities in Tennessee to help the school lay out and streamline this mini factory.

In addition, the school has been approached by James Chambliss of Magnolia Entertainment regarding filming a documentary about this highly successful teaching project. According to Copes, “The documentary will show how these students are creating a transportation revolution of people’s lives as rural villagers are now able to leave their animal-drawn carriages and implements for affordable transportation.”

“Not only does this vehicle provide a means to transport one’s goods and services, but it is being outfitted with a three-point hitch, water well drilling equipment, welding machine/generator, and a water pump capable of irrigating crops and pumping fresh life-giving drinking water to villages. This is a multifunctional vehicle that could be used to support and expand farming in rural countries.”

The students have conceived of an entire product line that would include the basic vehicle, bus, ambulance, 4 x 4, and water well drilling vehicle.

“Through this project I have personally seen students transform from kids who hated school to students who couldn’t wait to get to school,” Copes said. “Many of the students have developed leadership skills and are inspired to continue their education. This is my true success as an educator.”

Fig. 3 — Members of the Birmingham AWS Section help Calera High School students improve their welding skills.
LeTourneau University Offers Degree Programs in Welding and Materials Joining

**A rapidly expanding university now offers a master of science degree in Engineering with concentration in Materials Joining Engineering**

**BY HOWARD M. WOODWARD**

The Man behind the University

LeTourneau University (LETU), Longview, Tex., was founded by Robert Gilmour LeTourneau, a prolific inventor, and designer and manufacturer of earth-moving machinery. Awarded nearly 300 patents, he provided about 70% of the earth-moving equipment used during World War II.

He left school at age 14 to work many jobs, including maintenance assistant at the Mare Island Naval Shipyard, Vallejo, Calif., where he honed his welding and machinist skills. Although he was essentially self-educated, LeTourneau was a firm believer in the effectiveness of practical instruction combined with classroom studies. In 1946, he and his wife, Evelyn, purchased the Longview site where they established LeTourneau Technical Institute. The institute became LeTourneau College in 1961, then was accredited for university status in 1989. Today, the university offers degrees in engineering, aeronautical sciences, and liberal arts, combined with a Christian influence that includes compulsory chapel attendance for students.

Locations and Educational Offerings

The university has become known for its engineering and aviation curricula, with more than 85 academic programs offered to prepare students for success in these fields as well as business, education, kinesiology, psychology, health care, the humanities, and the sciences.

In addition to the Longview location, undergraduate programs for working adults in business, education, and psychology and graduate programs in business, leadership, and education are offered online and on-site at education centers in Austin, Bedford, Dallas, Houston, and Tyler, Tex. Today, nearly 3200 students from all 50 states and 25 nations are enrolled in the university. Nearly 1400 students take classes at the Longview campus, located on 162 acres in the piney woods of eastern Texas.

Materials Joining Engineering Credentials

Materials Joining Engineering is one of the hallmarks of the LETU School of Engineering and Engineering Technology, which also includes biomedical, civil, computer, electrical, and mechanical engineering design concentrations. Engineering degrees are accredited by the Engineering Accreditation Commission and the Technology Accreditation Commission of the Accreditation Board of Engineering and Technology (ABET). The university now offers a master of science degree in engineering.

Dale A. Lunsford, LETU president, said, “Our rich heritage of welding and materials-joining engineering is one of the most highly regarded programs in the world. Students with a LeTourneau materials-joining engineering degree have unlimited potential in the global economy.”

LETU students regularly compete with larger public and private schools and take top honors at regional and national competitions in many fields, especially electrical, mechanical, and aeronautical design engineering. LETU engineering students recently placed first regionally then placed fourth internationally at the 2010 ASME “Earth Saver” Student Design Competition in Vancouver, B.C., Canada.

“Materials-joining engineering is often a ‘best-kept secret’ among high school students considering an engineering degree,” said Tom Hellmuth, dean, School of Engineering and Engineering Technology. Hellmuth added, “But the ability to join together two distinct materials, now called materials joining, includes welding and has far-reaching implications in the manufacturing world, for students seeking high-paying and stable careers.”

To reflect the inclusion of joining ceramics, polymers, and composite materials as well as metals with distinct properties, the welding engineering program was renamed materials joining engineering in 2005.

“By the time our materials-joining engineering students reach graduation, they are offered multiple job opportunities at high starting salaries. First, because the need is great and, second, because our students are so well prepared for the workplace,” said Yoni Adonyi, professor, Materials Joining and Welding Engineering, and the Omer Blodgett Chair of the Materials Joining Engineering program at the university.

Facilities and Equipment

The LETU materials joining lab includes equipment such as the Gleeble® 1500 thermomechanical simulator, which has been described as a “hot rod” of simulators — Fig. 1. The Gleeble 1500 is a leading piece of equipment for welding process simulation. LeTourneau is among two dozen universities in the world to own one. With welding process and research equipment valued at more than $1 million, the 7300-sq-ft lab includes are welding

HOWARD M. WOODWARD (woodward@aws.org) is associate editor of the Welding Journal.
Steve Wolbert runs weld tests using sophisticated Gleeble® testing equipment in the materials joining laboratory. Wolbert, a 2009 graduate of the LeTourneau University materials joining engineering program, currently works for AREVA.

Fig. 2 — A LeTourneau University engineering student hones his robot-programming skills.

LETU students benefit from small class sizes and personal interaction with their professors on equipment that other schools often reserve only for use by graduate students. The program was recently awarded a National Science Foundation Grant of nearly $800,000 for upgrades that will increase the capacity to operate more complex equipment in the lab for joining advanced engineering materials. Completion of additional upgrades to the facilities totaling $1.2 million is expected by fall 2011.

LETU’s state-of-the-art labs allow students to perform high-quality, relevant research in biomechanics, fluid dynamics, automation and robotics, advanced materials development, and materials-joining engineering. Seniors work on their capstone design projects in a machine tool and design lab, and many have placed at the top of national design competitions. Various corporations and businesses around the country have been supportive of the growth and upgrades to LETU’s materials joining program. Much of the university’s success in providing state-of-the-art equipment can be attributed to corporate philanthropic support from those in the industry who desire to invest in training the next generation of materials joining graduates.

The Faculty

Yoni Adonyi (Fig. 3) has been in charge of the Metals Joining Engineering program since arriving at the university in 1996. Former Program Coordinator Bill Kielhorn led the program for 30 years before Adonyi arrived and has continued to be involved for another 15 years as an adjunct professor. In recognition of his service, the newly updated materials joining lab will be named in Kielhorn’s honor.

Associate Professor Robert Warke (Fig. 4), an LETU alumnus, is a metallurgical engineer with expertise in failure analysis and ferrous metallurgy, including stainless steels. Since 2003, he has introduced joining of metals and design topics and promoted the introduction of an MJE minor track for students who choose not to double-major in mechanical and materials joining.

Martin Watson, MJE lab technician, joined the staff in 2007 to manage the program’s state-of-the-art equipment.

Materials Joining Courses

The Materials Joining Engineering (MJE) concentration for the bachelor of science in engineering degree requires an average of 17 academic credit hours per semester. In the typical course sequence, freshmen students take engineering courses such as manufacturing processes, engineering graphics, fundamentals of engineering design, and materials-joining fundamentals.

In the manufacturing processes lab, students gain lab experience in basic manufacturing processes including mechanical and thermal processes for materials separation and joining. Safety issues and the proper use of precision measuring devices are stressed. In materials-joining fundamentals, students learn the fundamentals of welding, theory, and principles. The course includes basic welding power sources, electric arcs, elec-
trode classifications, welding symbols, joint selection and preparation, an introduction to welding processes, procedures, economics, and cost estimation.

Sophomore students study statics, materials engineering, electric circuits, dynamics, and materials science of joining. In the latter, students study microstructural changes associated with welding thermal cycles, nonequilibrium solidification and heat-affected zone transformation phenomena, microstructure/property relationships, weld discontinuity formation, and weldability testing.

Junior students study computer science, statistics and engineering courses in digital electronics, instrumentation and measurements, thermodynamics, joining processes, mechanics of materials, heat transfer, joining of advanced materials, design topics in materials joining, and engineering project management. In joining of metals, students apply welding metallurgy principles to fusion welding of ferrous and nonferrous engineering alloys, including carbon, high-strength low-alloy (HSLA) steels, stainless steel, tool and die steels, aluminum, plus nickel-based and titanium alloys. The lab work includes metallographic sample preparation and evaluation techniques. In the design topics in materials joining, students learn the conventional and modern methods of joint design and flaw assessment for static, dynamic, and cyclic loading.

Students learn the effects and control of residual stresses and distortion and the principles of failure diagnosis. They learn the use of numerical methods, quality and reliability concepts, codes and standards, cost estimation, and process selection. The joining of advanced materials course studies the effects of solid-state joining processes on advanced material properties. Dispersion-strengthened metals, powder-metallurgy products, ceramic and polymeric-composites, and dissimilar combinations are discussed with emphasis on interface phenomena. The lab work includes use of advanced analytical evaluation techniques such as the scanning electron microscope.

The senior-level engineering courses include electrical power systems, mechatronics, robotics and manufacturing applications, senior design, and nondestructive evaluation of materials. In the latter class, students use elastic and electromagnetic wave/material interactions for dimensional analysis, material property determination, and flaw detection. Students learn the basics of liquid penetrant, magnetic particle, radiography, ultrasonics, and eddy current testing. Experimental techniques are applied to engineering materials testing, including both metals and composites.

Graduate Engineering Program

The master of science in engineering degree program was launched in fall 2010 at the Longview campus. This 30-semester-hour, thesis-based degree, follows the same format as the undergraduate degree, with a common core with specializations in materials joining engineering, electrical, civil, mechanical, and biomedical engineering. It allows students to begin their undergraduate research at LETU and continue building on that research in their graduate programs. It also attracts students with bachelor’s degrees in engineering from other institutions. LeTourneau freshmen can plan to complete both the BS and MS degrees in just five years. Visit www.letu.edu for more information.

Tuition and Financial Aid

The university tuition is a flat rate of $21,510 per academic year (fall and spring) for students taking 12 to 18 credit hours per semester. The rate is the same for in-state and out-of-state students. Books, supplies, personal expenses, and
transportation costs are additional. The Financial Aid staff is dedicated to helping students afford their educations through scholarships, grants, and other means. More than 95% of students receive financial aid. Prospective students are urged to apply to determine whether they qualify.

Life on Campus

All 16 on-campus residence locations are designed to be comfortable places to sleep and study, and all have been either recently renovated or newly built. A new, 200-bed residence hall is currently under construction and slated to open fall 2011.

Outside of the classroom, students engage in service work and intramural sports. The university competes at the NCAA Division III level in the American Southwest Conference. LETU offers 13 varsity sports including baseball, basketball, cross country, golf, soccer, and tennis for men; and basketball, cross country, golf, softball, soccer, tennis, and volleyball for women.

International learning opportunities, both in missions and research, take students around the world. LETU student teams travel with LeTourneau Engineering Global Solutions (LEGS) to ease human suffering with low-cost prosthetics for amputees in developing countries such as Kenya, Senegal, and Bangladesh. Others have worked on ground-breaking research, including visual literacy in Kenya, micro-finance in Ethiopia, or macroeconomics in South America. Students co-author and present their research at international conferences.

Research Projects and Funding

Even as undergraduates, students conduct research and design. In the past 15 years, the LETU materials-joining program has provided research experiences for hundreds of students and attracted more than $2 million in external funding from government and industry. Ongoing research in MJE senior design projects involve development of a hybrid process using friction stir welding (FSW) and high-frequency welding, as well as research into the contamination effects on nickel-based, superalloy deposits for the nuclear industry.

The FSW project seeks to improve tool life when welding steels. The project uses a retrofitted 50-hp welding machine initially used for welding ½-in.-thick aluminum alloys. The tool life is improved by use of simultaneous high-frequency and frictional heating. Thermal and mechanical wear modeling is combined with infrared camera recordings and strain gauge load/torque measurements. Design of a transverse loading fixture is completed and tested, with induction coil design for the high-frequency processes ahead of the FSW tool.

LETU recently received $180,000 in research funding from the Federal Highway Administration R&D Center to develop a hybrid friction stir and high-frequency welding process for modern bridge steels. This work will be done in close cooperation with NASA in Huntington, Ala., and the Navy Surface Warfare Center in Carderock, Md.

Another senior MJE design project involves thermoelectric element joining research that aims to find technologies to replace soldering and brazing at temperatures for semiconductors operating above 500°C. The purpose is to reclaim heat loss in areas where thermal-to-electrical energy conversion is difficult, such as in automobile exhaust systems. This project challenges undergraduate students to perform cutting-edge research on an advanced materials project aimed at improving interface stability of bismuth and lead telluride semiconductors. The main limitations in joining these thermoelectric elements, which are essentially brittle ceramics, are related to low thermal conductivity and variable electrical conductivity. Resistance brazing, ultrasonic, laser beam, and microwave joining are processes being studied. Fundamental research associated with this thermoelectric element joining is being funded by the II-VI Foundation.

“Close cooperation with industry enables us to pull in projects that not only give our students practical experience that prepares them for the real world, but puts them ahead of other graduates entering the workforce,” Adonyi said. “What we once called ‘hands-on’ learning has evolved with the use of modern analytical tools that require modeling and simulation.”

How Graduates Have Fared

Joshua Sleigh graduated in 2007 with five employment offers, but the one he accepted was as a materials specialist with ExxonMobil in Houston. He said he chose LETU because he was looking for a Christian college with a strong engineering program. He said the hands-on projects in the machine shop helped him understand how parts are made in the real world and that has made him a better engineer.

“I do welding engineering on a daily basis and approve material selection on projects worldwide,” Sleigh said. “Getting involved in outside company research is one of the most useful and hands-on practical experiences I had in school.”

LETU alumnus Dave Waskey of Lynchburg, Va., is the manager of welding and component repair design department at AREVA, a world leader in commercial nuclear power generation. Waskey, too, has hired LETU engineering alumni. “I always tell new engineers that college just prepares you to be able to start your education in the real world on the job,” Waskey said.

Dave Landon, AWS District 16 director and manager of the welding engineering department at Vermeer Manufacturing, said when he graduated from LeTourneau in 1981, he had multiple job offers, and since then, has seen his career take him around the world. He has hired LeTourneau engineering graduates and has found them well-prepared for their careers.

“One of the aspects of LeTourneau’s program is the blend of hands-on with the theoretical learning,” Landon said. “As a welding engineer, that is critical to have the knowledge of practice in the trade and the understanding of the physics and engineering.”

LeTourneau University
Main Campus
2100 S. Mobberly Ave.
Longview, TX 75607
www.letu.edu

Contact LETU Admissions
(800) 759-8811
admissions@letu.edu
or
Yoni Adonyi, Ph.D., P.E.
Professor, Materials Joining and Welding Engineering
(903) 233-3918
YoniAdonyi@letu.edu
Heat Straightening for Correcting Damaged or Deformed Members

Before you begin a heat straightening operation, you should inspect the base metal and weld metal in the area that will be straightened for existing cracks or tears that might propagate during straightening operations. Cracks can be removed by grinding, repaired by welding, or you can blunt the ends of cracks by drilling arresting holes. You should inspect welded repairs prior to the straightening operation. After the repairs are completed, additional inspection should take place to ensure no damage has occurred to adjacent components as a result of the repair.

Restraining Forces

You should set restraining forces — usually applied by jacks — to restrain the steel during heating but that will allow free contraction during cooling. In addition, these restraining forces should be applied in a direction that tends to restore the member and should be limited so that the material is not overstressed during heating (see the section on restraint-load stresses).

Heat Application

Heat patterns and external restraints should be based on Report FHWA-IF-99-004, Heat Straightening Repairs of Damaged Steel Bridges — A Technical Guide and Manual of Practice, unless an alternative technical guide is specified by the Engineer or proposed by the Contractor and accepted by the Engineer.

Temperature Limits

Table 1 shows the maximum recommended temperature limits for heat application.

Exceeding the maximum temperature may be a basis for rejection of the part, unless extensive metallographic analysis, hardness testing, or other nondestructive examination can justify acceptance. After applying the planned heat patterns for one sequence, the steel should be allowed to cool to below 250°F (120°C), so net effects can be measured before additional heat is applied. Adjustments in heating patterns and the number of cycles to suit actual field conditions are expected.

Additional steels may be heat straightened as well. You should consult documents in Cause 2 Normative References and Annex A Informative References of AWS D1.7 for appropriate temperatures or procedures to establish appropriate temperatures for the steel in question.

<table>
<thead>
<tr>
<th>Steel Grade</th>
<th>Max. Temperature°F/C</th>
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<tbody>
<tr>
<td>36</td>
<td>1200 [650]</td>
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<tr>
<td>50, HPS 50, 50W</td>
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<tr>
<td>HPS 70W</td>
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<td>70, Q&amp;T</td>
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<td>100, Q&amp;T</td>
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and Table 2 — Torch Tip Guide

Table 2 — Torch Tip Guide

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<th>Steel Thickness(in. mm)</th>
<th>Orifice Type</th>
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<tr>
<td>&lt;1/% &lt;6</td>
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<td>¾ 10</td>
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<td>4</td>
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<td>¾ 13</td>
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<td>¾ 16</td>
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<td>¾ 20</td>
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<td>&gt;4 &gt;100</td>
<td>Rosebud</td>
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and Annex A Informative References of AWS D1.7 for appropriate temperatures or procedures to establish appropriate temperatures for the steel in question.

Safety Catch Blocks

Prior to initiating the heating process, intermediate safety catch blocks should be placed at suitable intervals between supports to ensure deflections achieved do not exceed desired limits and buckling does not occur.

Procedures

Prior to the work, prepare computations and a sketch describing the procedures of heating and loading. You should establish all tolerances for final results as part of the procedure documents.

RestRAINT-LOAD STRESSES

It is of benefit to minimize static tensile stress due to applied loads during heat straightening. Preloading a member to restrict undesired displacement during heating should not cause total stresses attributed to existing dead load plus applied loads exceeding 0.6Fy at ambient air temperature. Preloading reduces the number of heating cycles required to produce the desired displacement.

Heating Equipment

Standard equipment for heat straightening includes oxygen and fuel gas, torches, hoses, single or multiple orifice tips, and temperature-monitoring crayons or equipment.

Heating

Apply the heat via single or multiple orifice tips. The size of the tip should be based on the thickness of the heated material and desired displacement. Cutting tips should only be used in special cases and the flame should be a neutral or reducing flame. An oxidizing flame is not permitted for use with cutting tips.

Table 2 shows common torch tips for various thicknesses.

Temperatures

You can use temperature-sensitive crayons, pyrometers, or infrared noncontact thermometers to verify temperatures during heating operations. Each product should be used within the limits of the manufacturer’s recommendations. Heat measurements should be made between 5 and 10 s after you remove the heating flame from the steel.

Cooling

Cooling with dry compressed air is allowed after the steel has cooled to 600°F (320°C). Quenching with water or with a combination of water and air should not be allowed above 600°F (320°C).

Braces

During heating, if intermediate stiffeners are placed on only one side of a girder web, temporary intermediate braces (i.e., wood blocks or posts) should be placed on the opposite side to prevent rotation of the flange.

Conference on
Welding in Shipbuilding

May 10-11, 2011
Seattle, Washington

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**POSTER ABSTRACT SUBMITTAL**

Annual FABTECH International & AWS Welding Show
Chicago, IL – November 13-16, 2011

**Submission Deadline: April 22, 2011**
(Complete a separate submittal for each poster.)

**Primary Author (Full Name):**

School/Company:

Mailing Address:

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**Poster Title (max. 50 characters):**

**Poster Subtitle (max. 50 characters):**

**Co-Author(s):**

<table>
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<th>Name (Full Name)</th>
<th>Affiliation</th>
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**Poster Requirements and Selection Criteria:**

- Only those abstracts submitted on this form will be considered. Follow the guidelines and word limits indicated.
- Complete this form using MSWord. Submit electronically via email to mventura@aws.org or print and mail.
- Any technical topic relevant to the welding industry is acceptable (e.g., welding processes & controls, welding procedures, welding design, structural integrity related to welding, weld inspection, welding metallurgy, etc.).
- Submittals that are incomplete and that do not satisfy these basic guidelines will not be considered for competition.

Posters accepted for competition will be judged based on technical content, clarity of communication, novelty/relevance of the subject & ideas conveyed and overall aesthetic impression.

Criteria by category as follows:

(A) **Student**
- Students enrolled in 2 yr. college and/or certificate programs at time of submittal.
- Presentation need not represent actual experimental work. Rather, emphasis is placed on demonstrating a clear understanding of technical concepts and subject matter.
- Practical application is important and should be demonstrated.

(B) **Student**
- For students enrolled in baccalaureate engineering or engineering technology programs at the time of submittal.
- Poster should represent the student’s own experimental work. Emphasis is placed on demonstrating a clear understanding of technical concepts and subject matter.
- Practical application and/or potential relevance to the welding industry is important and should be demonstrated.

(C) **Student**
- For students enrolled in graduate degree programs in engineering or engineering technology at time of submittal.
- Poster should represent the student’s own experimental work. Poster must demonstrate technical or scientific concepts. Emphasis is placed on originality and novelty of ideas presented.
- Potential relevance to the welding industry is important and should be demonstrated.

(D) **Professional**
- For anyone working in the welding industry or related field.
- Poster must demonstrate technical or scientific concepts. Emphasis is placed on original contributions and the novelty of the presentation.
- Potential relevance to the welding industry is important and should be demonstrated.

(E) **High School**
- Junior or Senior high school students enrolled in a welding concentration at the time of submittal.
- Presentation should represent technical concepts and application to the welding industry.
- Practical application and creativity are important and should be demonstrated.
Check the category that applies:

- (A) Student 2-yr. or Certificate Program
- (B) Student 4-yr. Undergraduate
- (C) Graduate Student
- (D) Professional
- (E) High School

**Poster Title (max. 50 characters):**

**Poster Subtitle (max. 50 characters):**

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<th>Abstract:</th>
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<td><strong>Introduction</strong> (100 words) – Describe the subject of the poster, problem/issue being addressed and its practical implications for the welding industry.</td>
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| Technical Approach & Results (200 words) – Explain the technical approach. Summarize the work that was done as it relates to the subject of the poster. |

| Conclusions (100 words) – Summarize the conclusions and how they could be used in a welding application. |

Return this form, completed on both sides, via email to mventura@aws.org

**MUST BE RECEIVED NO LATER THAN April 22, 2011**
PROFESSIONAL PROGRAM ABSTRACT SUBMITTAL
Annual FABTECH International & AWS Welding Show
Chicago, IL - November 13-16, 2011

Submission Deadline: March 25, 2011
(Complete a separate submittal for each paper to be presented.)

| Primary Author (Full Name): | | |
|-----------------------------|-----------------------------|
| Affiliation:                |                            |
| Mailing Address:            |                            |
| City:                       | State/Province:            |
|                             | Zip/Mail Code:             |
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| Email:                      |                            |

| Co-Author(s):               | | |
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| Name (Full Name):           | Name (Full Name):           |
| Affiliation                 | Affiliation                 |
| Address:                    | Address:                    |
| City:                       | City:                       |
| State/Province:             | State/Province:             |
| Zip/Mail Code:              | Zip/Mail Code:              |
| Country:                    | Country:                    |
| E-Mail:                     | E-Mail:                     |

Answer the following about this paper

Original submittal? Yes □ No □ Progress report? Yes □ No □ Review paper? Yes □ No □ Tutorial? Yes □ No □

What are the welding/Joining processes used?

What are the materials used?

What is the main emphasis of this paper? Process Oriented □ Materials Oriented □ Modeling □

To what industry segments is this paper most applicable?

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Stray Grain Formation and Solidification Cracking Susceptibility of Single Crystal Ni-Based Superalloy CMSX-4

Stray grain area fraction and cracking susceptibility were correlated to welding process and parameters

BY T. D. ANDERSON AND J. N. DUPONT

ABSTRACT

The stray grain formation behavior and susceptibility to solidification cracking in autogenous welds on single crystal alloy CMSX-4 have been investigated. Welds were prepared using the electron beam (EB) and gas tungsten arc welding (GTAW) processes. The stray grain area fraction and cracking susceptibility were determined and correlated to the processing parameters and process type. The stray grain content initially increased and then decreased with increasing travel speed. This effect is attributed to the complex effect of travel speed on the temperature gradient and growth rate and resulting amount of constitutional supercooling in the weld. The stray grain content decreased with decreasing weld power. In general, the amount of stray grains and resultant cracking susceptibility were observed to decrease by the use of low heat inputs. The stray grain content and cracking susceptibility of welds prepared with the GTA process was always higher than welds made with the EB process. This difference is attributed to differences in power density and temperature gradient, where the EB process produced a higher temperature gradient that reduced the amount of stray grains and resultant susceptibility to cracking. For the conditions evaluated in this work, EB welds produced at heat inputs below ~13 J/mm produced welds that were crack-free with stray grain contents < 5%.

Introduction

Nickel-based single crystal superalloys are used for turbine blades for their excellent creep resistance. These materials are very expensive as a result of the complex fabrication conditions required to maintain the single crystal structure during casting. Some blades may be scrapped after casting because the formation of defective “stray” grains (SG), while other blades may need to be replaced after finite service exposures due to damage associated with wear, fatigue, or creep. Thus, there is a need to develop reliable welding techniques in order to rejuvenate damaged blades or repair blades with casting defects. This involves the establishment of welding parameters that will avoid the formation of SG in the weld. The SG formation tendency is a strong function of the local solidification conditions, which are controlled by the welding parameters. Another type of welding defect that is commonly observed in this class of alloys is solidification cracks. Solidification cracks are commonly associated with SG formation, but the particular range of welding parameters over which cracking can occur is not typically well established. The complex relations between welding parameters, solidification parameters, resultant SG formation, and solidification cracking susceptibility make the development of reliable weld repair strategies difficult.

Stray Grain Development

Stray grain formation is known to be a result of constitutional supercooling (CS), which is controlled by temperature gradient (G) in the liquid directly ahead of the solid/liquid interface and the growth rate (V). Research has shown that a low G/V ratio will promote the nucleation of SG by introducing excessive liquid undercooling ahead of the solidifying columnar dendrite front (Ref. 1). There exists a wide range of G and V across the solidification interface of a weld pool. In a polycrystalline material, dendrite growth will generally be opposite to the direction of heat flow, so G and V are considered normal to the solid/liquid interface. For the case of a single crystal (SX) material, the growth directions are limited to one of the six crystallographic <100> easy growth vectors. The relevant G and V for SX solidification are those parallel to the local dendrite growth directions, G_{hkI} and V_{hkI}. These can be calculated using a geometric model (Refs. 2-4) if the weld pool shape and SX substrate orientation are known. The dendrite tip velocity V_{hkI} is calculated with the relationship:

\[ V_{hkI} = S \frac{\cos \theta}{\cos \psi} \]  

where S = travel speed, \( \theta \) = the angle between the travel speed direction S and the interface normal, and \( \psi \) = the angle between the interface normal and the active dendrite growth direction.

Current approaches to predict SG formation in weld structures stem from models originally developed to describe the columnar-to-equiaxed transition (CET) in castings (Ref. 2). The model has been applied to the case of fusion welding, and the equation used to calculate the SG area

KEYWORDS

EB Process
GTAW Process
Cracking
Single Crystal
Stray Grains
Superalloy

T. D. ANDERSON is a research engineer, ExxonMobil Upstream Research Co., Houston, Tex. J. N. DUPONT (jnd1@lehigh.edu). R. D. STOUT Distinguished Professor, is with Lehigh University, Bethlehem, Pa.
fraction \( (\phi) \) is given by (Ref. 3)

\[
\phi = 1 - \exp \left( -\frac{4\pi N}{3 + 1} \left[ \frac{1}{(n + 1)} \left( \frac{G}{aV} \right)^{l/2} \right] \right)
\]

where \( N_0 \) is the nuclei density and both \( a \) and \( n \) are material constants. The nuclei density is a critical factor because stray grains nucleate independently in the liquid. Estimates of \( N_0 \) have been made based on SG measurements (Ref. 3). The incidence of SG formation has also been related to the presence of a wide solidification temperature range, \( \Delta T_s \) (Ref. 4).

Recent solidification studies of Alloy CMSX-4 suggest a solidification temperature range of \( \sim 200^\circ C \) (360°F) based on a Scheil analysis (Ref. 5). However, more detailed modeling has demonstrated that the Scheil model overestimates \( \Delta T_s \), and the true value of \( \Delta T_s \) for this alloy is about 80°C (Ref. 5).

**Solidification Cracking**

Weld solidification cracking in the fusion zone of Ni-based alloys has been the subject of considerable investigation and the mechanism is generally well understood. As is characteristic of weld solidification cracking in other systems, cracks form during the terminal stages of solidification when liquid films are distributed along solidification grain boundaries and, in some cases, interdendritic sites. At this stage, shrinkage strains across the partially solidified boundaries can become appreciable. If the terminal liquid is distributed along the boundaries as a continuous film, the strains cannot be accommodated and the boundaries separate to form a crack.

Susceptibility to weld solidification cracking is a function of both metallurgical factors and the level of local strain present at the end of solidification. In terms of metallurgical factors, it is well established that the solidification temperature range as well as the amount and distribution of the interfacial terminal liquid are the primary factors that control solidification cracking susceptibility of Ni-based alloys (Refs. 6-8). Solute redistribution plays an important role in solidification cracking as it affects the solidification temperature range and amount of terminal liquid.

The effect of the solidification temperature range can be understood in simplified terms by considering its influence on the size of the solid + liquid (mushy) zone. During welding, the mushy zone trails behind the liquid weld pool. It is this mushy region that is susceptible to cracking under the influence of shrinkage strain and external restraint. For a fixed temperature gradient in the mushy zone (constant processing parameters), alloys with relatively high solidification temperature ranges can be susceptible to cracking due to a rather narrow crack-susceptible mushy zone.

The actual distance a solidification crack propagates through the mushy zone depends on the distribution of terminal liquid that exists near the end of the solid + liquid region (Ref. 8) and the level of local strain present. When the amount of terminal liquid is moderate (typically between approximately 1 and 10 vol-% (Ref. 8)) and/or the surface tension is low, the liquid tends to wet the boundary and form a continuous film. This type of morphology is most detrimental as it interferes with the formation of solid/solid boundaries, thus reducing the ability of the material to accommodate strain. When the amount of terminal liquid is relatively high, (greater than approximately 10 vol-%), it can often flow into the cracks and provide a “crack healing” effect (Ref. 8).

Since solidification cracking in superalloys is primarily associated with grain boundaries, SX weld zones have typically been observed to crack when SG formation has introduced grain boundaries into the weld metal. The large \( \Delta T_s \) combined with the relatively small grain boundary surface area make these areas especially susceptible to cracking. Moreover, the character of the grain boundary itself can contribute toward cracking susceptibility. High-angle boundaries are more likely to crack than low-angle boundaries due to the prolonged time interval that these boundaries require to coalesce (Ref. 9). While substrate preheating can be used to help reduce the restraint and possibly reduce cracking tendency (Ref. 10), it also reduces the overall G/V ratio in the weld zone, making a columnar-to-equiaxed transition (CET) far more likely to occur. The resultant nucleation and growth of equiaxed grains will significantly increase the solidification cracking susceptibility. Since solidification cracks have never been observed without SG, the avoidance of such cracks can be achieved by reducing or eliminating SG formation. Past studies (Ref. 11) have shown that weld parameters that produce higher G/V ratios can effectively eliminate solidification cracking.

The development and application of heat/fluid flow and solidification modeling techniques for predicting SG formation in welds has recently been described in a companion paper (Ref. 12). In that work, a detailed heat/fluid flow model was first validated for prediction of the melt pool shape and variation in temperature gradient around the melt pool. The heat/fluid flow results were then integrated into a solidification model for determining the ac-

**Fig. 1** — Two EB weld microstructures with superimposed OIM maps. A — 500 W, 95 mm/s; B — 1500 W, 25 mm/s.
tive growth directions as well as the temperature gradient and solidification velocity along the dendrite growth direction as an aid to predicting conditions that lead to the formation of stray grains. Details of the modeling approach and validation are explained in that paper (Ref. 12). The general effects of welding parameters, substrate orientation, and welding process type on the development of stray grains over a wide range of conditions has also recently been investigated and described (Ref. 13). The absorbed power of these welds was taken to be equal to the transmitted power by assuming an absorption coefficient of 1.0, since the transfer efficiency of the EB weld process is known to be very high. For comparison, a smaller set of autogenous welds was also conducted using the gas tungsten arc welding (GTAW) process. The particular powers were selected such that the absorbed powers would overlap some of the EB welds after taking into account the arc transfer efficiency of ~0.7 for the GTAW process (Ref. 14). (All power values cited in this work are absorbed powers.) The torch travel speed also ranged from 1 to 100 mm/s (2.4 to 240 in./min), similar to the EB welds. All welds described in this paper were produced in the [100] direction on the (100) plane.

Experimental Procedure

A series of autogenous welds was prepared in order to study the SG formation behavior and cracking susceptibility as a function of welding parameters and welding process. The Ni-based superalloy CMSX-4 (Table 1) was selected as a representative alloy used in SX applications for its widespread use in the industry. The alloy composition, as measured through wet-chemical techniques, is given in Table 1. Substrates with dimensions 155 x 80 x 6 mm (6.1 x 3.1 x 0.25 in.) were cast such that the (001) crystal plane was parallel to the sample surface. The substrates were solution heat-treated with a schedule used in industrial practice for Alloy CMSX-4 (heated to 1310°C [2390°F]) for 7 h while under vacuum. Electron beam (EB) welds were performed on the CMSX-4 substrates at beam powers up to 1500 W and travel speeds up to 95 mm/s using a large-chamber Leybold-Heraeus EB welding apparatus. The absorbed power of these welds was taken to be equal to the transmitted power by assuming an absorption coefficient of 1.0, since the transfer efficiency of the EB weld process is known to be very high. For comparison, a smaller set of autogenous welds was also conducted using the gas tungsten arc welding (GTAW) process. The particular powers were selected such that the absorbed powers would overlap some of the EB welds after taking into account the arc transfer efficiency of ~0.7 for the GTAW process (Ref. 14). (All power values cited in this work are absorbed powers.) The torch travel speed also ranged from 1 to 100 mm/s (2.4 to 240 in./min), similar to the EB welds. All welds described in this paper were produced in the [100] direction on the (100) plane.

Cross sections from the welds were prepared using standard metallographic techniques. Orientation imaging microscopy (OIM) analysis was conducted using an electron-backscattered diffraction (EBSD) camera on a Hitachi 4300 field-emission-gun scanning electron microscope (FEG-SEM) in order to determine the area of SG. The weld structures were then revealed by immersing the specimens for 5 s in a reagent consisting of 50 mL of HCl, 50 mL of H2O, and 2.5 g of CuCl2. Light optical microscopy (LOM) photomicrographs of the weld cross sections were used to measure the weld pool dimensions and the fusion zone area. The SG area fraction was determined by dividing the SG area (determined via OIM) by the fusion area (determined by LOM). The average of three different cross sections was acquired for each weld condition. A more thorough description of the experimental weld trials and analysis is provided in separate papers (Refs. 12, 13).

Results and Discussion

Figure 1 contains typical examples of OIM-generated grain maps superimposed upon the LOM photomicrographs of EB weld microstructures from which they were collected. In these figures, stray grains are identified by the color pixels. The weld structure shown in Fig. 1A resulted from a relatively low heat input (500

| Table 1 — The Composition of the Base Metal CMSX-4 Used in this Study. All values in wt-%. |
|-------------|-----------|
| Ni          | Bal       |
| C           | 0.002     |
| Cr          | 6.36      |
| Co          | 9.68      |
| Mo          | 0.63      |
| W           | 6.34      |
| Ta          | 6.52      |
| Ti          | 1.00      |
| Al          | 5.62      |
| B           | 0.0       |
| Zr          | 0.0       |
| Hf          | 0.10      |
| Re          | 2.87      |
Fig. 4 — Solidification cracking susceptibility. A — In the EB welds as a function of absorbed beam power and travel speed; B — in the GTA welds as a function of absorbed power and travel speed.

Fig. 5 — Comparison of crack/crack-free processing regimes for the EB and GTA welds.

Fig. 6 — Effect of heat input on the stray grain area fraction and solidification cracking susceptibility in EB welds.

W, 95 mm/s) and represents a crack-free weld with essentially no SG. By comparison, a high heat input (1500 W, 25 mm/s) EB weld is shown in Fig. 1B. This weld exhibited a high SG content of 70%. The presence of a solidification crack is illustrated by a line of black pixels and is bordered on both sides by stray grains.

While stray grain formation behavior is directly a function of local solidification parameters, these values are functions of the overall welding parameters. Figure 2 shows the overall SG area fraction as a function of beam power and travel speed for the EB welds. (SG measurements were not made at travel speeds below 20 mm/s for welds made at power levels of 1000 and 1500 W because the welds were very large and required long sampling times. In addition, simple metallographic inspection indicated that these large welds had high SG contents.) The maximum SG area fraction is reached at an intermediate travel speed of ~6 mm/s. Beyond this value, the SG content decreases with increasing travel speed. This variation in SG content with travel speed has been observed in other work (Ref. 4) and can be explained based on the relative increases in temperature gradient and growth rate with changes in travel speed. When the travel speed is low, initial increases in the speed will cause an increase in the growth rate with only minor changes in the temperature gradient. As a result, the G/V ratio generally decreases, and the amount of SG will therefore increase. Further increases in the travel speed will induce larger increases in the temperature gradient, and, according to Equation 2, G has a larger effect on SG formation than V. Thus, SG formation will subsequently decrease with further increases in the travel speed. The negative influence of increasing weld power on SG formation can be understood by considering its effect on the temperature gradient. An increase in the power will produce a decrease in the temperature gradient, thus promoting more SG to form in the weld.

A limited set of SG measurements was performed on the GTA weld structures. Those results are shown in Fig. 3 along with data from welds conducted using the EB processes at an equivalent absorbed power of 180 W. Data for several laser welds made at an equivalent absorbed power are also shown for comparison (Refs. 12, 13). Note that the GTA welds always exhibit more SG than the EB welds, and the laser welds are intermediate to these two cases. It is interesting to note that the trend in SG content between the three processes correlates to the differences in energy density. The energy density of the heat source influences the temperature gradient in the weld pool, where welds produced with higher energy density processes will experience higher temperature gradients. Thus, welds produced with higher energy density processes will experience higher temperature gradients. Thus, welds produced with higher energy density processes are expected to exhibit lower SG contents than welds made from lower energy density processes at equivalent levels of input power and travel speed. This accounts for the relatively high SG grain content of the GTA welds.

Figure 4 summarizes the cracking sus-
ceptibility of all the EB (Fig. 4A) and GTA (Fig. 4B) welds as a function of absorbed power and travel speed. These results clearly show that crack-free welds are produced by low heat inputs (i.e., low power and high travel speed). This result is not surprising considering the influence of processing parameters on SG formation, and the link between SG formation and cracking susceptibility. Since SG can generally be reduced under low heat input conditions, the cracking susceptibility will also be reduced as the heat input is decreased. The reduced heat input may also be beneficial due to its effect on solidification shrinkage and size of the crack-susceptible mushy zone. The smaller welds produced under lower heat input conditions will exhibit reduced strain from solidification shrinkage along with a smaller crack-susceptible mushy zone, and these factors may also contribute to the reduced cracking susceptibility. It should also be noted that the formation of SG does not directly indicate that cracking will occur. Crack-free welds can be made when SG are present if the mechanical stress and strain for crack formation is low enough. It is also important to note that the low heat input welds are generally wide and shallow, relative to the higher heat input welds that are typically deeper and more narrow. An example of this is readily available by inspection of the two welds shown in Fig. 1. Thus, deeply penetrating welds should generally be avoided when SG and solidification cracking are important to eliminate.

Careful examination of Fig. 4 indicates there is a significant difference in the range of processing parameters between the two processes that can be used to produce crack-free welds. This is shown in Fig. 5, which compares the position of the crack/crack-free boundary for each process. Although the positions of these boundaries are only approximate and apply only to the conditions used in this investigation, the results clearly demonstrate the beneficial effect of the EB process over the GTA process. Reference to Fig. 5 indicates this likely can be attributed to differences in power density and resultant temperature gradient. The higher power density and temperature gradient of the EB process reduces the SG content and, therefore, helps reduce the incidence of cracking.

As previously mentioned, successful weld repair of single crystal turbine blades requires minimizing both the amount of SG and solidification cracks. Fortunately, a reduction of the SG content typically leads to crack-free welds, and each defect, in turn, can be minimized by reductions in the heat input. In view of this, Fig. 6 summarizes the influence of heat input on SG area fraction and cracking susceptibility for the EB welds. These results show that, for the current conditions, there is a critical heat input of ~13 J/mm. Welds made below this heat input level are consistently crack-free with very low SG contents (<5%). Above this value, the formation of SG and associated solidification cracks are more erratic. It is important to note that effective weld repairs can still be accomplished when small amounts of SG form. Welds produced with small amounts of SG typically exhibit a very shallow layer of SG near the top of the weld at the centerline, since G/V is the lowest in that location (Ref. 15). Most practical repairs require the deposition of multiple layers. Thus, the shallow layer of SG can be removed by subsequent passes as long as the depth of melting from the next pass is greater than the depth of stray grains from the preceding pass. With this approach, the SG can be “pushed” up to the final layer, where they can be easily removed by machining. This approach has recently been applied to successfully prepare a 12-layer single crystal deposit using the laser-engineered net shaping process (Ref. 15).

Conclusions

Autogenous welds were prepared on the single crystal CMSX-4 using the EB and GTA welding processes. The stray grain (SG) area fraction and cracking susceptibility were determined and correlated to the processing parameters and process type. The following conclusions can be drawn from this work:

1) The SG content initially increases and then decreases with increasing travel speed. This effect is attributed to the complex relationship of travel speed on the temperature gradient and growth rate. Stray grain content decreases with decreasing weld power. In general, the SG content and cracking susceptibility can be reduced by welding at low heat inputs.

2) The SG content and corresponding cracking susceptibility was higher for welds prepared with the GTA process compared to the EB process. This difference is attributed to differences in power density and temperature gradient, where the EB process produces a higher temperature gradient that leads to reduced SG and less solidification cracking.

3) For the conditions evaluated in this work, EB welds produced at heat inputs below ~13 J/mm produced welds that were crack-free with very low SG contents (<5%).

Acknowledgments

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References

Three-Sheet Spot Welding of Advanced High-Strength Steels

The weldability of thin, low-carbon steel to two thicker, high-strength steels is studied through factorial experimentation and statistical analysis

C. V. NIELSEN, K. S. FRIIS, W. ZHANG, AND N. BAY

ABSTRACT

The automotive industry has introduced the three-layer weld configuration, which represents new challenges compared to normal two-sheet lap welds. The process is further complicated by introducing high-strength steels in the joint. The present article investigates the weldability of thin, low-carbon steel to two thicker, high-strength steels of high-strength low-alloy (HSLA) 340, DP600, or TRIP700. Factorial experimentation and statistical analysis are used to illustrate how the robustness of the process is affected by the electrode size and is heavily influenced by the protective zinc coating. The weld mechanisms are analyzed numerically and compared with metallurgical analyses showing how the primary bonding mechanism between the thin, low-carbon steel sheet and the thicker sheet of high-strength steel is solid-state bonding, whereas the two high-strength steels are joined by melting, forming a weld nugget at their mutual interface. Despite the absence of the typical fusion nugget through the interface between the low-carbon steel and high-strength steel, the weld strengths obtained are acceptable. The failure mechanism in destructive testing is ductile fracture with plug failure.

Introduction

The automotive industry is constantly seeking product and production optimization. Resistance spot welding is a key technology in automotive assembly production. The process is fast and can easily weld many different material combinations that are difficult or even impossible to join by other welding techniques. The development of new, advanced high-strength steels (AHSS) for use in the automotive industry represents new challenges to the resistance welding of these steels. These new steels are often used in supporting parts of the car and in parts that are designed to absorb the impact of a crash. The parts are typically joined to considerably thinner and softer low-carbon sheet materials that act as the outer panels of the car.

The weldability of different AHSS in two-layer lap joints has been investigated by several authors including the present ones (Refs. 1–5). Problems due to the formation of hard martensite phases during the rapid cooling after welding increase the risk of the joints having brittle fracture. Narrow weld lobes initiated work (Ref. 6), where an insulating adhesive layer is added between the sheets to form a weld bond. The adhesive layer increases the heat and, thereby, the nugget size due to higher contact resistance. Wider weld lobes were shown, but the addition of the adhesive layer complicates the assembly process.

Joining three sheets by resistance spot welding is an increasing trend in automotive assembly. Compared to two-sheet spot welding, joining three sheets is significantly more complicated because of the extra interface introduced. The use of different material combinations and different sheet thicknesses in the three layers complicates the process even further. Spot welding of three low-carbon steel sheets was investigated (Ref. 7), where it was recommended that three-sheet spot welding should be avoided whenever it could be replaced by two spot welds of two sheets. Among the difficulties were coating, varying surface quality, and enhanced alignment problems between three sheets compared to two. Successful welds were made, but it was shown that the three-sheet welds are more sensitive to changing parameters. Lack of confidence in weld quality is also mentioned for spot welding three sheets (Ref. 8), which in industry results in many more welds than actually needed for the required structural performance. In their study, the focus was on the heat development for uncoated and coated low-carbon steels. For these steels, they obtain acceptable weld quality for three-sheet welding.

When resistance spot welding three sheets, the joint has two sheet-to-sheet interfaces with positions relative to each other and the electrodes depending on the individual sheet thicknesses. If one of the outer sheets is considerably thinner than the other two sheets, the interface between this and the center sheet is located closer to the neighboring electrode than the other interface. In this case, the large heat conduction to the electrode creates an asymmetrical heat distribution causing problems achieving a successful weld. If the heat input is too small, the nugget will not develop in the thinner sheet, and the weld will be unsuccessful. On the other hand, if the heat input is too large, splash is often observed between the two thicker sheets, leading to uncontrollable material removal, loss of strength, and excessive electrode wear. In many cases, this implies unsatisfactory weld strength. Of importance to car manufacturing, spot welding of a thin, low-carbon steel sheet to two thicker, high-strength steels is an example with the above complications.

Innovative solutions to the above type of three-sheet spot welding have been developed (Refs. 9, 10). One solution (Ref. 9) is intelligent control of the electrode force and current levels to ensure nugget formation in both interfaces. Using a high current and low force setting in the beginning of the weld, a nugget is formed in the interface between the thin, low-carbon...
sheet and the neighboring thicker high-strength steel. The later part of the weld is performed using relatively lower current and larger force, whereby the nugget forms in the interface between the two thicker high-strength steels. Another solution to the problem is to use a process tape between the electrodes and sheets (Ref. 10). By choosing a proper resistance of the process tape in contact with the thinner low-carbon sheet, it is possible to produce relatively more heat at the interface to the thin sheet. The two methods (Refs. 9, 10) both ease the challenges to this three-sheet combination. However, both methods require advanced equipment available, either variable weld current and force during the weld time, or introduction of process tape around the electrode tip.

It may be difficult to achieve the optimum parameter settings for such a joint and the robustness of the process might be poor and highly influenced by stochastic variations. When welding high-strength steels, the electrode force required to avoid splashing is often high due to the high hardness of the steels. However, when spot welding two layers of AHSS with a third layer of soft, low-carbon steel, the latter will typically experience significant electrode indentation due to the high load, which in many cases is unacceptable due to aesthetic reasons.

The present work deals with the weld mechanism and weldability of three-layer spot welding of a thin, low-carbon steel and AHSS sheets investigating different material combinations. None of the methods (Refs. 9, 10) are applied, such that the present work reflects spot welding with common conventional welding equipment. The objective is to study the influence of the main parameters on weld strength and nugget development in order to improve the understanding of the problems involved in three-sheet spot welding. Factorial experimentation is used to design and analyze the experiments with regard to the weld strength. Furthermore, the nugget size and resulting microstructure have been investigated. The experimental results are compared with a numerical model using the finite element method and experimentally determined material data.

**Experimental**

**Experimental Procedure**

Experiments were performed on a TECNA 8105 AC welding machine with a TE-180 weld controller. The electrical system can deliver up to 85 kA with 50 Hz. The actual current was measured continuously using a piezoelectric force transducer. The applied electrodes were Ø20 mm (% in.) and Ø16 mm (% in.) ISO type B CuCrZr with tip diameters Ø8 mm (% in.) and Ø6 mm (% in.), respectively. Splash was recorded during welding both visually and by observing any irregular fluctuations in the measured weld force. The materials available for the investigation are listed in Table 1 including sheet thicknesses as well as nominal compositions. They include two types of AHSS (DP600 and TRIP700), a HSLA steel (HSLA 340), and a low-carbon steel (DC06). Figure 1 shows the tensile properties at room temperature. Except for the HSLA 340, all steels were tested at various temperatures by hot tensile testing (Refs. 11, 12). Data for the HSLA 340 steel are taken from the existing material database of the simulation software, SORPAS® (Ref. 13). The sheets were cut into samples of 25 x 100 mm (1 x 3.9 in.) and welded according to the setup shown in

![Fig. 1 — Room temperature tensile properties of the applied steels. The curves represent best-fit Hollomon equations of tested data.](image)

![Fig. 2 — Test specimens’ alignment; A — During welding; B — before tension shear testing.](image)

### Table 1 — Specification of Sheet Materials

<table>
<thead>
<tr>
<th>Material</th>
<th>Supplier</th>
<th>Thickness [mm (in.)]</th>
<th>Coating</th>
<th>Nominal composition [wt-%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>DP600</td>
<td>SSAB</td>
<td>1.5 (0.059)</td>
<td>—</td>
<td>C 0.11 Mn 0.9 Cr 2.0 Si 0.6</td>
</tr>
<tr>
<td>TRIP700</td>
<td>ThyssenKrupp</td>
<td>1.2 (0.047)</td>
<td>Zn: 14</td>
<td>C 0.24 Mn 0.6 Cr 0.3 Si 0.4</td>
</tr>
<tr>
<td>HSLA 340</td>
<td>SSAB</td>
<td>0.8 (0.031)</td>
<td>—</td>
<td>C 0.05 Mn 0.40 Cr 0.4 Si 0.01</td>
</tr>
<tr>
<td>DC06</td>
<td>SSAB</td>
<td>0.6 (0.024)</td>
<td>—</td>
<td>C 0.002 Mn 0.15 Cr 0.4 Si 0.01</td>
</tr>
</tbody>
</table>
The weld strength was tested in tension shear tests on a 100 kN (22.5 kbf) Amsler universal testing machine. The sheet samples were bent 20 deg prior to testing — Fig. 2. Prebending was applied in order to fit the samples into the available equipment in a way where a uniform test condition could be ensured. Testing was carried out by pulling the thin, low-carbon steel sheet apart from the two high-strength steels.

The influences of RMS current $I$, electrode force $F$, and weld time in cycles $T$ on the weld strength were investigated. Furthermore, the effect of increasing tip diameter $B$ of the bottom electrode from 6 mm (% in.) to 8 mm (% in.) was studied. No up- or down-slope of the current or force were used.

The experimental investigations were designed as unreplicated factorial designs with $n_c = 3$ center points. This design was chosen in order to get an overview of the influence of the main parameters as well as possible interactions on the weld quality, i.e., failure type, strength, and splash/no splash. The center points were used to estimate the variability due to stochastic error in the experiments. The experiments were divided into seven series. The first three series investigated welding of DC06 to HSLA 340 as the middle sheet and either DP600 or TRIP700 as the bottom sheet. These series are named DC06-HSLA 340-DP600/TRIP700. The last four series investigated welding of DC06 to DP600 and TRIP700 in the four possible combinations. An overview of the factorial experiments is given in Table 2.

Series 1 and 2 were carried out as initial studies to test the overall weldability of DC06 to HSLA and AHSS. Furthermore, the influence of increasing the size of the bottom electrode was included in these series. Based on the first two series, the third series was carried out with identical process parameters for the two material combinations and using larger bottom electrode, Ø8 mm (% in.) tip. Beside the factorial experimentation, series 3 was studied further to investigate nugget formation and weld strength over the entire current range at two force levels. The last four series, 4–7, were made to increase the complexity of the welding process even further by introducing AHSS next to the DC06 in different combinations while keeping the weld parameters the same for all combinations.

Performing the weld series 1–7, the weld current was entered on the control unit according to the values in Table 2. Measurements of the actual RMS weld current were used in the simulation instead of the prescribed values on the controller.

### Numerical Procedure

The numerical software SORPAS® (Ref. 13) was used to simulate the process of three-layer spot welding. The software is a numerical tool specialized for resistance welding processes with simulation, optimization, and planning features. It is based on the finite element method, having a mechanical, thermal, electrical, and metallurgical model implemented. The three models are coupled in each time increment. Besides an existing material database, the software allows for material data provided by the user, such that specific materials can be simulated. The stress-strain curves for varying temperatures of the low-carbon steel, DC06, and the two high-strength steels, DP600 and TRIP700, were determined by hot tensile testing (Refs. 11, 12) and inserted in the numerical simulation.
software. The stress-strain-temperature curves for HSLA 340 as well as all thermal and electrical properties were taken from the existing material database of SOR-PAS®. In all simulations presented in this work, minimum two elements were used in the thickness direction of the sheets, and the time step was set to 0.2 ms.

Results

Weld Strength

In Table 3 the ANOVA tables of the reduced, fixed effects models for the experimental series 1 to 3 are collected employing specific procedures (Ref. 14). A relatively tight significance level of 2.5% was chosen in order to clarify only the most significant factors. Hence, factors with a significance level larger than 2.5% were dropped from the model and their sum of squares (SS) were pooled in the residual SS. The significance level (Prob. > F₀) for each significant factor (factor abbreviations are listed in Table 2) and factor interaction is listed in Table 3 together with the calculated sum of squares and its degree of freedom (DF). All factors only have two levels, and hence, all factors have one degree of freedom. The mean square is calculated and the ratio F₀ between factor mean square and the mean square of the total experimental variability, the residual, is calculated. Using the F-distribution, the null hypothesis is tested, and the probability that the variance in the experimental data is caused by stochastic error alone, and not by the variation of the factor levels, is calculated. A low probability implies that the factor or factor combination has a significant effect on the strength of the welds. The sum of squares of the residual consists partly of pure error calculated from the three center point repetitions and partly of the sum of squares from the insignificant factors that are dropped from the model. Finally, the overall mean weld strength and standard deviation are given as well as the values of the center point itself.

As an example on how the models were reduced using a significance level of 2.5%, the iteration of series 1 is shown in Table 4. It is seen from the table that the electrode force and weld time are close to being significant, which is expected, but in the reduced model of series 1 the main factor contributing significantly to increasing the weld strength is the electrode size B, and the main interactions are between electrode size and force BF as well as electrode size and weld time BT. The two significant interactions are shown in Fig. 3. Had the parameter range been chosen differently (i.e., lowering the minimum values), the main parameters F, T, and I would most likely have had a significant effect. The fact that different factors have an effect depending on the chosen parameter range can be attributed to the experimental variation and errors introduced by the linearity assumption of the 2-level factorial design.

In series 1, where DC06-HSLA 340-DP600 is the weld combination, it is seen how increasing weld time decreases strength using the small electrode, while the strength is increased if using a larger bottom electrode — Fig. 3A. This is attributed to the fact that the small electrode promotes splash at longer weld time, while the larger electrode allows for the growth of a larger nugget resulting in higher strength. The force has no effect on the weld strength using the small electrode, while the strength decreases when increasing the load with the large bottom electrode — Fig. 3A. This is explained by considering the relation between pressure and contact resistance. Using the small electrode, the pressure is higher compared to the large electrode, and for high pressures the effect on contact resistance and heat generation levels out. Furthermore, increasing electrode size alone raises the strength — Fig. 3. The current shows no influence on weld strength. This is most likely because the actual current values in the experiments were considerably lower and lying closer to each other (<1 kA) than prescribed on the controller. On top of this, the nugget size becomes more robust in regard to weld current when approaching the splash limit, which is the case here.

Series 2 involves welding of DC06-HSLA 340-TRIP700, where different weld parameter settings than the previous are used (Table 2). In the ANOVA analysis of series 2, the current I, force F, and weld time T now have significant effects on the weld strength, while on the other hand, the electrode size B does not have an effect. The fact that I, F, and T influences are significant suggests that the ranges of the factor levels are wide enough to cover the nugget growth. For higher levels of these factors, their effect on nugget size and strength saturates, thereby becoming insignificant. For this material combination, the weld strength did not increase when increasing the size of the bottom electrode. The current and the nugget size alone is the case here.
Due to the fact that increasing the size of the bottom electrode promoted higher strength and eliminated splash in series 1 as well as having no effect in series 2, it was chosen to apply the larger size bottom electrode with tip Ø8 mm (% in.) in the remaining series 3–7, which were then focused on the effect of the material combinations. Series 3 was run with a large lower electrode and common factor levels for the two material combinations: DC06–HSLA 340–TRIP700/DP600. The factor level ranges were set to overlap the ranges of the two previous series, hereby increasing the average heat input when using the TRIP steel and decreasing the average heat input when using the DP steel. The ANOVA analysis (Table 3) suggests that the factors material M, current /, force F, and weld time T all have significant effects on the weld strength. Changing the material from TRIP to DP or increasing the electrode force decreases the average weld strength, while an increase in current and weld time increases weld strength. At the high heat input settings for the TRIP combination, splash starts being a problem, although the weld strength is not negatively influenced by this. Since no interactions involving the material type of the bottom sheet are significant, the factors I, F, and T have the same effects on the relative weld strength independent of material type. This suggests that the lower absolute values of the factor level range for

<table>
<thead>
<tr>
<th>Series 1: DC06 – HSLA340 – DP600</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
</tr>
<tr>
<td>B</td>
</tr>
<tr>
<td>BF</td>
</tr>
<tr>
<td>BT</td>
</tr>
<tr>
<td>Residual</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Series 2: DC06 – HSLA340 – TRIP700</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
</tr>
<tr>
<td>F</td>
</tr>
<tr>
<td>T</td>
</tr>
<tr>
<td>I</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Series 3: DC06 – HSLA340 – DP600/TRIP700</th>
</tr>
</thead>
<tbody>
<tr>
<td>Factor</td>
</tr>
<tr>
<td>M</td>
</tr>
<tr>
<td>F</td>
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<tr>
<td>T</td>
</tr>
<tr>
<td>I</td>
</tr>
<tr>
<td>Residual</td>
</tr>
</tbody>
</table>
DP steel covers more of the nugget growth region than in series 1. The strength is, therefore, now influenced by these factors. The standard deviations of the center runs indicate that the TRIP steel gives higher variability than the DP steel.

Series 4-7 were all carried out with the large bottom electrode tip of Ø8 mm (⅛ in.). Analysis of the results from the factorial experiments using the ANOVA procedure presented some problems. This is mainly due to the fact that the ANOVA analysis works best with process responses that are continuous. When a certain parameter configuration yields no weld, the recorded weld strength is zero, which gives a large discontinuous jump in the response. Furthermore, some of the welds resulted in an abnormally high indentation of the top electrode, which resulted in a highly increased nugget size and again a jump in weld strength. These jumps will corrupt the ANOVA analysis and either show large effects from factors that are not expected to be significant, or show no effect due to a too high variability in the results. In Table 5, the results of the different series are collected showing the overall and center point averages and standard deviations. The overall averages and standard deviations for series 4-6, including the TRIP steel, show large variability in the chosen range of the factor levels, meaning that changing the process parameters causes a large change in response of the process. Comparing with the standard deviations of the center points, it is clear that the main process parameters highly affect the results of these welds.

The DC06-TRIP700-TRIP700 combination showed splash at high heat input settings and practically no welds at low heat input. Furthermore, splash was also observed for one of the low heat input settings indicating that the TRIP sheet itself is inducing variability to the process. This is also seen from the relatively large standard deviation of the center point runs and the fact that splash was not consistent for the repeated center point runs.

Table 4 — Iteration Scheme Using the 2.5% Significance Level to Drop Factors from the Model

<table>
<thead>
<tr>
<th>Factor</th>
<th>DF</th>
<th>Iteration 1</th>
<th>Iteration 2</th>
<th>Iteration 3</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td>Ms</td>
<td>P</td>
<td>Ms</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>228711.1</td>
<td>0.07%</td>
<td>1</td>
</tr>
<tr>
<td>F</td>
<td>1</td>
<td>13286.6</td>
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</tr>
<tr>
<td>T</td>
<td>1</td>
<td>5413.3</td>
<td>2.70%</td>
<td>-</td>
</tr>
<tr>
<td>I</td>
<td>1</td>
<td>1178.9</td>
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<td>12353.3</td>
<td>9.66%</td>
<td>-</td>
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<td>152.4</td>
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</tbody>
</table>

Fig. 6 — Weld combination DC06-HSLA 340-TRIP700 welded with 6.3 kA during 16 weld cycles at 4 kN weld force. Upper A — Initial crack formation after maximum load. The rear of the thin sheet has started folding. Lower A — Complete separation showing a plug failure with subsequent tearing of the thin sheet, which is now folded over the remaining button; B — cross section showing the plug failure and nugget, which has not formed into the thin, low-carbon sheet.
Fig. 7 — DC06-HSLA 340 interface in welds series 2.

Fig. 8 — Area of bonded interface, series 2.

DP600-DP600. This combination is extremely robust in the chosen parameter range as the weld strength hardly changes and no splash is observed. An ANOVA analysis on this series suggests that only the current has notable influence and that the effect is small.

The experimental investigation of weld strength shows that the zinc-coated TRIP steel makes the process more sensitive to process variations. When including this sheet in the combination, the process window for making a successful weld diminished. The dominant failure mode during tension shear testing was identified as plug failure and subsequent tearing of the thin low-carbon steel sheet.

Nugget Formation

The nugget formation mechanism in three-layer welding of a low-carbon sheet to two high-strength steels was investigated using numerical simulation of the process. The simulations give the temperature distribution in the material at a given time during the process. An analysis of temperature development during welding revealed that for the present configuration of materials and sheet thicknesses, the heat generation was concentrated around the interface between the two thicker high-strength steels, which was the location of initial nugget formation. Depending on the material combination and the thickness of the sheets, the weld nuggets grow toward the interface to the thin, low-carbon steel. Conventionally, the optimal weld is achieved if the nugget is allowed to grow a considerable amount into all the sheets being joined. However, the problems regarding the investigated three-sheet welds were to achieve nugget growth into the thin low-carbon steel sheet without getting splash and internal defects in the weld.

Looking at the cross-section micrographs of the center-point runs of series 1 through 7(Fig. 4), it is seen how the resulting weld nuggets appear. The simulated temperature distribution and weld nuggets are shown for comparison; the white line drawn in the micrograph showing the predicted nugget. The micrographs indicate that the nugget has not been able to grow into the thin, low-carbon steel sheet in any of the weld series’ center point runs. The nuggets tend to grow close to the interface of the low-carbon sheet, but then it stops, in some cases practically at the interface. For other weld configurations than the center-point settings, the nugget penetrates slightly into the low-carbon steel.

From the simulations, it is furthermore observed that the weld nugget generation is strongly influenced by the presence of the zinc coating on the TRIP steel. According to the simulations, the initiation of the weld nugget formation is delayed due to the improved contact conditions in the interface and the resulting reduced heat generation. The simulations suggest that the nugget formation initiates in the bulk part of the sheets rather than at the interface, but then almost immediately after grows through the interface forming a weld nugget between the two high-strength steels. In general, rather good agreement between simulated and experimentally obtained nugget sizes is observed — Fig. 4. The largest discrepancy is noticed in weld series 3 when introducing the TRIP steel, where the simulated nugget size is somewhat larger than the experimentally obtained. This was likely caused by the modeling of the contact resistance at the two zinc-coated surfaces of the TRIP steel, where the simulated heat generation and the squeeze out of the liquid coating is overestimated compared to the real situation.

A detailed study of the nugget growth and resulting strength was carried out for series 3. The resulting nuggets for the two material combinations, DC06-HSLA 340-

<table>
<thead>
<tr>
<th>No.</th>
<th>DC06 —</th>
<th>Overall Std. Dev.</th>
<th>Center Point Std. Dev.</th>
<th>Failure mode of center point</th>
<th>Center point weld splash</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>TRIP-TRIP</td>
<td>2169 (487.6)</td>
<td>973 (218.7)</td>
<td>2706 (608.3)</td>
<td>155 (34.8)</td>
</tr>
<tr>
<td>5</td>
<td>TRIP-DP</td>
<td>1867 (419.7)</td>
<td>1467 (329.8)</td>
<td>2011 (452.1)</td>
<td>121 (27.2)</td>
</tr>
<tr>
<td>6</td>
<td>DP-TRIP</td>
<td>3062 (699.4)</td>
<td>632.0 (142.1)</td>
<td>2904 (652.8)</td>
<td>103 (23.2)</td>
</tr>
<tr>
<td>7</td>
<td>DP-DP</td>
<td>2836 (637.6)</td>
<td>91.0 (20.5)</td>
<td>2830 (636.2)</td>
<td>25.0 (5.6)</td>
</tr>
</tbody>
</table>
TRIP700/DP600, were examined for different current settings. The current was varied from the minimum setting on the machine (about 6 kA) in steps until splash was reached. The welding time was increased to 16 cycles to increase possibility of nugget growth into the thin, low-carbon sheet. The two force levels were kept at 3 and 4 kN. Figure 5 shows the nugget diameters at the two interfaces as well as the obtained strength for the four combinations (two material combinations and two weld force levels). In agreement with previous discussion, the combination including the coated TRIP steel has a narrower weldability range. Splash is reached at lower currents, and the nugget growth at the DC06-HSLA 340 interface (referred to as upper interface in Fig. 5) is more difficult to achieve. At 3 kN weld force for the TRIP combination, no nugget was formed before splash appears, whereas the DP combination has a relatively large current range at 3 kN, where a nugget forms into the thin DC06 sheet. The corresponding strengths are shown by Fig. 5 (lower). As all points in Fig. 5 are unreplicated, an idea of the standard deviation is obtained by comparing with the center runs for series 3 (Table 5). As the weld settings are changed, a larger deviation is assumed in order to be conservative. Reading the strength curves in Fig. 5 as ± 0.1 kN corresponds to ± 2.3 times the maximum standard deviation obtained in the original series 3. Having this in mind, a general trend is increasing strength with increasing current as the nugget also increases by increasing heat input.

An interesting discovery from the strength tests is that all tested welds failed with plug failure and subsequent tearing of the thin, low-carbon sheet. This being regardless of whether or not nugget formation appears in the DC06-HSLA 340 interface. Figure 6 shows an example of a weld without nugget formation into the thin sheet, but with plug failure. The example is a DC06-HSLA 340-TRIP700 combination welded with 6.3 kA during 16 cycles using a weld force of 4 kN. The upper part of Fig. 6A shows the initial crack and the rear sheet starting to fold. The lower part of Fig. 6A shows the configuration after complete separation. A button has formed from the thin sheet, and the thin sheet behind the button has been torn apart from the remaining thin sheet. Figure 6B shows the button on top of the two high-strength steels, and it shows the nugget, which has only penetrated roughly half through the HSLA 340 sheet, thus not forming a nugget in the critical interface to the thin low-carbon sheet. The strong bond between the low-carbon steel and the neighboring high-strength steel is a solid-state bond facilitated by heat and plastic deformation.

**Bonding Mechanism**

The tension shear tests resulted in a rather high strength of the joints compared to previous studies (Ref. 3) as well as plug failure followed by ductile fracture of the low-carbon steel in most cases, although in some cases, the nugget only penetrated slightly or not at all into the thin, low-carbon sheet. This implies that the low-carbon steel is effectively joined to the high-strength steels. A closer inspection of the micrographs revealed several different weld interfaces between the low-carbon and high-strength steel.

Contaminant film and oxide layers are broken by heating and plastic deformation uncovering virgin metal surfaces, which leads to direct metal-to-metal contact and formation of a strong metallic bond, i.e., a solid-state joint. In some cases the entire interface is bonded, while less favorable bonding conditions only allow for parts of the interface to form strong bonds. This is seen in Fig. 7 showing the interface between low-carbon steel and HSLA in weld series 2. Outside the boxed areas, the original interface is still intact and visible as a black line separating the two steels. Inside the boxes, the interfaces have grown together, and the interface line is no longer present as seen in the magnification — Fig. 8. The larger bonding area, the higher is the expected tension shear strength of the welds. Three different material zones are distinguished in Fig. 7. Zone 1 consists of the low-carbon steel, zone 2 is the weld nugget now transformed into martensite, and zone 3 is the heat-affected zone of the HSLA in contact with the low-carbon steel. With reference to the tension shear strength of the center point run of weld series 2 given in Table 3, it is clear that a strong bond is created even though the weld nugget clearly has not reached the joining interface.

**Discussion**

From the factorial experimental series 1 and 2, it is shown that increasing the tip diameter of the bottom electrode from Ø6 mm (1/4 in.) to Ø8 mm (5/32 in.) significantly increases the tension shear strength of the weld combinations with DP600, but not with TRIP700. As proposed in section 3.1, the main reason for this is that the maximum nugget size had been reached using the small electrode and a larger electrode allows for the growth of a larger nugget. The process parameter range of the TRIP700 was not chosen as close to the maximum nugget size, and hence, an increased electrode size could not generate a larger nugget for the chosen weld parameters. On the other hand, it is noticed that a change in process parameters gave stronger welds and presumably larger weld nuggets.

As seen from the factorial experiments, especially series 4–7, the three-layer welding generally becomes less robust toward changes in process variables when the coated TRIP steel is included in the material combination. Comparing the tensile properties (Fig. 1), it is seen that the TRIP steel itself is stronger than the DP steel. However, it is the tensile properties of the DC06 that is most important for the strength when the failure mode is plug failure. A numerical simulation, where the material properties of DP600 in weld series 3 were replaced by the properties of TRIP700, showed that the difference in nugget diameter was less than 4%. Thus, the effect of the different mechanical properties of the TRIP and DP is limited. The electrical properties of the bulk materials are furthermore not differing significantly since all the materials are steel alloys with relatively low amounts of alloying elements. The fact that the TRIP steel is thinner than the DP steel affects the welding process, as the cooling capacity of the sheet itself is decreased, but on the other hand the interfaces move closer to the electrodes, thereby facilitating cooling. The main factor influencing the weldability of the TRIP steel is believed to be the 14 μm (% μin.) zinc coating, as also the influence of coating on low-carbon steels has been shown previously (Ref. 8). The coating is soft and a good electrical conductor resulting in low contact resistance of the interfaces and slower heat generation, thereby delaying the nugget formation, in agreement with the previous measurements and discussions (Ref. 8). This implies that longer weld times or higher currents are needed to initiate nugget growth. As the melting point of zinc is considerably lower than that of the steels, the coating melts before the nugget forms at a given interface. Due to the high contact pressure, the melted coating will be squeezed out. The coating only stays at an interface in cases where the temperature stays below the melting temperature of the coating. In practice, this implies that whenever a nugget forms at a zinc-coated interface, the coating has been squeezed out.

After the coating has been squeezed out, the molten zinc will segregate in the periphery of the nugget, thereby increasing the contact area. This increased contact area counters the increased contact resistance in the area that the coating has left. In the previous work (Ref. 8), a larger welding current was applied for the coated case than for the uncoated case. In this case, similar nugget growth rates were obtained for the two cases, since the larger welding current compensated for the
larger contact area. A numerical study of series 3, using SORPAS® (Ref. 13), showed that the nugget diameter increased by more than 23% when removing the zinc coating in the HSLA 340-TRIP700 interface under the same welding parameters. This is in agreement with the choice in Ref. 8, where the optimal welding current was found to be larger in the coated case.

Conclusions

The mechanism of nugget formation has been identified to initiate between the two high-strength steels from where it develops and grows into the sheets. Depending on the heat input, the nugget might grow close to or in some cases even slightly penetrate into the thin, low-carbon steel. It was found that increasing the size of the bottom electrode improved the strength of the joints by increasing the weld nugget diameter. This, however, was only observed for weld settings where the growth of the nugget was restricted not due to a low heat input but to geometrical concentration of the current, i.e., in cases where the weld current and time were enough to form a nugget of at least the size of the bottom electrode tip.

By examining micrographs of the welds, it was found that bonding between the low-carbon steel and high-strength steels predominantly appeared in solid state rather than by a fusion nugget. The solid-state bonding is facilitated by the high temperatures and plastic deformation during the welding process breaking the oxide layer to form metallic bonds. The weld strengths measured by tension shear tests were found to be relatively high compared with previous investigations utilizing the same low-carbon steel (Ref. 3). Furthermore, fracture was typically in the form of ductile tearing of the low-carbon steel around the formed plug failure. Only a few of the weaker welds failed in a brittle manner through the interface, and this was mainly observed for interfaces with zinc coating involved, i.e., for the TRIP steel.

It was investigated whether it was possible to model the three-layer welding process by numerical simulation using material models of the strength of the materials determined by hot tensile testing. The simulations proved good correlation with the experimental results, which shows that the numerical analysis can be used as a tool to optimize individual weld configurations of three-layer spot welding of AHSS.

As mentioned in the introduction, lack of confidence in weld quality for threeshot spot welding results in many more welds than needed for the required structural performance (Ref. 8). Another reason for applying too many welds could be incorrect quality measures. Nugget size has traditionally been a quality measure, but the results obtained in the present work show that a satisfactory high strength involving plug failure can be achieved even without forming a fusion zone across the interface to the thin, low-carbon steel in typical three-layer welds. Increased confidence in such welds, e.g., obtained by performing additional types of strength, fatigue, or impact tests, may lead to fewer welds if a larger span of welds can be accepted.

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