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Cloud Gate, a massive stainless steel sculpture by artist Anish Kapoor on display in Chicago's Millenium Park, was recently awarded the American Welding Society's Outstanding Achievement in Welding Award. (Photo by Patrick L. Pyszka/City of Chicago.)
Government Launches Federal Contracts Database

The U.S. Office of Management and Budget has finally unveiled its Congressionally mandated, publicly accessible database of government contracts, grants, loans, and other financial assistance. Searches may be conducted by name of contractor, federal agency, products and services, as well as contract performance site. There is also a current list of the 100 largest contracts.

USAspending.gov was created to meet the mandates of the Federal Funding Accountability and Transparency Act of 2006, which had established a deadline for launch of the site of January 1, 2008.

Regulatory Agenda Now Available Online

For the first time, the Semiannual Regulatory Agenda is available in a searchable format online at www.reginfo.gov.

The Semiannual Regulatory Agenda, also known as the Unified Agenda, which summarizes the rules and proposed rules that each federal agency expects to issue during the next six months, has traditionally been published in print form twice a year (usually in April and October) in the Federal Register. The migration of the agenda to the Internet is intended to enhance availability of the listed federal regulatory actions. These listings typically include brief descriptions, timetables, and contact information for each of the planned regulatory actions.

There are 3882 entries in the current agenda, consisting of federal regulations in various stages of preparation. This is only the second time in 20 years that the number of entries has been lower than 4000.

OSHA to Revise Shipyard Regulations

The U.S. Occupational Safety and Health Administration (OSHA) has announced its plans to revise the standards on general working conditions in shipyard employment.

The OSHA proposal updates and clarifies provisions in the shipyard employment standards (29 CFR Part 1915 subpart F) that have largely gone unchanged since OSHA adopted them in 1972. OSHA proposes to revise and update existing provisions and to add new provisions, including the control of hazardous energy, such as lockout/tagout, and motor vehicle safety. Proposed updates include establishing minimum lighting for certain work sites, accounting for employees at the end of work shifts if they work in confined spaces or alone in isolated spaces, and adding uniform criteria to ensure shipyards have an adequate number of appropriately trained first-aid providers. The proposal also updates sanitation requirements.

The agency will be accepting public comments on the proposed rule until March 19, 2008.

FOIA Reform Legislation Signed into Law

The Freedom of Information Act (FOIA) is about to undergo its most extensive revision in more than 30 years. The Openness Promotes Effectiveness in our National Government Act — or OPEN Government Act of 2007 — effects several reforms, including making it easier for a FOIA requester to recover attorney fees when the requester successfully challenges a final agency rejection in court.

The most important new measure, however, is the establishment of a FOIA ombudsman to mediate disputes between requestors and agency officials. Realistically, there is little recourse for denial of an FOIA request, short of litigation which usually only well-financed media entities are willing to pursue. An ombudsman, therefore, is an extremely welcome change and one that could have a significant impact. In addition to facilitating the mediation of disputes, the ombudsman will have the authority to audit agency FOIA departments and suggest changes.

U.S.-Peru Free Trade Implementation Legislation Signed

Legislation that will implement the U.S.-Peru Trade Promotion Agreement has been enacted, clearing the way for the treaty to become effective later in 2008. The U.S.-Peru agreement is the only such agreement passed by Congress in 2007. Three others are pending: Colombia, Panama, and South Korea. Negotiation of tougher labor and environmental standards has been the primary point of dispute and cause for the delay in approval.

OSHA Issues Final PPE Rule

The Occupational Safety and Health Administration (OSHA) has issued a final rule generally requiring employers to pay for personal protective equipment (PPE) for their employees when such PPE is used to comply with an OSHA standard. This completes a process that began in 1999 when OSHA first issued a proposed regulation regarding PPE. In the intervening years, numerous states have adopted their own rules requiring employer payment for PPE, and therefore the largest impact of the new OSHA final rule will be on employers doing business in states without such a requirement.

Types of PPE covered by this rule includes helmets, gloves, boots, and eye and hearing protection.

This rule becomes effective on February 13, 2008, and must be fully implemented by May 15, 2008.

Regulatory Relief Legislation Passed by House

The U.S. House of Representatives has unanimously adopted legislation designed to greatly improve the effectiveness of the Regulatory Flexibility Act (RFA). The RFA, which became law in 1980, mandates that federal agencies consider the potential economic impact of federal regulations on small entities. The RFA also requires agencies to examine regulatory alternatives that achieve the agencies’ public policy goals while minimizing small entity impacts.

In its application, several weaknesses in RFA have come to light, in particular the failure of agencies to assess the indirect impact of regulations, i.e., downstream effects on businesses that are not a direct target of a regulation itself. In addition, many times, especially with environmental regulation, the duty of regulating is passed on to the states without any corresponding analysis or requirements for states to consider less burdensome alternatives for small business.

The “Small Business Regulatory Improvement Act” (H.R. 4458) is intended to address these and related issues.

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Navy, Northrop Grumman Newport News Investigating Faulty WELDS

Weaknesses in the welding process associated with some nonnuclear piping welds on Virginia class submarines were discovered by the Navy in mid November, according to a statement from the U.S. Navy dated December 10, 2007. The problems were discovered during routine testing and did not endanger the safety of the crews or submarines.

The first indications of this problem were found when two failures occurred during routine testing: the first in August 2007, and the second in October 2007. A broader investigation also began due to the close proximity of failures coupled with a NAVSEA audit. “The investigation revealed inadequate processes at Newport News allowed the improper use of the wrong weld filler metal in nonnuclear piping systems over an extended period of time,” the statement said. “The failures during testing were caused by trace amounts of copper alloy filler material incorrectly welded into Corrosion Resistant Steel (CRES) socket-welded joints. The copper alloy weld filler in CRES piping joints can lead to cracking of the joints, which could result in leaks.”

The Navy, Northrop Grumman Newport News (NGNN), and General Dynamics Electric Boat conducted a detailed assessment of completed welds through record reviews, additional inspections, and testing.

The short-term effects have been addressed by the Navy through testing all of the critical NGNN-fabricated nonnuclear socket welded joints on current Virginia class ships. And to ensure the existing problems are fixed, and to prevent future ones, the Navy is working with Newport News.

Additionally, according to a Navy statement from December 18, 2007, a technical assessment of nonnuclear piping systems will take place with all vessels constructed or maintained by NGNN since 2000. Virginia class submarines, Los Angeles class submarines, aircraft carriers, and in-service surface ships built or maintained by NGNN from 2000 to 2007 are included in the long-term investigation. “NGNN has revised its procedures and is retraining its workforce on the new procedure. Both NGNN and the Navy are providing additional deckplate oversight to monitor conformance to the revised process,” the Navy reported.

Air, water, and hydraulic fluid inside the hull of the vessel are transported by the internal piping systems under review.

This spring, the Navy and NGNN will complete an analysis of the long-term effects of the weld problem, and identify the steps to be taken. Reworking some welds and conducting routine monitoring or testing of the welds are actions that may be taken.

AWS Foundation Receives $100,000 Donations from OKI Bering and Hobart Institute of Welding Technology

The American Welding Society (AWS), Miami, Fla., and the AWS Foundation recently announced they have received a $100,000 donation from OKI Bering, Cincinnati, Ohio, a wholesaler of welding, safety, and industrial supplies, as well as a $100,000 donation from the Hobart Institute of Welding Technology, Troy, Ohio, a provider of training and education about various welding technologies, to help relieve the nationwide shortage of welders.

The donations were granted to the AWS Foundation Welder Workforce Development Program. This program is part of the AWS Foundation’s $10 million capital campaign, “Welding for the Strength of America.”

The OKI Bering donation will be granted over a five-year term. The funds are earmarked for the development of a welding industry career Web site that will allow job-seekers to search and apply online for job opportunities at many levels. Also, over the next five years, OKI Bering will direct all of the company’s surplus inventory materials to welding schools across the nation. It is expected that the total inventory to be donated by the company will amount to more than $1 million.

Airgas Obtains Smith Welding/Bayer Welding

Airgas, Inc., Radnor, Pa., has acquired the assets and operations of Smith Welding Supply & Equipment, Inc., and its affiliated company, Bayer Welding Supply, LLC.

The companies had combined annual sales of $16 million in calendar 2006. Its central industrial gas fill plant in Ferndale, Mich., supported branches in Wixom, Clinton, Detroit, and Auburn Hills, plus a location in Warren operating as Bayer Welding.
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Achieving Strength through Diversity

I recently returned to my south Mississippi home following a visit to my mother and brother who both live in the Phoenix, Ariz., area. The differences in topography and climate always amaze me when I travel to different parts of the country. Where the Gulf Coast of Mississippi has a plentiful supply of water resources and pine tree forests, the desert country of Arizona has much less water and never-ending rows of saguaro cactus. The geography of the United States is comprised of extremely diverse units that when combined form a remarkable country.

During my flight home, I realized that the membership of the American Welding Society is much the same. The organization’s membership includes a variety of ages, ethnic backgrounds, nationalities, and professions. This richly diverse membership was apparent this past fall during the FABTECH International & AWS Welding Show. If you stood in one of the aisles in the exhibition hall or sat in one of the technical briefings, you noticed the remarkable diversity of people participating in the events.

One of 2007 AWS President Gerald Uttrachi’s objectives was to reach out and make welcome in the American Welding Society people not typically considered to represent the core members of the Society. The Membership Committee supports this effort and is continuing into 2008 to develop initiatives and plans to upgrade the benefits of AWS membership, seeking to attract those in our industry who may consider the existing benefits package as lacking for their needs.

A recently completed major task was to receive guidance from people who are full-time welders. Although this occupational group forms a relatively small percentage of AWS membership, a survey was developed requesting input from a large population of welders to help us plan an improved program that would be attractive to the professional welder. I expect a program will be released this year that will address the stated needs of welders.

Similarly, women form another segment that is underrepresented as members. I have had the opportunity to work with many women in the shipyard and in my AWS activities, and based upon my experiences, AWS will benefit by leading the effort to attract greater numbers of women into welding professions by highlighting the depth of opportunities available in industry, education, and the other many occupations that comprise the welding field.

Why am I an advocate for AWS becoming a very diverse organization? I have seen how the energy and excitement levels increase when a group of people from different cultures, backgrounds, and experiences work together with a common objective. This is demonstrated annually during the AWS Leadership Symposium. The 25–30 members who meet in Miami for an extended weekend may not know anyone else in the group prior to their arrival, but by the time they head home, strong friendships have developed. The dynamics exhibited in their interaction and participation in identifying common Section problems and potential solutions is a great example of what can be accomplished when a mix of people gather and work together.

In conclusion, I want to challenge all of our members to reach out and invite someone to join AWS. By making this offer to everyone who is involved in a welding profession, AWS will grow and develop a more diverse membership. Although it is true that there is strength in numbers, there is even more strength when we can draw on the wisdom, energy, and knowledge of the full range of welding professionals.

Lee G. Kvidahl
Chair, AWS Membership Committee
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Aerojet Awarded $62 Million for U.S. Air Force’s F-22 Raptor Program

Aerojet, Sacramento, Calif., has recently been selected by The Boeing Co. to provide additional forward boom ship sets, worth $62 million over a three-year period, for the U.S. Air Force’s F-22 Raptor program.

The company is under contract to build the welded titanium forward boom for Lockheed Martin’s F-22 Raptor. The forward boom is a structural component providing wing, engine, and horizontal tail attach points to carry much of the F-22 aft fuselage load.

Aerojet uses an electron beam (EB) welding process to join titanium pieces to precise dimensional tolerances. Also, the EB welding process allows the airframe design to incorporate complex features into a single component.

License Application Filed to Build Two Nuclear Reactors in Texas

A combined construction and operating license application has been filed recently by NRG Energy Inc. and South Texas Project Nuclear Operating Co. for building two General Electric Advanced Boiling Water Reactors at the South Texas Project plant site in Matagorda County, according to Nuclear Energy Insight.

This marks the first full license application for a nuclear power plant that the U.S. Nuclear Regulatory Commission (NRC) has received in nearly three decades.

An acceptance review process for the license application is being conducted by the NRC; if it approves the application, NRG said it expects to begin construction in 2010, with the reactors beginning electricity production in 2014 and 2015.

In the coming years, 17 companies and consortia have plans to submit applications for more than 30 reactors.

Chart Gives $50,000 for Western Technical College Welding Scholarships

Chart Energy and Chemicals, an independent global manufacturer of equipment used at cryogenic temperatures for the production, storage, and end use of hydrocarbon and industrial gases, presented Western Technical College, La Crosse, Wis., with a $50,000 endowment to set up scholarships for welding students. This will be used to provide two $1000 and one $500 scholar-
A $50,000 endowment from Chart Energy and Chemicals to Western Technical College will provide scholarships to welding students. At the presentation (from left) are Joel Guberud, Chart VP of manufacturing; John Martin, welding instructor; Rich Westpfahl, dean of industrial technologies; Kenric Sorenson, welding instructor; Ron Bell, Chart senior principal welding engineer; Mike Sexauer, Western Foundation board member; and Lee Rasch, president, Western Technical College.

A $50,000 endowment from Chart Energy and Chemicals to Western Technical College will provide scholarships to welding students. At the presentation (from left) are Joel Guberud, Chart VP of manufacturing; John Martin, welding instructor; Rich Westpfahl, dean of industrial technologies; Kenric Sorenson, welding instructor; Ron Bell, Chart senior principal welding engineer; Mike Sexauer, Western Foundation board member; and Lee Rasch, president, Western Technical College.

arships annually to students pursuing the college’s one-year welding technical diploma.

"Welding is one of the manufacturing careers that is experiencing skilled worker shortages," said Lee Rasch, president of Western Technical College. "We are pleased that Chart Energy and Chemicals is partnering with Western to help meet this need."

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Bockey, Small Business award, Greiner Industries, Inc.; Ken Krueger, Large Business award, Bucyrus International Inc.; John Husfeld, AWS Section award, the AWS Houston Section; and Carl Occhialini, Individual award.

Korea Opens Door to Pulsar

Pulsar Ltd., Yavne, Israel, recently announced the first sale of its magnetic pulse welding system in Korea. Provided in the framework of the Pulsar Research and Education Program, the sale to Korea’s Research Institute of Industrial Science and Technology (RIST) is a milestone for the company.

RIST plans to use the system to develop processes for joining aluminum to copper tubes. This research is particularly applicable to the production of heat exchangers used with solar, geothermal, and other renewable energy sources.

Chattanooga State Technical Community College Hosted NextGen 2007

The first annual NextGen Advanced Manufacturing Seminars was recently held at Chattanooga State Technical Community College, Chattanooga, Tenn. The two and a half days of seminars were designed to introduce educators, business and industry professionals, high school and college students, and other individuals to the next generation of advanced manufacturing processes, products, employment opportunities, and the college’s campus.

The educators seminars provided classroom and hands-on demonstrations of new tools, materials, and welding equipment to 59 educators from three states. The Business and Industry session hosted 61 regional company representatives who were given an opportunity to see welding equipment and processes from Lincoln Electric, and materials joining and finishing tools and materials from the 3M Co. In addition, the final session was open to students from local high schools, the Tennessee Technology Center, and the engineering technology students, and provided them an opportunity to observe a variety of welding and material joining processes as well as finishing processes.

The event was coordinated by Jack Sample and Richard Burke of Chattanooga State Technical Community College, and assisted by the Chattanooga Manufacturers Association’s Ray Childers.


Lincoln Electric Holdings, Inc., Cleveland, Ohio, has entered into a majority-owned joint venture with Zhengzhou Heli Welding Materials Co., Ltd., a privately held manufacturer of submerged arc flux based in Zhengzhou, China. The joint venture will manufacture submerged arc flux and wire in Zhengzhou. Shown sitting (from left) are Thomas A. Flohn, president, Lincoln Electric Asia-Pacific, and Zhang Hong-Wei, chairman and general manager of Zhengzhou Heli Welding Materials Co., Ltd.

— continued on page 95
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Reader Questions Accuracy of Research Paper

This letter is in reference to “Response of Exothermic Additions to the Flux Cored Arc Welding Electrode — Part 2,” by S. H. Malene, Y. D. Park, and D. L. Olson, published November 2007 (pp. 349-s to 359-s). The author’s response follows.

This paper was not adequately researched by the authors for information on the interactions between gas tungsten arc welding (GTAW) arcs and power supplies. The review committee did not challenge any of the misinformation presented. The oldest references cited were published in 1980. A great deal of information on these general topics was published in the 1950s and 1960s. The authors must have had a “lot of fun” doing the research in the laboratory. I have no quarrel with their results. However, some diligent hard copy research would have uncovered the earlier work and perhaps saved some money and time. Unfortunately, this is not a unique case. Many of today’s researchers fail to do in-depth diligent hard copy research. The review committee should, also, be more expert and diligent in its review process.

In the appendix, Malene states, “Not enough is known about the physics of the plasma to be able to control or measure the necessary physical characteristics to effect closer tolerance of the process.” Then this author presents a simple circuit in Fig. A, upon which the electrical analysis is made. That analysis is okay from a mathematical standpoint, but is completely incorrect from an arc physics standpoint.

A much more accurate simple circuit is shown, and analyzed, in a Welding Research Council Bulletin1 and IEEE Transactions2, 3. GTAW arcs have three components, which are well known. First is a fixed equivalent voltage to represent the anode and cathode falls. The second is a variable voltage based on an arc gap gradient and the gap length. The third is a resistive component based on the slope of the arc’s volt/ampere characteristic at the region of interest. The resistive component does not change with variations in length, only the gradient portion changes.

The author observes, “Interestingly, the power being dissipated in the arc, P_L, during welding is also being matched and dissipated by that of the power supply, P_S. The same quantity of heat energy being used to weld from the arc is being dissipated by the power supply.” If that were true, at the so-called peak power condition, the power supply would be 50% efficient and burn up. Power supplies are

---

much more efficient than that. The volt/ampere slope of most power supplies is created by magnetics or solid-state manipulations, not power-dissipating resistive components.

In conclusion, the authors’ simple circuit analysis is not worthy of being part of a Welding Research article.

August F. Manz
AWS Fellow
Union, N.J.

The esteemed AWS Fellow August F. Manz brings out an important but subtle point regarding the circuit analysis of the Appendix that should have been more clearly elucidated. How can the math be right yet the reality so incongruous? The heat terms referred to can only be related to Joule heat components of the power supply and the arc. Although the math makes this clear by definition, it’s worth repeating that the power supply and load resistance heating terms must exclude any chemical heating and most importantly any arc ionization energy. In this sense, the circuit analysis more closely relates to resistance welding than arc welding, again barring any physical phase changes. Still, there must be a relevant I2R component to the arc.

I’m glad to have provoked some stimulating thoughts and opinions.

The Appendix in question represents a most general derivation taken directly from Ohm’s Law. Why shouldn’t it be considered in a welding power supply context? It turns out that Ohm’s Law is phenomenological and comes about through the very definitions of the electrical terms employed and is not strictly speaking fundamental. Ohm’s Law breaks down with very high current densities and very low current densities, and obviously doesn’t apply at all when consideration is given to superconductors.

I agree that this Appendix doesn’t belong in the body of the work, and I didn’t include it in the body of my original dissertation either. However, calling it “...not worthy of being part of a Welding Research article” I find is a bit harsh. It is an Appendix after all and is offered as food for thought to provide an alternative insight into explaining, at least in part and in theory, why electrical arc welding systems exhibit parametric variance.

Arcs, of course, are not this simple. When the number and species of charge carriers in the arc can change for whatever reasons with just slight variations of the immediate environmental surroundings, simple circuit or not, the arc cannot be considered as being entirely a steady-state entity. The arc remains a rather inhospitable component in any electrical circuit.

I thank A. F. Manz for his response and the provided references.

S. H. Malene
Materials Compatibility &
Welding Technology Group
Savannah River National Laboratory
Washington, Savannah River Co.
Aiken, S.C.

Reader Likes Sperko’s Updates
on ASME Section IX

This letter is in reference to Walter J. Sperko’s articles published in April 2007 pp. 68, 69; and December 2007 pp. 54, 55. Sperko’s response follows.

I have always greeted your summary of changes in ASME Section IX with interest.

In the December 2007 Welding Journal, it was good to see that the Committee plans to assign new designations (P-15A through P-15G) for the 91, 92, etc., materials. Will the additional requirements for welding and postweld heat treatment (PWHT) be more specific than those in the April 2007 Welding Journal?

Don Underwood
Director, Welding Services
DZ Atlantic
(A Day & Zimmermann Co.)
Tulsa, Okla.

Thank you for taking the time to read my Section IX update in the December Welding Journal; it’s always good to read that code users find them of interest.

The primary purpose of separating the high-performance Cr-Mo steels from the others is so that issues with them, such as special requirements for heat treating, can be easily addressed by the construction codes (Section I, B31, etc.), which is where you will find any special requirements. While requirements given in the construction codes are minimum, please note that simply meeting the Code is not a substitute for education, experience, or sound engineering judgment, i.e., there are some technical matters such as filler metal selection, performing PWHT with adequate instrumentation to know what was actually done, monitoring shop and field activities such as square-up, etc., that will still need to be included in your specification.

Walter J. Sperko, P.E
Sperko Engineering Services, Inc.
Greensboro, N.C.

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Friends and Colleagues:

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

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

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

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

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

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I was wrong about the recent Chicago Welding Show. I thought it would be “just another welding show.” I grew up in Venezuela, and my father once told me how the locals cynically described foreign salesmen touting their wares with the expression, “es el mismo m’sieu con otro cachimbo,” meaning “it is the same guy with yet another gimmick.” So like the Venezuelans, I was less than overwhelmed with the thought of attending the welding show. After all, what is really new in welding? Combine the “sameness” with setup problems; long hours; boredom; problems with customs officers at the border; and incorrect hotel reservations (hotels never seem to charge you less than you booked, do they?) ...all the same issues you always seem to incur wherever you go. But, instead, it was memorable. Let me explain.

As we approach Chicago on Interstate 90 from the south, the tall buildings seem to rise out of the lake as we turn north. After passing what appears to be an industrial wasteland of ruined buildings and abandoned factories, not perhaps the best side of America’s geography, the solid mass of concrete and steel high-rises loom, Babel-like, stabbing the sky in their brash confidence. It is an impressive display of solidity, wealth, and raw power. It is a sweeping vista, one without the pretension and insecurity of Shanghai. Chicago has arrived; Shanghai is still arriving.

The McCormick Center itself is a grand building. Walking in the massive and high tunnels under the building, you look up and see these huge pipes of “glycol water” some 50 feet above you. In my mind, it is really the grandest of venues of all the welding shows. The RWMA’s training school was in room 402B, and the view alone from the room was worth the cost of the course. The tall windows look out over the highway toward the lake, and what a fabulous view it is. The reception after the course was, typically, good — food, drinks, and good friends — but being able to watch the sun go down and the colors deepen before fading was the crowning touch. It was lovely, and it is so rare for a modern architect to be so inspired and to get it right.

Of course, the days of a show are just a haze of committee meetings, technical presentations, and of meeting suppliers, customers, potential customers, and competitors. What a legacy we owe to those who set up the American Welding Society. I don’t know of any other international welding society with the same commitment to education and volunteerism. And with volunteerism comes friendship, the ultimate bond.

But what made it such a special welding show was the resurgence of optimism with the decline of the dollar. Clearly, to those who export, the collapse is a godsend. Sales are up and we are now competitive. Now to those who think that the world ends at Buffalo and Laredo, maybe not much has changed. Indeed, for two of my friends in Ohio, who run a small welding supply company, the world is ending and the talk is all of gloom and doom. In fact, all their talk is of how the Old New World is becoming the Old World as China rises and everything is made elsewhere. But just as all the jobs were NOT sucked down the drain to Mexico, China has issues and its own worries, too. The secret is to innovate and seek what your customers need ...wherever they are. Such was the advice our fathers gave.

I walked up Michigan to the Magnificent Mile in the evening, and what a wonder it is: the Wrigley building, the glaze on the river, and the reflected, twinkling lights; the Christmas decorations; the honking traffic; the lights blazing from restaurants; and the crowds and crowds of shoppers who were all going somewhere and everywhere with their packages. I don’t think we realize how lucky we are and what opportunities we have. It is too easy to be negative; it isn’t the end of the world. Sure, times will be a little tough in 2008, but a lower dollar will help us all. Remember what Confucius said, “The price of comfort is weakness” — we have been too comfortable for too long.
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WELCOME AND OVERVIEW OF ALUMINUM WELDING
Tony Anderson, ESAB Welding & Cutting Products, Florence, SC
An overview covering the various applications of aluminum welding, the numerous alloys, appropriate welding processes, and fundamental differences between the welding of aluminum and other materials.

THE ALUMINUM DESIGNATION SYSTEM & CHARACTERISTICS OF ALUMINUM ALLOYS
Tete Pollak, The Aluminum Association, Inc., Washington, DC
Presentation explains AA’s aluminum alloy and temper designation system, as well as the physical and mechanical properties of aluminum alloys.

ALUMINUM WELDING METALLURGY
Tony Anderson, ESAB Welding & Cutting Products, Florence, SC
The basics of aluminum alloy metallurgy and the effects of welding on alloy properties.

METAL PREPARATION FOR ALUMINUM WELDING
William Christy, Novelis Inc., Kingston, Ontario
Metal preparation is one of the key steps in producing good quality welded joints.

FILLER ALLOY SELECTION PRIMARY CHARACTERISTICS
Tony Anderson, ESAB Welding & Cutting Products, Florence, SC
Attendees will gain an understanding of the various filler alloy selection variables, including welded component service requirements and the characteristics of the base alloy being welded. The understanding of these variables is essential when designing a successful welding procedure specification.

GAS METAL ARC WELDING OF ALUMINUM ALLOYS
Mark Burke, Indalco, Mississauga, Ontario
Talk considers metal transfer modes, shielding gas types, wire feed systems, and power source selection — constant voltage, constant current, pulse or variable polarity.

GAS TUNGSTEN ARC WELDING AND VARIABLE POLARITY PLASMA ARC WELDING OF ALUMINUM
William Christy, Novelis Inc., Kingston, Ontario
Mr. Christy will discuss the application of gas tungsten arc welding and variable polarity plasma arc welding to the welding of aluminum.

ALUMINUM WELD DISCONTINUITIES: CAUSES AND CURES
Kyle Williams, Alcoa Technical Center, Alcoa Center, PA
Learn about discontinuities normally encountered in aluminum arc Welds, methods to detect them, possible causes of the faults, and the means to avoid them.

DESIGN AND PERFORMANCE OF ALUMINUM WELDS
Tony Anderson, ESAB Welding & Cutting Products, Florence, SC
Presentation will focus on how to factor strength, toughness, fatigue, corrosion and other variables into design of aluminum welds to extract maximum performance.

APPLICATION OF THE AWS D1.2 STRUCTURAL WELDING CODE—ALUMINUM
Kyle Williams, Alcoa Technical Center, Alcoa Center, PA
Presenter serves on the D1.2 Committee and reveals the extent of the Code’s latest revision: when, where and how to apply the D1.2 for qualification provisions to ensure quality workmanship and structural integrity.

ROBOTIC APPLICATIONS
Jay Sider, ESAB Welding & Cutting Products, Florence, SC
This speaker discusses the latest developments in arc welding power source design and wire feeding concepts for robotic arc welding of aluminum. New programmable power source output wave forms for popular aluminum wire chemistries offer additional flexibility for those seeking to optimize production applications.

HIGH ENERGY DENSITY BEAM WELDING OF ALUMINUM
William Christy, Novelis Inc., Kingston, Ontario
Mr. Christy will discuss laser and non-vacuum electron beam welding of aluminum alloys.

CUTTING METHODS FOR ALUMINUM ALLOYS
Jay Sider, ESAB Welding & Cutting Products, Florence, SC
The speaker will discuss the advantages and disadvantages of various cutting methods for aluminum (plasma, water jet, laser, grinding etc.).

OVERVIEW OF SOLID STATE JOINING PROCESSES FOR ALUMINUM
Kyle Williams, Alcoa technical Center, Alcoa Center, PA
Overview of solid state joining processes used on aluminum including ultrasonic, upset butt, flash, friction, high frequency and explosive welding.

FRICITON STIR WELDING—CHALLENGES FOR AEROSPACE ALUMINUM
Leanna M. Micona, The Boeing Company, Seattle, WA
Friction stir welding (FSW) is a viable solid-state technology for joining aluminum alloys. Certain challenges present themselves when applying FSW to aerospace applications. Possible opportunities and associated challenges for implementation in aerospace will be presented.

EXPLOSION BONDING WITH ALUMINUM
Don Butler, High Energy Metals
Mr. Butler will describe the explosion bonding process along with the processes strengths and weaknesses. He will also discuss and show examples of how and why aluminum is explosion bonded to dissimilar metals.

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- AWS D1.2/D1.2M:2003, Structural Welding Code—Aluminum
- Aluminum Standard and Data - 2006
- Pink Sheet - Designation and Chemical Composition Limit for Aluminum Alloys in the Form of Casting and Ingot, April 2002
- Teal Sheets - International Alloy Designations and Chemical Composition Limits for Wrought Aluminum Alloys, 2006

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Specialty Cored Wires for Wear and Corrosion Applications

Unique approaches to the design of hardfacing alloys using cored wires are presented

BY RAVI MENON AND JACK WALLIN

This article details the developments in hardfacing cored wire technology and complements two other articles on hardfacing developments (Refs. 1, 2) published in the Welding Journal. This presentation shows examples of wire development where alloy compositions were formulated for unique applications. These include applications in the cement, power, and oil and gas industries. The development and applications of wires that can withstand a combination of erosion and corrosion are also described.

Cored wires continue to provide a unique route in the development of specialty alloys for hardfacing. Most hardfacing alloys have relatively low ductility and cannot be produced as monolithic continuous wires without incurring significant processing cost. The construction of common grades of these wires has been described earlier in the literature (Ref. 2) and will not be covered here.

The largest share of hardfacing welding consumables is held by the iron-based alloys. They are the most economical alloys for hardfacing. Most hardfacing alloys have relatively low ductility and cannot be produced as monolithic continuous wires without incurring significant processing cost. The construction of common grades of these wires has been described earlier in the literature (Ref. 2) and will not be covered here.

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such as coal pulverizer rolls and cement grinding rolls even up to thicknesses of 1–2 in. (25–50 mm). These wires are extensively used in most hardfacing applications where there is moderate to severe abrasion and low to moderate impact. They are of relatively low cost and are typically available in diameters ranging from 1⁄8 in. (3.2 mm) to 0.035 in. (0.9 mm). However, for many special applications that require a greater degree of wear resistance, these compositions are modified.

Traditionally, the complex carbides containing Mo, W, Nb, and V (6C-19Cr-5Mo-5Nb-2W-2V) can provide better wear resistance; however, these deposits tend to be extremely brittle. Moreover, wire costs escalate significantly with the addition of the alloying elements such as Mo, V, and W. A microalloyed version, 5C-25Cr-M, has been very successfully used in critical applications where a combination of wear and toughness are required. Examples of use for pulverizer roll rebuilding have been described before (Ref. 2). This type of wire also finds significant use in the cladding of pipe used for slurry transport, e.g., in the Canadian tar sands.

Many of these applications require a minimum degree of wear resistance as measured with the G65 test on the as-cladded surface as well as at a depth 75% below the surface. In addition to this requirement, no underbead cracking is permitted. Wires of the 5C-25Cr-M type have been used very successfully in this application. A comparison of the G65 wear resistance of the conventional 5C-25Cr against the microalloyed version is shown in Fig. 1. The microalloyed version shows better wear performance on the as-cladded surface as well as at a depth 75% below the surface.

For more severe abrasion applications, a modified complex version, 5C-25Cr-CLX (5C-25Cr-Nb-V) has been developed. These deposits provide an enhanced degree of wear resistance due to the presence of secondary carbides of Nb and V. In contrast to the complex carbides of the 6C-19Cr-5Mo-5Nb-2W-2V type, this alloy is leaner in the secondary carbide formers. This results in the wire being multipassable and the deposits having better ductility. The leaner composition also results in a more economical wire. G65 test comparisons of the complex carbide deposits to other chromium carbides are shown in Fig. 2A.

The complex carbide deposits also perform well in pin-on-disc tests (Ref. 3) that are designed to simulate high-stress abrasion — Fig. 2B. This alloy therefore is well suited for grinding applications such as in coal and cement mills. In these applications, the 5C-25Cr-CLX deposits have been reported to give about 25% better life than the 5C-25Cr-M type cladding. In slurry-jet testing (Fig. 2C) specific to the application required for slurry pipe (Ref. 4), the complex carbide deposit performs better than the microalloyed version. This makes it a strong candidate for slurry pipe applications that involve severe wear such as the extrados area of elbows.
Figure 3A–C shows the microstructures of the chromium carbide deposits. Figure 3B shows the refined carbide microstructure of the 5C-25Cr-M deposit when compared to that of the 5C-25Cr deposit shown in Fig. 3A. The microstructure of the 5C-25Cr-CLX deposit shown in Fig. 3C consists of precipitates of Nb and V carbides located in the matrix between the primary chromium carbides.

In summary, modified complex carbide wires of the 5C-25Cr-CLX type possess optimal properties for a wide variety of wear environments that include low stress and high stress abrasion as well as slurry jet erosion.

Crack-Free Hardfacing Wires

As discussed before, the most widely used hardfacing alloy system is chromium carbides in an iron-based matrix. While chromium carbides provide good wear resistance at a very economical cost, the weld deposit (especially the hypereutectic composition) can exhibit cracks. This is sometimes referred to as a “cross-checking” pattern in the weld deposit. These cracks are also known as “relief check-cracks.”

Check-cracks occur in brittle claddings and help relieve contraction stresses resulting from weld solidification and subsequent cooling to room temperature. However, these cracks can accelerate abrasive wear in the hard weld deposit surface and make the cladding susceptible to breakage or spalling, especially under high-impact and high-stress conditions.

Check-cracking is acceptable in some applications, but problematic in others. As multiple layers of welding are applied, stresses continue to build, concentrating at the root of the check-cracks, until separation occurs between the base metal or the buffer and the hardfacing deposit. This problem may occur typically in high impact applications such as mining and drilling.

Cracks also present problems in industries where the material being processed gets into the cracks making cleaning and resurfacing difficult. This problem is commonly seen in pulverizer rolls used in thermal power plants and cement grinding rolls. This can also be an issue with food processing rendering screws and oil drill tooling. Cracks also result in an increase in friction thus resulting in higher fuel consumption. This particularly is a problem in agricultural components such as tillage tools, dredge parts, extruder screws, and earth-moving equipment.

Crack-free martensitic alloys (0.6C-6Cr-0.6Mo) have been utilized in hardfacing applications for many years (Table 2). These alloys have a relatively high hardness (typically HRC 58) but poor abrasion resistance. The welding characteristics of these wires are, in general, excellent due to the relatively low alloy content.

Tool steel alloys such as of the M7 composition (0.8C-3.5Cr-9Mo-1.8W-1.8V) offer improved wear resistance. These alloys also exhibit high hardness (typically HRC 60) along with improved abrasion resistance — Fig. 4. The welding characteristics of these wires are relatively inferior when compared to the martensitic materials.

The next-generation crack-free alloy (2C-7Cr-6Ti) is also a martensitic alloy enhanced with evenly dispersed titanium carbides. This alloy achieves hardness values between HRC 50-56. As has been de-

### Table 2 — Iron-Based Crack-Free(a) Hardfacing Alloys

<table>
<thead>
<tr>
<th>Designation/Nominal Composition</th>
<th>Typical Hardness (HRC)</th>
<th>Microstructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.6C-6Cr-0.6Mo</td>
<td>58</td>
<td>Martensite</td>
</tr>
<tr>
<td>M7 (0.8C-3.5Cr-9Mo-1.8W-1.8V)</td>
<td>60</td>
<td>Martensite + WC, VC</td>
</tr>
<tr>
<td>2C-7Cr-6Ti</td>
<td>53</td>
<td>Martensite + TiC</td>
</tr>
<tr>
<td>CF-1(b) (1C-9Cr-Mo-Nb-Ti)</td>
<td>64</td>
<td>Martensite + NbC, TiC</td>
</tr>
<tr>
<td>CF-2(b) (1C-4Cr-Mo-W-V)</td>
<td>66</td>
<td>Martensite + WC, VC, NbC, TiC</td>
</tr>
</tbody>
</table>

(a) With use of proper base materials and welding procedures.
(b) Patent pending.
required, especially with the CF-2 alloy de-
free weld deposits. Adequate preheat is
recently developed that produce crack-
CF-2 (1C-4Cr-Mo-W-V-Nb-Ti) have been
martensitic composition, CF-1(1C-9Cr-
transfer of titanium.
slag system incorporated to improve the
rates are still relatively low due to the basic
proved the slag removal, arc transfer, and
more extensively. Recent modifications to
characteristics. Titanium is very reac-
tive, and so if the arc is not shielded with
basic flux, very little titanium is recov-
dered in the weld deposit. The basic slag
system results in poor slag removal and
arc transfer. In the past, poor welding
characteristics have prevented the martensitic-TiC alloys from being utilized
more extensively. Recent modifications to
the formulation of this wire have im-
proved the slag removal, arc transfer, and
spatter levels thus enhancing the popular-
ity of these wires. However, deposition
rates are still relatively low due to the basic
slag system incorporated to improve the
transfer of titanium.

This has led to the fourth and present-
day generation of crack-free wires. A
martensitic composition, CF-1(1C-9Cr-
Mo-Nb-Ti) and a tool steel composition,
CF-2 (1C-4Cr-Mo-W-V-Nb-Ti) have been
recently developed that produce crack-
free weld deposits. Adequate preheat is
required, especially with the CF-2 alloy de-
pending on the base material on which it
is applied. These deposits have wear re-
sistance and hardness similar to or greater
than that of chromium carbide weld de-
posits (Table 2 and Fig. 4). The typical
hardness of the martensitic alloy is HRC
64 and that of the tool steel alloy is HRC
66. The crack-free weld deposits are
achieved by generating nucleation sites to
control matrix grain size by balancing tita-
nium and/or niobium with carbon content.
The average size of the NbC/TiC precipi-
tate is significantly smaller than that of the
relatively coarse chromium carbides, which
provide a continuous path for crack
propagation. The resulting weld deposit
consists of a matrix that has a fine grain
size with small, evenly dispersed Nb and
V carbides and a relatively small amount
of carbon in the matrix. This reduces the
possibility of cracking as well as improv-
ing the toughness of the hardfacing.

The microstructure of the TiC-bearing
alloy is contrasted with that of the NbC,
VC bearing CF-2 in Fig. 5A and B, re-
respectively. The wear characteristics of
these crack-free wires make them suitable
for both metal-to-metal and metal-to-
earth applications. Also, as these composi-
tions are relatively low in titanium, they
possess good weldability. These new al-
loys are being used in applications invol-
ving high impact where conventional
cladding are prone to spalling due to
cross-checking. Examples of such appli-
cations are earth-moving equipment, min-
ing equipment, crushing equipment, and
various types of hammers.

Other applications where these crack-
free alloys are being utilized are where the
presence of cracks results in an increase
in the friction coefficient, which can re-
sult in increased fuel consumption and en-
ergy cost. This includes agricultural tillage
tools, dredge parts, auger flights, render-
ing screws, extruder screws, slitter blades,
shredders blades, cutting and shaving
knives, fan blades, and down hole drilling
equipment.

Figure 6A shows an application of the
CF-1 wire on the edges of a plough sweep.
These are traditionally hardfaced with
chromium carbide rods using an oxy-
acetylene process. As the plough materi-
als are typically AISI 1070 or 1080 steels,
it is important that the hardfacing be
crack-free due to the relatively poor weld-
ability of the base materials. The use of
the crack-free hardfacing wires enables
the deposition of a superior abrasion resis-
tance material without the check-
cracking issues that are of concern with a
chromium carbide deposit. Further, the
use of the gas metal arc process results in
a significant improvement in productivity
and a lowering of the overall cost. Figure
6B shows the application of the CF-2 wire
on the edge of a tire shredder. In this case,
these new materials are replacing tool
steel materials such as M7. In this appli-
cation, a 30% improvement in life has
been reported.

**Out-of-Position Welding with Crack-Free**
**Hardfacing Wires**

Many applications require welding out
of position where a component cannot be
positioned for hardfacing in the flat posi-
tion. An example may be a side of an
earth-moving bucket. Recent flux cored
technology has been used to develop wires
that can be applied out of position in a
manner similar to flux cored joining wires.
Chromium carbide wires of the 5C-25Cr
composition are not available as all-
position wires. Due to the leaner nature
of the compositions of some of the crack-
free wires, the 0.6C-6Cr-0.6Mo and the CF-1 wires are available in the all-position type. An example of the application of the CF-1 wire for all-position welding is shown in Fig. 6C.

In summary, new crack-free hardfacing wires are available that can provide an optimum combination of wear resistance and toughness. The wires also find application on components fabricated from high-carbon steels where any cracks generated in the hardfacing could potentially migrate rapidly into susceptible heat-affected zones. The development of the all-position crack-free hardfacing wires offers significant benefits as far as application on large components that cannot be easily positioned.

Wires for Corrosion and Wear

Nickel-Based Wires

Nickel-based wires of the Ni-Cr-B-Si type have been used for many years. Several versions of these wires with tungsten carbide (WC) incorporated into them have gained popularity for applications that encounter severe wear and/or corrosion. These wires (Table 3) have evolved into those that contain mixtures of cast carbides of various particle sizes (Ni-WC1) and those that contain a mixture of cast and macrocrystalline carbide (Ni-WC2). Larger wire diameters such as ⅛ in. (3.2 mm) and ⅜ in. (2.8 mm) can encapsulate up to 65% carbide by weight, whereas the smaller wires, typically ¼ in. (1.6 mm), can hold up to 45%.

In G65 tests (Fig. 7A) and slurry-jet tests (Fig. 7B), the Ni-WC2 deposits performed the best when compared to Ni-WC1 as well the 5C-25Cr-M and 5C-25Cr-CLX chromium carbide deposits. Note that the wear data are measured in the units of volume loss as the comparison is being made between materials of differing densities. Specifically, for application in the tar sands piping, slurry-jet erosion tests show the superior performance of the blended cast-macrocrystalline deposit (Ni-WC2). In Fig. 7B, the Ni-WC2 deposit outperforms the Ni-WC1 as well as chromium carbide deposits of the 5C-25Cr-M and the 5C-25Cr-CLX types. The superior performance of the Ni-WC2 deposits is related to the greater ability of the macrocrystalline carbide to withstand degradation during arc welding as well as matrix hardening that occurs due to the decomposition of the cast carbide. This has led to the specification of such wires for applications in the tar sands where the performance of conventional chromium carbides deposits is not adequate. An example of this is shown in Fig. 8 where a short pipe transition piece has been overlaid in the longitudinal orientation using a ⅛-in. (2.8-mm) wire of the Ni-WC2 type. As the carbides are susceptible to dissolution in the matrix, the use of low heat input is critical in achieving the required deposit microstructure and properties. This wire can be applied at a relatively low heat input (18 V, 300 A) open arc (no gas shielding), resulting in a very uniform carbide distribution as shown in Fig. 9.

Nickel-based tungsten carbide con-
taining wires can be specified for applications where conventional chromium carbides do not meet specified wear resistance requirements. However, with the escalating cost of nickel as well as tungsten carbide, the need exists to look at lower-cost solutions when corrosion and wear are simultaneously encountered.

**Stainless Steel Wires for Corrosion and Wear**

In this group of wires, the concept of utilizing a second phase such as NbC and TiC to provide wear resistance has been extended to the stainless steel alloy system. These wires (Table 3), labeled 316Nb/TiC and 420Nb/TiC, deposit a microstructure that comprises a matrix of the 316 or 420 compositions with dispersed precipitates of NbC/TiC. This results in a significant improvement in the wear performance of the deposit when compared to stainless steel without any degradation in its corrosion resistance. Figure 10 shows the G65 test data for the 316TiC and the 420TiC deposits in comparison to austenitic AISI 304 and martensitic AISI 410 wrought base materials. The results indicate a more than a three-fold improvement in low stress abrasion resistance of the cladding deposits. In testing methodology newly developed at the National Research Council of Canada (Ref. 4), the synergistic effects of wear and corrosion were evaluated. In Fig. 11, the results of these tests indicate the superior erosion corrosion performance of the deposits over the base AISI 316 stainless steel. The test separates out the influence of erosion and corrosion. Thus, although the results indicate a significant improvement in the erosion behavior of the TiC-bearing deposits, there is no degradation in the corrosion resistance. The microstructures of the deposits are shown in Fig. 12. They are very similar for the austenitic as well as the martensitic deposits showing a fine dispersion of submicron TiC precipitates in their respective matrices.

These new wires offer the exciting potential of obtaining superior wear performance from stainless steels without a loss in their corrosion resistance. Applications where they are being field tested include slurry pipe, and cladding applications for boiler tubes.

**Summary**

Conventional hardfacing alloys may not provide the solutions that are required by today’s industries. The cored wire route offers a powerful method to design unique wires for such applications. In the iron-based alloy family, special complex carbide wires can significantly improve life for applications involving crushing and grinding as well as material transport. The development of “crack-free” alloys provides equivalent or better degree of wear resistance as chromium carbide deposits along with significantly better impact resistance and out-of-position applicability.

Finally, composite systems based on stainless steels and nickel alloys have been

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**Table 3 — Nickel- and Stainless Steel-Based Hardfacing Alloys for Corrosion-Wear Applications**

<table>
<thead>
<tr>
<th>Designation</th>
<th>Bulk Hardness (HRC)</th>
<th>Microstructure</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ni-WC1</td>
<td>55</td>
<td>45–65% cast tungsten carbides in a Ni-Si-B matrix</td>
</tr>
<tr>
<td>Ni-WC2</td>
<td>55</td>
<td>45–65% cast and macrocrystalline tungsten carbides in a Ni-Si-B matrix</td>
</tr>
<tr>
<td>316 Nb/TiC(a)</td>
<td>21</td>
<td>NbC and TiC in an austenitic (316) stainless steel matrix</td>
</tr>
<tr>
<td>420 Nb/TiC(a)</td>
<td>48</td>
<td>NbC and TiC in a martensitic (420) stainless steel matrix</td>
</tr>
</tbody>
</table>

(a) Patent pending.
designed that can provide an optimum combination of wear and corrosion resistance.

Acknowledgments

The authors wish to thank Dr. Rees Llewellyn of the National Research Council of Canada for providing data on the ASTM G65 and the slurry-jet erosion tests. The authors also wish to thank Dr. Mark Jones of the same institution for conducting the Erosion-Corrosion tests.

References

By all accounts, the 2007 FABTECH International & AWS Welding Show was an impressive success. More than 30,800 attendees were at the exhibition during its four days of operation from Nov. 11 to 14 — Fig. 1. The visitors came from more than 75 countries, making it a truly global event. The attendance represented a 27% increase from the last time the exhibition was held in Chicago. The AWS side was filled with 523 exhibitors, including a special Thermal Spray Pavilion organized by the International Thermal Spray Association. The total number of exhibitors for the combined fabricating, tube and pipe, stamping, and welding groups of the exhibition was 1004 — Fig. 2.

News from the AWS Annual Meeting

At the AWS annual business meeting, outgoing President Gerald Uttrachi spoke of the problems that lay ahead for the United States if it cannot provide enough skilled welders to reconstruct our aging infrastructure and to build the greenhouse industries that are needed to move toward energy independence. He noted the seriousness of the shortage, stating recent studies indicate that U.S. manufacturers cannot find enough skilled labor. These same shortages are also being felt in Europe and parts of Asia, making it a worldwide problem.

Incoming President Gene Lawson is making it one of his goals to address the shortage of welders by promoting programs from AWS that encourage welding as a career and improve the image of welding. Other goals he mentioned for the coming year included increasing AWS membership, both domestically and internationally, and promoting outreach at the local level with increased recognition of individual AWS Sections. He also will

ANDREW CULLISON (cullison@aws.org) is editor, KRISTIN CAMPBELL is assistant editor, and MARY RUTH JOHNSEN is senior editor of the Welding Journal.
place an emphasis on certification and standards, especially promoting them on an international basis.

He noted that the raised awareness of the welder shortage offers AWS new opportunities to increase membership and promote certification and standards, especially by working with countries around the world who are experiencing the same problem. The AWS is moving forward with programs such as the Welder Workforce Development Program and the Welding for the Strength of America Capital Campaign, which are programs that can provide financial support to attack the critical shortage of welders. He also spoke of how the Image of Welding Awards Program positively promotes the welding industry and provides examples to schools to advocate welding as a career.

He feels strongly about promoting AWS at the local level and providing recognition to the grass root efforts of the Society. “The men and women within our Sections are the voices of AWS. They are our industry recruiters, our advocates, and our messengers,” he said. “If our roots remain strong then our voice will be heard.” The local Section is also an ideal place to reach out to welding students who are the future of AWS.

Lectures and Technical Program

Following the business meeting, John Elmer, Lawrence Livermore National Laboratory, presented the Adams Lecture. The topic was “New Path for Understanding Microstructural Evolution during Welding Using Synchrotron Radiation.” He spoke of his continuing research into using the synchrotron as a high-energy radiation source to investigate phase transformations in real time during welding. This in situ observation of transformation, compared to typical methods that observe after the weld has solidified, provides greater insight into the phenomena.

With the radiation provided by the synchrotron, individual phases can be investigated as they happen, which can provide important microstructural information for the development of new alloys and the methods for welding them. There are presently 50 synchrotrons worldwide available for welding research.

On Tuesday, Nov. 13, Andy Godley, director of Training, Southern Co., Birmingham, Ala., presented the Plummer Memorial Education Lecture, “Observations from 40 Years of Welding Training” — Fig. 3. He has dedicated a great deal of time toward welding education with a career that includes teaching welding in the public school system at the Jefferson County Adult Center, along with serving on the National SkillsUSA Technical Committee and the AWS Education Committee. “In order to weld, the mind has to be faster than the hand, and then the mind has to tell your hands what to do in a few milliseconds,” Godley said. He stated in order to teach welding, several things are necessary — a welding facility with the right equipment; a student who wants to learn and has the ability; a supply of material to weld on and filler metals to match; an instructor who can do what he is trying to teach; and an instructor who wants to teach. As Godley’s career is coming to a close, “I can look back and say that I al-
Chicago’s Cloud Gate Sculpture Wins Extraordinary Welding Award for Outstanding Achievement in Welding

Cloud Gate, one of the world’s largest outdoor sculptures, was awarded the American Welding Society’s Outstanding Achievement in Welding Award Nov. 12 during the show. The award is part of AWS’s Extraordinary Welding Awards program, which is made annually to a welded structure that depicts exceptional design and technological achievements through welding.

Cloud Gate is located in Chicago’s Millenium Park. It weighs 110 tons, and is 66 ft long, 42 ft wide, and 33 ft high. Its surface consists of 168 stainless steel 3⁄8-in. plates that have been welded together, ground, sanded, and polished to a seamless, mirror-smooth finish. The mirror-like finish reflects the city’s famous skyline and the clouds above. An arch provides a “gate” to the concave chamber beneath the sculpture, wherein visitors can touch the surface and see their image reflected back from a variety of perspectives. Because of its shape, Chicagoans commonly refer to the sculpture as the “bean.” It is British artist Anish Kapoor’s first public outdoor work installed in the United States.

Fig. A — AWS Past President James Greer (left) and Steven Crown, board member, Millenium Park, Inc., display the plaque commemorating the park’s Cloud Gate sculpture winning AWS’s Outstanding Achievement in Welding Award.

The following individuals and companies are named on the award for their contributions to the development of Cloud Gate: Anish Kapoor, artist; Chris Hornzee-Jones, structural engineer; Performance Structures Inc., design, engineering, and fabrication; MTH Industries, fabrication; U.S. Equities Realty, development manager; Millenium Park, Inc., and AT&T donors; Richard M. Daley, mayor; city of Chicago, owner.

The welding was controlled manually, explained Lou Cerny of MTH Industries, but guided on a track with a geared motorized control assembly with a remote speed and feed amperage input — Fig. B. Shielded metal arc welding was used to construct the sculpture’s internal support structure.

“We worked from the top down,” Kozyra recalled. “Every 10 ft we were in a different position. Often we were hanging from rope climbing harnesses. We took the job with great pride and saw it all the way through.”
Leadership Summit Addresses Shortage of Skilled Workers in United States

A crowd of nearly 300 people packed the Innovation Theatre at 8:00 a.m. November 12, to learn how some organizations and companies are combating the problem of a lack of skilled workers in U.S. manufacturing.

Moderator for the leadership summit was Dan Swinney, executive director, Chicago Manufacturing Renaissance Council. Panelists were Anthony Swoope, administrator, Office of Apprenticeship Employment and Training Administration, U.S. Department of Labor; David Hanson, commissioner, Mayor’s Office of Workforce Development, Chicago; and Jim Reeb, director of Manufacturing R&D, Caterpillar.

The goal of the Chicago Manufacturing Renaissance Council (CMRC), Swinney said, is “establishing the Chicago region as a global leader in high-performance manufacturing.” He noted there are 12,000 manufacturing companies in the Chicago area, and they employ nearly 500,000 people. Yet a study conducted in 2001 regarding how to provide companies with the skilled workers they needed “found a nonsystem,” he recalled. “We were failing the people and the companies.”

Keys to the CMRC efforts, he said, were that the area naturally would lose low-skilled jobs to workers overseas or elsewhere, but that it should “lead the effort to lead the race to the top of high-performance, high-quality jobs.” In addition, the council should represent a social partnership between industry, government entities, and educators; and that it should be a council that takes action. He discussed creation of Austin Polytech Academy, Chicago’s first high school aimed at preparing students for high-tech production positions, management, and ownership in manufacturing. When students graduate from that school, he explained, not only will they be college ready, but they will have work experience.

The budget for the Mayor’s Office of Workforce Development totals $30 million, David Hanson said. Its task is to provide opportunities for job-seeking Chicagoans, work with companies, and help retrain displaced workers. To that end, it works with 27 different providers of job skill training and preemployment training.

“Who wants their kids to be welders?” Only a few raised their hands. “You are the problem,” he said. Of all students in the United States, only 17% graduate from college and actually work in jobs that require their degree, yet parents don’t encourage their children to enter manufacturing. “Why is there a labor shortage in the U.S.? It’s because the image of manufacturing, and especially welding, is that its dark and dirty,” Reeb said.

Seventy-six million baby boomers will soon be retiring, but only 46 million Generation Xers will be coming in. If changes aren’t made, Reeb said, U.S. companies won’t be outsourcing only because of a shortage of skilled labor, but because they’ll be in need of all types of workers.

One way to offset the shortage of labor is through technology, Reeb said. Another is to create the right environment and embrace all cultures; for example, making your factory a welcoming place for Hispanic workers.

To help recruit workers, Reeb said, “Bring high school guidance counselors to shows like this and to your factories.”

One Head Does It All. The TruLaser 5030 (Fig. 6) was introduced to North America at the FABTECH International & AWS Welding Show. This laser cutting machine is capable of cutting from sheet metal to plate thicknesses with one cutting head. There is no need to change heads for different thicknesses, which helps speed production cycles. The laser beam is designed to automatically adjust to the different conditions. Trumpf President/CEO Rolf Biekert noted the company is growing to become a single source provider for laser and metalforming needs, even offering financial services. He noted $366 million in sales in North America this past fiscal year, and a new 85,000-sq-ft facility is planned to open in 2008 in the U.S. Trumpf, Inc., (860) 255-6000, www.us.trumpf.com.

A Lot of Capability in a Small Package. The Invertec® V155-S doesn’t quite weigh 15 lb, but it has an output of 155 A, 16 V at 30%, and 100 A, 14 V at 100%, which is good for many gas tungsten arc welding (GTAW) applications. It can operate from a portable generator, 115/230 V input power, or a 230-V extension cord up to 200 ft long. This DC GTAW unit utilizes touch start ignition, which eliminates high-frequency starting. The unit also performs shielded metal arc welding (SMAW) with popular covered electrodes. The welding machine and its accessories can be purchased in a TIG Ready-Pak sturdy suitcase (Fig. 7) for ease of transport. The package includes electrode holder, cable, shoulder strap, gas regulator, GTAW torch, and accessory kit. Lincoln Electric Co., (216) 481-8100, www.lincolnelectric.com.

Fig. 7 — The Invertec V155-S and accessories can all be transported in a convenient case.

Fig. 6 — The TruLaser 5030 incorporates a single head for cutting multiple thicknesses of plate.
**American Made Cuts Delivery Time.**
The 2-, 4-, and 6-kW Lasertex Series of CO₂ laser cutting machines (Fig. 8) from Koike Aronson are now manufactured in the United States. Delivery times are cut drastically as are production costs by manufacturing the product domestically. The units take advantage of a specially designed enclosure for the laser beam to prevent accumulations of airborne particles on the beam mirror. The capability range for mild steel is from ¼ to 1 in. and for stainless steel ¼ to ½ in. President and CEO Gerald Leary sees demand for laser cutting machine sales remaining strong into 2008, especially with the growth of greenhouse industries. Koike Aronson, Inc., (585) 492-2400, www.koike.com.

**Catch More Particles, Extend Filter Life.** United Air Specialists introduced a new filter technology called nanofiber filtration. In the construction of the filter, the core material is covered with a web of micron-sized synthetic fiber that is about 1000 times smaller than a human hair. Since the nanofibers are resting on the filter surface, the entrapped particles are more easily released during the cleaning operation and the overall life of the filter is extended. This new type of filter is capable of collecting submicron particles at MERV 15 efficiency levels. United Air Specialists, Inc., (800) 252-4647, www.uas-inc.com.

**Submerged Arc Goes Robotic.** Earmarking the shipbuilding industry, Wolf Robotics introduced robotics to the submerged arc welding (SAW) process. Adapted to deliver granular flux (Fig. 10), the robot is expected to increase productivity, reduce operator monitoring, and add versatility in movement to SAW applications. The SAW process is normally operated in a straight path, but the robot can be programmed to follow varying paths. The robotic SAW system also utilizes tactile sensing to find the weld path in both single and multipass applications. Wolf Robotics, Inc., (970) 225-7600, www.wolfrobotics.com.

**Discs Deliver Uniform, Consistent Finishes.** The 3M™ Clean Sanding Discs, featuring patented multihole patterns, are useful at evacuating dust and increasing disc life — Fig. 12. The design achieves a balance between abrasive and dust-extraction holes. Also, the company’s Hookit™ attachment system for backing support and reuse further optimizes disc life. The discs can be used for a variety of aluminum finishing and dry sanding applications. They are available in different types — 216U comes in 3- and 5-in. sizes, and 236U as well as 360L are in 3-, 5-, and 6-in. sizes. The discs are aimed at several markets including aerospace, marine, and fabrication. 3M, (888) 364-3577, www.3m.com.

**Fig. 8 — The Lasertex Series of laser cutting machines are now manufactured in the U.S.**

**Fig. 9 — Magnetic fitting tools such as this Mag-Pry hold plate flat for tack welding.**

**Fig. 10 — Flux delivery system is integrated with the robot.**

**Fig. 11 — Many tools, such as center and outlet wire guides along with plated contact tips, are included in this aluminum kit.**

**Fig. 12 — These discs facilitate good dust extraction when used with a well-functioning dust extraction system.**

**Kit Facilitates Welding with Aluminum Wire.** The Aluminum Optimization Kit features various tools to modify the company’s wire feeders and welding guns to facilitate their use with aluminum wire and reduce birdnesting — Fig. 11. It includes a jumper sleeve, liners for 0.035- and ⅜-in. wires, center and outlet wire guides, groove drive rolls, plated contact tips, and a plated nozzle, all designed to improve aluminum feedability. In addition, the kit includes The Welding of Aluminum Pocket Guide, a manual to help welders better understand aluminum welding, overcome its challenges, and improve their aluminum welding productivity. ESAB Welding & Cutting Products, (800) 372-2123, www.esabna.com.

**Magnet Has Sticking Power.** A new introduction at the show was No-Mar magnetic fitting tools. With a twist of a handle on Mag-Pry (Fig. 9), a magnet with up to 4000-lb holding strength is activated. A leverage bar attached to the magnet then can be used to flatten the edge of sheet metal or plate for weld tacking. Another device called the No-Mar Stiff Jack, which also utilizes strong magnets, is designed to pull plate up tight to stiffeners for tack welding. A pin is positioned on the top of the stiffener, the magnets are activated, and a jacking device brings the plate into contact with the stiffener. Fit Up Gear, (281) 440-1725, www.fitupgear.com.
Plasma Cutting Machines Deliver More Punch. The company launched three models from its CUTMASTER® TRUE™ Series at the Show — Fig. 13. The model 39, a 30-A unit, has a recommended cut of ¼ in. and a maximum cut of 5⁄8 in.; the model 52, a 60-A unit, has a recommended cut of ½ in. and a maximum cut of 1 1⁄8 in.; and the model 82, an 80-A unit, has a recommended cut of ¾ in. and a maximum cut of 1½ in. The other two models in the line, CUTMASTER 102 and CUTMASTER 152, will be available in March. The series feature the patented 1 Torch® TRUE Guard™, a rugged roll bar; and front panel LED’s. The suggested list price for the models are approximately as follows: 39 model, $1400; the 52 model, $2000; and the 82 model, $2600. Thermal Dynamics, (636) 728-3000, www.thermal-dynamics.com.

Electric Arc Spray System Comes Equipped with All Hoses, Cables. The ValuArc® Pro-200 electric arc spray system is an all-purpose unit that can apply a wide range of hard and soft solid arc wire materials for many different coating applications — Fig. 14. It produces coatings for a wide range of applications including aqueous and chemical corrosion protection, wear resistance, and general-purpose restoration. The system is composed of four modules. The power supply has been engineered for the electric arc spray process; additionally, a transformer-rectifier system delivers arc current of 200 A at 100% duty cycle. Start/stop cycles can be as short as 4 s. The wire spray gun weighs 3.7 lb, can be integrated into automated equipment, and comes with a tool post for machine mounting. The wire drive unit is a push-type mechanism equipped with variable speed control. The energy hose package is composed of a hose, insulated wire guides, and cable set. Sulzer Metco (US) Inc., (516) 334-1300, www.sulzermetco.com.

Increased Cooling Extends Cap Life. The CMW® Finned Cap Electrodes (patent pending) are designed for resistance to deformation when welding aluminum, coated, TRIP, duplex, and dual-phase steels — Fig. 15. Cap life is extended with adequate water flow. Brass buildup is reduced. The nuggets meet or exceed industry standards. They achieve good welds at lower power levels. The products are aimed at resistance welding applications including automotive, appliance, electrical enclosures, and business furniture. They are priced based on volume usage. CMW Inc., (317) 634-8884, www.cmwinc.com.

Welding Machine Provides Improved Weld Force Repeatability. The Servo-Ac- tuated SlimLine spot welding machine is used for spot, cross wire, and projection welding; it can also weld nuts and studs — Fig. 16. Featuring a high-thrust-force servo-controlled actuator with slow approach, the upper tip of the product moves fast and then decelerates just before making contact with the metal to be welded. Its highlights include the following: the weld force is generated instantly; no need for compressed air; monitors built in to verify proper part stack-up and to monitor tip wear; set-down monitor with programmable limits for projection welding; part stack-up monitor can detect missing weld nuts; retractable stroke, if needed; user-friendly color touch screen interface; and built in data logging. The cost is $48,000 for the mid-frequency direct current (MFDC) inverter, and the alternating current (AC) version is about $38,000. The two models available can be customized with a multigun. T. J. Snow Co., Inc., (800) 669-7669, www.tjsnow.com.

Tool Helps Make Perfect Corners. As a fab shop owner, company President Bob Walker needed something to hold the metal when making corner welds. That was the incentive for the development of the Corner Helper™ — Fig. 17. The tool, made of die cast, CNC milled, high-strength aluminum, clamps and squares at the same time. It can hold round, square, angle, and plate material, and comes in several sizes. The tool lists for under $40. FABTOOLS.com, (530) 877-1970, www.fabtools.com.
Professional Welders Show Off Their Skills at Welding Competition

The recent AWS 2007 Professional Welders Competition drew 188 participants. This year’s Professional Welders Competition yielded a record number of contestants, and we are thankful to all of our judges and support staff who were able to make this our most exciting event yet,” said Ray Shook, AWS executive director.

A record number of contestants entered the third AWS Professional Welders Competition, which was held November 12 and 13. Volunteers from the AWS Indiana Section helped to organize and operate the competition, supported by instructors and students from the Chicago area, Wyoming, and Texas. The event, which is sponsored by the Professional Welders Competition Committee, attracted 188 welders from across the United States and Canada.

“When you win this contest, it is a big deal,” then incoming AWS President Gene Lawson said at the awards ceremony on November 14. “I’m glad for everybody who participated.”

Each welder was given 5 min to complete a ¾-in. fillet weld using E7018 electrode on low-carbon steel. The project involved welding a 3 × 3 × ¾-in. angle to a ½-in-thick horizontal plate using shielded metal arc welding (SMAW). A team of AWS Certified Welding Inspectors judged the entries using criteria specified by AWS D1.1/D1.1M-2006, Structural Welding Code — Steel. The judges’ results were verified using automated inspection equipment supplied by Servo-Robot, Inc.

The top three winners had something in common — it was the first time they had competed in a welding contest. The $2500 grand prize went to Luis Aceves, a welding instructor at Manitowoc Cranes, Inc., Manitowoc, Wis. “It was a good feeling. It was an excellent moment,” Aceves said upon hearing he placed first. “I did good in there — when I finished the plate test, I was happy with myself.”

Aceves used to work for a shipbuilding company where he performed a lot of SMAW. When he was shown a picture of the contest’s details, he was reminded of “when I learned to run the same welding rods,” he said. He practiced 2 h to prepare for the contest.

Aceves relaxed a little bit, took a walk, and saw how other welders did the task before participating in the event. While competing, he stayed focused. “It was hard. It was a challenge,” Aceves said of the contest and working under pressure. He finished in 2 min, 17 s.

Overall, Aceves had a great experience. “I saw good plates, don’t get me wrong, but I gave it a try and then it happened — I got the first prize,” he said. “I was sitting in my chair in my office and about fell out,” Kodi Welch said about winning the contest. He was used to making the type of weld required, and he finished in 2 min, 33 s.

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Jairo Tinoco, a deaf welding student from Gateway Technical College, Elkhorn, Wis., competed as well. His sign language interpreter, Lisa Sadowski, translated for him.

Tinoco wanted to challenge himself and see if he could do the pass. “I felt like I was confident, and I understood the concept,” he said. “The people were really encouraging.” Tinoco added about the contest volunteers.

Chris Pollock, AWS director, Research and Development, serves as secretary to the Professional Welders Competition Committee. “This is a very successful event,” Pollock said. “We’ve showcased welding as a career, gotten great publicity for our industry, and had the opportunity to choose the nation’s top welder.”

Pollock’s expectations for the event include highlighting the benefits of welding as a career. “We want to reach out to the rest of the world and show them what welding can do,” he said.

The next competition is scheduled for the 2009 Show in Chicago, Ill.
Plasma System Cuts Thick Metals at High Speeds. Kalibrum introduced its Spirit 400A high-current-density plasma arc cutting system (Fig. 18) at the show, a product geared for any industry needing to cut heavier materials. The system is rated at 400 A at 200 V, 100% duty cycle. It can pierce and production cut up to 2-in.-thick steel. One of its major benefits is higher processing speed on 1-in.-thick materials — up to 85 in./min, which is 30% faster than the company’s earlier 275-A machine. The 80-kW system maintains a cut edge quality of ≤2-deg bevel and delivers square, smooth, and nearly dross-free cuts. It uses the same consumables as the company’s other plasma cutting systems as well as its HfOT (Hafnium Optimizing Technology), which extends electrode life and helps improve overall cut quality and consistency. Kalibrum, (843) 795-4286, www.kaliburn.net.

Noncontact Measurement of Welding Preheat Temperatures. Since specifications can cite any of three methods for determining weld preheat temperatures — temperature-indicating crayons, infrared thermometers, and contact indicators — Tempil® General Manager Roger Hornberger said the company plans to meet customer’s surface temperature needs in all three areas. Therefore, the company introduced the IRT-16 infrared thermometer at the Show — Fig. 20. The instrument measures temperatures through reflected heat emissions. The welder presses the trigger and aims the gun at the target metal. The temperature then immediately appears in °C or °F on the backlit LCD. At a distance of 16 in. away from the surface, it measures a 1-in. spot and can detect temperatures from –76° to 1200°F. The instrument’s suggested list price is $135. Tempil®, (908) 757-8300, www.tempil.com.

Belt Sanders Developed for Heavy-Duty Industrial Use. Fein employees demonstrated the effectiveness and durability of the company’s Grit GI series of belt Sanders by pressing a rotary drill bit to the belt and grinding it down to a nub, then showing the belt still had abrasive properties remaining. The modular units were designed for heavy-duty industrial use — Fig. 21. The basic models are the GI 75 and GI 150. Both offer 3-in. and 6-in. belt sizes and one or two speeds. Radius, rotary, tube and pipe notching, and surface sanding modules can be added, as well as dust collection attachments. Fein Power Tools Inc., (412) 922-8886, www.feinusa.com.

Get Ready for the 2008 Exposition

Be sure to set aside October 6–8 in order to see the greatest collection of welding and metalworking equipment and supplies under one roof in North America at the 2008 FABTECH International & AWS Welding Show in Las Vegas, Nev. For more information, go to www.aws.org/expo/.
# New Products

**ESO® Strip Cladding System**

*Second Generation Design for ESW and SAW Cladding*

![ESO® Strip Cladding System Image]

Standard and custom systems are available for 30, 60, 90 and 120mm wide strip widths. For use in either the submerged arc (SAW) or electroslag (ESW) modes (shown above). Electrical extensions from 30 to 100mm provide up to 30% increase in deposition over standard strip cladding systems. These systems are in use worldwide.

**EURO DRY FLUX OVEN**

A unique rotary flux drying oven that permits drying flux up to 400 lbs per hour, depending on the type and density of flux, is now offered. Fluxes used for both SAW wire welding and strip cladding can be re-dried. Flux through-put of up to 400 lbs. (181 kgs) per hour are possible, depending on the flux. The unit meets CE, UL and CSA certifications. *(Available June 2008)*

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**EUROWELD, Ltd.**

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(704) 662-3993  Fax: (704) 662-9820  
http:www.euroweld.com

For Info go to [www.aws.org/ad-index](http://www.aws.org/ad-index)
The unique capability of laser cladding enables part processing with reduced heat and smaller grain structure compared to conventional welding. Applications for laser cladding include depositing a robust surface treatment to salvage and repair used parts. Laser cladding basics include an understanding of the laser light and the interaction of the laser beam with the material. In this article you will be introduced to several of the major components affecting the cladding process. The key components are integrated to form the laser cladding system.

Process Description

Laser cladding uses the high energy density generated by a laser beam to form a molten pool in a base material for metallurgically bonding with a filler material using a diffusion type of weld. The interaction between the laser beam and the base material is primarily a function of the following properties:

1. Laser beam absorption
   - Absorption of the beam generates the molten zone.
   - A shorter wavelength laser generally absorbs better in metals.
2. Laser beam reflection
   - Back reflection from the surface of the metal is high.
3. Laser beam transmission
   - For metals, penetration of the laser beam (photons) is low.
   - Absorption of the laser beam results in the heating of the base material. Very high energy densities are possible with a laser. Different material processing results can be achieved with increasing the energy density. The following examples are processes that follow a trend of increasing energy density:
   1. Surface heating (low energy density)
   2. Soldering
   3. Brazing
   4. Heat treating (surface hardening for appropriate alloys)
   5. Diffusion welding (low penetration)
   6. Cladding (diffusion welding plus extra energy for additive mass)
   7. Keyhole welding (greater penetration)
   8. Cutting (similar or greater keyhole welding energy density plus coaxial assist cutting nozzle)
   9. Drilling (generally pulsed beam)
   10. Ablative material removal (very high energy density)
   - Generally the power, pulse length, and beam quality of the laser determines what material processing techniques are possible. Typical energy densities for cladding or metal deposition range from $10^4$ to $10^5$ watts per square centimeter (W/cm²). Energy densities above $10^5$ W/cm² result in a keyhole welding process producing larger penetrations than the diffusion process. Diffusion welding of the clad deposit produces a narrow dilution zone between the clad and the base material. A portion of the filler material may be preheated by the laser beam just before wetting into the molten pool. The high energy density enables rapid heating and rapid self-quench times.

One of the key advantages of the laser cladding process over conventional welding (gas metal arc welding (GMAW) or gas tungsten arc welding (GTAW)) is the smaller dilution zone resulting in a smaller heat-affected zone (HAZ). Figure 1 shows a 200× magnified view through a metallurgical microscope of a laser deposit of 420 stainless powder deposited on 4140 steel. The microhardness diamond squares show a greater hardness in the deposit (HRC 60+ in the stainless deposit possible). For an example of the reduced heat possible with pulsed laser welding see Fig. 2. Laser cladding is similar to laser welding with filler material added to the weld pool. The rapid heating and cooling of a laser welded deposition can result in high hardness being achieved in the deposition.
The Molten Pool

The shape of the molten pool is primarily controlled by the laser spot shape and energy distribution, the incoming direction of new material plus effects from the filler material. Part geometry, mass, and the heat sinking properties of the material have an impact on how the part is processed. Powder scatters the laser beam and wire may distort the shape of the pool due to the heat sinking of the wire. The distribution of the laser energy can be modified with time or spatial techniques for shaping the thermal profile. Cooling of the part is also affected by the cover gas type and flow along with the fume removal flow rate.

The Laser Energy Source

The laser provides the energy to the molten pool. Cladding is generally done with a continuous beam laser. Pulsing the beam on and off is used to control the location and possible shape of the deposit. Several different types of lasers in the kilowatt class can be used. Table 1 shows the lasers used for cladding.

Table 1 — Types of Lasers Used for Cladding

<table>
<thead>
<tr>
<th>Laser</th>
<th>Wavelength</th>
<th>Beam Quality</th>
<th>Beam Delivery</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>10.6 microns</td>
<td>high</td>
<td>free space (mirrors)</td>
</tr>
<tr>
<td>Nd:YAG</td>
<td>1.06 microns</td>
<td>low</td>
<td>large fiber (typ. 0.4–0.6 mm)</td>
</tr>
<tr>
<td>Fiber</td>
<td>1.07 microns</td>
<td>high</td>
<td>small fiber (typ. 0.05–0.1mm)</td>
</tr>
<tr>
<td>Direct diode</td>
<td>0.8–1 microns typ.</td>
<td>low</td>
<td>free space (typ. rectangular beam)</td>
</tr>
</tbody>
</table>

Fig. 1 — Laser clad deposit of 420 stainless steel on 4140 (200 ×).

Fig. 2 — Laser beam welding and GTAW visual heat effects.

Fig. 3 — Diagram of laser cladding beam delivery head.

Fig. 1 — Laser clad deposit of 420 stainless steel on 4140 (200 ×).
Beam Delivery

To generate the required energy density, the beam out of the laser is focused onto the part to clad the surface — Fig. 3. The operational environment for a laser cladding head needs careful consideration of the processing environment. Provisions for robust cladding processing includes management in high back reflection environment, optics protection and cooling, shield gas provisions, feed material handling, head protection, fume removal, and maintenance.

A wire feed beam delivery in progress is shown in Fig. 4. The head is connected to a laser by an optical fiber. The spot size for this head is generally adjusted between 1 and 2 mm in diameter and used with a 1.6-kW, 100-micron fiber-delivered fiber laser.

The spot size and shape is controlled by the capabilities of the laser power and beam quality and the optical design of the beam delivery head. The requirements of the application drives the choices. To cover larger areas, rectangular-shaped spots may be used. A typical rectangular spot for a direct diode laser may be 1 × 12 mm with 4 kW of laser power. A deposit then would be made with the wide orientation of the beam producing bands of cladding that can be laid down side by side.

Filler Material

The filler method is generally integrated into the focusing head. Choice between coaxial and side powder feeder depends on the availability, application, and objective. Wire feeder systems generally come into the molten pool through a carefully oriented and aligned mechanical wire feeder. The laser cladding of a surface with a 4-kW direct diode laser with diffusion coupling using powder feed is shown in Fig. 5. Here the powder is brought into the side through a flattened copper tube. Long deposition times would require the powder nozzle to be water cooled. The thickness of the deposit may range from 0.25 to 0.75 mm depending on variables that include speed, power, powder rate, and feeding method.

Processing with keyhole beam coupling (ejected plasma is observed) with a precision wire feeder is shown in Fig. 6. The wire feeder is feeding a 0.01-in. wire into a molten spot created by a fiber laser. The wire is melted as it is fed into the molten zone. This process requires careful alignment and runs cleaner than the powder. Figure 7 shows a multipass example with the wire feeder using a fiber laser.

The Laser Cladding System

The operational environment for a CDRH certified Class 1 laser system includes an enclosure protection system that meets the Maximum Permissible Exposure (MPE) requirements for the laser beam; additional requirements according to ANSI Z136.1 (2007), Safe Use of Lasers; and information for the Laser Safety Officer (LSO), which can be obtained from the Laser Institute of America (www.laserinstitute.org).

The major components for a laser cladding system include the laser, beam delivery system, processing head, motion system, system control, enclosure, and material handling and automation as required. Process development including the metallurgy is a prerequisite for establishing a successful application.

Procedure

Laser cladding produces metallurgical bonds with the base material. The resulting process results can be considered as having the following zones.

1. Deposited material
2. Dilution zone
3. Heat-affected zone
4. Original base material.

Establishing a laser cladding process is similar to laser diffusion welding. First, the laser power and processing speed are adjusted for a smooth weld bead profile. Next, the filler material is added, usually along with a power increase to melt the additional metal. The process results then need evaluation with metallurgical analysis and processing parameters are adjusted for optimization.

Operator experience plus the system’s specifications and controls will determine the laser cladding capabilities. Process development includes defining the processing variables at the production rates desired. It is important to evaluate the capabilities and robustness of the process at production rates.

Conclusions

Laser cladding offers new capabilities for part repair. Additionally, laser cladding for new parts may offer improved capabilities for wear surfaces.

Most likely, the applications for laser cladding and precision metal deposition will increase in the future with education on the capabilities of laser metal additive processes. The increase in applications can be further enabled by lower cost lasers and new capabilities that will offer precision control of laser spot geometry and heat distribution. This will provide even greater flexibility with laser cladding.◆

Change of Address?  Moving?

Make sure delivery of your Welding Journal is not interrupted. Contact the Membership Department with your new address information — (800) 443-9353, ext. 217; smateo@aws.org.
Q: We are using BNi-2 filler metal to coat sheet metal parts, and are having difficulty getting a uniform coating. We have either an excess of filler metal, and it runs and drips, or we have dry spots, which appear to be caused by the filler metal not melting and smoothing out. We apply the filler metal with a spray process. The filler metal is put into a hopper and the binder into a tank. The two merge at the nozzle of the gun and are simultaneously sprayed on the parts.

A: This is another interesting use of a nickel-based filler metal. As filler metals in this group have high oxidation resistance, they improve the thermal fatigue resistance of many of the lower oxidation-resistant base metals when applied in this manner. They are also applied where corrosion and fretting resistance are required.

Fig. 1 may help you understand what is happening, and why. As you can see, the desired coating thickness for BNi-2 would be between the two curves. When the quantity of filler metal is above the top curve, excess flow will take place. If the filler metal is below the lower curve, the surface will look dry and appear as if the filler metal did not melt and flow. Examining the surface with a bright light, after spraying, would reveal that the base metal is shining through the filler metal in some areas. In this circumstance, it means that the filler metal particles were spread out so that they were not touching each other. Thus, when the powder is heated, it will liquate with the base metal and, as fast as the low-melting liquid is formed, it is diffused into the base metal. This leaves a high-melting nickel-chromium residue behind and creates the dry appearance in the unmelted areas.

It is necessary to apply enough filler metal to the surface so that the base metal is not visible through the coating. As shown from a to b on the graph, there is a greater latitude of coating thickness when furnace processing at the lower end of the
temperature range. When furnace fusing at the low end of the temperature range, the filler metal will remain in high hardness, which is exceedingly good for abrasion resistance. However, if the part is to be subsequently bent or formed, or some rework is necessary, this hard coating layer can crack.

To create a more ductile coating, the furnace temperature must be higher; temperatures up to 2050°F (1120°C) have been used in production. As indicated on the graph by the smaller distance between b and c, when the temperature is increased, the thickness of the coating becomes more critical. It is difficult to prevent an excess amount of filler metal from being applied. It may be necessary to spray a number of parts, inspect them after spraying, furnace fuse them, and then check them for uniformity.

There are also other factors that may require an adjustment in the amount of filler metal to be applied. If the base metal has been oxidized and then cleaned up in a hydrogen- or vacuum-furnace atmosphere, the base metal surface will absorb more filler metal than a bright, clean base metal that has not been oxidized or reduced.

The effects of nitrogen can pose another problem; certain base metals, such as 304LN, may have nitrogen added to improve the corrosion resistance. Some base metals have a nitrogen content as high as 0.3–0.4%. The nitrogen will nitride the boron in the filler metal, change the melting point, and prevent the filler metal from flowing. Even if the filler metal does flow, the nitrogen can create a skin on the surface, which doesn’t allow the filler metal to bond to the base metal.

Another factor to consider is the melting range of the filler metal. If it has a narrow melting range, such as the BNI-2, with a solidus of 1780°F (970°C) and liquidus of 1830°F (1000°C), control of the temperature and coating thickness is even more critical. Control is less critical when using a filler metal with a wider melting range.

Two recent processes have been developed for applying a filler metal coating that allow for more precise control of the coating application. These are the roller coating and screen printing application processes. You may want to investigate these as an alternative to the spray coating process you are now using.

R. L. PEASLEE is vice president emeritus, Wall Colmonoy Corp., Madison Heights, Mich. Readers may send questions to Mr. Peaslee c/o Welding Journal, 550 NW LeJeune Rd., Miami, FL 33126 or via e-mail to bobpeaslee@wallcolmonoy.com.
Working under ANSI procedures, the contributors and reviewers of AWS D1 codes have built upon the work of hundreds of prior experts who, since the first D1 code in 1928, have continuously labored to represent proven practices. The result is a resource that provides a consensus of the finest minds in the industry on the most reliable approaches to achieving a successful final outcome. That’s why D1 code books have been mandated by local, state, and overseas codes, approved by ANSI, adopted by the Defense Department, preferred by NASA, and required by contracts for countless industrial and construction applications.

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NEW PUBLICATION!
AWS D1.8/D1.8M:2005 Structural Welding Code—Seismic Supplement complements AISC Seismic Provisions to help ensure that welded joints designed to undergo significant repetitive inelastic strains as a result of earthquakes have adequate strength, notch toughness, and integrity to perform as intended.

NEW PUBLICATION!
AWS D1.9/D1.9M:2007 Structural Welding Code—Titanium covers requirements for design, welding, and inspection of any type of titanium structure. Includes qualification requirements for weld procedures and personnel.
Q: I was using a spool of aluminum gas metal arc wire, and on the spool label it stated that the wire conforms to specification ANSI/AWS A5.10 and that the wire classification was ER4043. What are the requirements of this specification, and how does the classification system work?

A: The American Welding Society (AWS) has more than 30 specifications in the A5 series; these documents all address filler metals, electrodes, rods, fluxes, and other consumables used in welding. The two specifications in this series that are directly related to aluminum are AWS A5.3, Specification for Aluminum and Aluminum-Alloy Electrodes for Shielded Metal Arc Welding, and AWS A5.10, Specification for Bare Aluminum and Aluminum-Alloy Welding Electrodes and Rods — Fig. 1. Any reputable manufacturer of aluminum filler metal will manufacture its product in accordance with the requirements of this national standard. The AWS A5.10 specification contains the following:

Part A — General Requirements. In this section, the standard addresses Normative References and describes the classification system. It states that any filler metal tested and classified as an electrode (ER) shall also be classified as a rod (R). However, if a filler metal tested and classified only as a rod shall not be classified as an electrode. Also, that electrodes and rods classified under this specification are intended for gas metal arc, gas tungsten arc, oxygen gas, and plasma arc welding, but that is not to prohibit their use with any other process for which they are found suitable. This section contains Table 1, which provides the chemical composition requirements for aluminum electrodes and rods. It also contains Table 2, the required tests. This table indicates the testing requirements for each classification of electrodes and rods.

Part B — Tests, Procedures, and Requirements. In this section, we find the detailed test requirements. It states that the purpose of the tests is to determine the chemical composition of the filler metal, soundness of the weld metal produced by gas metal arc welding electrodes, and the deposition characteristics of the welding rods. Section 9 describes the two different weld test assemblies, the groove weld for soundness and usability of electrodes, and the bead-on-plate weld test for usability of welding rods. Section 10 addresses the method to be used for chemical analysis of a sample of filler metal or the stock from which it is made. Section 11 addresses radiographic testing and provides the standard method for controlling quality of radiographic testing. Figure 1 shows the groove weld test assembly for radiographic tests, providing dimensional requirements and joint geometry. Figure 2A and 2B provides a graphical representation of radiographic acceptance standards for test assemblies in the overhead welding position, showing assorted rounded indications. The acceptance standards stipulate that indications that do not exceed 3/16 in. (0.4 mm) diameter or length, or both, shall be disregarded during interpretation. For 3/32-in. (5-mm-) and 3/32-in. (6.4-mm-) thick test assemblies, the maximum total area of porosity in 6-in. (150-mm) length of weld is 0.0225 in. (14.52 sq mm) based on 1.5% T per in. (25 mm), where T is the base metal thickness. For 3/32-in. (10-mm-) thick test assemblies, the total area of porosity in 6-in. (150-mm) length of weld is 0.0337 in. (21.7 sq mm) based on 1.5% T per in. (25 mm), where T is the base metal thickness. These radiographic acceptance standards are identical to those in MIL-E-16053L (Amendment 2, 20 October 1980) and as Class 3 NAVSEA 0900-LP-003-9000.

The specification requires that electrode diameters of 3/32 in. and smaller be tested in the overhead position and electrode diameters larger than 3/32 in. in the flat position. A bead-on-plate test is required for rod testing. The rod is required to produce weld metal that flows freely and uniformly without outpurring or other irregularities. The resultant weld metal shall be smooth and uniform with no visible evidence of cracks or porosity in order to pass the test.

Part C — Manufacture, Identification, and Packaging. Standard sizes, diameters, and dimensional tolerances for round filler metal in different forms of straight length, coils without support, and spools are as shown in Table 4 of the specification. The requirements for finish and uniformity are that all filler metal shall have a smooth finish that is free from slivers, depressions, scratches, scale, seams, laps, and foreign matter that would adversely affect the welding characteristics, the operation of the welding equipment, or the properties of the weld metal.

Standard package dimensions and weights for each form are given in Table 6, and the dimensions of the standard spool sizes shall be as shown in Figures 4 and 5 of the specification. Spools are required to be designed and constructed to prevent distortion to themselves and the filler metal during normal handling and use, and shall be clean and dry enough to maintain the cleanliness of the filler metal. The following product information (as a minimum) shall be legibly marked so as to be visible from the outside of each unit package:

1) AWS specification and classification designation
2) Supplier’s name and trade designation
3) Size and net weight
4) Lot, control, or heat number.

This specification also provides minimum precautionary information, which must be predominantly displayed in legible print on all packages of welding material.

Conclusion

As stated earlier, any reputable manufacturer of aluminum filler metal will manufacture its product in accordance with the requirements of this national standard. But does the AWS A5.10 specification marked on a box of aluminum wire guarantee that you will have a quality product that will consistently meet your requirements? Not necessarily, because it is one of the very important controls that can help to guarantee high-quality aluminum welding wire. The AWS A5.10 standard testing methods along with good manufacturing procedures, suitable and well-maintained manufacturing equipment, trained and experienced manufacturing personnel, all supported by a suitably designed and implemented management system, is really needed to produce consistently good quality aluminum welding wire.

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


WESTEC 2008 Advanced Productivity Expo and Conf. March 31–April 3, Los Angeles Convention Center, Los Angeles, Calif. Contact Society of Manufacturing Engineers. Call (800) 733-3976 or visit www.sme.org/westec.


Ohio Safety Congress & Expo. April 1–3, Columbus Convention Center, Columbus, Ohio. Sponsored by Ohio Bureau of Workers Compensation, Div. of Safety and Hygiene. Call (800) 644-6292; or visit www.ohiobwc.com.

Metef-Foundeq Conf. and Show. April 9–12, Garda Exhibition Centre, Montichiari, Brescia, Italy. Featuring international aluminum exhibition, high-tech die casting, foundry, extrusion, and finishing. Visit www.metef.com/ENG/home.asp.


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

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Mar 3-7 • May 19-23 • Aug 4-8 • Oct 13-17

Weldability of Metals, Ferrous & Nonferrous
Feb 11-15 • Mar 10-14 • Apr 7-11 • May 5-9

Liquid Penetrant & Magnetic Particle Inspection
Mar 31-Apr 4 • Aug 18-22 • Nov 10-14

Prep for AWS Welding Inspector/Educator Exam
Jan 28-Feb 8 • Mar 24-Apr 4 • Apr 28-May 9 • Jun 2-13

Prep for AWS Certified Welding Supervisor Exam
Feb 18-22 • Jun 23-27 • Aug 23-29 • Nov 17-21

1-800-332-9448
or visit us at www.welding.org
for more information.
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St. of Ohio Reg. No. 70-12-0064HT

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


Int'l Laser Technology Congress, AKL '08. May 7–9, Aachen, Germany. Visit www.lasercongress.org.


IIW Int'l Regional Congress, 2nd Latin America Welding Congress. May 18–21, Club Transatlantico, São Paulo, Brazil. Visit abs-soldagemlorg.br.


♦ **FABTECH International & AWS Welding Show.** Oct. 6–8, Las Vegas Convention Center, Las Vegas, Nev. This show is the largest event in North America dedicated to showcasing the full spectrum of metal forming, fabricating, tube and pipe, and welding equipment and technology. Contact: American Welding Society, (800/350) 443-9353, ext. 462; www.aws.org.

### Educational Opportunities


**ASME Section IX Seminars.** April 8–10, 2008, Las Vegas, Nev. Contact: ASME Continuing Education Institute. Call (800) 843-2763, or visit www.asme.org/education.


**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.** This is a ten-day program. Contact: Hobart Institute of Welding Technology. Call (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. Contact: Welder Training & Testing Institute (WTTI). Call (800) 223-9884, info@wtti.edu; or visit www.wtti.edu.

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

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

**Environmental Health and Safety-Related Web Seminars.** These 30-min-long Web seminars on various topics are online, real-time events conducted by industry experts. Most seminars are free. Visit www.augustmack.com/Web%20Seminars.htm.
EPRI NDE Training Seminars. EPRI offers NDE technical skills training in visual examination, ultrasonic examination, ASME Section XI, and UT operator training. Contact: Sherryl Stogner. Call (704) 547-6174, or e-mail sstogner@epri.com.

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


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

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

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

Laser Safety Training Courses. Courses based on ANSI Z136.1, Safe Use of Lasers, presented in Orlando, Fla., or at customer’s site. Contact: Laser Institute of America. Call (800) 345-3737, or visit www.laserinstitute.org.


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

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


Tool and Die Welding Courses. Contact: Hobart Institute of Welding Technology. 400 Trade Square East, Troy, OH 45373. Call (800) 332-9448, or visit www.welding.org.


Welding Introduction for Robot Operators and Programmers. This one-week course is presented in Troy, Ohio, or at customer’s location. Contact: Hobart Institute of Welding Technology. Call (800) 332-9448, ext. 5603, or visit www.welding.org.

Welding Skills Training Courses. Courses include weldability of ferrous and nonferrous metals, arc welding inspection and quality control, preparation for recertification of CWIs, and others. Contact: Hobart Institute of Welding Technology. Call (800) 332-9448, or visit www.welding.org.

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## AWS Certification Schedule

**Certification Seminars, Code Clinics and Examinations**

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

### Certified Welding Inspector (CWI)

<table>
<thead>
<tr>
<th>Location</th>
<th>Seminar Date</th>
<th>Exam Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Houston, TX</td>
<td>Feb. 24-29</td>
<td>Mar. 1</td>
</tr>
<tr>
<td>San Diego, CA</td>
<td>Feb. 24-29</td>
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<tr>
<td>Norfolk, VA</td>
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<td>Anchorage, AK</td>
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<td>Miami, FL</td>
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<tr>
<td>Mobile, AL</td>
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<tr>
<td>Rochester, NY</td>
<td>EXAM ONLY</td>
<td>Mar. 29</td>
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<td>York, PA</td>
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<tr>
<td>Dallas, TX</td>
<td>Mar. 30-Apr. 4</td>
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<tr>
<td>Chicago, IL</td>
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<td>Oklahoma City, OK</td>
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<td>Denver, CO</td>
<td>Jul 27-Aug. 1</td>
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<td>Philadelphia, PA</td>
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<td>Miami, FL</td>
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<td>Charlotte, NC</td>
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<td>Portland, ME</td>
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<td>Aug. 23</td>
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<td>Salt Lake City, UT</td>
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<td>Aug. 23</td>
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<tr>
<td>Houston, TX</td>
<td>Sept. 7-12</td>
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<td>Pittsburgh, PA</td>
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<tr>
<td>Miami, FL</td>
<td>EXAM ONLY</td>
<td>Sept. 18</td>
</tr>
</tbody>
</table>

For information on any of our seminars and certification programs, visit our website at [www.aws.org/certification](http://www.aws.org/certification) or contact AWS at (800/305) 443-9333, Ext. 273 for Certification and Ext. 455 for Seminars. Please apply early to save Fast Track fees. This schedule is subject to change without notice. Please verify the dates with the Certification Dept. and confirm your course status before making final travel plans.

### 9-Year Recertification Seminar for CWI/SCWI

<table>
<thead>
<tr>
<th>Location</th>
<th>Seminar Dates</th>
<th>Exam Date</th>
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<tbody>
<tr>
<td>Dallas, TX</td>
<td>Mar. 10-15</td>
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<tr>
<td>Sacramento, CA</td>
<td>Apr. 14-19</td>
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<td>San Diego, CA</td>
<td>Jun. 9-14</td>
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<td>Dallas, TX</td>
<td>Oct. 20-25</td>
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<tr>
<td>Miami, FL</td>
<td>Dec. 1-6</td>
<td>NO EXAM</td>
</tr>
</tbody>
</table>

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

### Certified Welding Supervisor (CWS)

<table>
<thead>
<tr>
<th>Location</th>
<th>Seminar Dates</th>
<th>Exam Date</th>
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<tbody>
<tr>
<td>Houston, TX</td>
<td>Mar. 10-14</td>
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<td>Nashville, TN</td>
<td>May 19-23</td>
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<tr>
<td>Manchester, NH</td>
<td>Jun. 9-13</td>
<td>Jun. 14</td>
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<tr>
<td>St. Louis, MO</td>
<td>Aug. 18-22</td>
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<tr>
<td>Denver, CO</td>
<td>Sept. 15-19</td>
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<td>Seattle, WA</td>
<td>Nov. 17-21</td>
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<tr>
<td>Jacksonville, FL</td>
<td>Dec. 8-12</td>
<td>Dec. 13</td>
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</table>

CWS exams are also given at all CWI exam sites.

### Certified Radiographic Interpreter (CRI)

<table>
<thead>
<tr>
<th>Location</th>
<th>Seminar Dates</th>
<th>Exam Date</th>
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<tr>
<td>Houston, TX</td>
<td>Mar. 10-14</td>
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<tr>
<td>Jacksonville, FL</td>
<td>Dec. 8-12</td>
<td>Dec. 13</td>
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</table>

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

### Certified Welding Educator (CWE)

Seminar and exam are given at all sites listed under Certified Welding Inspector. Senior 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 Welding Fabricator

This program is designed to certify companies to specific requirements in the ANSI standard AWS B5.17, Specification for the Qualification of Welding Fabricators. There is no seminar or exam for this program. Call ext. 448 for more information.

### Code Clinics & Individual Prep Courses

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

### On-site Training and Examination

On-site training is available for larger groups or for programs customized to meet specific needs of a company. Call ext. 219 for more information.
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Friction stir welding (FSW) is a variant of friction welding that uses a nonconsumable, rotating tool to create the weld. The rotating tool hot-works the material surrounding the weld interface to produce a continuous solid-state weld.

A common tool design has a shape of a rod with a concave area (shoulder) with a pin (probe) that is coaxial with the axis of rotation. The workpieces are rigidly clamped and supported by a backing plate that bears the load from the tool and constrains deforming material at the backside of the joint. In most cases, the pin is designed to be slightly shorter than the thickness of the weld joint to prevent contact with the backing plate.

To start the process, the rotating tool is plunged into the weld joint until the shoulder makes contact with the top surfaces of the workpieces. The motion of the tool promotes displacement of the softened material and the hot-worked metal is swept around the tool; the weld is produced behind it. The tool shoulder provides a forging force to the top surface of the weld. When the desired length has been achieved, the tool is removed. The process was originally designed to weld aluminum, but it has been tried on steel and titanium alloys.

Some of its advantages include minimal distortion with proper clamping, no fumes or spatter, little or no joint preparation, and the elimination of solidification-related discontinuities, such as porosity and cracking. High travel speeds can be achieved with the process.

A major limitation of FSW is the joint is not self supporting and must be properly restrained. Depending on the application, the tooling cost to support the joint might be significant.
The 2007 classes of AWS Fellows and Counselors were inducted at the recent FABTECH International & AWS Welding Show in Chicago.

2007 Class of Fellows

Valdemar Malin’s career spans more than 40 years both in the former USSR and the U.S., and encompasses significant contributions to numerous joining processes, materials, and applications. His latest activities include variable-polarity welding processes, laser beam and arc welding power measurement techniques, high-power direct diode cladding, electroslag welding processes, and automated welding processing. His ground-breaking research involving the phenomenon of power rectification enabled the development of stable welding power supplies for the variable polarity plasma arc welding process. Malin has been active in IIW Commission meetings and has contributed to publications of the Welding Research Council, Welding Handbook, and specification on electroslag welding for the AWS D1.5 Bridge Welding Code.

Israel Stol has been a major innovator, problem solver, and driving force in...
the advancement of fusion and solid based joining technologies during his career as a welding engineer in applied R&D. Through his research and publications, he has been influential in developing and implementing welding and joining technology for aluminum applications. His major contributions required innovative joining solutions such as friction stir welding, laser beam welding, and electron beam welding that had direct industrial and aerospace applications. His work has resulted in patents, published papers, and many technical presentations.

Paul T. Vianco has made significant contributions to the advancement of the technology of lead-free soldering and science-based modeling of solder joint reliability. His extensive solder and brazing research has included filler metal alloy development, interfacial wetting behavior, three-dimensional solid-state growth kinetics, thermomechanics, and lifetime predictions. Vianco’s investigations also include metal-metal and ceramic-metal brazing technologies. His work has involved development characterization of brazing filler metals and related processes. The research has provided an improved understanding of braze joint metallurgy and its impact on long-term reliability. He is author and coauthor of numerous peer-reviewed publications, is the recipient of several prestigious awards from private industry and the U.S. Department of Energy Defense Programs, holds two patents, has served as proceedings co-chair/editor, and served on the technical program planning committee for the joint AWS-ASM International Brazing and Soldering Conference. He is an active member of the AWS Brazing and Soldering Committee, and authored the third edition of the AWS Soldering Handbook.

Peng-Sheng Wei has contributed significantly to the knowledge and application of resistance welding through mathematical analyses coupled with verifying experimentation. Wei has published more than 40 technical papers on his extensive investigations of beam focusing characteristics and the effects of specular and diffuse reflections on energy absorption in high-inertial development chambers. He has presented interpretations of weld defects such as pore formation and growth, weld bead rippling, and the problems associated with welding dissimilar metals. His recent efforts have led to a kinetic analysis of energy and momentum transport across a space charge region in a thin layer between a plasma and workpiece surface.

2007 Class of Counselors
Wayne J. Engeron has served the metals-joining industry for more than 45 years, beginning as a technical representative for a welding equipment manufacturer. He became a partner in a welding supply company and later a company that specialized in pipeline construction. He also established Ace Welding Supply in Houma, La., before selling it in the late 1980s. Engeron has been active in brazing and soldering technology, and with his sons formed the Engeron Technology Group, of which he is chairman. The three company operations include welding systems and related products, on-site and office location training for brazing operators, and testing of welders, machine shop functions, and light fabrication. As an AWS Life Member, Engeron has served the Society at local and national levels. He organized the Morgan City Section, was active in the New Orleans Section, and revitalized the Atlanta Section. He served as District 5 director (2001–2004) and is a past member of the board of directors.

A. Rex Fronduti. Awarded posthumously, Fronduti served more than 50 years in steel fabrication. His training of technicians and tradespeople began with the fabrication of bridges, design of welding fixtures, and the building of railroad cars greatly contributed to the safety of the traveling public. He was for many years a member of the D1.1 Structural Welding Code Committee and its various subcommittees. He was a co-founder and member of the joint AASHTO and AWS D1.5 Bridge Welding Code Committee. His insights, expertise, and awareness of the critical issues facing both groups were instrumental in obtaining the required consensus and the acceptance of the joint document.

Jeffrey W. Post has been an active participant in promoting AWS Structural Welding Codes and associated documents, and has been a leader in the development of welding requirements for tubular structures. Post made significant contributions to the knowledge and fabrication industry and to the AWS D1 series of documents with his technical expertise, leadership, and wise counsel on many issues. He is engaged in many phases of welding engineering, including materials selection, welding procedures, and welder qualifications, fabrication practices and techniques, inspection, and nondestructive testing. He has published several papers on tubular structures and their joint details, fabrication techniques, and inspection. Post is a skilled practitioner in flame straightening and repair of out-of-tolerance distortions of structural components, including highway steel bridges, caused by welding.

J. F. (Fritz) Saenger has served the welding community for more than 30 years in product development, product management, international marketing, and research and development activities. He was a major force in the development and implementation of new technologies contributing significantly to the growth and health of the welding industry. He joined Edison Welding Institute as director of membership, later serving as director of marketing and international business development. He was an active participant in the Impact of Welding Study, and has presented ideas for enhancing the AWS Welding Show. Saenger, a graduate of The Ohio State University’s welding engineering program, is a curriculum author and instructor of a course that emphasizes practical solutions for welding engineers.

Harrison S. Sayre. Awarded posthumously, Sayre served AWS and the welding community for 60 years. His achievements as a Naval officer and welding engineer have impacted the establishment and refinement of quality standards for welding materials processes. He pioneered the introduction of underwater welding in the U.S. Navy and served as a consultant and member of national and international welding organizations. As an advisor and liaison between Navy supervisors of shipbuilding and inspectors of naval materials, he contributed to the development of welding materials and process standards for nuclear submarines. He was responsible for the evaluation of radiographic procedures and standards used at submarine construction shipyards. He established a high-impact shock testing capability at E.E.S. Annapolis that was specifically designed for evaluating weldments in naval materials, machinery, and electrical components. Sayre has given numerous invited lectures and talks covering a variety of marine and ship construction subjects, he contributed to the investigation of the USS Thresher submarine accident, and after retiring from the Navy in 1975, he became involved with investigations of ship propeller failures.

James J. Sekely has more than 35 years of experience in heavy industrial construction, specializing in welding and quality assurance/quality control. He began his career as an apprentice welder in the steel industry, advancing to welding supervisor, welding superintendent, and finally as welding manager. He has been a partner in a welding company, staff welder engineer, and chief and senior welding engineer. He developed, implemented, and directly managed welding programs and field operations in the fossil, nuclear, and cogeneration power industries, the steel industry, and the food, hospital, pulp and paper, and natural gas transmission industries. Sekely has been the driving force for the development of AWS Standard Welding Procedure Specifications (SWPS). Each SWPS was developed by collecting records from several
Robert K. Wiswesser has served the welding community and industry with great distinction. Since its inception in 1974, he has been involved with the AWS Certified Welding Inspector program. He has been a CWI since 1976, and a SCWI since 1997. He also holds certifications as a Level III NDT inspector in PT and MT, plus Level II in UT. As current chair of the Certification Committee and the Certification Exam Bank Subcommittee, his leadership has guided the committees through some interesting scenarios and the development of new certification programs. He has also served the Society at both the local and national levels. He held various officer positions in the AWS Lehigh Valley Section, served as District 3 Director (1984–1990), and was a past member of the Board of Directors. Wiswesser is the owner and president of Welder Training and Testing Institute in Allentown, Pa. He is involved in training and certifying welding personnel here in the United States and in other parts of the world. Wiswesser has also been involved in the daily inspection of many different types of fabrications, including CWI inspection for several Super Bowl half-time events, and the ultrasonic inspection of the structural components of the Walt Disney Mission Space ride.

Comfort A. Adams Lecture Award

John W. Elmer joined Livermore National Laboratory (LLNL) in 1982, received his ScD in metallurgy from Massachusetts Institute of Technology in 1989, and is currently acting program element leader for Stockpile Materials and Joining in the Chemistry and Materials Science Directorate of LLNL. Elmer’s group is responsible for metallurgy and joining using electron and laser beams, vacuum brazing, and diffusion bonding in support of the LLNL program missions. He has authored or coauthored more than 100 technical papers on topics relating to in situ observations of welds using synchrotron radiation, materials joining, metallurgy, rapid solidification, high-energy-density beam/material interactions, electron beam diagnostics, explosion welding, and the kinetics of phase transformations. He is an AWS Fellow and a Fellow of ASM International. He is a Professional Engineer, and holds ten U.S. patents. Elmer has received many AWS awards including the William Spraragen, Prof. Masubuchi-Shinsho Corporation, Davis Silver Medal, Warren F. Savage Memorial, and Samuel Wylie Miller Memorial Medal. Currently, he serves on a number of technical committees for AWS and ASM International, and is an adjunct professor at Pennsylvania State University.

Adams Memorial Membership Award

Harshad K. D. H. Bhadeshia received his PhD from the University of Cambridge, UK, where he currently is a professor of physical metallurgy. His field of expertise is solid-state transformations with emphasis on the prediction of microstructural development in complex metallic alloys, particularly for multicomponent steels. He was elected a Fellow of The Royal Society of London, the Institute of Physics, the institute of Materials, and The Royal Academy of Engineering, and this year was awarded Consulting professorship by Harbin Institute of Technology, China. Bhadeshia has received honors from institutions in Brazil, Japan, India, and the United States. He serves on the editorial boards of Material Transactions of JIM, and Australasian Journal of Welding and Materials Science & Technology. Bhadeshia is associate editor of Materials Science and Engineering, editor of Science and Technology of Welding and Joining, and is vice president of Industrial Trust.

Jyotirmoy Mazumder received his PhD in process metallurgy from the Imperial College, London, UK, in 1978. Since then, he was a research scientist with the Center for Laser Studies at the University of Southern California, and from 1980 to 1988 was a professor of mechanical engineering at the University of Illinois at Urbana-Champaign. He also served as head of the university’s Design and Materials Division, Department of Mechanical and Industrial Engineering and was codirector for the Center for Laser-Aided Materials Processing. Since 1996, he has been the director for the Center for Laser Aided Intelligent Manufacturing, Department of Mechanical Engineering and Applied Mechanics, and the Robert H. Lurie Professor of Mechanical Engineering and Applied Mechanics at the University of Michigan. He is also the director for the Center of Lasers and Plasmas for Advanced Manufacturing (LAM). He has guided more than 30 students through their graduate studies. He has authored a book and published numerous papers on manufacturing, physics, optics, processing, and laser manufacturing. Mazumder developed and patented the first closed-loop Direct Metal Deposition (DMD) technology, where functional engineering components can be made in near net shape directly from CAD. His research led to the development of a diagnostic technology known as Reflective Topography. He is currently involved in the development of a next-generation DMD system with surface finish features on the order of one nanometer.

Howard E. Adkins Memorial Instructor Membership Award

Bernhard Mueller has worked for more than sixty years in the welding industry. He began his career in 1948 with the Milwaukee Road Railroad. From 1950 to 1955, he worked for Heil Co. in the armored tank, milk tank, and rock body lines as a welding technician. From 1958 to 1986, he was with Manitowoc Shipbuilding Co., serving as chief welding technician. In addition to his regular employment, he taught at Manitowoc Vocational School. Since his retirement in 1989, Mueller has served at Lakeshore Technical College in Cleveland, Wis., as an evening instructor and certification officer for new and advanced welding students. Mueller has been an active AWS member for 52 years. He has been a member of the Milwaukee, Fox Valley, and Lakeshore Sections, and twice held the position of chairman of the Fox Valley and Lakeshore Sections. He was an AWS Certified Welding Inspector, and contin-
uses to conduct tests in compliance with AWS D1.1, *Structural Welding Code — Steel*, for welder certifications in the state of Wisconsin.

Ronald S. Theiss received his degree in applied technology from Sam Houston State University in 1984. He is a professor at North Harris College where he has taught welding, nondestructive testing, inspection, and other welding-related topics for 26 years. Theiss is a member of various advisory committees, serves as a judge on the district, state, and national levels for SkillsUSA competitions, and has developed curriculums for both welding and weld inspection. He has been a guest speaker, educational presenter, and a board member of the American Society of Nondestructive Testing. He has held all officer positions in the AWS Houston Section and served as District 18 director from 1996 to 1999. He also works with AWS as adjunct faculty teaching courses in welding inspection technology, code clinic, visual inspection, radiographic interpretation, and weld processes courses. Theiss is an AWS Senior Certified Welding Inspector. He has received several recognitions, including Section Educator Award, District 19 Educator Award, and the Dalton E. Hamilton Memorial CWI Award, District 19 Educator Award, and recognitions, including Section Educator Inspector. He has received several awards including the Koichi Masubuchi Award, William Spraragen Memorial Award, and Geoffrey Belton Award of The Iron and Steel Society. He won the ASM International Graduate Student Paper Competition, and earned an AWS Graduate Research Fellowship. His current research involves the characterization of phase transformations in structural materials.

John W. Elmer. (See biography under Comfort A. Adams Lecture Award.)

David G. Brasher received his BS in metallurgical engineering from the University of Washington and performed MS work at the New Mexico Institute of Mining and Technology. In 1997, he and Donald Butler founded High Energy Metals, Inc., an explosion welding metal fabricating shop, in Sequim, Wash. He specializes in unique dissimilar-metal bonded joints. Earlier, he was vice president of Northwest Technical Industries, Inc., a manufacturer of explosively bonded products. His papers have appeared in various research journals.

Donald J. Butler received his BS in mechanical engineering from Tulane University in 1982. In 1997, he and David Brasher founded High Energy Metals, Inc., an explosion welding metal fabricating shop, in Sequim, Wash. Earlier, Butler was a senior project engineer at Northwest Technical Industries, Inc., a manufacturer of explosion-bonded and formed products. He also wrote and received three Small Business Innovative Research grants and managed their completion, and is a published author in peer-reviewed scientific journals.

Robert Riddle received his PhD in mechanical engineering from the University of California, Berkeley. Currently, he is a system surveillance engineer at Lawrence Livermore National Laboratory. His re—continued on page 70
New Task Group Explores Need for a Standard on Computational Weld Mechanics

By John L. Gayler

A group composed of computer weld modeling developers (industry and academic) and industrial users have formed an AWS technical task group to investigate the possibility of publishing an American National Standard on computational weld mechanics. The initial reasons for pursuing a national standard on this subject vary among the participants, but they include the following:

- There are currently too many independent models each lacking a shared basis
- The modeling fundamental premises should better support industry needs
- Need to establish the minimum level of accuracy appropriate for general applications
- Need to establish a common benchmarking experimental data and standards for all models
- The need to form a methodology for continued improvement of these weld modeling methodologies for satisfying the need for the use of advanced materials and joining processes.

This task group held its first meeting in Chicago during the FABTECH International & AWS Welding Show on November 12, 2007.

The task group is looking for participation from all interested parties, especially users of computer models.

If you are interested in participating in this task group’s activities, contact John Gayler at gayler@aws.org, or call (800) 443-9353, ext. 472.

JOHN L. GAYLER is director of national standards activities and A9 secretary.

Standards for Public Review

AWS is an ANSI-accredited standards-preparing organization. AWS rules, as approved by ANSI, require that all standards be open to public review for comment during the approval process. Draft copies of these standards may be obtained from Rosalinda O’Neill, roneill@aws.org; (305) 443-9353, ext. 451.

B5.1:2003, Specification for Qualification of Welding Inspectors
Page 3, Table 1, under “Procedure Qualification” — repeated line — delete “(5) witness procedure qualification” and two “X”s on same line in far columns.
Page 4, Table 1, under “Inspection,” incorrect placement of “X” (two places) for items #4 and #5, the “X” in the column for AWI should be deleted, and an “X” should be added in the column for SWI for both #4 and #5.

D1.6/D1.6M:2007, Structural Welding Code — Stainless Steel

Errata B5.1 and D1.6

The following errata have been identified and corrected in current reprints of these documents.

B5.1:2003, Specification for Qualification of Welding Inspectors
Page 3, Table 1, under “Procedure Qualification” — repeated line — delete “(5) witness procedure qualification” and two “X”s on same line in far columns.
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D1.6/D1.6M:2007, Structural Welding Code — Stainless Steel

Technical Committee Meetings

March 4-7, D1 Committee on Structural Welding. Charlotte, N.C. Contact: S. Morales, ext. 313.
March 6, A5K Subcommittee on Titanium and Zirconium Filler Metals. Charlotte, N.C. Contact: S. Borrero, ext. 334.
March 6, G2D Subcommittee on Reactive Alloys. Charlotte, N.C. Contact: S. Borrero, ext. 334.

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The task group is looking for participation from all interested parties, especially users of computer models.

If you are interested in participating in this task group’s activities, contact John Gayler at gayler@aws.org, or call (800) 443-9353, ext. 472.

JOHN L. GAYLER is director of national standards activities and A9 secretary.
search includes thermal and stress analysis, fluid flow analysis, nuclear energy, surface science and interfaces, and materials. He is also involved with fracture, fatigue, and damage analytical methods, and the analysis of welding processes. He is a member of the American Society of Mechanical Engineers and a registered professional engineer.

**Structure Design**

*Mechanical Behaviors of Resistance Spot Welds during Pry-Checking Test*

Chon L. Tsai is a full professor in the welding engineering program at The Ohio State University. He holds a PhD from Massachusetts Institute of Technology, and has worked in welding engineering research and education for approximately 30 years. He has published more than 150 technical papers in various peer-reviewed journals. Tsai has developed innovative modeling techniques for analysis of welding-induced residual stresses and distortion. An AWS Fellow, he has received numerous technical and professional recognitions and awards.

David W. Dickinson received his PhD in welding metallurgy from Rensselaer Polytechnic Institute in 1972. He was an engineering specialist for Olin Corp. (1972–74), then served as section chief of the flat rolled products and welding research groups for Republic Steel Corp. (1974–84). Since 1984, Dickinson has been associated with The Ohio State University. In 1985, he helped establish Edison Welding Institute (EWI) and served as its first director of research until 1987. He served as a professor of welding engineering until he retired in 2007 as professor emeritus. Dickinson has received numerous awards, including the McKay-Helm Award, Merit Award from the James F. Lincoln Arc Welding Foundation, International Metallographic Award, AWS District Meritorious Award, and Plummer Memorial Education Lecture Award. An AWS member since 1967, Dickinson served as AWS president in 1992. He is a Fellow of ASM International and AWS. He has served on The Welding Research Council, The International Institute of Welding, The Metallurgical Society of AIME, and The Welding Institute where he was a Fellow and a former member of the Research Board. He serves in the Gateway Coalition of Colleges, Ohio Project Lead the Way Board, and the Ohio Kairos Prison Ministry Board.

**Choong-Yub Kim** is currently working on his PhD in welding engineering, and serving as a research associate and a teaching assistant at The Ohio State University. His dissertation is titled *Plasticity-Based Distortion Analysis for MIG Brazed Thin Plate*. He has coauthored a paper published in the *Welding Journal* and two papers presented at the Sheet Metal Conferences XI and XII.

M. D. Garnett is affiliated with DaimlerChrysler in Auburn Hills, Mich.

**Dalton E. Hamilton Memorial CWI of the Year Award**

John A. Willard is cofounder of Accurate American Inspecting & Consulting, LLC, Bonfield, Ill. Previously, he was a project manager with the Robert W. Hunt Co./Bureau Veritas, a nondestructive testing and inspection firm. His career in the steel industry began 40 years ago. His involvement with AWS began as a CWI for the Ironworkers training program. As chairman of the AWS Joliet/Aurora/Kankakee (JAK) Section, Willard helped establish a Section scholarship fund. He has served on JAK’s career education advisory boards, coordinated a careers in construction program, served on District committees, and presided over District scholarship distributions. He has been recognized with numerous awards from the AWS, his community, and Ironworkers Local 465.

**Honorary Membership Award**

David M. Beneteau received his degree in electrical engineering from the University of Detroit. Since 1983, he has worked for CenterLine (Windsor) Ltd., founded in 1957 by his father. He is currently vice president of the CenterLine group of companies. Beneteau is a recognized expert in the field of resistance welding. He has been awarded one U.S. patent and has another patent pending. He has been an active member of the Resistance Welder Manufacturers’ Association (RWMA) since 1985, and served as its president from 2001 to 2003. An AWS member since 1987, he currently serves as chair of the J1 Committee on Resistance Welding Equipment. He received the District 11 Meritorious Certificate Award in 2006. He was first elected to the Detroit Section executive committee in 1999, and currently serves as Section chairman.

Albert Sciaky is a strategist and technologist with more than 30 years of experience as a senior executive and advisor to companies and organizations in a broad range of industries. He currently advises several venture capital investors and serves on the boards of directors of a number of high-tech companies. He received his AB, MBA, and JD degrees from the University of Chicago.

**International Meritorious Certificate Award**

Daniel Beaufils received his postgraduate welding engineering degree from École Supérieure du Soudage et de ses Applications (ESSA), Paris, France. He joined the Institut de Soudure in 1965 as a chemist where he was head of the Chemical Analysis Dept. from 1979 to 1994. From 1994 to 2000 he was head of the French Committee for Welding Standardization, and from 1979 to 2000 he also served as a welding professor at ESSA. He has worked with the International Institute of Welding since 1980 as the French Expert on Commissions II and VIII, vice chair of Commission VIII, and a member of the the Select Committee on Standardization. From 1995 to 2000, he was the French Delegate to ISO/TC 44, CEN/TC 121, and the secretary for six working units. Since 2000, he has served as IIW chief executive officer.
David A. Fink has contributed to the welding industry for 36 years. He received a BS degree in chemical engineering from Case Institute of Technology in 1971, and subsequently completed graduate work. He joined The Lincoln Electric Co. in 1971 where he has served in the Consumable Research and Development Department, specializing in welding consumables design, testing, standards, and health and safety. He is presently manager, Compliance Engineering (Consumables). For more than 30 years, he has been active on AWS technical committees. He is currently chairman of the AS Committee on Filler Metals and Allied Materials, a member of the Technical Activities Committee, Safety and Health Committee, and several subcommittees. Fink is a member of the AWS International Standards Activities Committee (ISAC) since its inception, and presently chairs the U.S. TAG to ISO/TC 44/SC3 on Welding Consumables. He has been active in the International Institute of Welding since the 1980s, has served as the U.S. Delegate to Commissions II and XII, Vice Delegate to Commission VIII, and is a Delegate to ISO Technical Committee 44, Subcommittee 3 on Welding Consumables. Fink has received the R. D. Thomas Memorial Award and the George E. Willis Award. Fink has authored several technical publications and holds patents in the area of ultralow-hydrogen metal cored electrodes.

Walter J. Sperko, is president of Sperko Engineering Services, Inc., which he founded in 1981. He has extensive experience in welding and metallurgical engineering, design, failure analysis, and quality assurance, with specialization in piping and pressure vessels. He received his degree in metallurgical engineering from the University of Notre Dame. Sperko worked for Ebasco Services, ITT Grinnell Industrial Piping, and Richmond Engineering. He is vice chair of the ASME Boiler and Pressure Vessel Code Subcommittee IX, Welding and Brazing Qualifications; chair, ASME Subcommittee B31.9, Building Services Piping; and chair of AWS International Standards Activities Committee. He has been an ISO Observer to CEN 121 SC1 since 1994, and SC2 since 1998. He teaches courses in piping and ASME Section IX. He is an ASME Fellow, has published articles in various trade magazines, and holds three U.S. patents.

William Irrgang Memorial Award

David L. McQuaid received his degree in civil engineering from West Virginia University in 1964, then joined the American Bridge Division of U.S. Steel Corp. During his 31 years with the company, he served as senior welding engineer and manager of technical services. For the last eight years, he has been a welding consultant for D. L. McQuaid & Associates, Inc. He is a past chairman of the AWS D1 Structural Welding Code — Steel, AWS D1.5 Bridge Welding Code, and the AWS Technical Activities Committees. He serves as a member of the AWS/ISO Committee and the Authorized National Body. Last month, he was installed as an AWS director-at-large and as a member of the AWS board of directors. He chairs the National Research Council’s Transportation Research Board Committee on Fabrication and Inspection of Metal Structures, and is a registered professional engineer in West Virginia.

Charles H. Jennings Memorial Award

Amit Kumar received his PhD in materials science and engineering from Pennsylvania State University in 2006. From 2001 to 2002, he was a project research associate in the Mechanical Engineering Department at the Indian Institute of Technology, Kanpur, India. He has received several awards including the Kenneth Easterling Best Paper Award from the University of Graz and IIW, Graduate Fellowship from the American Welding Society, and a Kennametal Fellowship. He has authored more than 15 research papers on numerical modeling of welding. Currently, he is working as senior research engineer in the Materials Section at ExxonMobil Upstream Research Co., Houston, Tex.

Tarasankar DebRoy is professor of materials science and engineering at Pennsylvania State University. He received his PhD from the Indian Institute of Science, with postdoctoral work at the Imperial College of Science and Technology and Massachusetts Institute of Technology. His research focuses on the application of numerical heat transfer, fluid flow, and mass transfer to understand welding processes and the geometry, chemical composition, and structure of welds. He has published more than 200 papers on welding and modeling of various materials-processing operations. DebRoy has received the Adams Memorial Membership Award, McKay-Helm Award, Charles H. Jennings Memorial Award, Warren F. Savage Memorial Award, William Spraragen Memorial Award, and many others. He has received Penn State’s Faculty Scholar Medal for outstanding achievements in engineering. He is a Fellow of AWS and ASM International.

McKay-Helm Award

Microstructure and Microchemistry of Hard Zone in Dissimilar Weldments of Cr-Mo Steels

C. Sudha joined the Indira Gandhi Centre for Atomic Research (IGCAR) in 1999 after completing postgraduate studies in physics at the University of Madras. She is currently pursuing her PhD degree. Her research studies focus on mass transfer across dissimilar material interfaces under service conditions. Her awards include the Gold Medal in physics from the University of Madras, the Department of Science & Technology Award from the Indian government, a certificate of achievement and commendation from the World Nuclear University Summer Institute held in Stockholm, Sweden, and the TSM Shri Ram Arora Award for Materials Science and Engineering Education for 2007.

V. Thomas Paul joined the Indira Gandhi Centre for Atomic Research in 1990 where he is involved in the physical metallurgical studies of nuclear materials and their weldments related to fast breeder reactors. His master’s thesis, titled Embrittlement Mechanisms in Ferritic Steels, has been submitted to Anna Uni-
Saroja Saibaba received her PhD in 2000. In 1984, after three years with the Bhabha Atomic Research Centre, Mumbai, she joined Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam, where she heads the Physical Electron Microscopy and Analytical Transmission Electron Microscopy Laboratory with the Physical Metallurgy Section, Metallurgy and Materials Group. She has 26 years of research experience in the field of metallurgy and material science. Her areas of expertise are physical metallurgy of ferritic steels, the development of highly corrosion-resistant Ti-based alloys for structural application, phase transformation in Fe, Ti-, and Zr-based systems, and advanced techniques for materials characterization. She has published more than 92 articles, and is a Life Member of the Indian Institute of Metals and the Materials Research Society of India.

M. Vijayalkhamsi joined Indira Gandhi Centre for Atomic Research (IGCAR) in 1977, where she is head of the Physical Metallurgy Section, Metallurgy and Materials Group. She received her PhD in 1999. Vijayalkhamsi has applied principles of alloy design to a number of problems related to IGCAR’s fast reactor program. She developed a new corrosion-resistant alloy for reprocessing applications and discovered a new electron microscopy method for identifying point defects in materials after irradiation. She received a Young Researcher Award in 1998, was a Visiting Scientist, Forschungszentrum, Juelich, Germany, in 1999; received the MRSI Medal Lecture Award in 2004; and was inducted as a Fellow of the Indian Institute of Metals in 2005. She has worked at the University of Bristol, UK, and University of Lausanne, Switzerland, researching electron microscopy images.

National Meritorious Award

James E. Greer received his master’s degree from Chicago State University. He has been employed by Moraine Valley Community College for 31 years where he is a professor and coordinator of the welding program. He is also president of Techno-Weld Welding Consultants and a senior welding engineer, Pentair Electronic Packaging. He was chief welding engineer for General Railroad Co., and senior welding specialist for Standard Refrigeration Co. He is a hands-on welder qualified to AWS, ASME, MIL, and DNV specifications. Greer is active in the AWS Certification Committee, Exam Bank Subcommittee, and Committee on Welding Symbols and Definitions. He also serves on the Certification, Operations, Fabrication, and Safety Committee for American Institute of Steel Construction. Greer served as AWS president (2004–2005), District 13 director, and chairman of the Chicago Section. He has received the District Meritorious Award, Howard E. Adkins District Educator Award, Distinguished Member Award, and the Dalton E. Hamilton Memorial District CWI of the Year Award. He is an AWS Certified Welder, Certified Welding Educator, and Senior Certified Welding Inspector. He has been a guest speaker and instructor for various groups including OSHA Training Institute and the U.S. Department of Labor.

Robert K. Wiswesser. (See biography in the class of AWS Counselors.)

Plummer Memorial Education Lecture Award

M. Andrew (Andy) Godley, an AWS Life Member, received his bachelor’s degree from Livingston University in 1965, and continued his education at Oak Ridge Associated University and the University of Alabama at Birmingham. He worked 12 years as a welding instructor at the Jefferson County Alabama Adult Education facility. In 1981, he joined the Alabama Power Co. and Southern Company Generator as a training analyst and welding specialist. He is a past chairman of the Birmingham Section (1975–76) and has served as the Section’s technical representative for 30 years. He also serves on the Southern Company’s Corporate Welding Committee, Alabama State Advisory Council for Career and Technical Education, Jefferson County Advisory Council for Career and Technical Education, and several craft advisory committees for secondary and postsecondary technical schools. He was instrumental in organizing the Alabama Annual Welding Instructor Update program. For the past 31 years, he has been a member of the SkillsUSA Welding Technical Committee. Godley is an AWS Certified Welder, a Certified Welding Inspector, and a member of the AWS Educators Committee. He was awarded the Howard E. Atkins Instructor Membership Award in 1977 and the
Section Dalton E. Hamilton Memorial CWI of the Year Award in 1992.

Robotic and Automatic Arc Welding Award
Richard R. Lefebvre has more than 40 years of experience in factory automation, technology development, systems integration, application engineering, and management. Currently, he is president and owner of R. L. Automation, LLC. He has been a leader in the development of robotic material-handling, gas metal arc welding, Nd:YAG laser beam cutting, joint tracking, and other factory automation. Lefebvre has held a number of engineering, technical, and managerial positions at A. O. Smith and Tower Automotive. He pioneered and developed the first Unimate robotic press tending applications in North American utilizing five- and six-axis, servo-hydraulic robots. Another development was the first full-frame laser cutting applications where two cells and 20 robots cut more than 150,000 body and cab suspension features/day. In 1993, he received the Robotic Industries Association’s Joseph F. Engelberger International Award. He has published numerous papers on robotics and strategies for implementing manufacturing technologies.

Warren F. Savage Memorial Award
New Developments with C-Mn-Ni High-Strength Steel Weld Metals Part A — Microstructure
Enda Keehan received his PhD in materials science from Chalmers University of Technology, Sweden, in 2004. His thesis concerned the mechanical properties of high-strength steel weld metals through analyses of their microstructures. Keehan then joined ESAB AB, Sweden, as a research metallurgist. In 2005, he was awarded the IIW Henry Granjon Prize. Presently, he is employed as a metallurgist at Creganna Medical Devices, Galway, working on minimally invasive medical devices.

Leif Karlsson, an International Welding Engineer, received his PhD in materials science in 1986 from Chalmers University of Technology, Gothenburg, Sweden, and Docent in engineering metals in 1999. In 1986, he joined ESAB where he is currently manager of Research Projects. His work involves high-alloy and high-strength steel welding consumables and the metallurgy of friction stir welding. Since 1986, he has been a member of the Swedish Welding Commission, Working Group AG41a, and has served on IIW Subcommissions II-C and IX-H since 1987. In 2005, he was appointed chair of Subcommission IX-H. Karlsson has presented papers at many international conferences. He received the McKay-Helm Award from AWS and the Brookner Medal from The Welding Institute.

Hans-Olof Andrén received his PhD degree in physics from Chalmers University of Technology in Gothenburg, Sweden, in 1976, where he became a full professor in 2001. He has published more than 150 peer-reviewed papers, and he has supervised 19 PhD students. His research programs involve thermodynamic and atomistic modeling in addition to high-resolution microscopy and microanalysis. Andrén was awarded the Henry Marion Howe Medal by ASM International in 1993, and Thesis Advisor of the Year Prize from Chalmers University in 2001.

Harshad K. D. H. Bhadeshia. (See his biography under Adams Memorial Membership Award.)

Silver Quill Editorial Achievement Award
Where Have All the Welders Gone . . .
Ilian Brat has been a reporter in the Chicago bureau of the Wall Street Journal for several years. He covers the Midwest economy, manufacturing, and other important topics. He studied journalism and Spanish at Arizona State University.

William Spraragen Memorial Award
Predicting and Reducing Liquefaction-Cracking Susceptibility Based on Temperature vs. Fraction Solid
Guoping Cao received his PhD in materials science and engineering from the University of Wisconsin-Madison in 2006. His thesis concerned hot cracking during arc welding of high-strength aluminum alloys, friction stir welding of dissimilar metals, and hot tearing of creep-resistant magnesium alloy castings. Currently, Cao is a postdoctoral research associate in the Department of Mechanical Engineering at the university where he is researching high-strength magnesium matrix nanocomposites. From 1996 to 2001, Cao was a research engineer at the Beijing Institute of Aeronautical Materials where he conducted research on investment castings of titanium alloys and thermo-hydrogen heat treatment of titanium alloy castings. In 2006, he received the Warren F. Savage Memorial Award.

Sindo Kou received his PhD in materials science and engineering from the Massachusetts Institute of Technology. He worked at General Motors Research Laboratory (1978), and as an associate professor at Carnegie-Mellon University (1979 to 1983). In 1983, Kou joined the University of Wisconsin-Madison where he became a full professor in 1985. He served as chair of the Department of Materials Science and Engineering from 2000 to 2004. He has authored two texts: Welding Metallurgy and Transport Phenomena and Materials Processing. Kou has received the John Chipman Award from Iron and Steel Society of AIME, Adams Memorial Membership Award, ASM International Fellow, Chancellors’ Award for Distinguished Teaching from the University of Wisconsin, Benjamin Smith Reynolds Award for Excellence in Teaching from the College of Engineering at the University of Wisconsin, Charles H. Jennings Memorial Award, AWS Fellow, and the Warren F. Savage Memorial Award.
AWS Releases Updated Bridge Welding Code

In conjunction with the American Association of State Highway and Transportation Officials (AASHTO), the American Welding Society has released AASHTO Standard Specification for Highway Bridges, or AASHTO LRFD, Bridge Design Specifications. The Bridge Welding Code covers the best practices and general provisions of routine bridge welding applications. It is the culmination of many years of cooperative work by the joint AWS/AASHTO Committee on Bridge Welding. The code was developed in response to industry demand for a single document that provides management personnel, engineers, foremen, and welders with cost-effective bridge fabrication approaches, while at the same time addressing the issues of structural integrity and public safety.

The Federal Highway Administration of the U.S. Department of Transportation requires states using federal funds for the construction of welded highway bridges to conform to these standards for design and construction.

The 2008 code revisions include additions and updates to usage, handling, and storage requirements for consumables, performance test specifications, filler metal variables, inspection personnel qualifications, HPS-485W (70W) and HPS-50W high-performance steel grades, new commentary, and additional data.

The 410-page standard includes 37 tables, 86 figures, and 7 forms. The price is $198 for AWS members, $264 for nonmembers.

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

The 2008 catalog listing all AWS standards and other products is available for download from www.aws.org/catalogs.
New Sustaining Company  
SME Steel Contractors  
5955 W. Wells Park Rd.  
West Jordan, UT 84088  
(801) 280-0711; www.smesteel.com  
Representative: Richard E. Cook  

SME Steel Contractors is a single-source steel fabricating and erecting company that provides computer-aided design assistance and detailing. It offers fast-track logic, steel budgeting for project life profitability, and committed production. The company assures its project management professionals will provide complete customer satisfaction with all of its field erection services.

Supporting Companies  
Cal Mfg. Co., Inc.  
5500 E. V Ave.  
Vicksburg, MI 49097  

Castle Steel, Inc.  
3828 N. 35th Ave.  
Phoenix, AZ 85017  

ETAL, S.A. de C.V.  
Felipe Angeles #52  
Mexico City, 01140, Mexico  

Heavy Metal Fabricators  
4551 Custer St.  
Manitowoc, WI 54220  

Kline Engineering, P.C.  
52 Central Dr.  
Farmingdale, NY 11735  

Millennium Industries, LLC  
2323 Washington St.  
Waller, TX 77484  

National Bronze & Metals, Inc.  
2929 W. 12th  
Houston, TX 77008  

Ningbo Powerway Group Co., Ltd.  
Taiping Bridge, Yunlong Town  
Yinzhou District, Ningbo, Zhejiang  
315135, P.R. China  

Northeast Steel Fabricators  
4062 Grumman Blvd., Bldg. 81  
Colverton, NY 11933  

S and B Metal Products  
5301 Gateway Blvd.  
Lakeland, FL 33811  

Tamez Prodomax, S. de R.L.  
Avenida E. No. 531  
Parque Industrial Martel  
Apodaca, NL 66634, Mexico  

Educational Institutions  
Advanced Technology Institute  
5700 Southern Blvd.  
Virginia Beach, VA 23462  

Bits & Bytes Inst. of Welding Technology  
S. Bazar, Mackany, Kannur  
Kerala State 670002, India  

Brevard Community College  
1519 Clearlake Rd.  
Cocoa, FL 32922  

Lexington Technology Center  
2421 Augusta Hwy.  
Lexington, SC 29072  

Local 150 Apprenticeship  
19800 W. South Arsenal Rd.  
Wilmington, IL 60481  

Locklin Technical Center  
5330 Berryhill Rd.  
Milton, FL 32570  

Media Center – Harford Technical H.S.  
200 Thomas Run Rd.  
Bel Air, MD 21015  

Nash Community College  
522 N. Old Carriage Rd.  
Rocky Mount, NC 27804  

St. Johns Inst. of Welding Technology  
Merryland Bldg., near head post office  
Pathanamthitta, Kerala 689645, India  

Nominees Solicited for Robotic Arc Welding Awards  

Nominations are solicited for the 2009 Robotic and Automatic Arc Welding Award. December 31 is the deadline for submitting nominations. The nomination packet should include a summary statement of the candidate’s accomplishments, interests, educational background, professional experience, publications, honors, and awards. Send your nomination package to Wendy Sue Reeve, awards coordinator, 550 NW LeJeune Rd., Miami, FL 33126. For more information, contact Reeve at wreeve@aws.org, or call (800/305) 443-9353, ext. 293.

In 2004, the AWS D16 Robotic and Automatic Arc Welding Committee, with the approval of the AWS Board of Directors, established the Robotic and Automatic Arc Welding Award. The award was created to recognize individuals for their significant achievements in the area of robotic arc welding. This work can include the introduction of new technologies, establishment of the proper infrastructure (training, service, etc.) to enable success, and any other activity having significantly improved the state of a company and/or industry. The Robotic Arc Welding Award is funded by private contributions. This award is presented during the FABTECH International & AWS Welding Show held each fall.
Member-Get-A-Member Campaign

Listed are the members participating in the 2007-2008 AWS Member-Get-A-Member Campaign for the period between June 1, 2007, and May 31, 2008. For campaign rules and a prize list, see page 67 of this Welding Journal. Standings are as of 12/17/07. If you have any questions regarding your member proposer points, call the Membership Department, (800) 443-9353, ext. 480.

Winner’s Circle
Members who have sponsored 20 or more new Individual Members, per year, since June 1, 1999. The superscript indicates the number of times the member has achieved Winner’s Circle status.
J. Compton, San Fernando Valley
E. Ezell, Mobile
J. Merzthal, Peru
G. Taylor, Pascagoula
B. Mikeska, Houston
R. Peaslee, Detroit
W. Shreve, Fox Valley
M. Karagoulis, Detroit
S. McGill, NE Tennessee
L. Taylor, Pascagoula
T. Weaver, Johnstown/Altoona
G. Woomer, Johnstown/Altoona
T. Nielsen, Pittsburgh
C. Gilbert, East Texas
J. Nieto, Corpus Christi
F. Schmidt, Niagara Frontier
A. Sumal, British Columbia
R. Wright, San Antonio
P. Zammit, Spokane

Student Member Sponsors
Members sponsoring 3 or more new AWS Student Members.
J. Moore, New Orleans
C. Donnell, Northwest Ohio
M. Arand, Louisville
C. Kipp, Lehigh Valley
G. Seese, Johnstown-Altoona
J. Daugherty Louisville
M. Anderson, Indiana
I. Ducherty Louisvillle
G. Seese, Johnstown-Altoona
C. Kipp, Lehigh Valley
M. Arand, Louisville
C. Donnell, Northwest Ohio
T. Moore, New Orleans

Prof. Koichi Masubuchi Award Nominees Sought

November 3, 2008, is the deadline for submitting nominations for the 2009 Prof. Koichi Masubuchi Award, sponsored by the Dept. of Ocean Engineering at Massachusetts Institute of Technology. It is presented each year to one person who has made significant contributions to the advancement of materials joining through research and development.

The candidate must be 40 years old or younger, may live anywhere in the world, and need not be an AWS member. The nomination should be prepared by someone familiar with the research background of the candidate.

Include a résumé listing background, experience, publications, honors, awards, plus at least three letters of recommendation from researchers.

This award was established to recognize Prof. Koichi Masubuchi for his numerous contributions to the advancement of the science and technology of welding, especially in the fields of fabricating marine and outer space structures.

Submit nominations to Prof. John DuPont at jnd1@lehigh.edu.

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Board of Directors’ Actions Affecting Sections and Student Chapters

On November 11, 2007, after due consideration of the recommendations by Districts Council, the AWS Board of Directors approved the transfer of the AWS Cuautitlán Izcalli (Mexico) Section, from District 21 to District 18.

Westmoreland County Community College, District 7; Alamo Student Chapter, District 18; and Sierra College, District 22, were approved for AWS Student Chapter charters. The AWS Lehigh County Career and Technical Institute, District 3; WITC-Rice Campus, District 15; Texas A&M University, District 18; and Mt. Hood Community College, District 19, were disbanded.

DISTRICT 1
Director: Russ Norris
Phone: (603) 433-0855

BOSTON
December 10
Speaker: Tom Ferri, Section chairman
Affiliation: Thermadyne Holdings Corp.
Topic: Safety standards affecting oxyfuel cutting and welding equipment
Activity: Scott Houle received the District Meritorious Award. Ernest Houle received the District Educator of the Year Award. The meeting was held at Minuteman Regional High School in Lexington, Mass.

DISTRICT 2
Director: Kenneth R. Stockton
Phone: (732) 787-0805

NEW JERSEY
November 20
Speaker: Scott Schleicher, national sales manager
Affiliation: Air Products and Chemicals
Topic: MicroBulk technology for welding and laser cutting
Activity: The program was held in Mountainside, N.J.

DISTRICT 3
Director: Alan J. Badeaux Sr.
Phone: (301) 753-1759

DISTRICT 4
Director: Roy C. Lanier
Phone: (252) 321-4285

SOUTHWEST VIRGINIA
September 19
Activity: The Section held its annual golf outing at Hanging Rock Golf Club in Salem, Va., for 42 participants.

October 25
Activity: The Section hosted a social dinner and meeting at Dynasty International Restaurant in Salem, Va.

DISTRICT 5
Director: Steve Mattson
Phone: (904) 260-6040

FLORIDA WEST COAST
December 12
Speaker: Jim Singley, territory sales manager
Affiliation: ESAB Welding and Cutting

Topic: Laser beam and friction stir welding, and water jet systems
Activity: The meeting was held in Tampa, Fla.

Shown at the Boston Section program are (from left) Scott Houle, Ernest Houle, Chairman Tom Ferri, and Russ Norris, District 1 director.

Veteran committee member Steve Dagnall is shown at the New Jersey Section meeting.

Scott Schleicher (left) receives a speaker gift from Vince Murray at the New Jersey Section program.

Florida West Coast Section Chair Al Sedory (left) presents Jim Singley a speaker appreciation gift.
Shown are the attendees at the Columbus Section program in November.

Shown at far right, Johnstown/Altoona Section Chair Bart Sickles presents a speaker gift to Gary Anderson, Co-Gen plant manager.

Shown at the October Johnstown/Altoona Section program are (from left) District 7 Director Don Howard, Eldan Snyder, and Bill Krupa, secretary-treasurer.

DISTRICT 6
Director: Neal A. Chapman
Phone: (315) 349-6960

NORTHERN NEW YORK
DECEMBER 11
Activity: The Section hosted its second annual meeting with its Coxsackie Correctional Facility Student Chapter.

Speakers included Bruce Lavallee, welding instructor, and Linda Norton, vocational supervisor. The Chapter now has 18 members. The officers are James Brown, chairman; Don Merrill, vice chair; Dilomar Jimenez, secretary; and Jose Santiasa, treasurer. Six students were presented welding certificates from the National Center for Construction for completing the basic welding module.
service to the Society. John Folk received his Silver Member Certificate for 25 years of membership in the Society. The program was held in Chattanooga, Tenn.

**HOLSTON VALLEY**

**November 13**

Speaker: Charlie Tiller, apprenticeship coordinator

Affiliation: Eastman Chemical Co.

Topic: Welding careers and the apprenticeship programs at Eastman Chemical Co.

Activity: The program was held at Ryan’s Steak House Restaurant in Kingsport, Tenn.

**DISTRICT 9**

**Director:** George D. Fairbanks

**Phone:** (225) 673-6600

**ACADIANA**

**October 16**

Activity: The Section members toured Chart Energy and Chemical in the Port of New Iberia, La. Plant Superintendent Dennis Roets, and Welding Specialists Kylan Roberts and Tommy Roberts explained the various welding and cutting operations used for manufacturing products from stainless steel, aluminum, and carbon steel.

**DISTRICT 10**

**Director:** Richard A. Harris

**Phone:** (440) 338-5921

**DRAKE WELL**

**December 4**

Activity: Travis Crate was nominated Section secretary, and Rich Skidmore was nominated technical advisor. The Section’s technical library will be moved from Churchtown to Venango Technology Center. The business meeting was held in Franklin, Pa.

**DISTRICT 11**

**Director:** Eftihios Siradakis

**Phone:** (989) 894-4101

**CENTRAL MICHIGAN**

**September 18**

Activity: The Section members toured the John Crowley facility in Jackson, Mich. President Chris Clark and Bill Nevins, shop superintendent, conducted the program. The dinner was held at Charlie’s Pub & Grill in Jackson.

**October 16**

Speaker: Bruce G. Kelly

Affiliation: General Motors, retired

**DISTRICT 10**

**Director:** Richard A. Harris

**Phone:** (440) 338-5921

**DRAKE WELL**

**December 4**

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DISTRICT 12
Director: Sean P. Moran
Phone: (920) 954-3828

DISTRICT 13
Director: W. Richard Polanin
Phone: (309) 694-5404

DISTRICT 14
Director: Tully C. Parker
Phone: (618) 667-7744

INDIANA
November 7
Speaker: Dave Koutz
Affiliation: The Lincoln Electric Co.
Topic: Features of the Powerwave AC/DC 1000 multiarc system
Activity: Lincoln Electric hosted the meeting at its Indianapolis facility. Bill Davis received the District Educator Award, Tony Brosio received the District CWI of the Year Award, Gene Poe received the Section Meritorious Award, and Gary Tucker received the District Private Sector Educator Award.

November 12, 13
Activity: Indiana Section members helped to man and judge the Professional Welding Competition held at the AWS Show in Chicago. Pat Garten, owner of Sutton-Garten Welding Supplies and Gases, received the Image of Welding Award for Distributors.

December 8
Activity: The Indiana Section held its Christmas gathering at Turkey Run State Park and Myers Dinner Theatre in Hillsboro, Ind.

TRI RIVER
November 29
Speaker: Mike Bumgarner, owner
Affiliation: Bumgarner Welding and
Inspection
Topic: Career opportunities in welding and as a CWI
Activity: This Tri River Section program was held in Evansville, Ind.

**DISTRICT 15**
**Director:** Mace V. Harris  
**Phone:** (952) 925-1222

**ARROWHEAD**
**November 29**
Activity: The Section members toured the Tri Tec of Minnesota facility in Virginia, Minn. Mitchell Robertson, CEO, conducted the program. Highlights included a demonstration of a new CNC plasma cutting table for use by local high school and Mesabi Range Community and Technical College students. Sixty members and guests attended the program.

**KANSAS CITY**
**November 29**
Speaker: Jerry Mirgain  
Affiliation: Alcotec  
Topic: Alcotec’s involvement in production of aluminum catamarans  
Activity: Carl Orser received his Silver Membership Award for 25 years of service to the Society.

**DISTRICT 16**
**Director:** David Landon  
**Phone:** (641) 621-7476

**Arrowhead Section members are shown during their tour of Tri Tec of Minnesota.**

**Indiana Section members display their awards at the Nov. 7 program. From left are Bill Davis, Tony Brosio, Gene Poe, and Gary Tucker.**

**Indiana Section members manned the Professional Welding Competition booth in Chicago. Shown (from left) are Treasurer Mike Anderson, Secretary Bob Richwine, Past Chair Bennie Flynn, Vice Chair Tony Brosio, Chairman Gary Dugger, and Gary Tucker.**

**The Indiana Section members pose with Myers Dinner Theatre cast members at the annual Christmas gathering in December.**
Activity: The Section members visited Egger Steel Co., in Sioux Falls, S.Dak., to study its operations. Guests at the program were 20 students in the welding program at Northwest Iowa Community College in Sheldon, Iowa.

Activity: The Siouxland Section members toured Maintainer Corporation of Iowa facilities in Sheldon, Iowa. Students from the welding program at Northwest Iowa Community College joined the activity.

Siouxland Section members and students from Northwest Iowa Community College during their tour of Egger Steel Co.

Siouxland Section members and local welding students are shown during their tour of Maintainer Corp. in Sheldon, Iowa.

Shown at the North Texas Section tour are (from left) David Lovett, District 17 Director J. Jones, Scott O’Brien, Bryan Baker, and tour guide Rocky Christenberry.

North Texas Section Chair Robert Tessier kicks off the bidding at the silent auction.

Shown at the Tulsa Section program are (from left) Jamie Pearson, program chairman, with speaker Don Underwood.

Tulsa Section Chairman Barry Lawrence (center) is shown with Silver Membership Award recipients Edmund Rybicki (left) and Joe Fulton.

District 17
Director: J. J. Jones
Phone: (940) 368-3130

District 18
Director: John Bray
Phone: (218) 997-7273

DISTRICT 18
Director: Neil Shannon
Phone: (503) 201-5142

Siouxland
December 4
Activity: The Section members visited Egger Steel Co., in Sioux Falls, S.Dak., to study its operations. Guests at the program were 20 students in the welding program at Northwest Iowa Community College in Sheldon, Iowa.

December 18
Activity: The Siouxland Section members toured Maintainer Corporation of Iowa facilities in Sheldon, Iowa. Students from the welding program at Northwest Iowa Community College joined the activity.

Shown are Siouxland Section members and students from Northwest Iowa Community College during their tour of Egger Steel Co.

Siouxland Section members and local welding students are shown during their tour of Maintainer Corp. in Sheldon, Iowa.

District 17
Director: J. J. Jones
Phone: (940) 368-3130

East Texas
November 29
Activity: The Section members toured Priefert Manufacturing in Mt. Pleasant, Tex., to study its gas metal arc welding of thin-gauge tubing used on cattle ranches and rodeo facilities nationwide. Rocky Christenberry conducted the program.

North Texas
December 11
Activity: The Section hosted its second annual silent auction that raised $2400 for its scholarship fund. Chairman Robert Tessier hosted the meeting. The Section also sponsors an all-season-long program in support of the Dallas Food Bank Drive. The event was held at Spring Creek Barbeque in Irving, Tex.

Tulsa
November 27
Speaker: Don Underwood, director of welding services
Affiliation: The Atlantic Group
Topic: Welding trends in new nuclear construction
Activity: Silver Membership Awards for 25 years of service to the Society were presented to Joe Fulton, Durant Metal Shredding, and Prof. Edmund Rybicki, Tulsa University. The program was held at Furr’s Buffet in Tulsa, Okla.

District 19
Director: Neil Shannon
Phone: (503) 201-5142
The Albuquerque Section members pose during their tour of Wagner Equipment Co.

Southern Colorado Section members are shown during their tour of Siemans Water Technologies.

Speaker Linda Anyan-Brown is shown with Terry Sanchez, Spokane Section vice chair.

SPOKANE
OCTOBER 24
Activity: Hexavalent chromium hazards, personal protection, air-quality standards, and personal protective equipment were featured topics at this program. Linda Anyan-Brown, an industrial hygiene consultant with Washington State Dept. of Labor and Industry; Karl Susz with The Lincoln Electric Co.; and Rick Pfeifer with 3M products Inc., made presentations. Anyan-Brown discussed workplace safety regulations including the hexavalent chromium problems and the findings from recent inspections. Susz and Pfeiffer spoke about protective personal gear and ventilation systems. The program was held at the Association of General Contractors Building in Spokane, Wash.

ALBUQUERQUE
OCTOBER 25
Activity: Walter Kennedy conducted the Section members on a tour of Wagner Equipment Co. in Albuquerque, N.Mex., to study operations in its heavy equipment, truck division, and power systems.

COLORADO
NOVEMBER 8
Activity: Union representatives detailed welder training opportunities at the Colorado Carpenters/Millwright Apprentice Training Center and the Pipe Fitters Local 208 Training Center. The speakers included Jay Voth, Millwright Center welding instructor; Union representative Art Salazar, Pipe Fitters Local 208; and Paul L. Sturgill, CWI and CWI seminar instructor. Mark Trevithick, an instructor at Pipe Fitters Local 208, received the Private Sector Instructor Membership Award from Section Chair James Corbin.

SOUTHERN COLORADO
NOVEMBER 12
Activity: The Section members toured Siemans Water Technologies in Colorado Springs, Colo. John Brewer, welding supervisor, conducted the program and discussed pressure vessel and pipe welding using orbital and manual gas tungsten arc
Shown at the Colorado Section program are (from left) Chairman James Corbin, Jay Voth, Mark Trevithick, and Art Salazar.

Shown at the L.A./Inland Empire Section program are (from left) Secretary Mariana Ludmer, Chair George Rolla, District 21 Director Jack Compton, and Bob Gibson, a past Section chairman.

The San Fernando Valley Section members toured the Budweiser facilities in November.

Shown at the San Francisco Section program are (from left) Chairman Tom Smeltzer, Vice Chair Liisa Pine Schoonmaker, and speaker Scottie Chapman.

Shown at the L.A./Inland Empire Section program are (from left) Secretary Mariana Ludmer, Chair George Rolla, District 21 Director Jack Compton, and Bob Gibson, a past Section chairman.

Jason Rafter (left) receives a speaker gift from Brian Hardin, Sierra College Student Chapter chairman, at the Sacramento Section program.

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welding. This Southern Colorado Section program included a Pikes Peak Community College advisory board meeting.

DISTRICT 21
Director: Jack D. Compton
Phone: (661) 362-3218

L.A./INLAND EMPIRE

November 5
Speaker: Jack Compton, District 21 director
Affiliation: College of the Canyons
Topic: Welder certifications
Activity: Industrial Metal Supply Co. hosted this students’ night program at its new art metal service center in Riverside, Calif. Many students from Riverside C. C. and Pomona Adult and Career Education Center attended the event. The program concluded with a tour of the facility led by Jeff Cowger, general manager. Fifty-five members and students attended the program.

SAN FERNANDO VALLEY

November
Activity: The Section members toured the Budweiser plant in Van Nuys, Calif., to study the welding of stainless steel brewing tanks. Ed Potthoff, senior journeyman welder, conducted the tour.

DISTRICT 22
Director: Dale Flood
Phone: (916) 933-5844

SACRAMENTO

November 14
Speaker: Jason Rafter
Affiliation: Local Ironworkers Union, Sacramento, Calif.
Topic: Becoming a Union ironworker, employment outlook, wages, and training
Activity: Seventy-two members and guests toured the Sierra College welding department in Rocklin, Calif., prior to the talk. Brian Hardin, Student Chapter chairman, presented the speaker gift.

SAN FRANCISCO

December 5
Activity: Vice Chair Liisa Pine Schoonmaker and Scottie Chapman, Urban Roots, a landscape architecture company, discussed the technicalities and tricks of on-camera welding used for television shows. They discussed the making of a Monster Garage TV program in which they appeared. Following the talks, a DVD of the show was presented. The program was held at Spencer’s Restaurant in Berkeley, Calif.
Guide to AWS Services

AWS PRESIDENT
Gene E. Lawson
Managing Director, ESAB Welding and Cutting
25108 Margurite Pkwy. #116 Mission Viejo, CA 92692

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Frank R. Tarafa, ftarafa@aws.org (252)
Executive Director
Cassie R. Burrell, cburrell@aws.org (253)
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Gricelda Manalich, gricelda@aws.org (294)
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Jeff Weber, jweber@aws.org (246)
Executive Assistant for Board Services
Grac tidal@aws.org (250)
Programs
Jim Lankford, jml@aws.org (214)
Managing Director
Armando Campana, acampana@aws.org (296)
Director
Hidal Nuñez, hidal@aws.org (287)
Database Administrator
Natalia Swain, nswain@aws.org (245)
Human Resources
Director, Compensation and Benefits
Luisa Hernandez, luisa@aws.org (266)
Manager, Human Resources
Dora Shade, dshade@aws.org (235)

INT’L INSTITUTE OF WELDING
Senior Coordinator
Sisilebith Lopez, sisilebith@aws.org (319)
Provides liaison services with other national and international professional societies and standards organizations.

GOVERNMENT LIAISON SERVICES
Hugh K. Webster, hwebster@wc-b.com
Webster, Chamberlin & Bean, Washington, DC, (202) 466-2976; FAX (202) 835-0243. Identifies funding sources for welding education, research, and development. Monitors legislative and regulatory issues of importance to the industry.

Brazing and Soldering
Jeff Weber, jweber@aws.org (246)
RWMA — Resistance Welding
Managing Director
Susan Hopkins, susan@aws.org (295)

WEMCO — Welding Equipment Manufacturers Committee
Natalie Tapley, tapley@aws.org (444)

CONVENTION and EXPOSITIONS
Managing Director
Jeff Weber, jweber@aws.org (246)
Corporate Director, Exhibition Sales
Joe Kral, kral@aws.org (297)
Organizes the annual AWS Welding Show and Convention, regulates space assignments, regulations, items, and other Expo activities.

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PUBLICATION SERVICES
Department Information (275)
Andrew Cullison, cullison@aws.org (249)
Welding Journal
Publisher/Editor
Andrew Cullison, cullison@aws.org (249)
National Sales Director
Rob Saltstein, saly@aws.org (243)
Society and Section News Editor
Howard Woodward, woodward@aws.org (244)

Welding Handbook
Welding Handbook Editor
Annette O’Brien, abrien@aws.org (303)
Publishes The Society’s monthly magazine, Welding Journal, which provides information on the state of the welding industry, its technology, and Society activities. Publishes Inspection Trends, the Welding Handbook, and books on general welding subjects.

MARKETING COMMUNICATIONS
Director
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Adrienne Zaikind, azaikidn@aws.org (416)

MEMBER SERVICES
Department Information (480)
Deputy Executive Director
Cassie R. Burrell, cburrell@aws.org (253)
Director
Rhenda A. Mayo, rhenda@aws.org (260)
Serves as a liaison between Section members and AWS headquarters. Informs members about AWS benefits and activities.

CERTIFICATION SERVICES
Department Information (273)
Managing Director, Certification Operations
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Manages and oversees the development, integrity, and technical content of all certification programs.
Director, Int’l Business & Certification Programs
Priti Jain, pijain@aws.org (258)
Directs all Int’l business and certification programs. Is responsible for oversight of all agencies handling AWS certification programs.

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Director, Research and Development — Professional Programs
Christopher Pollock, cpollock@aws.org (219)
Assists Government Affairs Liaison Committee and Product Development Committees

AWS AWARDS, FELLOWS, COUNSELORS
Senior Manager
Wendy S. Reeve, wreeve@aws.org (293)
Coordinates AWS awards and AWS Fellow and Counselor nominees.

TECHNICAL SERVICES
Department Information (340)
Andrew R. Davis, adavis@aws.org (466)
Int’l Standards Activities, American Council of the Int’l Institute of Welding (IWI)
Director, National Standards Activities
John L. Gayler, gjayler@aws.org (472)
Personnel and Facilities Qualification, Computerization of Welding Information, Arc Welding and Cutting
Manager, Safety and Health
Stephen P. Hedrick, stvedick@aws.org (305)
Metric Practice, Safety and Health, Joining of Plastics and Composites

Technical Publications
AWS publishes about 200 documents widely used throughout the welding industry.

AWARDS, FELLOWS, COUNSELORS
Senior Manager
Rosalinda O’Neill, ronell@aws.org (451)

Staff Engineers/Standards Program Managers
Annette Alonso, aalonzo@aws.org (299)
Automotive Welding, Resistance Welding, Ox-yfuel Gas Welding and Cutting, Definitions and Symbols

Stephen Borroto, sborroto@aws.org (334)

Rakesh Gupta, rgupta@aws.org (301)
Filler Metals and Allied Materials, Int’l Filler Metals, Instrumentation for Welding, UNS Numbers, Assignment

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

Selvis Morales, smorales@aws.org (313)
Welding Qualification, Structural Welding

Kim Plank, kplank@aws.org (215)
Machinery and Equipment Welding, Robotic and Automatic Welding, Sheet Metal Welding, Thermal Spray

Reino Starks, rstarks@aws.org (304)

Note: Official interpretations of AWS standards may be obtained only by sending a request in writing to the Managing Director, Technical Services. Oral opinions on AWS standards may be rendered, however, such opinions represent only the personal opinions of the particular individuals giving them. These individuals do not speak on behalf of AWS, nor do these oral opinions constitute official or unofficial opinions or interpretations of AWS. In addition, oral opinions are informal and should not be used as a substitute for an official interpretation.
Nominees for National Office

Only Sustaining Members, Members, Honorary Members, Life Members, or Retired Members who have been members for a period of at least three years shall be eligible for election as a director or national officer.

It is the duty of the National Nominating Committee to nominate candidates for national office. The committee shall hold an open meeting, preferably at the Annual Meeting, at which members may appear to present and discuss the eligibility of all candidates.

To be a candidate, the candidate must be a member of the Society, other than a Student Member, must be frequently available to the national office, and should be of executive status in business or industry with experience in financial affairs.

Director-at-Large: To be eligible for election as a director-at-large, an individual shall previously have held office as chairman of a Section; as chairman or vice chairman of a standing, technical, or special committee of the Society; or as District director.

Interested persons should submit a letter stating which office they seek, including a statement of qualifications, their willingness and ability to serve if nominated and elected, and a biographical sketch.

National Meritorious Certificate Award: This award is given in recognition of the recipient’s significant contributions to the worldwide welding industry. This award reflects “Service to the International Welding Community” in the broadest terms. The awardee is not required to be a member of the American Welding Society.

International Meritorious Certificate Award: This award is given in recognition of the recipient’s significant contributions to the worldwide welding industry. This award reflects “Service to the International Welding Community” in the broadest terms. The awardee is not required to be a member of the American Welding Society.

Honorary Meritorious Awards

The Honorary-Meritorious Awards Committee makes recommendations for the nominees presented for Honorary Membership, National Meritorious Certificate, William Irrgang Memorial, and the George E. Willis Awards. These awards are presented during the FABTECH International & AWS Welding Show held each fall. The deadline for submissions is December 31 prior to the year of awards presentations. Send candidate materials to Wendy Sue Reeve, secretary, Honorary Meritorious Awards Committee, wreeve@aws.org; 550 NW LeJeune Rd., Miami, FL 33126. Descriptions of the awards follow.

National Meritorious Certificate Award: This award is given in recognition of the candidate’s counsel, loyalty, and devotion to the affairs of the Society, assistance in promoting cordial relations with industry and other organizations, and for the contribution of time and effort on behalf of the Society.

William Irrgang Memorial Award: This award is administered by the American Welding Society and sponsored by The Lincoln Electric Co. to honor the late William Irrgang. It is awarded each year to the individual who has done the most over the past five years to enhance the American Welding Society’s goal of advancing the science and technology of welding.

George E. Willis Award: This award is administered by the American Welding Society and sponsored by The Lincoln Electric Co. to honor George E. Willis. It is awarded each year to an individual for promoting the advancement of welding internationally by fostering cooperative participation in areas such as technology transfer, standards rationalization, and promotion of industrial goodwill.

Honorary Membership Award: An Honorary Member shall be a person of acknowledged eminence in the welding profession, or who is accredited with exceptional accomplishments in the development of the welding art, upon whom the American Welding Society sees fit to confer an honorary distinction. An Honorary Member shall have full rights of membership.

AWS Publications Sales

Purchase AWS standards, books, and other publications from World Engineering Xchange (WEX), Ltd. orders@awspubs.com; www.awspubs.com Toll-free (888) 925-3464 (U.S., Canada) (305) 824-1177; FAX (305) 826-6195

Welding Journal Reprints

Copies of Welding Journal articles may be purchased from Ruben Lara. (800/305) 443-9353, ext. 208; elastr@aws.org

Custom reprints of Welding Journal articles, in quantities of 100 or more, may be purchased from FosterReprints Toll-free (866) 879-9144, ext. 121 sales@fosterreprints.com

AWS Foundation

The AWS Foundation, Inc., is a not-for-profit corporation established to provide support for educational and scientific endeavors of the American Welding Society. Information on gift-giving programs is available upon request.

Chairman, Board of Trustees
Ronald C. Pierce

Executive Director, AWS
Ray Shook

Executive Director, Foundation
Sam Gentry

550 NW LeJeune Rd., Miami, FL 33126 (305) 445-6628; (800) 443-9353, ext. 293

General information: (800) 443-9353, ext. 689; vpunsky@aws.org

AWS Mission Statement

The mission of the American Welding Society is to advance the science, technology, and application of welding and allied processes, including joining, brazing, soldering, cutting, and thermal spraying.

It is the intent of the American Welding Society to build AWS to the highest quality standards possible. The Society welcomes your suggestions. Please contact any staff member or AWS President Gene E. Lawson, as listed on the previous page.
Conference on Automatic Welding
New Orleans
May 13-14, 2008

Automatic welding, for which the equipment requires little or no observation or manual adjustment, has enabled industry to dramatically accelerate output and increase quality. This conference covers new technologies in automatic controls, training and management innovations, and automation breakthroughs for the latest welding processes, including fiber and disk lasers, friction and thermal stir welding, hot-wire tungsten arc, laser/GMAW hybrid welding, as well as automation technologies for traditional processes, such as submerged arc.

Conference price: $680 ($550 for AWS members)
Registration code: COAWC
Registration deadline: April 12, 2008
Location: Hilton New Orleans Airport (call 504-465-1159 for special rates)

To register or to receive a descriptive brochure, call (800) 443-9353 ext. 455, (outside North America, call 305-443-9353), or visit www.aws.org/conferences
The project team led by the Navy Joining Center (NJC) received the Department of Defense (DOD) Manufacturing Technology Achievement Award at the Defense Manufacturing Conference held in Las Vegas, Nev., Dec. 3–7. The annual award is given to project teams from the government and/or private sector most responsible for a specific innovative manufacturing technology achievement.

Presented by John J. Kubricky, deputy under secretary of defense (Advanced Systems and Concepts), the award recognizes the accomplishments of a project that addresses a significant design challenge. The Navy ManTech project receiving the award was selected for the advantages found in the translational friction welding (TFW) of titanium engine bladed disks (blisks) — Fig. 1.

One-piece integrally bladed disks have replaced conventional blades and disks for fan and compressor stages in modern military aircraft engines. The one-piece blisk eliminates the weight inefficiency in mechanical dovetail attachment between the blades and disk. Blisks dramatically reduce engine weight, complexity (parts count), and life-cycle cost while improving engine performance. Use of blisks has become mandatory to meet weight and performance objectives in today’s military engines. Despite their advantages, forging and machining the complex geometry makes large blisks relatively expensive to manufacture. Present methods involve forging and finish machining with conventional and electrochemical procedures. New approaches, such as TFW, are needed to manufacture blisks to meet Navy needs for continued reductions in the life-cycle cost of aircraft.

Project team member General Electric Aviation investigated the feasibility of TFW blisks along with other potential manufacturing methods for large blisks. These investigations showed diffusion bonding, pressure welding, fusion welding, and special forging approaches were not practical for cost-effective manufacture of large blisks. Because the technical feasibility and cost advantages demonstrated by TFW, this Navy ManTech project was conducted to develop and transition TFW technology into the F414 engine’s first-stage fan for the F18 aircraft, both for new manufacture and repair.

The TFW process reduces both the cost of raw material and machining needed to produce a finished blisk. A TFW blisk starts with a smaller forging, which saves material. Less machining is required since blades can be nearer to their final net shape instead of machining them from a solid forging, which reduces the manufacturing cost and the cycle time to produce large blisks. In addition, a TFW blisk can be designed to use materials (titanium alloys) that optimize the properties for both the disk and airfoils. This TFW manufacturing technology also provides a unique method to produce solid-state blade replacements and repairs which will enable the Navy to save an additional 20 to 30% of damaged blisks that are beyond repair using current technology.

During the conference, EWI Project Manager Nancy Porter presented the development activity of a National Shipbuilding Research Program (NSRP) project named “Tandem Submerged Arc Welding for Navy Surface Combatants.” The presentation detailed recent research efforts that identified gaps in the welding technology required to fabricate thin steel in shipbuilding processes that were originally designed with thicker materials. The tandem submerged arc welding (SAW) parameters were developed for 5-, 8-, and 10-mm-thick DH36 plate. Distortion was minimal for each plate welded with the preferred procedures while at the same time the weld travel speed was doubled. Weld mechanical properties met all requirements for Navy procedure qualification. The tandem SAW process is now being implemented at several shipyards for building Navy ships.

EWI’s Conference Presentation

For more information, e-mail Larry Brown at larry_brown@ewi.org; or call (614) 688-5080.
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www.weldoffice.com
Welding Systems Products Pictured

The 36-page, well-illustrated, full-color MK Products Catalog details the company’s Cobra® welding systems including the CobraMig®400P pulsed power source and complete lines of positioners, spool guns, orbital equipment, contact tips, barrels, gas cups and other accessories. Explained are the push-pull technology, the CobraMAX™ and the advanced Python® gooseneck guns, Prince®XL push-pull pistol grip gun, Sidewinder® MiniSpool™ gun, and many other products. The catalog can be downloaded from the Web site.

MK Products
www.mkproducts.com
(949) 863-1234

Hardfacing and Joining Products Pictured

A 60-page catalog features detailed information on the latest products and application data for a wide variety of hard-facing and high-alloy joining requirements. Industry-specific information is provided to simplify the task of selecting the right product for each job. Included are an updated selection chart, welding parameters, part numbers, and packaging information.

Stoody®
www.stoody.com
(636) 728-3000
Welding High-Nickel Alloys Detailed in Brochure

A recently issued 16-page brochure describes the company's complete line of covered electrodes and bare wire products for welding high-nickel alloys. Included are detailed descriptions of the classifications, approvals, diameters, typical mechanical properties, and chemical compositions. It also specifies the broad range of welding applications for these products including nuclear power generation, petrochemical plants, offshore and marine environments, chemical processing plants, pipelines, pressure vessels, furnace equipment, and automotive exhaust systems. Included are charts for comparing the various covered electrodes and bare wires.

Arcos Industries, LLC
www.arcos.us
(800) 233-8460

Ultrasound Tutorial Presented Online

The company recently introduced on its Web site a self-guided tutorial on phased array ultrasound technology. The extensive but easy-to-follow tutorial serves as an introduction to ultrasonic phased array testing for newcomers and as a review of the basic principles for more experienced users. It begins by explaining what phased array testing is and how it works, then outlines some considerations for selecting probes and instruments, then concludes with links to phased array application notes and a glossary. In addition to text and illustrations, the tutorial features a number of interactive Flash files illustrating the key concepts. Currently, the tutorial consists of six sections: introduction, transducers, imaging basics, phased array instrumentation, applications, and the glossary.

Olympus
www.olympusNDT.com
(800) 419-3900

Bridge Welding Code Updated

The AASHTO/AWS D1.5/1.5M:2008, Bridge Welding Code, published by the American Welding Society, includes additions and updates to usage, handling, and storage requirements for consumables, performance test specifications, filler metal variables, inspection personnel qualifications, HPS-485W (70W) and HPS-50W high-performance steel grades, new commentary, and additional new material. The code covers the best practices
and general provisions of routine bridge welding applications. The 410-page document includes 37 tables, 86 figures, and seven forms. The list price is $264, $198 for AWS members.

Welding Engineering Exchange (WEX)
www.awspubs.com
(888) 935-3464/(305) 824-1177

PC Systems Handbook Offered

The 220-page PC Systems Handbook for Scientists and Engineers features more than 3000 scientific computing products, including computers, peripherals, accessories, data-acquisition, motion control, and communications equipment. New products featured are rugged metal-frame portable PCs, 19-in. 1U FoldAway™ monitor/keyboard combos, high-efficiency power supplies, and PCIe data-acquisition boards. Included are the latest models in the company’s proprietary NEMA 4X panel PCs and monitors that remain stable at temperatures to 122°F. Request your free copy of the handbook by phone or e-mail handbook@cyberresearch.com.

CyberResearch, Inc.
www.cyberresearch.com
(800) 342-2525;

Mechanical Components Catalog Announced

The 2008 Mechanical Components for Assembly Automation catalog is available in both metric and inch editions. The catalogs feature more than 3000 pages filled with 500,000 fixed and configurable mechanical components and other products for enhanced factory automation. Included are more than 6000 new products, as well as more than 3000 products with additional sizes and material compositions. A few highlights are standard-length linear shafts, self-lubricating linear bushings, single-axis actuators; linear guides with both rail and blocks with dowel holes to allow more accurate positioning, low-temperature black chrome plating on select product for corrosion control, locating pins in numerous shapes and materials, and urethane-coated rollers with selectable thickness and hardnesses. The catalog is available from the Web site.

Misumi USA, Inc.
www.misumiusa.com
(800) 681-7475

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For info go to www.aws.org/ad-index
We express our deep gratitude to the sponsors of the 2007 AWS Professional Welders Competition at the FABTECH Int’l & AWS Welding Show.

We also thank the AWS Indiana Section, Moraine Valley Community College’s Welding Program, and AWS Student Chapter of Sheridan College for their assistance in providing personnel for the booth.
CMW Fills Two Key Posts

William Love  Ericka Mason

CMW Inc., Indianapolis, Ind., has promoted William Love to welding manager, and appointed Ericka Mason as account specialist. Love, who joined the company as welding major account manager, is now responsible for managing the company’s network of authorized welding distributors, and other aspects of the company’s resistance welding business. Mason previously served as executive assistant to the CMW president and CEO. She now has responsibility for payables to customers, invoicing, and accounting policies.

Tregaskiss Taps Business Manager

Norm Greenlay

Tregaskiss Welding Products, Windsor, Ont., Canada, has hired Norm Greenlay as regional business manager for western Canada. Greenlay brings more than 20 years of experience to the position.

National Standard Adds Five Sales Managers

Paul Perkins  Tracy McElellan  Andrew Tanner  Todd Norton  Keith Shaver

National Standard, LLC, Niles, Mich., has named Paul Perkins and Tracy McElellan as regional sales managers, and Andrew Tanner, Todd Norton, and Keith Shaver as regional sales managers. Perkins will be based in Layton, Utah; McElellan in Albertville, Minn.; Tanner will service the western New York and Pennsylvania, northeast Ohio, and northern West Virginia markets; Norton will manage the Minnesota, Wisconsin, northeastern Iowa, and North Dakota markets; and Shaver is assigned the Florida market.

Lincoln Promotes Four

Bruce Chantry  Nahanni Nagle  D. Postlethwaite  John Corrado

The Lincoln Electric Co., Cleveland, Ohio, has promoted Michael S. Mintun to vice president, sales, North America; Bruce Chantry to product manager — advanced welding equipment; Nahanni Nagle to regional manager for the sub-Sahara region, headquartered in Midrand, South Africa; and Deanna Postlethwaite to the newly created position of product manager for the Automation division. Mintun, with the company since 1984, previously was sales manager for North America. Chantry, with the company for 12 years, recently completed a six-year assignment as regional manager for the sub-Sahara region. Nagle, a 13-year employee, most recently was sales and marketing manager for the company’s Indalco Alloys division. Postlethwaite, with the company since 2004, most recently served as product manager — high technology products.

VP Buildings Designates District Manager

Richard Tornabene

VP Buildings, Memphis, Tenn., a manufacturer of preengineered metal buildings, has named Richard Tornabene district manager of sales for Louisiana. Tornabene brings more than 20 years of sales experience to the position.

Weldquip Appoints District Managers

Ray Trudell  Todd Harris

American Weldquip, Inc., Sharon Center, Ohio, has appointed Ray Trudell and Todd Harris district sales managers. Trudell, most recently a territory manager for Praxair Canada, will service the Ontario, Canada, district. Harris, most recently an account manager at Airgas, will manage the Kentucky, southern Indiana, southern Illinois, and Missouri district.

Weld Mold Appoints Sales Director

John Corrado has joined Weld Mold Co., Brighton, Mich., as director of sales. Corrado, who has served the welding industry for more than 35 years, will be responsible for sales in the United States.

TRUMPF Announces New Director

Claudio Schutz

Claudio Schutz was named director of spare parts North America for TRUMPF Inc., Farmington, Conn. With the company since 1995, Schutz most recently served as managing director at TRUMPF Mexico.

Reactive Nano Technologies Names Sales VP

Mike O’Neil


Sonic & Materials Fills New Welding Position

Mike Patrikios

Sonic & Materials, Newtown, Conn., has appointed Mike Patrikios worldwide manager, metal welding products, to head its new Ultrasonic Metal Welding division. Patrikios, who has more than 30 years of experience in the business and holds 20 patents, is the founder and former CEO of American Technology.
Weldon Charles Graham

Weldon (Bud) Charles Graham, 85, died after a brief illness at his home in San Diego, Calif. During his WW II military training, he was recruited to work as a machinist on the Manhattan Project at the University of Chicago. After the war, he worked for the Argonne National Laboratory, Chicago, where he developed a mechanical manipulator for handling radioactive materials. A version of his manipulator was displayed at the Chicago Museum of Science and Industry for many years. In 1956, he moved to San Diego as the first head of the machine shop for General Atomic. While there, he became involved in welding technology during the construction of the Fort St. Vairain nuclear power plant in Colorado. While at General Atomic he developed an orbital weld head for welding tube sheets and a series of weld heads for tube-to-tube welding, for which he was granted a number of patents. After retiring from General Atomic, he formed Graham Arc Corp. to manufacture and market his weld heads.

Leonard T. Detlor

Leonard T. Detlor, 95, an AWS member for 60 years, died August 8, 2007, in Bethany Beach, Del. After earning his degree in engineering from Kansas State University, he joined Humble Oil (later Exxon). During his 43 years of service, he became the engineering specialist for the inspection section of Exxon Research and Engineering with primary involvement in the quality control of welds. Since he showed an early interest in the nondestructive testing of welds, he served as an active contributor to Section V (Nondestructive Examination) of ASME’s Boiler and Pressure Vessel Code. Detlor also was an instructor and highly respected mentor for Exxon’s next generation of inspectors. During WW II, he served in the Pacific theater as an officer in the Army Corps of Engineers, attaining the rank of major. Back in New Jersey, he participated in the local AWS Section where he served as chairman for two terms, and supported family and local charitable and community activities.

Stanley Donovan Roberts

Stanley Donovan Roberts, 18, of East Liverpool, Ohio, died June 7, 2007, in an automobile accident. Roberts worked as a welder at Gracion Fabrication Plant in Leetonia, Ohio. He was a graduate of Beaver Local High School, and attended Columbiana County Career Center’s welding program where he was an AWS Student Chapter member. Excelling at his craft, Roberts was recognized as the program’s top welder in his junior year. He danced with the Country Cloggers, played basketball, and had been active in sports.
NASCC
THE STEEL CONFERENCE
incorporating the
2008 Annual Stability Conference

Nashville, Tennessee  April 2–5, 2008

Who attends?
More than 3,000 structural engineers, steel fabricators, erectors, detailers, educators, and others involved in the design and construction of fabricated steel attend the conference each year. In addition to conference seminars, attendees have many networking opportunities, including the annual Fabricator Workshops, where fabricators can exchange ideas in a non-competitive environment.

What about the exhibit hall?
This year’s exhibit hall features more than 400 booths with more than 160 exhibitors demonstrating the latest products. You’ll find fabrication equipment, detailing software, connection products, safety equipment, engineering software, and coatings. Equipment manufacturers typically provide full demonstrations of their equipment—steel beams are cut, punched, and drilled right on the exhibit-hall floor! The exhibit hall is open April 2–4, 2008.

What will I learn?
Learn about topics ranging from composite steel joists to sharing digital models to designing to avoid floor vibration. Some sessions focus on technical engineering issues, while others focus on fabrication, erection, or detailing. Following up on our successful program offering “Top Hits from Top Pros,” this year we’re also offering “Essays from Experts.” In this new series of lectures, we’ve asked some of the top professionals to present a topic they find interesting. Speakers include Larry Griffis on wind, Duane Miller on welding, Robert McNamara on damping, and Ron Hamburger on simplifying design. The conference also offers a pre-conference short course on BIM and a post-conference short course on the design of low- and mid-rise buildings.

For more information, visit www.aisc.org/nascc

NASCC: The Steel Conference is a premier education event aimed at providing structural engineers, steel fabricators, erectors, and detailers with practical information and the latest design and construction techniques. More than 60 technical sessions offer a variety of educational opportunities:

- Sharing Digital Models Between Steel and Cladding Contractors
- Detailing in High Seismic Regions
- The Advanced Bill as a Deliverable
- BIM for Low-Rise Steel Projects
- 3D Software and Complex Hip and Valley Roof Systems
- Getting Dimensions: Will 3D Modeling Help?
- Got Stiffness?
- Latest Developments in Steel Plate Shear Walls
- Designing Deck Diaphragms for Ductile Systems
- Part One: An Introduction to Earthquake Engineering and Seismic Codes—Ductility
- Part Two: An Introduction to Earthquake Engineering and Seismic Codes—Seismic Provisions
- Part Three: An Introduction to Earthquake Engineering and Seismic Codes—Tips and Examples
- AESS and the New Canadian Matrix: A Category Approach
- Effects of Post-Tensioned Concrete Slabs on Composite Steel Beams
- Engineering Ethics: You Be the Judge
- Steel Solutions for Low-Floor-to-Floor Multi-Story Residential Housing
- Rules of Thumb for Steel Design
- Composite Steel Joists—Standards and Code of Standard Practice
- Quality Assurance for Engineers
- Around the Bend: How to Specify Curved Steel
- AISC Certification: Considerations for Special and Not-So-Special Inspection
- AISC Certification: Keeping It Simple and Effective
- Solving the Recruitment, Retention, and Training Dilemma
- Decreasing Your Insurance and Bonding Costs
- Shop Scheduling
- Fabricator Roundtable
- New Technology for Fabrication
- Business Valuation for Fabricators
- Greening the Shop: Strategies for Managing Your Environmental Footprint
- Constructability and Teamwork
- Procedures and Processes to Manage
- CNC Data
- The History and Status of HSS Stability Design in North America
- Five Useful Stability Concepts
- AISC Certification: New Directions and Continual Improvement
- Immigration Issues in Hiring Teamwork!
- Marketing for Erection: A Call for Professionalism
- Simple—But No Simpler
- Designing with Damping
- Lessons Learned
- Something About Wind
- Practical Erection Details
- Risk Management for Detailers
- Non-Destructive Examination and Special Inspection
- Deep Deck Floor Systems
- Designing Low-Cost Steel Structures
- The Steel Design Specification: A Designer’s Perspective
- Effective IT Strategies to Improve Your Bottom Line

and much more!
**TECHNICAL PROGRAM ABSTRACT SUBMITTAL**

Annual FABTECH International & AWS Welding Show
Las Vegas, October 6-8, 2008

(Complete a separate submittal for each paper to be presented.)

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**Answer the following about this paper**

- Original submittal? Yes [ ] No [ ]
- Progress report? Yes [ ] No [ ]
- Review paper? Yes [ ] No [ ]
- Tutorial? Yes [ ] No [ ]
- What welding processes are used? ______
- What materials are used? ______
- What is the main emphasis of this paper? Process Oriented [ ] Materials Oriented [ ] Modeling [ ]
- To what industry segments is this paper most applicable? ______
- Has material in this paper ever been published or presented previously? Yes [ ] No [ ]
  - If “Yes”, when and where? ______
- Is this a graduate study related research? Yes [ ] No [ ]
- If accepted, will the author(s) present this paper in person? Yes [ ] Maybe [ ] No [ ]

**Keywords:** Please indicate the top four keywords associated with your research below

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**Guidelines for abstract submittal and selection criteria:**

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- Technical/Research Oriented
  - New science or research.
  - Selection based on technical merit.
  - Emphasis is on previously unpublished work in science or engineering relevant to welding, joining and allied processes.
  - Preference will be given to submittals with clearly communicated benefit to the welding industry.
- Applied Technology
  - New or unique applications.
  - Selection based on technical merit.
  - Emphasis is on previously unpublished work that applies known principles of joining science or engineering in unique ways.
  - Preference will be given to submittals with clearly communicated benefit to the welding industry.
- Education
  - Welding education at all levels.
  - Emphasis is on education/training methods and their successes.
  - Papers should address overall relevance to the welding industry.

- Check the category that best applies:
  - [ ] Technical/Research Oriented
  - [ ] Applied Technology
  - [ ] Education
Abstract:
Introduction (100 words max.) – Describe the subject of the presentation, problem/issue being addressed and it's practical implications for the welding industry. Describe the basic value to the welding community with reference to specific communities or industry sectors.

Technical Approach, for technical papers only (100 words max.) – Explain the technical approach, experimental methods and the reasons why this approach was taken.

Results/Discussion (300 words max.) – For technical papers, summarize the results with emphasis on why the results are new or original, why the results are of value. For other papers, elaborate on why this paper is of value to the community, describe key work in the field and provide an integration of these separate activities into a "continuum."

Conclusions (100 words max.) – Summarize the conclusions and how they could be put to use – how and by whom

NOTE: Abstract must not exceed one page and must not exceed the recommended word limit given above

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FIRST ANNOUNCEMENT
and
CALL FOR PAPERS

4th International Brazing & Soldering Conference (IBSC)
Conference dates: April 27-29, 2009

Abstract Deadline: April 30, 2008     Manuscripts Due: July 31, 2008

The American Welding Society and ASM International® are again organizing its world recognized International Brazing & Soldering Conference (IBSC). This four-day event will begin with Short Courses offered on Sunday, followed by a three-day Technical Program Monday-Wednesday. IBSC brings together scientists, engineers and technical personnel from around the globe involved in the research, development, and application of brazing and soldering. Parallel sessions allow us to present the latest advances in these joining technologies and will be organized to permit interaction between the two disciplines.

IBSC 2009 Program Organizers invite to submit your work for consideration of inclusion in the technical program. They are accepting 150-200-word abstracts describing original, previously unpublished work. The work may pertain to current research, actual or potential applications, or new developments. Whereas commercialism must be avoided to maintain the high level of technical quality and integrity of the IBSC conferences, the new brazing applications and case histories are most welcome.

The technical program will include a special ½ day session focused on practical and innovative applications of brazing and soldering. The Tabletop Exhibit will provide a forum for commercial presentations and demonstrations of state-of-the-art brazing and soldering materials, processes and equipment. Check our website for details. The Poster Session will allow yet another opportunity to present the interesting developments in brazing and soldering technologies.

A Conference Proceedings containing only full manuscripts of the accepted research papers will be published to capture these high-quality technical presentations for later reference. Presentations focused on practical applications of brazing and soldering will also be included in the conference proceedings.

Below are some of the topical areas covered at IBSC

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To submit your work for consideration, visit our website at www.aws.org/ibsc then follow the instructions at “Click here to submit your abstract.” All abstracts submissions must be completed by close-of-business on Wednesday, April 30, 2008. Before submitting your abstract, we ask that you carefully consider your ability to present your work at the conference. Speakers are required to pay a (reduced) conference registration fee, and are totally responsible for their travel, housing and any related expenses.

This premiere event is truly one that anyone involved in the brazing and soldering community should plan to attend.

Mark your calendar now, and if you are interested in presenting your work at the conference, submit your abstract no later than April 30, 2008.
Friends and Colleagues:

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

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

Sincerely,

Nancy C. Cole
Chair, AWS Fellows Selection Committee
POSTER ABSTRACT SUBMITTAL
Annual FABTECH International & AWS Welding Show
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<td>Any technical topic relevant to the welding industry is acceptable (e.g. welding processes &amp; controls, welding procedures, welding design, structural integrity related to welding, weld inspection, welding metallurgy, etc.).</td>
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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 place 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):
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Abstract:
Introduction (100 words) – Describe the subject of the poster, problem/issue being addressed and it’s practical implications for the welding industry.

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.

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<td>National Polytechnic Inst./College of Oceaneering</td>
<td><a href="http://www.napoly.edu">www.napoly.edu</a></td>
<td>(800) 432-3483</td>
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<td><a href="http://www.nationalstandard.com">www.nationalstandard.com</a></td>
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<td><a href="http://www.postle.com">www.postle.com</a></td>
<td>(800) 321-2978</td>
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<td>(937) 295-5215</td>
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<td>Stoody/Thermadyne Industries</td>
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<td>Weld Hugger, LLC</td>
<td><a href="http://www.weldhugger.com">www.weldhugger.com</a></td>
<td>(877) 935-3447</td>
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<td><a href="http://www.weldmold.com">www.weldmold.com</a></td>
<td>(800) 521-9755</td>
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<td>(800) 733-4763</td>
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The Mechanism of Ductility Dip Cracking in Nickel-Chromium Alloys

Subsolidus cracking results from global stresses produced during fusion welding and local stresses generated when coherent or partially coherent second phases form

BY G. A. YOUNG, T. E. CAPOBIANCO, M. A. PENIK, B. W. MORRIS, AND J. J. McGEE

ABSTRACT. High-chromium (~30 wt-%) nickel-alloy filler metals are desirable for use in nuclear power systems due to their outstanding resistance to corrosion and stress corrosion cracking. However, these alloys are susceptible to welding defects, especially to subsolidus intergranular cracking commonly known as ductility dip cracking (DDC). In order to develop a high-chromium filler metal that is resistant to as-welded defects, a series of Ni-Cr alloys between 16 wt-% and 34 wt-% chromium were assessed for their susceptibility to cracking. Each alloy was evaluated by fabricating a restrained, multipass, automatic gas tungsten arc, V-groove weld, and counting the number of cracks per unit area observable at 50×. The type of cracking (subsolidus DDC or solidification cracking) was further differentiated via scanning electron microscopy. The results from these welds, coupled with microstructural characterization, chemical analyses, mechanical testing, microstructural modeling, and finite element modeling indicate that DDC in Ni-Cr alloys is caused by the combination of macroscopic thermal and solidification stresses induced during welding and local grain boundary stresses generated during precipitation of partially coherent (Cr,Fe)23C6 carbides. Cracking can be mitigated by alloying to minimize (Cr,Fe)23C6 precipitation (e.g., by Nb and Ti additions), lessening the misfit between the matrix and these precipitates (lowering the Cr and Fe concentration), and by minimizing welding-induced stresses. This mechanism of precipitation-induced cracking (PIC) via misfit stresses is consistent with subsolidus cracking in other alloy systems including superalloys, nickel-copper alloys, titanium alloys, and ferritic steels where ductility loss corresponds to the time/temperature regime where partial coherent or fully coherent second phases form.

Introduction

Nickel-chromium-iron alloys are used extensively in nuclear power systems for their resistance to general corrosion, localized corrosion, and environmentally assisted cracking. However, concerns with stress corrosion cracking of moderate chromium (14–22 wt-%) alloys such as Alloy 600 and its filler metals (E-182 and EN82) have driven the application of higher chromium (28–30 wt-%) alloys like Alloy 690 (Refs. 1–4). While Alloy 690 and its filler metals show outstanding resistance to environmentally assisted cracking in most water-reactor environments (Refs. 5, 6), these alloys are prone to welding defects, most notably to ductility dip cracking (DDC) (Ref. 4). Ductility dip cracks are intergranular and can be surface connected, which is often an unacceptable condition in components where fatigue, corrosion fatigue, or other forms of environmentally assisted cracking can occur.

KEYWORDS
Alloy 690
Chromium Carbides
Ductility Dip Cracking
EN52
Intergranular Cracking
Nickel-Based Alloys
Subsolidus Cracking
Weldability

Ductility dip cracking is a solid-state phenomenon, typically occurring in reheated weld metal or in base metal heat-affected zones at homologous temperatures between 0.4 and 0.9. The name “ductility dip” comes from the correlation of this cracking to a decrease in ductility, as determined from elevated-temperature tensile testing. This tensile ductility dip has been reported in several alloy systems including austenitic stainless steels (Refs. 7, 8), nickel-based alloys (Refs. 9–17) (including age-hardenable nickel-copper alloys (Refs. 18, 19)), and in both near-α and α+β titanium alloys (Refs. 20–23). In the nickel-chromium alloys of interest, DDC typically manifests itself as intergranular cracks of one grain or less length (Fig. 1) with a minimum in tensile ductility near 870°C (Ref. 24).

While there has been considerable research into DDC (Refs. 8, 11–13, 16, 25), the mechanism or mechanisms responsible for this cracking remain poorly understood (Refs. 7, 8, 12, 13, 16–18, 26–29). Factors suggested to influence DDC have recently been summarized by Collins, Ramirez, and Lippold (Refs. 9, 10, 12, 13) and include grain boundary sliding, second-phase precipitation, impurity element (S, P) segregation, grain boundary character (Ref. 16), degree of grain boundary migration (Refs. 12, 13) and hydrogen embrittlement. The purpose of the present research is to better understand the mechanism of DDC and to develop strategies to mitigate its occurrence.

Experimental Procedure

In order to assess the resistance to DDC and solidification cracking in the Ni-Cr alloy system, the following procedure was used. Welds were made with 24 different filler metals ranging from 15 to 34 wt-% chromium. Complete composi-
tions of each weld are detailed in Table 1 and include both commercial alloys (EN62, EN82, and EN52) as well as laboratory fabricated heats of material. The designation “commercial” in the notes column indicates that the material was commercially available. Details of the welding procedure, microstructural characterization, hot ductility testing, and computational analyses are given below.

Weldments

The susceptibility of a given alloy to DDC was assessed by counting the cracks observed in metallographic sections taken from a multipass, V-groove, gas tungsten arc weld with dissimilar metal side rails (carbon steel and 304L stainless steel). This weld is essentially a linear version of a piping safe-end weld common to many nuclear power systems and is shown schematically in Fig. 2. The welding parameters used for this mockup are given in Table 2. Furthermore, the stresses and strains developed in this weld were investigated via finite element modeling.

Microscopy

Each weld was sectioned into nine pieces for crack counts: eight end cut sections perpendicular to the welding direction and one diagonal slice from root to crown of the weld. These nine pieces were metallographically polished to a 0.05-micron finish and examined for defects at 50×. Any crack-like observations greater than 75 microns (0.003 in.) in length were recorded and were further examined by higher magnification light optical microscopy and by scanning electron microscopy to differentiate DDC from solidification cracking. This procedure examined approximately 16 square inches of material per weld and the alloys were ranked via the number of cracks per square inch.

The dilution in this weld joint was investigated via scanning electron microscopy and wavelength dispersive spectroscopy (WDS). The iron concentration of a cross section from one weld (Heat A3) was mapped to illustrate the degree of mixing between the iron-based siderail materials and the nickel-alloy weld. The measurements were made on a JEOL 8200 microprobe operated at 15 kV accelerating voltage, with a 90-nA probe current, and at 60-micron step intervals.

Lastly, the grain boundary microstructure from multipass welds of EN82H (Heat A5) and EN52 (Heat B1) were examined via transmission electron microscopy. For this work, grain boundaries in the reheated portion of a weld bead (i.e., in a location that was reheated but not remelted by subsequent weld beads) were first identified via light optical microscopy, and then mechanically sectioned, ground, and electropolished. Care was taken to investigate the reheated portion of the beads since DDC is observed in base metal or weld metal heat-affected zones (Ref. 30). The TEM was performed on a VG 603 dedicated scanning transmission microscope operated at 300 keV accelerating voltage. Phase identification was determined via selected area diffraction and semiquantitative energy dispersive spectroscopy.

Hot Ductility Testing

Hot ductility testing of EN52 was assessed at both Lockheed Martin and Lehigh University. In both bases, the samples used were standard round bars sectioned from multipass GTAW buildups and the Gleeble testing employed a heating rate of 93°C/s (200°F/s), a cooling rate of 32°C/s (90°F/s), and a stroke rate of 2 in./s. At Lockheed-Martin, 6.3-mm- (0.250-in.-) diameter tensile bars were used to investigate both the on-heating and on-cooling hot ductility in a Gleeble 1500D thermomechanical simulator. At Lehigh, 5-mm- (0.20-in.-) diameter tensile bars were used to confirm the on-cooling hot ductility behavior and to explore the effect of hold time at the ductility mini-
Table 1 — Summary of the Compositions Tested in the V-Groove Weld (wt-%) and Resulting Number of Cracks per Square Inch (a)

<table>
<thead>
<tr>
<th>Heat ID</th>
<th>Notes</th>
<th>Cr</th>
<th>Fe</th>
<th>C</th>
<th>Al</th>
<th>Ti</th>
<th>Nb</th>
<th>Mn</th>
<th>B</th>
<th>Zr</th>
<th>N</th>
<th>S</th>
<th>P</th>
<th>Si</th>
<th>Mg</th>
<th>Cracks/in.²</th>
</tr>
</thead>
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<tr>
<td>A1</td>
<td>1EN62 (commercial)</td>
<td>15.80</td>
<td>6.90</td>
<td>0.030</td>
<td>---</td>
<td>---</td>
<td>---</td>
<td>2.27</td>
<td>0.83</td>
<td>---</td>
<td>---</td>
<td>0.007</td>
<td>0.011</td>
<td>0.17</td>
<td>---</td>
<td>0</td>
</tr>
<tr>
<td>A2</td>
<td>Modified EN82</td>
<td>25.50</td>
<td>1.25</td>
<td>0.038</td>
<td>0.04</td>
<td>0.01</td>
<td>2.40</td>
<td>2.67</td>
<td>0.0003</td>
<td>&lt;0.01</td>
<td>0.0076</td>
<td>0.0021</td>
<td>0.0015</td>
<td>0.020</td>
<td>0.000015</td>
<td>0</td>
</tr>
<tr>
<td>A3</td>
<td>Modified EN82</td>
<td>27.30</td>
<td>1.14</td>
<td>0.036</td>
<td>0.85</td>
<td>0.25</td>
<td>2.45</td>
<td>2.83</td>
<td>0.0003</td>
<td>&lt;0.01</td>
<td>0.0091</td>
<td>0.001</td>
<td>0.008</td>
<td>0.02</td>
<td>0.001</td>
<td>0</td>
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<tr>
<td>A4</td>
<td>Low C EN82</td>
<td>21.43</td>
<td>2.16</td>
<td>&lt;0.0100</td>
<td>0.10</td>
<td>0.37</td>
<td>2.36</td>
<td>1.84</td>
<td>0.0030</td>
<td>---</td>
<td>0.0059</td>
<td>0.001</td>
<td>0.006</td>
<td>---</td>
<td>---</td>
<td>0.001</td>
</tr>
<tr>
<td>A5</td>
<td>EN82 (commercial)</td>
<td>19.00</td>
<td>1.34</td>
<td>0.037</td>
<td>0.044</td>
<td>0.30</td>
<td>0.2</td>
<td>2.96</td>
<td>0.00008</td>
<td>0.0018</td>
<td>0.0059</td>
<td>0.001</td>
<td>0.006</td>
<td>---</td>
<td>---</td>
<td>0</td>
</tr>
<tr>
<td>A6</td>
<td>EN82 (commercial)</td>
<td>19.85</td>
<td>1.05</td>
<td>0.035</td>
<td>0.06</td>
<td>0.27</td>
<td>2.57</td>
<td>3.20</td>
<td>&lt;0.001</td>
<td>&lt;0.01</td>
<td>0.0138</td>
<td>&lt;0.003</td>
<td>&lt;0.003</td>
<td>0.12</td>
<td>0.008</td>
<td>0.002</td>
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<td>Modified EN82</td>
<td>24.05</td>
<td>3.18</td>
<td>0.027</td>
<td>0.03</td>
<td>0.19</td>
<td>2.94</td>
<td>3.05</td>
<td>&lt;0.001</td>
<td>&lt;0.01</td>
<td>0.0182</td>
<td>0.001</td>
<td>0.002</td>
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<td>0.003</td>
<td>0.15</td>
<td>0.0003</td>
<td>0</td>
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<tr>
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<td>9.03</td>
<td>0.020</td>
<td>0.67</td>
<td>0.56</td>
<td>&lt;0.01</td>
<td>0.25</td>
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<td>0.0100</td>
<td>&lt;0.001</td>
<td>0.003</td>
<td>0.14</td>
<td>0.004</td>
<td>0.95</td>
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<td>29.80</td>
<td>2.91</td>
<td>0.030</td>
<td>0.06</td>
<td>0.19</td>
<td>2.50</td>
<td>3.05</td>
<td>0.0002</td>
<td>&lt;0.01</td>
<td>0.0097</td>
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<td>0.003</td>
<td>0.14</td>
<td>0.0003</td>
<td>1.00</td>
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<tr>
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<td>29.20</td>
<td>9.01</td>
<td>0.023</td>
<td>0.075</td>
<td>0.25</td>
<td>0.94</td>
<td>0.95</td>
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<td>0.52</td>
<td>0.57</td>
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<td>0.0048</td>
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<td>0.30</td>
<td>0.27</td>
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<td>0.0157</td>
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<td>9.07</td>
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<td>0.77</td>
<td>0.28</td>
<td>&lt;0.01</td>
<td>0.16</td>
<td>0.0010</td>
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<td>0.0098</td>
<td>&lt;0.001</td>
<td>0.004</td>
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<td>29.21</td>
<td>8.97</td>
<td>0.027</td>
<td>0.68</td>
<td>0.47</td>
<td>&lt;0.01</td>
<td>0.24</td>
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<td>0.001</td>
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<td>9.09</td>
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<td>1.46</td>
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<td>(c)</td>
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<td>0.92</td>
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<td>(27)</td>
</tr>
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<td>28.82</td>
<td>9.92</td>
<td>0.040</td>
<td>0.98</td>
<td>&lt;0.01</td>
<td>0.02</td>
<td>0.26</td>
<td>&lt;0.001</td>
<td>&lt;0.01</td>
<td>0.0030</td>
<td>0.005</td>
<td>&lt;0.002</td>
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<td>&gt;30</td>
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<tr>
<td>D2</td>
<td>Modified EN52</td>
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<td>9.07</td>
<td>0.050</td>
<td>0.74</td>
<td>0.01</td>
<td>0.27</td>
<td>&lt;0.01</td>
<td>&lt;0.01</td>
<td>0.0150</td>
<td>0.004</td>
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<td>0.13</td>
<td>---</td>
<td>&gt;30</td>
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<td>D3</td>
<td>Modified EN52</td>
<td>33.28</td>
<td>8.91</td>
<td>0.020</td>
<td>0.60</td>
<td>0.51</td>
<td>&lt;0.01</td>
<td>0.15</td>
<td>0.001</td>
<td>---</td>
<td>0.0022</td>
<td>0.003</td>
<td>&lt;0.002</td>
<td>---</td>
<td>---</td>
<td>&gt;30</td>
</tr>
</tbody>
</table>

(a) The crack counts represent DDC except for heats C3 and C4, which displayed both DDC and solidification cracking.
(b) Heats did not crack if weld joint had similar metal siderails (B1: all Alloy 600, B5: all carbon steel).
(c) Welds contained both DDC and solidification cracks and were excluded from subsequent DDC correlations.

The finite element modeling was performed via commercially available Sysweld software (Ref. 31). The purpose of this work was to explore the experimental observation that, if the siderail materials in the V-groove weld were identical (e.g., both Alloy 600 or both carbon steel), DDC was suppressed, while dissimilar metal siderails (e.g., one austenitic stainless steel and one carbon steel) promoted DDC. In order to investigate this notion, a simplified two-dimensional finite element model consisting of two siderails and a single weld bead was utilized. The model consisted of three sections corresponding to the left and right siderails and a single weld bead. Linear quadrilateral and triangular elements were used since linear elements are generally better suited for analyses involving plasticity. A single finite element model with identical thermal and structural boundary conditions was used to investigate the effects of siderail material and filler metal. The model temperature was driven by ramping from...
Fig. 3 — Illustration of the stresses developed in a single-pass V-groove weld as a function of siderail materials and filler metal. Note that dissimilar metal siderails produce higher maximum principal stresses with EN82H (C) and EN52 (D) than similar metal siderails (A) and (B).

Fig. 4 — Summary of V-groove weld cracking data vs. chromium concentration in the alloy. In general, lower Cr alloys and EN82H-like compositions (i.e., alloys with ~3 wt-% Nb and 3 wt-% Mn) are resistant up to 29 wt-% Cr.

Fig. 5 — Correlation between the number of ductility dip cracks and the ratio of MC-type carbide formers (Nb+Ti) and Cr, which promotes M23C6-type carbides in high-chromium (> 20 wt-% Cr) nickel alloys.

room temperature to 2912°F (1600°C) in the first second, holding constant for four seconds, and cooling to ambient temperature by convection and radiation. For the stress analysis, the model was constrained horizontally and vertically at the bottom-left siderail, vertically at the bottom-right siderail, and evaluated in the plain strain condition. Loading for the structural analysis is due to thermal expansion and based on the temperature distribution and the interference strain due to phase transformation in the carbon steel end rail. The material combinations investigated were 1) Alloy 600 siderails with EN82 and EN52 filler metals and 2) 304SS and ASTM 516 Grade 70 siderails with EN82 and EN52 filler metals. In all cases, alloy-specific, temperature-dependent material properties were used.

The solidification behavior of each V-groove weld was investigated via JMatPro, version 4.0 software (Ref. 32). This analysis was performed to estimate the amount of carbon in fcc gamma phase at the end of solidification. The calculations utilized the Ni-Fe alloy database and considered the following elements for each alloy (Ni, Al, Cr, Fe, Mn, Nb, Ti, B, C, and N) and the following phases (liquid, fcc nickel, M23C6, M7C3, MC, and Laves phase). Note that JMatPro 4.0 utilizes a Scheil-Gulliver solidification model, modified for fast diffusion of carbon and nitrogen (Ref. 33).

The microstructural modeling used both JMatPro and FactSage (Ref. 34) software. JMatPro was used to assess the effect of alloying elements on the precipitation kinetics of M23C6-type carbides, to generate time-temperature-transformation diagrams for select alloys, and to estimate the misfit between γ’ (or γ″) and the matrix of selected nickel-based superalloys. For the TT T calculations, the solvus temperature for 100% γ was first determined, and curve for 0.1% precipitation of γ’ or γ″ calculated. For these calculations, the nominal compositions of the alloys, supplied by the software, were used.

The FactSage calculations were performed to assess the effects of temperature, chromium, and iron concentration on chromium-rich carbide stability. These calculations used the SGTE 2004 database, considered the γ, M7C3, and M23C6 phases, and were performed assuming 1 atm of pressure for a temperature range of 1000°–2000°F (538°–1093°C), chromium concentrations between 15 and 35 wt-%, and at two different iron levels (1 and 10 wt-%).

The elastic constants of the Cr23C6 carbide phase were calculated via first-principles methods. To give a sense of the accuracy of this methodology, the elastic constants of nickel were also calculated at
the same level of theory and with identical input parameters. Geometry optimizations and total energies were calculated via density functional theory as implemented in the Vienna Ab Initio Simulation Package (VASP) version 4.6 and the MedeA version 2.1 interface (Ref. 35). The computational procedure for these calculations was to relax the structure to <0.01 eV/angstrom and then calculate the elastic constants using the MedeA/MT Module. The following parameters were used in the calculations: the Perdew-Burke-Ernzerhof parameterization of the generalized gradient approximation, spin polarized magnetism, a planewave cutoff energy of 500 eV, the projector-augmented-wave method, the Ni-pv, Cr-pv, and C pseudopotentials, an $11 \times 11 \times 11$ k-mesh, and three strains (0.001, 0.0025, and 0.005).

Results and Discussion

Results from the V-Groove Weld

Results of the crack counts for the V-groove weld are summarized in Table 1. The data are grouped by the number of cracks per square inch, i.e., A heats showed no cracking, B heats between 0 and 10 cracks/in.$^2$, C heats between 10 and 30 cracks/in.$^2$. The data show little correlation suggesting little dependence on tramp elements (S and P) as well as sulfide-forming elements (Mg and Mn).

Fig. 6 — Summary of V-groove weld cracking. A — with sulfur; B — with sulfur + phosphorus; C — with manganese; D — with magnesium; E — with manganese/sulfur ratio; F — with magnesium/sulfur ratio. In general, the data show little correlation suggesting little dependence on tramp elements (S and P) as well as sulfide-forming elements (Mg and Mn).
cracks/in.², and D heats greater than 30 cracks/in.². With the exceptions of Heat B2, where cracking was biased adjacent to the stainless steel siderail, DDC occurred uniformly throughout the weldment. This weld produced repeatable results, i.e., multiple heats of EN82 (A4, A5, A6) did not crack and similar heats of EN52 (B1 and B5) produced the same extent of cracking. Furthermore, this weld differentiates the extent of cracking in the alloys from no cracks in Heats A1–A8, to >30 cracks/in.² in Heats D1–D3. Note that in addition to DDC, hot cracking was observed in two heats of material (C3 and C4), which confounds the crack counts. These heats were not included in subsequent correlations of DDC to composition.

The Effect of Alloy Composition on DDC

In general, lower chromium alloys such as EN62 and EN82 are immune from DDC in this weld, while higher chromium alloys such as EN52 are susceptible to DDC as shown in Fig. 4. While EN82 did not show DDC in this weld, it is notable that an EN82-like heat without niobium exhibited DDC (Heat B8). Furthermore, EN82-like compositions with typical Nb and Mn levels (~3 wt-%) but higher chromium levels did not DDC, until reaching a level of 29.8 wt-% chromium. Lastly, lowering the titanium of EN52-like heats appears to exacerbate cracking (Heats D1 and D2). Since Nb and Ti are both strong MC-type carbide-forming elements, these observations suggest that carbides may have an important role in DDC. The tendency to form MC-type carbides (vice chromium-rich carbides) is assessed in Fig. 5 which plots the number of ductility dip cracks vs. the (Nb+Ti)/Cr ratio. As shown in Fig. 5, heats with a high (Nb+Ti)/Cr ratio, i.e., a strong tendency to form MC-type carbides vs. Cr-rich carbides, show resistance to DDC.

The occurrence and extent of DDC shows little correlation with bulk levels of tramp elements (S, P) or with sulfide-forming elements (Mn and Mg) as shown in Fig. 6. While sulfur embrittlement of nickel and nickel alloys is well established (Refs. 36–38), it is important to note that very well desulfurized heats (e.g., Heats B8, B9, and C1 with 0.002, 0.00056, and <0.001 wt-% S, respectively) exhibit significant DDC. Additionally, relatively high sulfur heats (e.g., A1 with 0.007 wt-% S) do not DDC in this weld. Furthermore, the DDC data show little correlation with sulfide-forming elements (Fig. 6C and D) or with Mg/S ratio. While there is some trend of decreased DDC with increased Mn/S ratio (6E), the data are cross correlated with Nb as noted on the plot. The few heats with high Mn but low Nb (e.g., B4 and B8) exhibit DDC, discounting a dominant role of MnS formation in DDC resistance. These findings, as well as the different time/temperature dependence for DDC and grain boundary segregation discussed below, indicate that for the alloys tested, sulfur embrittlement is not a primary factor in ductility dip cracking.

Microstructural Findings

As noted previously, one observation from the V-groove weld data is that EN82-like compositions are resistant to DDC (A1–A8) while EN52-like compositions...
(low Nb) are susceptible to DDC. Moreover, DDC in low Ti variants of EN52 show increased cracking susceptibility (e.g., D1 and D2). These observations suggest that these elements, which are known strong MC-type carbide and carbo-nitride formers (where M = Nb, Ti) may play a role in DDC resistance. In fact, the predominant type of carbide is one key difference between EN82, which typically displays a mixture of Nb-rich, MC-type, and M23C6-type grain boundary carbides and EN52, which forms primarily (Cr,Fe)23C6-type carbides (with occasional Ti-rich, MC-type carbides) as shown in Fig. 7.

The observation of semicontinuous precipitation of (Cr,Fe)23C6-type carbides along the grain boundary in a DDC susceptible alloy (EN52) is consistent with the work of Capobianco and Hanson who performed scanning Auger microscopy on in-situ fractured ductility dip cracks and found extensive (Cr,Fe)23C6 precipitation on the fracture surface (Ref. 11). It is also notable that the carbides are partially-coherent with one side of the grain boundary with a cube-on-cube ((100)M23C6 || (100)fcc alloy) orientation relationship (Refs. 39, 40). Lastly, it is important to note that since M23C6 carbides are stable to high temperatures and their precipitation displays fast kinetics in Ni-30 wt-% Cr alloys, the microstructural observations of this work and the work of Capobianco and Hanson represent a complex thermal history from multipass welds.

A backscatter scanning electron micrograph and the corresponding compositional map of the iron concentration in the weldment is shown in Fig. 8. As expected, there is significant enrichment in iron adjacent to the carbon steel and 304L stainless steel siderail materials. The iron concentration near the root of the weld is on the order of 30 wt-%, while the iron enrichment adjacent to the siderails is on the order of 15 wt-% and falls off to the filler metal iron concentration in approximately 0.4 in. (10 mm). As discussed previously, while Heat B2 displayed DDC biased toward the stainless steel siderail, ductility dip cracks were observed uniformly throughout the weldment for the bulk of the alloys that were susceptible to DDC. The uniformity of cracking indicates that this weld is a good test for the DDC susceptibility of the filler metal.

**Gleeble Hot Ductility Testing**

Results of the Gleeble hot ductility testing on EN52 are shown in Fig. 9. Consistent with previous studies on the hot ductility of austenitic alloys, EN52 shows little evidence of ductility loss on-heating but a significant tensile ductility dip on-cooling (Refs. 7, 26, 41). The minimum in ductility as determined by % reduction in
area occurs at approximately 860°C (1580°F). As suggested by Nippes and others (Refs. 7, 17, 41), this ductility minimum corresponds to a temperature regime where second-phase precipitation is occurring. Note the very good correspondence between the minimum in ductility and the nose of the (Cr,Fe)_{23}C_{6} TTT curve near 860°C. Additionally, the recovery of ductility with hold time at temperature has important mechanistic implications because in this temperature regime (i.e., at homologous temperatures ~0.6–0.7) it would be expected that tramp elements such as sulfur are segregating to the grain boundary and exacerbating embrittlement, not moving away from the grain boundary and improving ductility (Refs. 36, 37, 42, 43).

The Mechanism and Modeling of DDC

The results of the V-groove weld, the TEM study in front of a ductility dip crack, and the Gleeble testing indicate that DDC is associated with the tendency to form grain boundary (Cr,Fe)_{23}C_{6}-type carbides. As shown by the V-groove welds, high levels of Cr tend to promote DDC (Fig. 4), while strong MC-type carbide forming elements such as Nb and Ti impart resistance to DDC — Fig. 5. Furthermore, microstructural investigations reveal semicontinuous (Cr,Fe)_{23}C_{6}-type carbides in a DDC susceptible alloy (EN52) (Fig. 7) and on DDC fracture surfaces (Ref. 11). Additionally, Gleeble testing shows that regime of ductility loss corresponds to the temperature range of (Cr,Fe)_{23}C_{6} carbide precipitation (Fig. 9) and that ductility loss recovers with hold time at temperature — Fig. 10. Note that all of the alloys susceptible to DDC will form M_{23}C_{6}-type carbides in the ductility dip temperature range determined for EN52 (1400°–1800°F) as shown by the thermodynamic stability of the carbides as a function of temperature and bulk chromium concentration in Fig. 11. Notably, lower-chromium, DDC-resistant alloys (e.g., Heat A1, EN62) tend to form pseudo-hexagonal M_{7}C_{3}-type carbides (which are typically incoherent) rather than partially coherent M_{23}C_{6}-type carbides (Refs. 39, 44, 45).

The tendency of a given alloy to form M_{23}C_{6}-type carbides can be assessed by plotting the bulk (Cr + Fe) concentration and the calculated free carbon in solution after solidification. The chromium and iron concentrations are summed because Fe can substitute for Cr in the M_{23}C_{6} carbide. Thermodynamic-based models indicate that approximately 1–2 atomic % of Fe can substitute for Cr in the M_{23}C_{6} carbide. The Scheil solidification calculation of the free carbon in the fcc gamma phase integrates the effects of MC-type carbide and...
WELDING RESEARCH

The correlation of these compositional parameters with the results of the V-groove welds are shown in Fig. 12, which separates the data into three distinct regions: 1) low Cr+Fe and free carbon where the alloys tested are immune to DDC in this weld, 2) a region of increased susceptibility as Cr+Fe and free carbon are increased. In this region, DDC was observed near the stainless steel weld side, in one heat (B2), possibly due to increased iron and carbon from base metal dilution, and finally 3) a region of general susceptibility to DDC as Cr+Fe and free carbon are further increased. In this regime, DDC occurs uniformly in the weld joint and is not biased by side rail dilution. The dashed lines on Fig. 12 give the approximate extent of DDC, which increases up to the right (i.e., with increased tendency for (Cr,Fe)\textsubscript{23}C\textsubscript{6} precipitation).

While Fig. 12 provides important insight into interpreting the results of the V-groove weld and offers a practical methodology to develop DDC-resistant alloys, other factors likely affect the tendency for DDC. One notable comparison is between Heats B6 and B2, which have similar compositions with the exception of the iron level (8.75 wt-% in B6 and 2.91 wt-% in B2). Heat B6 with higher iron displayed 2 cracks/in.\textsuperscript{2}, throughout the weld, while Heat B2 displayed fewer cracks (1 crack/in.\textsuperscript{2}), that were biased toward the stainless steel side rail dilution area. In the side rail dissolution areas, iron and free carbon in the weld metal can be enriched (see Fig. 8 and note that the 304L side contains \sim 0.02 wt-% C and \geq 65 wt-% Fe), likely increasing the driving force for (Cr,Fe)\textsubscript{23}C\textsubscript{6} precipitation. The effect of increased iron increasing the time-temperature-transformation kinetics of model Ni-30Cr-XFe-0.03C (wt-%) alloys is shown in Fig. 13.

Additionally, research on Ni-Cr-Fe ternaries indicates that increasing iron levels will increase the carbide/matrix misfit (Ref. 46), as discussed below.

The correspondence of DDC with the time/temperature regime of the onset of M\textsubscript{23}C\textsubscript{6} precipitation and the noted effect of welding-induced stresses indicates that DDC in Ni-Cr alloys results from the combination of global stresses induced from welding (or applied during tensile testing) and a local effect associated with precipitation of grain boundary M\textsubscript{23}C\textsubscript{6} carbides. One difference between M\textsubscript{23}C\textsubscript{6} and carbides in DDC-resistant alloys is that M\textsubscript{23}C\textsubscript{6} carbides typically nucleate with partial coherency (\langle 100 \rangle M\textsubscript{23}C\textsubscript{6} \parallel \langle 100 \rangle \text{fcc matrix}), while MC-type and M\textsubscript{7}C\textsubscript{3}-type carbides are typically incoherent with the fcc matrix (Refs. 39, 40, 44, 47, 48). The cube-on-cube orientation relationship between the carbide and one grain at a grain boundary likely generates appreciable elastic stresses and, in combination with global stresses from welding (or applied during tensile testing), is postulated to result in local intergranular cracking, i.e., ductility dip cracking. Precipitation-induced grain boundary stresses in Ni-30Cr alloys are likely a maximum near the onset of precipitation and decreases with time as: 1) the chromium concentration near the grain boundary is depleted by carbide precipitation and subsequent growth (discussed further below), 2) the carbide/matrix interface grows off the original plane of the grain boundary (i.e., as the precipitation-induced stresses are spatially removed from the grain boundary), and 3) dislocations are generated to help accommodate the interfacial misfit. The mechanism of precipitation-induced cracking is outlined in Figure 14, which shows A — the formation of partially coherent, grain boundary M\textsubscript{23}C\textsubscript{6} carbides and a schematic of the lattice misfit; B — how local tensile stresses develop between carbides and promote crack nucleation; and C — macroscopic stresses generated on cooling (e.g., thermal and solidification stresses) often link the inter-carbide cracks and result in ductility dip cracking along the crystallographic grain boundary.

Table 3 — Summary of Lattice Parameters and Cr\textsubscript{23}C\textsubscript{6}Carbide/Matrix Misfit for Selected Ni-Cr-Fe Alloys

<table>
<thead>
<tr>
<th>Material</th>
<th>Lattice Parameter (Angstroms)</th>
<th>d(100) (Angstroms)</th>
<th>( \delta = \frac{d(Cr\text{23}C\text{6}) - d(M23C6)}{d(M23C6)} )</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr\textsubscript{23}C\textsubscript{6}</td>
<td>10.6595</td>
<td>3.5532</td>
<td>...</td>
<td>(62)</td>
</tr>
<tr>
<td>A600</td>
<td>3.553</td>
<td>3.553</td>
<td>0.006</td>
<td>(63)</td>
</tr>
<tr>
<td>EN82H</td>
<td>3.570</td>
<td>3.570</td>
<td>-0.473</td>
<td></td>
</tr>
<tr>
<td>A690</td>
<td>3.5757</td>
<td>3.5757</td>
<td>-0.633</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 14 — Illustration of the mechanism of ductility dip cracking in Ni-Cr alloys. A — Partially coherent grain boundary M\textsubscript{23}C\textsubscript{6} carbides form in reheated weld metal with significant misfit between the carbide and the alloy as shown above and in Fig. 15; B — precipitation generates local grain boundary tensile stresses between carbides promoting crack nucleation; and C — macroscopic stresses generated on cooling (e.g., thermal and solidification stresses) often link the inter-carbide cracks and result in ductility dip cracking along the crystallographic grain boundary.

The cube-on-cube orientation relationship between the carbide and one grain at a grain boundary likely generates appreciable elastic stresses and, in combination with global stresses from welding (or applied during tensile testing), is postulated to result in local intergranular cracking, i.e., ductility dip cracking. Precipitation-induced grain boundary stresses in Ni-30Cr alloys are likely a maximum near the onset of precipitation and decreases with time as: 1) the chromium concentration near the grain boundary is depleted by carbide precipitation and subsequent growth (discussed further below), 2) the carbide/matrix interface grows off the original plane of the grain boundary (i.e., as the precipitation-induced stresses are spatially removed from the grain boundary), and 3) dislocations are generated to help accommodate the interfacial misfit. The mechanism of precipitation-induced cracking is outlined in Figure 14, which shows A — the formation of partially coherent, grain boundary M\textsubscript{23}C\textsubscript{6} carbides and a schematic of the lattice misfit; B — how local tensile stresses develop between carbides and promote crack nucleation; and C — the result of these inter-carbide cracks linking up with subsequent stressing to form a typical ductility dip crack along the crystallographic grain boundary.

The effect of the misfit between M\textsubscript{23}C\textsubscript{6}-type carbides and the matrix can be further assessed by considering the spacing of \{100\} planes in each phase. The difference between the room-temperature lattice parameters of the Cr\textsubscript{23}C\textsubscript{6} carbide and selected alloys are summarized in Table 3. The room-temperature lattice parameter is a good estimate for the d-spacing in the DDC temperature
range (~1400°–1800°F), since the thermal expansion of these both the alloys and Cr23C6 carbides is similar and small in magnitude (<10⁻⁵ in./in.–°F) (Refs. 5, 49). The misfit strain, \( \delta \), was estimated via Equation 1, where \( d \) is the (100) interplanar spacing of either the carbide or the alloy.

\[
\delta(\%) = \left( \frac{d_{\text{Cr}_{23}\text{C}_6} - d_{\text{Alloy}}}{d_{\text{Cr}_{23}\text{C}_6}} \right) \times 100
\]  

As shown in Fig. 15, the carbide/matrix misfit is a maximum for high chromium (~30 wt-%) alloys and decreases as the chromium content is lowered to ~15 wt-%. For the case of hot-ductility testing performed “on-cooling” from a high solutionizing temperature, this maximum misfit corresponds to short aging times, before grain boundary chromium carbide precipitation can deplete the local chromium concentration. The change in carbide/matrix misfit as chromium is depleted is consistent with the transient nature of the ductility dip (Fig. 10) and with a precipitation-based mechanism of cracking. Furthermore, the effect of chromium on the carbide/matrix misfit agrees with experimental observations of the known resistance of Alloy 600 to DDC (Refs. 7, 17) and the susceptibility of higher chromium alloys such as EN52 and Alloy 690 (Refs. 11, 24).

Fig. 15 — Illustration of how the lattice parameter changes in Ni-Cr alloys and the estimated elastic strain with Cr23C6 carbides. The misfit is small for Alloy 600 and increases as chromium is increased. High-chromium weld metal like EN52 should have large misfit similar to Alloy 690.

In contrast, these observations are inconsistent with the notion that elemental segregation is causal to DDC for the following reasons:

- There is no clear correlation between the bulk sulfur content and the degree of ductility dip cracking — Fig. 6A.
- If grain boundary sulfur segregation was causing or exacerbating intergranular fracture in the DDC temperature range, the effect should persist on-cooling to lower temperatures, not recover as shown in Fig. 9.
- Since 1400°–1800°F is a temperature regime where sulfur should be segregating to nickel grain boundaries (Refs. 36, 37), the observation of ductility recovery with hold time (Fig. 10) is inconsistent with a segregation based mechanism.

The magnitude of the elastic stress produced in the matrix from nucleation of M23C6-type was used to assess the stiffness of the carbide since experimental values were not found. The calculations, summarized in Table 4, show reasonable agreement between the experimental and the calculated elastic constants for nickel (\( E_{100}^{\text{calculated}} = 112 \) GPa vs. \( E_{100}^{\text{experimental}} = 150 \) GPa), and the calculations reproduce the correct trend for nickel (increasing stiffness from <100> to <110> to <111>). These calculations show that

Fig. 16 — Intermediate temperature ductility loss in some other nickel-based alloys. A — Inconel X-750, which occurs in the temperature regime of M23C6 carbide precipitation; B — Inconel 718, which occurs in the temperature regime of M6C precipitation; C — Monel K-500, which shows large ductility loss in the temperature regime of \( \gamma^\prime \) precipitation.
The elastic stress produced in the nickel alloy matrix during nucleation can then be estimated from Equation 2, where E and ε are taken as the modulus and the strain in the <100> direction. This estimation (E=112 GPa, ε=0.64%) results in elastic stresses near 690 MPa (100 ksi), which is far in excess of typical yield strengths for A690 or EN52 [typically in the range of 207-414 MPa (30-60 ksi) at room temperature]. While this is a crude approximation of the actual stresses at the carbide/grain boundary interface, it does show that the elastic misfit stresses are appreciable and could result in cracking, especially when additional global stresses are present as in the case of welding or mechanical testing.

$$\sigma = E \varepsilon$$  \hspace{1cm} (2)

While misfit strains will partially offset the energy benefit of nucleating with partial coherency on the grain boundary, recent work on Alloy 690 shows that even on high angle grain boundaries, \(M_2\)\(_{3}C_6\)-type carbide precipitate with partial coherency (Ref. 47). In other words, the misfit strain between the carbide and matrix is not so large as to negate the benefit of the cube-on-cube precipitation. However, grain boundary misorientation does affect the rate of precipitation as discussed by Lim et al. (Ref. 47). Notably, the misfit between the \(M_2\)\(_{3}C_6\) carbide and Alloy 690 quoted by Lim (~0.67%) is similar to the present study (~0.63%).

The effects of coherent precipitate interfacial stresses on second-phase stress, strain, and compositional profiles have been studied in more detail by W. C. Johnson (Ref. 50). Johnson’s analyses show that long range stresses can develop from the interface of a coherent second phase and that, using reasonable parameter estimates, the magnitude of the interfacial stress is on the order of ~10-1000 MPa (1.45-145 ksi). While mainly driven by thermodynamic modeling of phase equilibria, Johnson’s work gives further evidence that misfit strains from coherent or partially coherent precipitates can lead to appreciable local stresses and potentially to cracking of the interface.

As shown schematically in Fig. 15, the \(100\) d-spacings of the \(C\)\(_{13}\) carbide are smaller than in high-chromium nickel alloys indicating that the misfit stresses are compressive at the carbide/grain boundary interface. As multiple carbides nucleate along a grain boundary, this causes regions of tension between the carbides and could produce intermittent grain boundary cracks, consistent with some experimental observations of DDC shown in Fig. 14. Similarly, failure could also occur at the partially coherent side of the carbide/matrix interface. Of course, the exact ductility dip crack morphology is likely a complex function of a given material’s tendency to form \(M_2\)\(_{3}C_6\) carbides, local grain boundary orientation, and the magnitude and direction of the global stresses and strains.

**Ductility Loss in Other Alloy Systems**

The good correspondence between ductility dip cracking in high-chromium nickel alloys and (Cr,Fe)\(_{23}C_6\) precipitation, suggests that the same mechanism of precipitation-induced cracking may affect other alloys. Review of nickel-based alloy literature data shows that Alloys X-750, 718, and Monel® K-500 all display significant intermediate temperature ductility dips as shown in Fig. 16 (Refs. 15, 19, 51-53). In the case of X-750, ductility loss corresponds to precipitation of partially coherent \(M_2\)\(_{3}C_6\)-type carbide, similar to EN52 and A690. In Alloy 718, the tensile ductility dip correlates to the temperature range of precipitation of \(M_6C\)-type carbides. Like \(M_2\)\(_{3}C_6\)-type carbides, \(M_6C\) have a complex cubic structure, a lattice parameter similar to \(M_2\)\(_{3}C_6\)-type carbides (11.26 Å vs. 10.66 Å) and likely have a \(100\)\(_{M6C}|| (100)\(_{FeC} alloy\) orientation relationship with the matrix (Ref. 54). Monel K-500 exhibits a large ductility dip, both in terms of breadth of temperature range (~620° to 1610°F) and ductility loss (~25% to 2% elongation). The tensile ductility dip corresponds to the temperature regime where \(\gamma^\prime\) will precipitate (Ref. 19), consistent with precipitation-induced cracking. It is also notable that Monel 400, which does not form \(\gamma^\prime\), does not exhibit this large ductility loss (Ref. 52).

The correspondence of ductility loss with \(\gamma^\prime\) precipitation in Monel K-500 is suggestive of strain-age cracking in nickel-based superalloys (Ref. 55). As shown by Hughes and Berry (Refs. 56, 57), and later by Franklin and Savage (Ref. 58), strain-age cracking occurs in the time/temperature regime of \(\gamma^\prime\) precipitation, analogous to the correspondence of DDC with \(M_2\)\(_{3}C_6\) precipitation in EN52-type alloys. Furthermore, studies on the superalloy Rene® 41, show that strain-age cracking is caused by the combined action of global restraint stresses and precipitation-induced stresses (Refs. 59, 60), the same basic mechanism that is postulated for ductility dip cracking. This assertion is supported by the \(JMatPro\) calculations of misfit strain and precipitation time (Ref. 32), i.e., alloys that are prone to strain-age cracking (e.g., Udiment® 700, IN-100, and Astrolloy®) have fast precipitation kinetics and large negative \(\gamma^\prime\)\(-\gamma^\prime\) mismatch relative to alloys that are resistant to strain-
age cracking (e.g., Inconel® 718, Inconel® X-750, and Waspaloy®) which display longer times before γ nucleation occurs and positive mismatch (i.e., matrix compression on precipitation). A summary of precipitation times, temperatures, misfit strains, and tendency to strain-age crack are given in Table 5.

Lastly, it should be noted that the mechanism of precipitation-induced cracking presented herein is very similar to those proposed by Rath et al. for the subsolidus cracking of α/β titanium alloys and by Swift and Rodgers for stress-relief cracking of 2%Cr-1Mo steels (Refs. 20, 61). In titanium alloys system, cracking occurs in the temperature regime of the β→α transformation and Rath and coworkers have postulated that the stress associated with this transformation causes cracking. Similar to the present study, grain boundary α typically nucleates with the Burger’s orientation relationship (110)ₐ || (0001)ₐ, [111]ₐ || [1120]ₐ, and is believed to generate significant local stresses (Ref. 20). While there is no general agreement on the mechanism or mechanisms of subsolidus cracking in titanium alloys, the precipitation-based mechanism of Rath et al. is generally consistent with the susceptibility of a wide range of model alloys (Ref. 20). Similarly, the research of Swift and Rodgers indicates that reheat cracking in 2%Cr-1Mo steels occurs when partially coherent (110)ₐ || (001)₀₂₇, and [100]₀ || [1120]₀ carbides form. Resistance to cracking is reestablished when precipitates grow in size and are no longer able to impart coherency strains on the matrix (Ref. 61).

The correspondence of ductility loss to precipitation of a partially or fully coherent precipitates in other alloys helps validate the findings of the present study and indicates that DDC, strain-age cracking, reheat cracking, and observations of intermediate temperature ductility loss are often caused by precipitation-induced cracking. In alloys where precipitation of partially coherent or coherent precipitates with large misfit occurs at short times (e.g., A690, EN52, Astroloy and IN-100), the result is a weldability problem. In alloys where precipitation of the misfitting second phase is sluggish, ductility loss is often observed during hot tensile testing or deformation processing (e.g., X-750, Inconel 718, and Monel K-500). The key point is that ductility loss occurs in the temperature regime where the global stresses overlap with the local, precipitation-induced stresses. Welding-induced cracks are promoted by large precipitation-induced stresses, large global stresses (e.g., high weld constraint), and with increasing volume fraction of the detrimental second phase.

Conclusions

Ductility dip cracking in Ni-Cr alloys is likely a form of precipitation-induced cracking similar to intermediate temperature tensile ductility loss noted in several other nickel-based alloys, strain-age cracking in superalloys, subsolidus cracking in titanium alloys, and stress-relief cracking in ferritic steels. In Ni-(20–30 wt%-Cr) alloys, DDC is caused by the combination of macroscopic thermal and solidification stresses induced during welding and local stresses generated during grain boundary precipitation of partially coherent (Cr,Fe)₃C₆ carbides. The strong correlation between the time/temperature dependence of DDC with precipitation, but not with grain boundary impurity segregation (e.g., sulfur) indicates that for the compositions tested, segregation is not a significant factor. Cracking can be mitigated by alloying to minimize grain boundary (Cr,Fe)₃C₆ precipitation (e.g., by Nb and Ti additions), lessening the misfit between the matrix and these precipitates (lowering the Cr concentration), and by minimizing welding-induced stresses (e.g., by avoiding dissimilar metal welds). The alloying strategies outlined herein, offer promising avenues to improve the weldability of high-chromium nickel-alloy filler metals while maintaining the outstanding corrosion resistance required for many power generation applications of these materials.

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WELDING RESEARCH

Consumable Double-Electrode GMAW
Part II: Monitoring, Modeling, and Control

Selecting bypass arc voltage, proposing an interval control algorithm, and conducting step responses along with closed-loop control experiments for this process were undertaken

BY K. H. LI AND Y. M. ZHANG

ABSTRACT. Consumable double-electrode gas metal arc welding (DE-GMAW) is an innovative welding process that can significantly increase the deposition rate without raising the base metal heat input to an undesired level. To be qualified as a practical manufacturing process, feedback control is required to ensure the presence and stability of the bypass arc. To this end, the bypass arc voltage was selected to monitor the state of the bypass arc. Further, the authors proposed an interval control algorithm for models whose parameters are bounded by given intervals. This algorithm does not require the specific values for parameters, but only their intervals, which can be identified through a selected set of experiments. By conducting step responses under different conditions, a few models were obtained and the parameter intervals were determined and enlarged to increase the stability margin. Using the obtained parameter intervals in the interval control algorithm, closed-loop control experiments have been conducted to verify the effectiveness of the proposed control system for the consumable DE-GMAW process.

Introduction

The consumable DE-GMAW was implemented by adding another gas metal arc welding (GMAW) gun and constant current (CC) power supply to a conventional GMAW setup — Fig. 1. The CC power supply provides the bypass current and the constant voltage (CV) power supply provides the base metal current. The total melting current, which melts the main welding wire, is the sum of the bypass current and base metal current: \( I = I_1 + I_2 \). Here the base metal current is denoted as \( I_1 \) or \( I_{\text{base}} \) and the bypass current is denoted as \( I_2 \) or \( I_{\text{bp}} \). This notation also applies to other variables or parameters, such as arc voltage and wire feed speed: \( V_1, V_2, WFS_1, \) and \( WFS_2 \).

The bypass welding wire is primarily melted by the bypass current, and the base metal is primarily heated by the base metal current. Hence, it is possible to use a high total melting current for increased deposition rate, while maintaining a low base metal current and heat input. An additional deposition rate increase is obtained from the bypass wire, which is primarily melted by the bypass current.

However, as discussed in Part I, without proper control the process can only remain stable when the welding parameters are carefully selected and do not vary in large ranges. If the process becomes unstable and the bypass arc extinguishes periodically, the bypass loop would break and all the melting current would be imposed onto the base metal. Such a large base metal current can melt through and damage the workpiece. Thus, to ensure the consumable DE-GMAW process functions properly, its stability must be controlled and guaranteed. To this end, an appropriate signal must be found to characterize the process stability. This signal must accurately reflect the process stability and be monitored conveniently in a manufacturing environment. Then a process model can be obtained to design a suitable control algorithm. Hence, this paper (Part II) is devoted to the monitoring, modeling, and control of the consumable DE-GMAW process.

Stability Monitoring

Vision Signal

The most direct indication of stability is obtained by monitoring the bypass arc, especially the location of the tip of the bypass welding wire in relation to the main arc. Experiments show that when the bypass arc is stable, the tip of the bypass welding wire must be close enough to the main arc. However, machine vision (Ref. 1) requires an imaging system, which should be installed to and move with the welding torch. This makes the welding system complicated. Machine vision may not be the most preferable method for welding processes.

Sound Signal

Usually there is a characteristic sound in welding associated with each particular operating mode. For example, in plasma arc welding there is a characteristic sound when the keyhole is established. In GMAW, the sound can vary quite drastically and is dependent on the mode of metal transfer. A similar phenomenon was observed in the consumable DE-GMAW. For instance, when the bypass arc was unstable, the sound was hard and accompanied by spatters. But once the bypass arc became stable, the metal transfer became a spray transfer mode because of the high melting current, thus there was no spatters and sharp sound.

Thermal Signal

Thermal signal reflects the temperature field, which heavily depends on the distance for a specific thermal point. Take the consumable DE-GMAW process as an example: the bypass arc can be seen as a thermal point. In the axis direction of the bypass welding wire, different positions will have different temperatures depending on their distances from the welding arc. Thus, a fixed position thermal coupler theoretically can be used to monitor the relative movement of the tip of the bypass welding wire.

Current Signal

Current signal is often used in welding processes. It has been successfully used in
double-sided arc welding (DSAW) to detect the establishment of the keyhole (Refs. 2, 3). In DE-GMAW, the bypass current can tell the existence of the bypass arc. However, because the bypass power supply is a CC welding machine, the bypass current does not change with the arc length. Figure 2 illustrates an experiment with the following parameters: $WFS_1 = 14$ m/min (550 in./min), $V_1 = 36$ V, $WFS_2 = 5.1$ m/min (200 in./min), and $I_2 = 150$ A. The bypass current was set to a high value to make the bypass arc unstable. It can be seen that the bypass current was present once the bypass arc was ignited. When the bypass arc became longer and longer, the bypass current did not change. Once the bypass arc extinguished, the bypass current dropped to zero abruptly. Thus, the bypass current can only indicate two discrete states: bypass arc on or bypass arc off, but not the trend to become unstable.

**Voltage Signal**

Arc voltage signals — arc length (Refs. 4, 5), for example — are often used to monitor welding processes. Normally, the arc voltage is proportional to the arc length. The following can be observed during DE-GMAW experiments:

1. The bypass arc voltage is equal to the main arc voltage when the bypass welding wire touches the workpiece. This happens when the bypass wire feed speed is too fast.
2. When the length of the bypass arc increases, $V_2$ increases as illustrated in Fig. 2.
3. There is an optimal $V_2$ that appears to establish an optimal operating point to stabilize the process.
4. When the bypass arc tends to extinguish, $V_2$ tends to increase to a high level. The arc voltage can thus reflect the state of the bypass arc. The state of the bypass arc can be predicted from the bypass arc voltage. Hence, the bypass arc voltage may be used to characterize the stability of the consumable DE-GMAW process.
Process Analysis

As discussed earlier, the consumable DE-GMAW process has two parallel arcs: the main arc established between the main welding wire and the workpiece, and the bypass arc established between the main welding wire and the bypass welding wire. The main welding wire is the common anode of the two arcs, and its melting is determined by the sum of the two currents or the total current.

When the main wire feed speed \( WFS_1 \) and arc voltage \( V_1 \) are given, the total current is approximately fixed. The use of the CV power supply ensures a constant distance from the tip of the main welding wire to the workpiece (between them \( V_1 \) is measured). This distance is not affected by variations in the bypass arc length.

The bypass welding wire is primarily melted by the cathode heat of the bypass arc. The bypass current \( I_2 \) needed for a given bypass wire feed speed is approximately fixed, even though a perturbation is introduced for \( WFS_2 \). In fact, if \( WFS_2 \) is increased, the cathode heat would become insufficient to melt the bypass welding wire. As a result, the distance from the contact tube to the tip of the bypass welding wire will increase, and the extension of the bypass welding wire increases. In the meantime, the resistive heat (proportional to \( I_2^2 \) and the stickout length (Refs. 6, 7)) also increases. If \( WFS_2 \) is decreased, the cathode heat will tend to melt the bypass welding wire faster, but a reduced extension will reduce the resistive heat. In both cases, new equilibriums will be reestablished at different locations, but the measured \( V_2 \) will be changed. The process shifts from the optimal condition. To maintain the stability, the authors proposed to adjust the cathode heat to maintain the bypass welding wire at its optimal location in relation to the main welding wire.

The previous discussion and analysis suggest that the process to be controlled for the bypass arc stability can be defined as a dynamic system with \( V_2 \) as the output and \( I_2 \) as the input. It appears that the dynamic model, which correlates the input and output, may be affected by the bypass wire feed speed, but possible effects from \( WFS_1 \) and \( V_1 \) setting should not be significant. This implies that the dynamic model established using a particular \( WFS_2 \) may be just a local model. When a different \( WFS_2 \) is used, the process dynamics may be subject to change.

As can be seen, the control of the bypass arc stability requires the bypass current to be adjusted in real time. Although the base metal current will change with the bypass current, the stability of the main arc will be maintained by the CV power supply. When \( WFS_2 \) and the desired \( V_2 \) setting are given, the required \( I_2 \) is approximately fixed and the real-time adjustment of \( I_2 \)
will be made in a relatively small range. Then the base metal current does not change significantly. For most applications, no further control is needed for the base metal current because small variations should be tolerated. If the base metal current needs to be controlled strictly, $WFS_2$ can be adjusted together with $I_2$ and will not be discussed here. This study focuses on the most fundamental issue: the control of the bypass arc stability. To this end, a control algorithm needs to be de-
signed to adjust the bypass current to maintain the bypass arc voltage \( V_b \) at a desired optimal value while \( WFS_1, WFS_2, \) and \( V_1 \) are constants. Figure 3 shows the closed-loop control system to be developed. The solid arrow associated with \( WFS_2 \) implies that \( WFS_2 \) may possibly affect the dynamics of the process, and the dashed arrows associated with \( WFS_1 \) and \( V_1 \) indicate that the possible effects of \( WFS_1 \) and \( V_1 \) on the dynamics are insufficient and negligible.

**Control Algorithm**

For manufacturing systems, their models are typically affected by the manufacturing conditions. Experiments can be conducted to identify different models with different sets of manufacturing conditions. These models represent the process dynamics in those manufacturing conditions. If all models have the same structure but different values of parameters, an interval (a minimal value and a maximal value) can be found for each parameter in the model structure. The model can be described using the bounded known intervals for the given ranges of manufacturing conditions. This type of model is referred to as an interval model. The interval model control algorithm is a standard program and does not require any design work. Hence, unlike other techniques such as adaptive control, neural network, and predictive control (Refs. 8–15), the interval model based modeling and control is suitable for welding engineers without systematical training in control. It can be used even if the intervals are relatively small. In particular, the intervals can be artificially enlarged to increase the stability margin of the closed-loop system.

The original interval model control algorithm (Ref. 16) is based on linear systems described using an impulse response model:

\[
y_k = \sum_{j=1}^{N} h(j)u_{k-j}
\]

where \( k \) is the current instant, \( y_k \) is the output at time \( k, u_{k-j} \) is the input at \( (k-j) \) \( (j > 0) \), while \( N \) is the system order and the real parameters of the impulse response function. The \( h(j) \)'s \( (1 \leq j \leq N) \) are unknown but bounded by the intervals:

\[
h_{\min}(j) \leq h(j) \leq h_{\max}(j) \quad (j = 1, ..., N) \quad (2)
\]

where \( h_{\min}(j) \) and \( h_{\max}(j) \) are the minimum and maximum values of the \( h(j) \)'s \( (1 \leq j \leq N) \) and known. That is, if the parameters of the actual model are bounded by the (nominal) intervals, it is guaranteed that \( y_k = y^* \), where \( y^* \) is the set point of the output. The objective of the control algorithm is to de-
termine the feedback control action \( u_k \) such that the closed-loop system achieves the given set point.

Assume the control actions are kept unchanged after instant \( k \), i.e., \( \Delta u_{k-1} = 0 \) \((\forall j > 0)\). Predicting the output \( \Delta \)-step-ahead yields:

\[
y_{k+N}(\Delta u_k) = y_k + \sum_{j=2}^{N} h(j)\Delta u_{k-j} + s(N)\Delta u_k
\]

(3)

where \( \Delta u_k = u_k - u_{k-1} \), \( s(i) \) is the unit step response function and its upper and lower limits \( s_{\text{max}}(i) \) and \( s_{\text{min}}(i) \) satisfy

\[
s_{\text{max}}(N)s_{\text{min}}(N) > 0
\]

(4)

It is apparent

\[
y_{k+N}(\Delta u_k) = y_k + s(N)\Delta u_k
\]

(5)

Where \( y_k + s(N)\Delta u_k \) is the \( \Delta \)-step-ahead prediction of the output made at instant \( k \), assuming the control actions are not changed at and after instant \( k \), i.e., \( \Delta u_{k+j} = 0 \) \((\forall j > 0)\). The control action \( \Delta u_k \) is thus determined:

\[
\max y_k + s(N)\Delta u_k = \max y_k + s(N)\Delta u_{k-1} + + s(N)\Delta u_k
\]

(6)

The control algorithm in Equation 6 can be further written as

\[
\max s(N)\Delta u_k = y^* - \max y_k + s(N)\Delta u_{k-1}
\]

(7)

where \( a = h_{\text{max}}(j)(u_{k-1} - u_{k-j}) \), \( b = h_{\text{max}}(j)u_{k-j} \). Denoting \( d_n = \max s(N)\Delta u_k \), the control action can be calculated as

\[
\Delta u_k = \text{abs}(d_n)\min\left(\frac{\text{sign}(d_n)}{s_{\text{max}}(N)} \frac{\text{sign}(d_n)}{s_{\text{min}}(N)}\right)
\]

(8)

where \( \text{sign}(x) \) is a function to return the sign of its parameter. Then, the output of the control algorithm can be calculated as

\[
\Delta u_k = u_{k-1} + \Delta u_k
\]

Figure 4 illustrates the control algorithm described above. In the control system, \( \Delta u_k \) was limited to \([-10\ A \ 10\ A]\) in each step to avoid an abrupt change in the bypass current. Obviously, an abrupt change in welding current will burn the contact tip. Once the new output \( u_k \) is calculated, the input history \( u \) must be updated.

**Process Modeling**

To model the consumable DE-GMAW process, step response experiments have been conducted with \( WF3 \) equal to 14.0 m/min (550 in./min) and \( V_s \) equal to 36 V. Because the bypass wire feed speed may affect the process dynamics, experiments were conducted in major ranges of the bypass wire feed speed: 16.5 m/min (650 in./min) at the high range, 10.2 m/min (400 in./min) in the moderate range, and 5.1 m/min (200 in./min) in the low range. The main welding wire as well as the bypass welding wire was 1.2-mm (0.045-in.-) diameter low-carbon steel (ER70s-6). Shielding gases (pure argon) were provided through the main gun at a flow of 18.9 L/min (40 ft³/h).

Figure 5 illustrates an experiment in the high range of the bypass wire feed speed (650 in./min). It can be seen that step changes in the bypass current resulted in immediate changes in the base metal current as well in the bypass arc voltage. However, the total melting current did not change with the bypass current.

Figure 6 shows the step response experiment in which the bypass current increased from 170 to 240 A. A careful examination indicates 1) the process can be approximated by a first-order system; 2) the bypass voltage \( V_2 \) increased 3.11 V (the signal \( V_2 \) was multiplied by a factor 3 such that it can be plotted together with other signals); 3) the time constant is 0.0228 s. Hence, the transfer function can be expressed as a transfer function \( H(s) = 0.0444/(0.0227s + 1) \), with a static gain equal to 0.0444 V/A.

Comparing the simulated \( V_2 \) plot to the actual \( V_2 \) plot in Fig. 6 suggests that the first-order system has accurately modeled the process.

In another segment of Fig. 6, the bypass current was decreased from 150 to 90 A. A careful examination indicates 1) the process can be approximated by a first-order system; 2) the bypass voltage \( V_2 \) increased 3.11 V (the signal \( V_2 \) was multiplied by a factor 3 such that it can be plotted together with other signals); 3) the time constant is 0.0228 s. Hence, the transfer function can be expressed as a transfer function \( H(s) = 0.0444/(0.0227s + 1) \), with a static gain equal to 0.0444 V/A.

Comparing the simulated \( V_2 \) plot to the actual \( V_2 \) plot in Fig. 7 suggests that the first-order system has accurately modeled the process.

Figure 8 shows an experiment in the moderate range of the bypass wire feed speed. It can be seen that the total current was maintained around 395 A even though the bypass current changed. Also, the base metal current changed with the bypass current.

Figure 9 gives the segment when the bypass current increased from 130 to 180 A. It can be seen that the system can be modeled as \( H(s) = 0.0395/(0.0228s + 1) \) for the moderate bypass wire feed speed. In the segment shown in Fig. 10, the bypass current decreased from 180 to 130 A. Obviously, the system is still a first-order system with a transfer function \( H(s) = 0.04/(0.0258s + 1) \).
sponses would cause no effect on the stability of the closed-loop system. Using these intervals, the control algorithm described in Equation 6 and Eq. 4 can be used to calculate the manipulator \( J_1 \) based on the feedback of \( V_{f} \). In addition, the intervals in Table 1 were obtained with a bypass wire feed speed from 5.1 m/min (200 in./min) to 16.5 m/min (650 in./min). The closed-loop system using these intervals would work when the bypass current varies in a large range.

**Control Experiments**

**Experimental Setup**

The consumable DE-GMAW setup illustrated in Fig. 1 has been implemented at the University of Kentucky by adding a second GMAW gun and CC power supply to a standard GMAW system. A current sensor was used to feed back the basic metal current to the control system. A voltage sensor was utilized to feed back the bypass arc voltage. A second current sensor was used to monitor the bypass current, while an additional voltage sensor was connected to monitor the main arc voltage. The control signals passed D/A boards and isolation boards before they acted on the power supplies. An Olympus high-speed camera equipped with a narrow-banded light filter (central wavelength: 940 nm, bandwidth: 20 nm) was used to record the arc behavior and metal transfer. During experiments, the guns moved together from right to left at a travel speed (TS) of 0.64 m/min (25 in./min). The workpiece was low-carbon steel with a thickness of 0.5 in. (12.7 mm). Pure argon was used as shielding gases only through the main GMAW gun.

**Interval Model Control Experiments**

Experiments have been performed to verify the proposed control system for the bypass arc stability. The main wire feed speed was set to 14.0 m/min (550 in./min), but the bypass wire feed speed was changed during experiments. The expected output for the bypass voltage was 39 V while the main arc voltage was 36 V.

In Fig. 15, the bypass wire feed speed was fluctuated around 14 m/min (550 in./min). It can be seen that the bypass voltage was controlled around 39 V even though the bypass wire feed speed changed. An increase in the bypass wire feed speed resulted in an increase in the bypass current due to the closed-loop control. As a result, the feeding-melting balance can be maintained, and a stable bypass arc was obtained. As expected, the total current maintained constant and smooth because of the corresponding change in the base metal current.

A segment of Fig. 15 was zoomed in to show the response characteristics of the control algorithm — Fig. 16. It can be seen that when the bypass wire feed speed decreased from 15.2 m/min (600 in./min) to 12.7 m/min (500 in./min), the bypass arc voltage was controlled without any obvious change. This verified the appropriate and rapid adjustment in the bypass current from the control algorithm.

A similar experiment was done by decreasing the bypass wire feed speed to a lower level around 7.6 m/min (300 in./min). The experimental results are plotted in Fig. 17. It can be seen that the bypass arc voltage can be controlled at the desired voltage (39 V). Furthermore, the changes in the bypass wire feed speed did not affect the total melting current or the bypass voltage.

When the bypass wire feed speed increased abruptly from 6.4 m/min (250 in./min) to 8.9 m/min (350 in./min), the bypass arc voltage was still controlled at the desired value 39 V shown in Fig. 18. To achieve this, the bypass current was triggered to increase rapidly from 150 to 185 A. The previously mentioned experiments verified that the proposed control algorithm can effectively control the bypass arc voltage at a desired level resulting in a stable bypass arc. A stable bypass arc in turn allows for a stable consumable DE-GMAW process. Figure 19 demonstrates a uniform weld bead of consumable DE-GMAW.

**Conclusions**

This paper details how to control the stability of the bypass arc in the consumable DE-GMAW process. The authors have found:

1. The bypass arc voltage can provide a measurement for the state of the bypass arc to monitor its stability.
2. The interval model provides an effective method to describe the uncertainty of a process whose model depends on manufacturing conditions;
3. The interval model control algorithm only requires the intervals of the model parameters. These intervals may be obtained from a selected set of experiments. Thus, the interval model control algorithm is suitable for manufacturing engineers without systematical training in control;
4. A stable bypass arc plays a critical role in assuring the consumable DE-GMAW process to be an effective manufacturing process; and
5. Closed-loop control experiments verified the effectiveness of the proposed interval model control system.

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Observation of Arc Start Instability and Spatter Generation in GMAW

Spatter generation due to arc start instability was studied and a temperature model was developed to better understand electrode failure

BY U. ERSOY, S. J. HU, AND E. KANNATEY-ASIBU

ABSTRACT. Arc start instability is a common problem in gas metal arc welding (GMAW) where the arc initially fails to ignite, resulting in low weld penetration and high spatter generation. In this paper, the mechanism of arc start instability is studied using high-speed camera images and sensor data (voltage, current, and wire feed rate), and the spatter generation associated with it is explained in detail. It is shown that the extent of spatter generation due to this instability can be monitored using the voltage and wire feeding rate. An electrode temperature model that incorporates the contact resistance effects at the electrode tip and contact tube is also developed to provide a better understanding of wire disintegration with blunt tip electrodes. It is shown that the contact resistance plays an important role in electrode disintegration.

Introduction

Gas metal arc welding (GMAW) is extensively used in industry for joining sheet metal due to its high productivity and low cost. During GMAW, stable metal transfer is necessary to obtain good-quality welds that are free of spatter and weld bead discontinuity. Arc start instability is a common welding problem during GMAW. If the arc is unable to start successfully, there will be no metal deposition until the arc resumes and excessive spatter will be generated. This will result in low penetration and poor surface quality around the weld.

When the arc fails to start, the electrode comes into contact with the workpiece and heats up as a result of joule heating followed by electrode wire disintegration. The disintegrated wire pieces fly away from the tip of the electrode and stick to the workpiece as spatter. A significant amount of work exists on spatter generation during metal transfer in gas metal arc welding (Refs. 1–3). Kang and Rhee (Ref. 1) have developed a model for estimating the amount of spatter in short-circuiting metal transfer mode considering arc extinction. Various waveform (current, voltage) features were used to develop a regression model to estimate the spatter amount. Chen et al. (Ref. 2) explained the mechanism of spatter production in the short-circuiting mode of metal transfer. It is shown that spatter is mainly generated due to CO gas explosion at the instant the short circuit breaks. Kang and Na (Ref. 3) explained the spatter production using the integral of current. The influence of arc current and droplet volume on spatter production was investigated quantitatively. While most models in the literature put more emphasis on the spatter generation during successful modes of metal transfer (globular, spray, short circuiting) due to droplet-weld pool interaction, the mechanism of spatter formation during arc start instability has a different nature compared to such spatter mechanisms since there is practically no weld pool, and the spatter is mostly in the form of solid pieces of electrode wire.

The arc start problem has been studied by Farson et al. (Ref. 4) using high-speed camera imaging and current/voltage signals. The integral of measured current is used as an indication of arc start behavior. It has been shown by a temperature model that during arc initiation, finely pointed tip electrodes disintegrate close to the base metal whereas blunt end tip electrode wires were more likely to disintegrate in the middle section. In the model, the effect of contact resistance at the electrode tip and contact tube was neglected.

Incorporating contact resistance effects at the contact tube and workpiece interface enables a better understanding of the electrode disintegration.

In this paper, the failure mechanism of arc start in GMAW is studied in detail with the support of high-speed camera imaging and sensor data (voltage, current, and wire feed rate). A spatter index is developed to estimate the amount of spatter generated during the unstable arcing period using voltage and wire feeding rate measurements. In addition, a one-dimensional (1-D) electrode temperature model is developed to estimate the location of electrode wire disintegration by considering the effect of initial contact resistance at the electrode tip and contact tube. Experimental observations of the electrode wire disintegration are in good agreement with model prediction.

Experimental Procedure, Materials, and Equipment

Figure 1 illustrates the general arrangement of the experimental setup. All welding experiments were conducted using the process conditions listed in Table 1 with a stationary weld gun. The welding conditions correspond to a mixed mode of short-circuiting and globular metal transfer. The welding wire material used was AWS ER70S-6 with a diameter of 1.1 mm (0.045 in.) and the workpiece used was ASTM A36M with a thickness of 3 mm (0.12 in.). A Lincoln Power Wave 455 (constant voltage power source) was used during the experiments.

The welding current was measured using a split core Hall effect sensor and the voltage was measured across the contact tube and the workpiece. The wire feed rate was measured using an optical encoder located ahead of the wire feeder motor. Current and voltage were recorded at a sampling rate of 5000 Hz and the wire feed speed was recorded at 100 Hz. The high-speed camera images were recorded at 1000 frames per second with appropriate...
ate optical filters and backlighting using a Kodak EktaPro Imager, 1000HR. An ultraviolet filter (Quantaray 52 mm UV) was used with three neutral density filters (Hoya HMC 52 mm NDx4) in series during high-speed imaging. The ultraviolet filter basically absorbs the ultraviolet and blue rays, and the neutral density filters decrease the light intensity. The backlighting was used to capture more details at the boundary of the electrode. Since the experiments were conducted on different days, the setup (backlighting angle, camera location) was subject to variation and not all the high-speed camera images have the same image quality.

Twenty experiments were conducted that resulted in improper arc starting. The high-speed camera images together with current and voltage signature were recorded simultaneously. The welding wire tip was cut carefully before each experiment so that the tip had a blunt geometry. Spatter was collected by conducting the experiments in a copper box so that all spatter generated was captured. The spatter that stuck to the workpiece was also collected.

**Observation of Unstable Arc Start**

Under normal welding conditions, the arc starts just after the electrode tip touches the workpiece surface — Fig. 2. As the electrode tip approaches the workpiece, the first spot to make contact is subjected to high current flow. This is accompanied by rupture of asperities. The gas surrounding the spot is superheated and begins to ionize, forming the plasma. Finally, an electric discharge flows through the plasma, which starts the welding arc. As the arc starts, the tip of the electrode wire starts melting and reaches equilibrium at some melting rate. The resulting metal transfer mode is determined by the welding conditions (voltage, wire feeding rate, shielding gas, etc.). If the arc fails to start successfully, the electrode is not melted and comes into contact with the workpiece as a solid wire. Figure 3 shows a series of images for the case when the arc fails to ignite after the first contact. The electrode tip stays in contact with the workpiece along the asperities for some period until the electrode tip thermally welds to the workpiece. Due to excess heat generation, asperity explosions can be observed in Frame 2 of Fig. 3. Asperity softening and melting for stationary contacts was studied in detail by Holm et al. (Ref. 5). It is shown that due to contact softening, the contact asperities move toward each other and finally the current is conducted in solid state. As the electrode heats up, it disintegrates at some point along its extension.

**Table 1 — Welding Parameters**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage</td>
<td>34V</td>
</tr>
<tr>
<td>Wire feed rate</td>
<td>340 in./min (8.64 m/min)</td>
</tr>
<tr>
<td>Wire diameter</td>
<td>1.1 mm (0.045 in.)</td>
</tr>
<tr>
<td>Contact tube-to-work distance</td>
<td>18 mm (0.71 in.)</td>
</tr>
<tr>
<td>Shielding gas</td>
<td>100% CO₂</td>
</tr>
</tbody>
</table>
Based on the twenty experiments with arc start failure, the electrode disintegration took place at three different regions along the electrode extension. Figure 4 shows three different disintegration cases observed during arc welding experiments using the process conditions in Table 1. Thirteen of the experiments resulted in failure near the tip of the contact tube (Fig. 4A), whereas six of them failed near the electrode tip (Fig. 4B). Only one experiment resulted in failure around the middle extension (Fig. 4C). During failure near the contact tube and middle extension, the arc completely extinguished since the welding current was interrupted by an open circuit. It is observed that during tip failure, the arc resumed immediately after disintegration if the electrode tip was close enough to the workpiece.

Arc start instability has a periodic nature in the sense that the electrode wire may experience consecutive breakups until the arc starts successfully. Most of the experiments resulted in multiple electrode wire disintegrations before the arc successfully started. Once the unstable arcing cycle starts, electrode wire disintegration is necessary for the next arc start attempt, otherwise the wire may coil itself on the workpiece, which is undesirable. Arc start failure is accompanied by substantial amounts of spatter due to wire disintegration. In the next section, a spatter index will be studied to estimate the spatter quantity due to unstable arc start using process signature.

**Spatter Estimation with Unstable Arc Start**

Spatter is defined as particles of molten metal expelled during welding. During the unstable arc start period, the major portion of spatter is in the form of solid pieces and a little portion in the form of molten splashes. The molten splashes are usually generated during the asperity explosion (Fig. 3, Frame 2). They are also observed to emanate from the breakage location during wire disintegration due to high temperatures around these regions (Fig. 4C, Frame 5). The wire pieces generated as a result of an unstable arc start have more potential to contaminate the workpiece surface due to their large size.

Arc start instability can easily be monitored using voltage and current sensors in the welding circuit. Figure 5 shows a typical voltage and current signature from the welding process during the unstable arcing period. Note that the electrode wire experienced four consecutive disintegration events and the high-speed camera images show only the second disintegration event. All four disintegration events occurred near the tip of the contact tube.

As the electrode wire approaches the workpiece, the voltage recorded by the sensor is equal to the open circuit voltage, and the current is zero (Fig. 5, Frames 1, 2). The open circuit duration of the first disintegration event took relatively longer compared to the other three events since the wire feed speed was less than the steady-state value. When the electrode touches the workpiece, the voltage across the electrode first decreases and then gradually increases due to the increasing resistivity of the electrode wire with temperature (Fig. 5, Frames 3, 4).

For failure close to the electrode tip, the voltage and current signature basically follows the same pattern as in Fig. 5, except that the open circuit durations are relatively shorter due to the short length of the disintegrated wire tip.

The spatter amount can be estimated by monitoring the voltage and wire feed rate signature during the unstable arc start period since each jump of the voltage from its low value to the open circuit voltage value corresponds to a piece of wire separating from the electrode material. To quantify the amount of spatter during the unstable arcing period, a spatter index is defined as follows:

\[
SI = \pi r^2 \rho \sum_{i} \Delta T_{oc,i}
\]

(1)

where \( r \) is the electrode radius, \( \rho \) is the electrode density, \( \bar{\Delta T}_{oc} \) is the average wire feed speed, and \( \Delta T_{oc,i} \) is the open circuit duration during the \( i \)th opening event. Physically, the index is a measure of the total mass of the electrode material lost by the electrode wire disintegration, which is equal to the spatter amount. The mass of broken wire is calculated using the open circuit period, electrode speed, and the wire dimensions and density. A threshold level is used to determine when the open circuiting conditions have been achieved. Note that since the electrode speed is measured before the wire feeder, the interruptions of the wire feeding rate due to electrode contact with the workpiece.

---

**Table 2 — Numbers of Unstable Arc Start Cycles (Open-Circuiting Events)**

<table>
<thead>
<tr>
<th>Measured spatter (g)</th>
<th>0.08</th>
<th>0.087</th>
<th>0.12</th>
<th>0.21</th>
<th>0.26</th>
<th>0.27</th>
<th>0.27</th>
<th>0.31</th>
<th>0.035</th>
<th>0.41</th>
<th>0.49</th>
<th>0.55</th>
<th>0.69</th>
<th>0.71</th>
</tr>
</thead>
<tbody>
<tr>
<td>Predicted spatter (g)</td>
<td>0.21</td>
<td>0.31</td>
<td>0.19</td>
<td>0.24</td>
<td>0.35</td>
<td>0.34</td>
<td>0.46</td>
<td>0.36</td>
<td>0.33</td>
<td>0.65</td>
<td>0.51</td>
<td>0.67</td>
<td>0.72</td>
<td>0.83</td>
</tr>
<tr>
<td>No. of open circuits</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>2</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
</tbody>
</table>
piece are not felt at the measurement point. Therefore, the measured wire feeding rate is not an exact indication of the actual electrode speed at the electrode-workpiece interface and should be used with some reserve.

Figure 6 shows a linear correlation between the measured and the predicted spatter quantity measured during the unstable arcing period. Table 2 lists the number of unstable arc start cycles (open-circuiting events) for each experiment. Note that the total amount of spatter increases as the number of unstable arc cycles and the total duration of the open circuiting events increase. In the next section, a temperature model is presented that incorporates the effect of contact resistance heating to provide a better understanding of different electrode wire disintegration cases observed experimentally.

Electrode Temperature Model

During electrode contact with the workpiece, a high short-circuiting current heats up the electrode. A model for temperature distribution along the electrode is necessary to better understand the electrode disintegration since it is most likely to occur in high-temperature regions on the electrode.

Assumptions

The main assumptions incorporated in the temperature model are as follows:

1) During the electrode contact with the workpiece, the electrode length is assumed to be constant since the electrode comes to a complete stop. Therefore, it is a stationary contact at the electrode-contact tube interface.

2) The electrode is only in contact with the contact tube at its lower tip (Fig. 7A) so that branching of current due to multiple contact points along the upper electrode extension is neglected. The contact tube wear during GMAW was experimentally observed to be maximum at the tip of the contact tube, which supports this assumption (Ref. 6).

3) Contact adherence due to melting at high temperatures is neglected at the
electrode-workpiece and electrode-contact tube interface. Therefore, the contacting surfaces are assumed to have a constant area.

4) The contacting members at the electrode-workpiece and electrode-contact tube have similar resistivities.

5) Heat flow along the electrode is one dimensional.

**Governing Equations**

The electrode extension between the contact tube and the workpiece, termed lower electrode extension, is heated up by joule heating due to bulk resistance \((R_b)\). The contact resistances at the two ends of the lower electrode extension act as two heat sources. Contact resistance between the electrode and the contact tube \((R_{c1})\) is due to the loose contact (i.e., clearance gap between the electrode and contact tube) between the two surfaces — Fig. 7A. Similarly, there exists a contact resistance component \((R_{c2})\) between the electrode and the workpiece after the electrode touches the workpiece surface — Fig. 7B.

By using the configuration in Fig. 8, the governing heat equation is as follows:

\[
\frac{\partial^2 T}{\partial x^2} + \frac{q}{k} \left( T - T_0 \right) = \frac{\varepsilon \sigma P}{k A_e} \left( T^4 - T_0^4 \right) + \frac{\rho c \varepsilon P}{k} \frac{\partial T}{\partial t}
\]

(2)

where \(q\) is the heat source term due to joule heating, \(k\) is the thermal conductivity, \(P\) is the convection coefficient, \(A_e\) is the electrode area, \(T\) is the temperature, \(T_0\) is the room temperature bulk resistance, \(R_b\), \(\varepsilon\) is the emissivity, \(\sigma\) is the Stefan-Boltzmann constant, and \(\rho\) is the density. Equation 2 is a bulk resistance heating term along the lower electrode extension. Both the bulk resistance and the contact resistances are functions of temperature. The piecewise joule heating term due to contact and bulk resistance heating is given by the following expression:

\[
\begin{align*}
q & = I^2 R_{c1} \left[ T, x = 0 \right] \\
q & = I^2 R_{c2} \left[ T, x = L \right] \\
q & = I^2 R_b \left[ T, x \in (0, L) \right]
\end{align*}
\]

The initial and boundary conditions for the electron column are formulated as follows:

\[
\begin{align*}
T(x,0) & = 0 \\
T(-L,t) & = T_0 \\
T(L + L_w,t) & = T_0
\end{align*}
\]

(3)

The current flowing across the electrode wire does not change much during the electrode contact with the workpiece as can be observed from Fig. 5. The initial and boundary conditions given by Equation 4 only hold for the first electrode contact. If the electrode comes into contact with the workpiece multiple times, then during each additional contact event the electrode has some initial temperature distribution to start with. Therefore, the model does not account for the temperature distribution for additional contacts. Hence, the temperature-dependent bulk resistance of the electrode material is often modeled as

\[
R_b(T) = R_b \left[ 1 + \alpha (T - T_0) \right]
\]

(5)

where \(R_0\) is the resistance at room temperature and \(\alpha\) is the temperature coefficient of resistance. \(R_0\) is obtained by measuring the resistance of the electrode wire at room temperature. It is assumed that the electrode has constant asperity density (constant area) at the contact points and the contact resistance is also a function of temperature. By also assuming that the contacting surfaces have similar material properties, the temperature dependence of contact resistances at the contact tube and the workpiece interfaces follow a similar rule as in Equation 5 except that the temperature coefficient of resistance should be modified by a factor of 2/3 (Ref. 7). Therefore, the temperature dependence of contact resistances is modeled as
WELDING RESEARCH

\[ R_{ci}(T) = R_0(1 + 2/3\alpha(T-T_0)) \]  

(6)

where \( R_0 \) denotes the contact resistance, whereas \( R_0 \) is the room temperature contact resistance for the contacting surfaces \((i = 1,2)\).

Measurement of Contact Resistances at Room Temperature

The room temperature contact resistances at the contact tube \((R_{01})\) and workpiece \((R_{02})\) were experimentally measured by a 4-wire Kelvin method. The measured resistance between the electrode and workpiece ranged between 16 and 40 m\(\Omega\) for blunt electrode tips. The resistance value between the electrode and contact tube is highly dependent on the clearance gap between the two surfaces. For new contact tubes where the gap between the electrode and contact tube was small, the contact resistance measurements ranged between 14 and 60 m\(\Omega\), whereas for worn-out contact tubes, it ranged between 150 and 200 m\(\Omega\). The dependence of contact tube wear on contact resistance in GMAW has been studied by Zwicky and Krupp (Ref. 8). It was shown that the contact resistance at the contact tube increases as the electrode wears. It should be noted that different contact tubes and electrode materials will result in different contact resistance values at room temperature.

Simulation Results

Equation 2 was solved using Matlab with 100 time steps and 200 mesh points in the spatial coordinate. The parameters used in the heat equation are summarized in Table 3. The solution method (spatial discretization of parabolic equations) is explained in Ref. 9. The effect of heat lost by convection and radiation on the temperature distribution was negligible compared to joule heating. Figure 9 shows an example simulation result for temperature distribution along the lower electrode extension in the early stages after the electrode contact with the workpiece.

The upper electrode extension and the workpiece act as a heat sink, so the temperature has a steep gradient at the boundaries of the lower electrode extension. The room temperature contact resistance at the electrode-contact tube interface was chosen as the average of the measured values for a new contact tube free of wear. Although the temperature distribution along the electrode during the actual welding process could not be measured, it is obvious from the color intensity of the image (Fig. 9) that the electrode is hotter at the electrode tip and in the vicinity of the contact tube, which supports the model. The color intensity in the middle portion of the electrode is uniform indicating that the temperature is fairly constant as predicted by the simulation. Note that different electrode contact conditions (surface film, greasy surface, etc.) may result in variation of the temperature level in the contact regions.

The simulation results indicate that disintegration is most likely to take place at the boundaries of the lower electrode extension since melting will first start around these regions due to high temperatures. The simulation results appear to be in agreement with the high-speed camera observations. As mentioned previously, more than half of the experiments resulted in failure at the tip of the contact tube (Fig. 4A), whereas all but one of the rest had failure at the tip of the electrode (Fig. 4B). Middle section failure was observed only in one case (Fig. 4C). The contact resistance values at the two ends of the electrode play a key role in determining where the disintegration will take place since melting first starts in these regions.

For contact tubes with poor electrical conductivity due to wear and contamination during service, the electrode wire disintegration will most likely occur near the contact tube due to higher contact resistance compared with the electrode tip. For pointed tip electrodes, the electrode tip-workpiece contact resistance is expected to exceed the contact tube-electrode contact resistance, in which case the model will predict hotter spots at the electrode tip. It’s believed that the disintegration may occur around the middle section due to coupled mechanical effects due to buckling, which was not studied in this paper.

Conclusions

In this paper, the mechanism of unstable arcing due to arc start instability and its effect on spatter generation was studied. Unstable arc start can generate substantial amount of spatter depending on the electrode disintegration location as revealed by high-speed camera images. It is shown that the amount of spatter generated is directly proportional to the duration of this instability (i.e., duration of open circuiting events).

Methods are developed to monitor the unstable arcing period using the process signature and to estimate the spatter quantity associated with this instability. A temperature model that includes the effect of contact resistance is also used to enhance our understanding of the electrode wire disintegration.

It is shown that during electrode contact with the workpiece, melting first starts at the boundaries of the lower electrode extension due to the high tempera-
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