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Mazda Develops Steel and Aluminum Joining Technology that Uses Friction Heat

According to Mazda Motor Corp., Hiroshima, Japan, it has developed the world's first direct spot joining technology to join steel and aluminum.

This new technology was first employed in 2003 in the development of the company's RX-8 sports car, and used friction heat to join separate aluminum sheets. The technology has evolved and will be used to join the trunk lid and bolt retainer for the company's updated MX-5 sports car.

Welding two different metals such as steel and aluminum has been a difficult task — but by optimizing the rotating tool shape and joining characteristics, and by using galvanized steel on one side, joining steel and aluminum has been made possible. The process is similar to that of joining two pieces of aluminum when a joining gun holds the parts from both sides with a welding tool. The joining tool is then made to spin while force is applied, which in turn generates frictional heat that subsequently joins the aluminum materials to the steel sheet metal. Galvanized steel helps prevent the galvanic corrosion that results from the contact of two different types of metal.

Mazda has applied for more than 20 patents related to this technology.

Hyundai Opens Its First U.S. Manufacturing Facility

Hyundai Motor Manufacturing Alabama, LLC (HMMA), recently celebrated its grand opening. The $1.1 billion plant in Montgomery, Ala., has been under construction since 2002. It is the company's first U.S. manufacturing facility.

The 2-million sq-ft manufacturing plant resides on 1744 acres of land. It includes a stamping facility, paint shop, vehicle assembly shop, a two-mile test track, and an engine shop. It can produce 300,000 vehicles per year at full capacity.

All material flow from the stamping shop into the welding shop is 100% automated. After arriving by electro-monorails from the stamping shop, more than 250 robots in the welding shop move the material, weld, and seal, converting stamped steel into vehicles by complete automation. Automation minimizes damage to the steel.

The plant employs more than 2000 team members. Sixty-four suppliers have located businesses throughout North America to support this new plant. Altogether, these suppliers are expected to create 5500 additional jobs with a combined capital investment of $500 million.

Northrop Grumman to Build New Huntsville Campus

Northrop Grumman Corp. will construct a new five-building complex in Cummings Research Park, Huntsville, Ala. It has selected developer Colonial Properties Trust for the $80 million project to be located off Interstate 565.

The company employs about 1200 people in the Huntsville area in more than 20 facilities. Most current operations will be consolidated in the new headquarters facility, which will house offices, laboratories, and research and development centers.

The team managing the Kinetic Energy Interceptors missile-defense portion of the program is in Huntsville. Other Huntsville activities include developing and fielding advanced tactical command posts under the Command Post Platform program; serving as the prime contractor for Forward Area Air Defense; and producing the Longbow missile and Viper Strike munition.

Drew Industries Acquires Venture Welding

Drew Industries, Inc., White Plains, N.Y., recently announced its Lippert Components, Inc., subsidiary has completed the acquisition of certain assets and the business of Venture Welding, Elkhart, Ind., for approximately $19 million.

Venture Welding, a manufacturer of chassis and chassis parts for manufactured homes, modular homes, and office units, had annualized sales prior to the acquisition of approximately $18 million.

Drew said the acquisition also included several patents. The patents will permit Lippert to manufacture chassis using a cold camber process, as well as the hot cambering process currently being used.

Lippert also acquired two of Venture's four factories and will consolidate production of certain of Venture's products into its existing factories.
In today’s fast paced environment, time is valuable. Searching for safety products can rob you of that valuable time which is why Jackson Products is committed to providing our customers with high-quality safety systems. From auto-darkening welding helmets to face shields, hardhats, glasses and more, Jackson’s full line of safety products will keep you up to speed. As a trusted source for over 80 years, we are driven to providing 100% customer satisfaction. Shift into high performance protection and take our top-of-the-line NexGen Auto-Darkening welding helmet for a test drive; 14 days, risk free. Visit www.jacksonproducts.com for details on how you can experience the NexGen today.
What Stage Are You In?

As July turns into August, my daughter will celebrate her wedding day. She is not just my only daughter, but also my only child. Recently, I have been spending much of my quiet time reminiscing and recalling our years together.

As I reflect back, I can clearly identify the changing stages in her life. There were the times of her climbing into my lap to learn her numbers on a handheld calculator, growing into those parent-trying years of teenage driving, and now an adult changing her last name and beginning the foundation for her own family.

I believe that these growth stages are typical of life and are analogous to the stages of maturity we have with our membership in AWS. As new members, we are anxious to learn more about the basics of the organization. Most likely we are helped by a senior member of our local Section who serves as a mentor. After a period of time, we become more involved in AWS and are interested in working on a committee or a special project to employ our knowledge and talents. Gaining more experience, we then grow into additional stages of AWS membership.

AWS is a volunteer-driven organization. Simply stated, the organization exists only because of the work and services provided by its many active volunteers.

I recently had the opportunity to review the collective inputs of the attendees of the six Leadership Symposiums. One of the group activities of the program is to identity and offer potential solutions to common problems faced by Section leaders. In the team environment of the symposiums, the groups come together and provide great insights into the issues facing AWS Sections.

The number one problem identified each year by symposium attendees is the need for additional volunteer participation in Section activities, especially in the various leadership roles. Many of our Sections struggle to locate new volunteers to plan a meeting or special event, or who are willing start the process of becoming a Section officer. Only by the active participation of us, the AWS volunteers, can our Sections remain viable and meaningful sources of information, technology exchange, and as networks of friends and colleagues.

The numerous AWS committees are additional opportunities for personal growth in membership participation and technical knowledge. These committees include technical, educational, certification, and other subject-specific volunteer groups that come together to enhance the science and technology of welding. As with the Sections, these committees require volunteers from the membership to step forward and participate at various levels of the organization. There are opportunities for involvement on topic-specific subcommittees, through the more expansive role of technical committees, and continuing to the more global subjects discussed at the Standing Committee level of activity.

Speaking from my personal experience, there is great satisfaction in participating in AWS. I have had the good fortune to become active in many committees and subcommittees of the Society and have found these opportunities to be very rewarding, both personally and with regard to my career. Similar to my life as a dad, I can reflect back and define various stages of maturity in my AWS membership.

So I ask you, at what stage in AWS membership are you? Whether as a neophyte or sage veteran, there is a place for you in working with the nearest AWS Section or committee. Take the time to volunteer and participate.

Lee G. Kvidahl
Chair, AWS Membership Committee
Interactive Job Board for Robotics Industry Launched

Robotic Industries Association (RIA). This trade group for the robotics industry recently added an interactive career center to its Web site. Job seekers can post résumés, search job listings, and save their job search criteria so that they are automatically notified by e-mail of new listings that match their specifications. Employers can enter job descriptions, check the status of postings, edit information, renew or discontinue postings, and make payments online. With a paid job listing, employers can search the database of résumés and contact candidates. There is an automatic notification system when new résumés match an employer’s criteria. Along with each job posting, employers can provide information about their company and a link to their Web site.

www.roboticsonline.com

Online Steel Database Available

ASTM International. Users who subscribe to ASTM’s new Passport to Steel online steel database can find information about more than 20,000 alloys and standards from standards development organizations around the world. The database, developed in partnership with CASTI Publishing, Inc., incorporates steel data from ASTM, Association Française de Normalisation, American Petroleum Institute, SAE International, Deutsches Institut für Normung, British Standards Institution, Canadian Standards Association, European Committee for Standardization, Japanese Standards Association, and the International Organization for Standardization.

Subscriptions are available from ASTM Customer Service at (610) 832-9585 or mailto:service@astm.org. A one-year subscription for an individual workstation, one user, single PC access only, costs $995. For a one-year subscription, multi-user access at a single site, the cost is $1750.

Options allow users to search using the following fields:
- Standards developing organization
- Specification title
- Standard designation
- Grade, class, type, symbol, steel name
- Steel number or UNS number
- Product form (18 forms)
- Alloy group (8 groups)
- Chemical composition (search 36 elements by minimum, maximum, minimum/maximum range, nominal composition, or search for alloys containing any amount of a specific element)
- Mechanical properties such as tensile or yield strength, elongation, reduction of area, impact strength, and hardness.

Results from each search can be sorted and selected according to user preferences. Results can also be copied into programs such as Microsoft Excel® to save information electronically.

www.astm.org

Motion Controls Robotics, Inc. This Fremont, Ohio, based company recently changed its name from Motion Controls Plus, Inc., and launched a new corporate Web site. The company provides automation solutions for a variety of applications, including material handling, material removal, sanding, deflashing, arc welding, and vision-guided systems. The site offers a company history and information regarding products, service, parts replacement, and applications. It also includes several case studies that describe how robotics were used to solve specific problems. In addition, customers can register to access the customer resource center.

www.motioncontrolsrobotics.com

Web Site to Help Engineers with Industrial Automation

CMP Media LLC – Electronics Group. The company’s EE Times recently launched the Industrial Control DesignLine Web site, which is targeted at design engineers and engineering managers involved in the development of networking systems, factory equipment, robotic systems, motor control systems, and other devices used in industrial automation. Visitors can sign up for a weekly e-mail newsletter, check out the site’s technical library, participate in an online forum, read a variety of how-to articles and a blog by site editor Terry Costlow. The site also includes product information and industry news items.

www.industrialcontroldesignline.com
ESAB Equipment Chosen for Wind Tower Manufacturing Plant in Tennessee

The company's Avenger cutting machines, along with other systems, will be put to use in North America's first automated wind tower production facility in Chattanooga, Tenn.

ESAB Welding and Cutting Products, Florence, S.C., has been selected by Aerisyn, LLC, to supply all the cutting, assembly, welding, and material-handling equipment for North America's first automated wind tower production facility in Chattanooga, Tenn. The plant is expected to be in full production in August.

ESAB assisted with the plant layout and material flow design. This will be the first installation in North America of the company's automated assembly.

In addition, Aerisyn will utilize several of the company's systems, including two large cutting machines, positioning equipment, specialized welding manipulators, as well as submerged arc filler metals, and a variety of handheld welding and shop equipment.

The key to making wind towers is the ability to produce dimensionally accurate parts with precise weld preparation beveling on all sides. Two of the company's cutting machines produced at the Florence, S.C., plant will handle the task — the Avenger 1, a 14-ft-wide plasma contour bevel machine, and the Avenger 3, a 30-ft-wide model equipped with dual oxyfuel bevel heads.

Aerisyn is investing more than $7 million in equipment and capital improvements to the Alstom Building in Chattanooga. It is estimated that it will be able to produce up to 200 of the 200-300-ft-tall towers in the first year of production.

Lincoln Electric Company of Canada Celebrates its 75th Anniversary with Launch of Mobile Demonstration Unit

The Lincoln Electric Company of Canada, which is celebrating its 75th anniversary, recently launched a mobile demonstration unit (MDU). Embarking on a cross-Canada tour, the MDU comes fully equipped with some of the company’s newest welding technology.

WEPAN Award Winners Honored

The Women in Engineering Programs & Advocates Network (WEPAN) recently honored five individuals, companies, and programs for their work in the support of women in engineering.

• Barbara Bogue, Affiliate Associate Professor of Engineering Science and Mechanics and former Director of the Women in Engineering Program at The Pennsylvania State University, received the 2005 Founders Award. This award recognizes Bogue's dedicated service to the advancement of WEPAN and her contribution to an engineering infrastructure conducive to the success of women in the engineering profession.

• Clemson University’s Women in Science and Engineering Program was the recipient of the Women in Engineering Initiative Award that recognizes a program or project that serves as a model for other institutions.

• Hewlett-Packard won the 2005 Breakthrough Award for “creating a work environment that enhances the career success of women engineers of all ethnicities.” This award signifies the ability of an employer to “break through” the artificial barriers that prevent women engineers of all ethnicities from attaining their full potential.

• Sheryl Sorby, Ph.D., chair of engineering fundamentals and associate dean of engineering at Michigan Technological University, received the 2005 Betty Vetter Research Award that recognizes achievement in research related to women in engineering.

• Worcester Polytechnic University’s Diversity and Women’s Programs received the Engineers Week Award for its contributions to Introduce a Girl to Engineering Day. This is a national program aimed at encouraging young girls in their pursuit of sci-
ence, math, and engineering.

The awards were presented at the 2005 WEPAN NAMEPA (National Association for Minority Engineering Program Administrators) Annual Conference held in Las Vegas, Nev., April 10–13.

Tenaris Acquires Romanian Steelmaking Facility

Tenaris S.A., Luxembourg, has completed the acquisition of a 97% shareholding in Donasid S.A., a Romanian steel producer, for approximately $48 million.

The company is also assuming approximately $22 million in long-term debt held by Donasid with AVAS, the Romanian state privatization agency, and expects to spend an additional approximately $32 million in investments to adapt the steel shop to produce round steel bars and other improvements.

Donasid’s assets include a steel shop located at Calarasi on the river Danube in the south of Romania. The steel shop, which has an annual capacity of 470,000 tons, includes an electric arc furnace and continuous casting facilities, and uses steel scrap as its principal raw material.

Ferris State University Welding Students Receive Scholarships

Five students in the Welding Engineering Technology Department at Ferris State University, Big Rapids, Mich., have been awarded the William A. Beegle Memorial Scholarship.

The scholarship recipients were Jason Ball, Adam Blaskowski, Kenneth Camling, Jeffrey Lemke, and Brandon Reinhold.

The scholarships are in remembrance of William “Bill” Beegle, a past faculty member in the Welding Technology and Welding Engineering Technology programs at Ferris State from 1975 to 1995. Beegle was an active member of the American Welding Society and the originator of the AWS Student Chapter at Ferris State.

The scholarships were funded by Beegle’s wife, Carol, and donations from private welding industry individuals.

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World Trade Center 9/11 Investigation Could Result in New Generation of Building Safety and Fire Prevention Codes

The International Code Council (ICC) will use its code development process to address building safety and fire prevention code issues raised in the National Institute of Standards and Technology (NIST) findings from its World Trade Center investigation.

As a result of the World Trade Center attacks and proposed code changes to address terrorism-related issues in the built environment, the ICC formed an Ad Hoc Committee on Terrorism Resistant Buildings. The committee, which is made up of code officials, engineers, architects, and other building professionals, will look at the NIST report and its forthcoming recommendations, and other research.

The ICC updates its codes every three years through a governmental consensus process.

Global Metal Injection Molding Market to Reach $571 Million by 2009

According to a soon-to-be-released report from Business Communications Co., Inc., RGB-306 Metal Injection Molding, the global metal injection molding market was estimated at $382 million in 2004. This market is projected to grow at an average annual growth rate (AAGR) of 8.4%, reaching $571 million by 2009.

The metal injection molding (MIM) companies in the developed world with high-wage structures have to compete with metal and alloy parts made by conventional and established routes using low-wage earners in the developing countries. Also, there are new companies in the low-wage countries that are adopting the MIM technology.

North America comprises the bulk of the market with a share of 44.5% in 2004. Its share is likely to drop to 42% as it grows at an AAGR of 7.1% through the forecast period.

The MIM market in Japan stood at $112 million in 2004. This is the fastest growing market with an AAGR of 10.6% through 2009.

For more information, contact the company at (203) 853-4266, ext. 309 or e-mail publisher@bccresearch.com.

Industry Notes

- FANUC Robotics America and Robotic Production Technology (RPT), Auburn Hills, Mich., jointly announced the signing of a new five-year agreement where RPT is reappointed as FANUC Robotics' distributor/market channel for all water-jet and nonmetallic routing applications in the Americas.

- Airgas, Inc., Radnor, Pa., has completed acquiring the assets and operations of Vancouver Welding Supply, Inc., based in Vancouver, Wash., and Cumberland Welding & Supply Co., Inc., in Cumberland, Md.

- Rath Manufacturing, Inc., of Janesville, Wis., and Gibson Tube,

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We have been told that we are the best-kept secret in the welding industry. In an effort to correct this situation we advise that:

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<table>
<thead>
<tr>
<th>Stainless</th>
<th>Cast Iron</th>
<th>Cobalt</th>
<th>AISI</th>
<th>Nickel</th>
</tr>
</thead>
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<tr>
<td>410NiMo FC</td>
<td>33% Ni</td>
<td>1</td>
<td>4130</td>
<td>ENiCrFe-2</td>
</tr>
<tr>
<td>502 FC</td>
<td>55% Ni</td>
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<td>4140</td>
<td>ENiCrFe-3</td>
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<tr>
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<td>4340</td>
<td>ENiCrCoMo-1</td>
</tr>
<tr>
<td>E2553 FC</td>
<td>21</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>904L FC</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

THE ABOVE ARE JUST A FEW OF THE CORED WIRES THAT WE MAKE. FOR MORE INFORMATION CALL:

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Circle No. 14 on Reader Info-Card
Inc., of North Branch, N.J., are merging. A new tubing company is being formed, and it will be known as RathGibson.

- Century Aluminum Co., Monterey, Calif., recently announced that Nordural ehf., a wholly owned subsidiary, has signed an agreement with a Icelandic geothermal power producer, Hitaveita Sudurnesja hf., and the municipality of Reykjaneshaf, Iceland, to explore the feasibility of constructing a new aluminum smelter in Helguvik, Iceland, or at another mutually agreeable site. The agreement gives Nordural exclusive rights to the project. First production of primary aluminum would be targeted for 2010-2015.

- Nachi Robotic Systems, Inc., (NRS) is moving the U.S. training center to a newly constructed building, adjacent to NRS headquarters in Novi, Mich. The facility will provide 20% more training lab floor space. The company is also acquiring floor space in the same location for a 50% expansion of its U.S. manufacturing. In addition, Nachi-Fujikoshi (NF) is doubling its robot manufacturing floor space in Toyama, Japan. This facility is an investment of approximately $10 million and is situated within the main NF Toyama campus. Both facilities became fully operational in June.

- Automated Concepts, Inc., has built and moved into a new 65,000-sq-ft facility in Council Bluffs, Iowa, that provides more than 60% more space in which to design, manufacture, and program complete turnkey robotic applications.

- Draeger Safety, Inc., Pittsburgh, Pa., has been named one of three Draeger corporate central distribution points for delivering the company's respiratory protection and gas-detection products around the world. These three operating centers, located in Germany, Pittsburgh, and Singapore, will be known as operating "Hubs" within the company.

- Motion Controls Plus, Inc., Fremont, Ohio, has changed its name to Motion Controls Robotics.

- Esmark, Chicago, Ill., has completed the purchase of Piqua, Ohio-based Miami Valley Steel Services, Inc., a flat-rolled steel and value-added specialist that sells approximately 200,000 tons of steel per year, for $81 million in cash.

- Maverick Tube Corp., St. Louis, Mo., has begun work on a $12 million project to expand the capacity of its Precision Tube coiled tubing facility by more than 50%. The previously announced expansion is taking place at the company's Precision Tube Houston, Tex., facility and is expected to be completed in the first quarter of 2006.

- Alberici Constructors, St. Louis, Mo., has been awarded the national AGC/Willis 2003 and 2004 Construction Safety Excellence Award in the "Heavy Construction, Over One Million Work Hours" category. Award recipients are chosen for their commitment and approach to safety and health issues, as well as statistical results measured throughout the year.

- Chart Industries, Inc., Garfield Heights, Ohio, has completed the acquisition of Changzhou CEM Cyro Equipment Co. Ltd., a wholly owned subsidiary of CEM International (Asia).

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Circle No. 28 on Reader Info-Card
Reader Comments on Austenitic Stainless Steel Article

The following letter was sent in reference to Arthur H. Tuthill’s article "Corrosion Testing of Austenitic Stainless Weldments," which appeared in the May 2005 issue of the Welding Journal. The author’s response follows.

I wish to compliment Mr. Tuthill for his May 2005 Welding Journal article that summarized the corrosion mechanisms associated with austenitic stainless steel weldments. It was a good idea for the Welding Journal to address such welding-related subjects.

Naturally, Mr. Tuthill did not provide a detailed review of the chemicals that corrode the SS under different temperature and pressure conditions. This must be addressed by the equipment operators and, with one exception, cannot be influenced by the welding activities.

The one exception deals with welding processes that employ coated electrodes and fluxes that produce slag. When using such processes, most coatings and fluxes contain some halogens such as fluorides to chemically break down the high melting temperature oxides and thereby reduce the risk of inadequate fusion. Some of these halogens will be retained in the slag, and they can be leached out when exposed to an aqueous environment and form a strong acid. This highlights the need to remove all slag after welding.

There is no problem doing this on the OD of a pipe weld. However, it must be realized that some slag will form on the underside of a root pass and that it is often impossible to remove it on the pipe ID and some other inaccessible locations. The use of backing rings or strips does not help since some slag will form in the space between the ring and the pipe. I recall one project where a small amount of slag ate through 2 in. of stainless steel during a four-hour-long exposure to high-temperature water.

We must be sure that the welding does not contribute to any corrosive attack. Based upon the above, it is advisable to thoroughly remove all slag and not to employ any slag-producing welding process for SS root passes and for welds that are not accessible from the back side, whenever there is the possibility that the weldments will be exposed to an aqueous environment.

Harry W. Ebert, PE
Fellow of the American Welding Society

I wish to thank Mr. Ebert for his comments on problems arising from welding processes employing coated electrodes and fluxes that produce slag. Coated electrodes and fluxes were not used or covered in the work reported in the Welding Journal article, but do pose special problems as Mr. Ebert points out.

My own experience is that it is relatively easy to remove about 90% of the slag from welds made with coated electrodes, and extremely difficult to remove that last 5% left on either side of the weld bead. As Mr. Ebert points out, slag remaining on either side of the weld bead and on the ID of pipe welds can lead to "underslag" corrosion in many aqueous environments. These problems with coated electrodes are a good reason to prefer gas tungsten arc (GTAW) and gas metal arc welds (GMAW) for stainless steel pipe and vessel fabrications. For large vessels where multipass welds are required, shielded metal arc welding (SMAW) is sometimes used for completion after the root pass has been made using GMAW or GTAW.

AWS Member Reacts to Article about Temperature-Indicating Methods

The following letter was sent in reference to Robert K. Wiswesser’s article “Temperature-Indicating Methods Are Tested,” which appeared in The American Welder section of the May 2005 Welding Journal. The author’s response follows.

I was disappointed in the data clarity in the article “Temperature-Indicating Methods Are Tested” in several different ways.

First, the four figures in the article showed graphs with one axis labeled as "calibrated temperature" while the other axis was labeled "data points." Nowhere in the article or graphs were the "data points" listed or explained. Yes, it is obvious that they correspond to the indicated temperature of the measurement method. It is my contention that the graph axis for each plot should have been labeled precisely that, i.e. "indicated temperature." (By the way, whatever happened to the convention of using the independent variable on the x-axis?)

Second, the graph color selection made it almost impossible to distinguish one of the data sets. Just because graphing programs permit a user to apply different background colors and patterns does not mean that they should be used, particularly when it results in a loss of readability. There is nothing wrong with using a standard white background for graphs. Use of background patterns or colors should be reserved for cases where those patterns or colors provide useful additional information.

Third, I found the table listings for the stick melt point data to be curious and unclear. If the test sequence, as described in the article, includes using calibrated temperature increments of 50°F, how does the stick melt point temperature get reported as a temperature different than the calibrated temperature and to a precision of 0.1°F? Did the author plot the data and then extract the table data from the linear correlation line? I would guess so, but that is the point of my comment. The reader should not need to have to guess at how the data was achieved.

For technical articles, clarity in the data presentation is important in allowing the reader to, hopefully, come to the same conclusions as the authors. The concerns listed above detracted from what otherwise would have been a useful and interesting article.

Tom Doody, AWS Member

Regarding the first and second points, I agree with the commenter that the graphs are very hard to see with the colors selected. The commenter is also correct that the "data points" are the actual temperatures that were established on the heated test specimen.

The third point refers to the manner in which the temperature-indicating crayons' melting point was determined. We placed a cut section of the crayon on the specimen as the heat was increased through each data point temperature. In some cases, the crayon melted slightly below, and in other cases, slightly above the data point temperature. We recorded that temperature when the crayon started melting.

We were very surprised to observe that the crayons melted within ± 1°F of the label temperature.

One typographical error appeared in the printed article. The "Emittance of Gun 2" as referenced below the tables should be 0.95.

Dear Readers:

The Welding Journal encourages an exchange of ideas through letters to the editor. Please send your letters to the Welding Journal Dept., 550 NW LeJeune Rd., Miami, FL 33126. You can also reach us by FAX at (305) 443-7404 or by sending an e-mail to Kristin Campbell at kcampbell@aws.org.
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Circle No. 11 on Reader Info-Card
AWS Foundation is proud to announce its 2005-2006 National Scholarship Recipients

Paul Boulware
The Ohio State University
Welding Engineering
Howard E. Adkins Memorial Scholarship

"It is an honor to receive the Howard E. Adkins Memorial Scholarship. I greatly appreciate the AWS Foundation's support of welding education, and hope to use this scholarship to help make positive strides in the welding industry."

Adam Rolfe
The Ohio State University
Welding Engineering
Airgas – Jerry Baker Scholarship

"I am honored to be the recipient of the Airgas-Jerry Baker Scholarship. I would like to thank the American Welding Society and the Airgas-Jerry Baker Scholarship Committee for selecting me for the national scholarship. Your generosity is greatly appreciated."

Steven C. Woods
The Ohio State University
Welding Engineering
Airgas – Terry Jarvis Memorial Scholarship

"I am honored to be the recipient of the 2005-2006 Airgas-Terry Jarvis Memorial Scholarship. I would like to thank the American Welding Society and Airgas for their support of welding engineering students. This scholarship will allow me to focus my efforts on furthering welding technology. Lastly, thanks to my parents for their support and motivation."

Timothy Schanken
Pennsylvania College of Technology
Welding & Fabrication Engineering Technology
Edward J. Brady Memorial Scholarship

"Receiving the Edward J. Brady Memorial Scholarship is an incredible honor and I would like to thank the AWS Foundation and all of the people involved in selecting me for this prestigious award. I look forward to using the award to further advance my education in the field of welding engineering."

Adam Uziel
The Ohio State University
Welding Engineering
William A. and Ann M. Brothers Scholarship

"I am honored to be nationally recognized as a recipient of the William A. and Ann M. Brothers Scholarship. I deeply appreciate the efforts of the AWS Foundation to encourage the pursuit of careers in welding engineering. This financial support will assist me a good part of the way to finishing my welding engineering degree next year. My sincere thanks to all that made this possible."

Kurt Verhoff
The Ohio State University
Welding Engineering
Donald F. Hastings Scholarship

"I am truly honored to be the recipient of the Donald F. Hastings Scholarship. This scholarship will provide support and be a source of motivation as I pursue my degree in welding engineering. I would also like to thank the AWS Foundation for this opportunity and the national recognition."

James R. Cuhel
Ferris State University
Welding Engineering Technology
Arsham Amirikian Engineering Scholarship

"I am greatly honored to be the recipient of the Arsham Amirikian Engineering Scholarship. This scholarship is a great aid in helping me continue my education in welding engineering technology. I am also thankful for the AWS Foundation for their dedicated support for higher education."

Justin Nielsen
LeTourneau University
Welding & Mechanical Engineering
Donald and Shirley Hastings Scholarship

"The financial support provided by the Donald and Shirley Hastings Scholarship has greatly assisted my pursuit of a career in welding engineering. I look forward to the opportunity of making contributions to the field of welding engineering and am grateful for the AWS Foundation's assistance in providing me this opportunity. Thank you for supporting my education."

Circle No. 6 on Reader Info-Card
Each year, the American Welding Society Foundation provides scholarship funds to help hundreds of students who otherwise would be unable to afford a welding education. We are the only industry foundation with the specific mission of helping to fund the education of welding students. In so doing, we create the careers that sustain and grow our industry.

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To make a scholarship contribution or set up your own National Scholarship, contact Wendy Sue Reeve at the AWS Foundation. Call 800-443-9353, x293 or email wreeve@aws.org.

Thank you for your continuing support.
Q: I'm trying to consistently pass qualification tests on 3/16-in. (4.8-mm) 409 stainless steel, including a transverse face bend required by my customer. The surfaces of the bend specimens are first ground down to eliminate any notches at the bead edges. The bend radius is 3/4 in. (19 mm), so that should be easy. We are using one-side submerged arc welding (SAW). With 309L filler metal, we pass every time. But with 409Cb filler metal, we fail about half of the bend samples. The bend samples that fail are fracturing in the weld after very little bending. But the sample right next to a failed one, from the same plate, is likely to pass. What's wrong?

A: Type 409 is a very lean ferritic stainless steel that is borderline for formation of some martensite in the heat-affected zone (HAZ). ER309L works well for such a joint because the diluted weld metal will be stable austenite with quite a bit of ferrite. The austenite retains any hydrogen, largely preventing it from causing any embrittlement in the HAZ, and the weld metal itself is immune to hydrogen damage. The austenite is also not sensitive to grain size effects. The only thing that can cause problems with ER309L filler metal is excessive dilution, which can result in a fusion zone with considerable martensite, and then the fusion zone would likely fracture in a bend test. But that does not seem to be the problem in your case.

However, there are several potential problems with the ER409Cb weld metal. These include grain growth, martensite formation in the HAZ and fusion zone, and diffusible hydrogen causing loss of ductility or cold cracking. Table 1 lists the composition of the three current versions of Type 409 in ASTM A240, along with that of the ER409Cb from AWS A5.9.

Table 1 — 409 Plate and ER409Cb Compositions

<table>
<thead>
<tr>
<th>Type</th>
<th>UNS Number</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Si</th>
<th>Cr</th>
<th>Ni</th>
<th>N</th>
<th>Ti</th>
<th>Nb (Cb)</th>
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<tr>
<td>409</td>
<td>S40910</td>
<td>0.030</td>
<td>1.00</td>
<td>0.040</td>
<td>0.020</td>
<td>1.00</td>
<td>10.5 to 11.7</td>
<td>0.50</td>
<td>0.030</td>
<td>6×(C+N) to 0.50</td>
<td>0.17</td>
</tr>
<tr>
<td>409</td>
<td>S40920</td>
<td>0.030</td>
<td>1.00</td>
<td>0.040</td>
<td>0.020</td>
<td>1.00</td>
<td>10.5 to 11.7</td>
<td>0.50</td>
<td>0.030</td>
<td>8×(C+N) min.; 0.15 to 0.50</td>
<td>0.10</td>
</tr>
<tr>
<td>409</td>
<td>S40930</td>
<td>0.020</td>
<td>1.00</td>
<td>0.040</td>
<td>0.020</td>
<td>1.00</td>
<td>10.5 to 11.7</td>
<td>0.50</td>
<td>0.030</td>
<td>Ti + Nb = [0.08 + 8×(C+N)] to 0.75; Ti = 0.05 min.</td>
<td>—</td>
</tr>
<tr>
<td>ER409Cb</td>
<td>S40940</td>
<td>0.08</td>
<td>0.8</td>
<td>1.0</td>
<td>0.04</td>
<td>0.03</td>
<td>10.5 to 13.5</td>
<td>0.6</td>
<td>—</td>
<td>10C to 0.75</td>
<td></td>
</tr>
</tbody>
</table>

1. A single value is a maximum unless otherwise indicated.

Figure 1 shows two samples of welds you made with ER409Cb, one bent and one broken. Even at the low magnification of the macros, it is easy to see the grain growth that has occurred in the mostly ferritic microstructure of the weld metal and HAZ. A nearly continuous grain boundary along the centerline of each sample is visible. Such centerline grain boundaries are a plane of weakness and have been known to be prone to centerline cracking during solidification, but that is not what has happened to either sample. Note that the fracture path in the broken sample is not along the weld centerline.

At higher magnification, as can be seen in Fig. 2, it is clear that both welds contain some grain boundary martensite, indicating partial transformation to austenite during cooling from solidification. But the grain boundary martensite is not the crack path.

Note that the main crack path is across ferrite grains, and that there are secondary cracks in the ferrite beside the main crack path. The secondary cracks are parallel to the main crack or to one of two other planes in the grain. The cracking appears to be cleavage along certain crystallographic planes. I believe the cracking is due to the action of diffusible hydrogen under the slow strain conditions of bending.

Normally, one doesn't think of ferrite as being susceptible to diffusible hydrogen damage, but it has been known to happen in very coarse-grained ferritic stainless steels. You should be able to establish that diffusible hydrogen is the cause of the failures by removing the diffusible hydrogen before bending. I suggest that, after welding, you cool the sample to room temperature (to make sure that austenite has transformed to martensite), then age the samples at 250°C (482°F) for 16 h, or at 100°C (212°F) for 48 h, to remove diffusible hydrogen before bending. If you can now consistently pass the bend test, that will identify diffusible hydrogen as the cause of the failures.

Of course, you would not want to have to age the finished product at elevated temperature before putting it into serv...
ice, but a week or two at room temperature will accomplish the same hydrogen removal. And, if the weldments are intended for service in an engine exhaust system, the high temperatures of the service will accomplish the same hydrogen removal.

If diffusible hydrogen is the problem, you can very likely lessen or eliminate its effect by eliminating the sources of the diffusible hydrogen. A very significant possibility is that your flux has picked up moisture. Baking the flux at 345° to 425°C (650° to 800°F) before welding should lessen the hydrogen available from the moisture in the flux. That may be enough to eliminate the failures without any aging.

DAMIAN J. KOTECKI is Technical Director for Stainless and High-Alloy Product Development for The Lincoln Electric Co., Cleveland, Ohio. He is president of the American Welding Society, and a vice president of the International Institute of Welding (IIW). He is a member of the A5D Subcommittee on Stainless Steel Filler Metals; D1 Committee on Structural Welding, D1K Subcommittee on Stainless Steel Welding; and a member and past chair of the Welding Research Council Subcommittee on Welding Stainless Steels and Nickel-Base Alloys. Questions may be sent to Dr. Damian Kotecki c/o Welding Journal, 550 NW LeJeune Rd., Miami, FL 33126; or send e-mail to Damian_Kotecki@lincolnelectric.com.

Fig. 2 — Fusion zone photomicrographs of 409 stainless steel submerged arc welded with ER409Cb. Left — Successful bend specimen. Right — failed bend specimen.

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---continued on page 83---
The most common applications for the vehicles, and rocket fins.

2xxx series alloys are aerospace, military strength heat-treatable aluminum alloys. These alloys include some of the highest facilitate precipitation hardening. These substantial increases in strength and other elements. The copper provides copper alloys typically contain between 2 and 6% copper, with small additions of other elements. When we consider the seven aluminum alloy series used for wrought alloys (Table 1), we can see that the main alloying elements used for producing each series are immediately identifiable. Further examination of each of these elements' effects on aluminum is possible.

The principal effects of alloying elements in aluminum are as follows:

**Pure Aluminum** 1xxx. Although the 1xxx series alloys are almost pure aluminum, they do respond to strain hardening, especially if they contain appreciable amounts of impurities such as iron and silicon. However, even in the strain-hardened condition, the 1xxx series alloys have very low strength when compared to the other series of aluminum alloys. The most common applications for the 1xxx series alloys are aluminum foil, electrical bus bars, metalizing wire, and some chemical tanks and piping systems. These alloys are not heat treatable.

**Copper** (Cu) 2xxx. The aluminum-copper alloys typically contain between 2 and 6% copper, with small additions of other elements. The copper provides substantial increases in strength and facilitates precipitation hardening. These alloys include some of the highest strength heat-treatable aluminum alloys. The most common applications for the 2xxx series alloys are aerospace, military vehicles, and rocket fins.

**Magnesium (Mg) 3xxx.** The addition of magnesium to aluminum increases strength to an extent through solution strengthening. It improves strain hardening and does not significantly reduce ductility or corrosion resistance. These are moderate strength, non-heat-treatable materials that retain strength at elevated temperatures. However, they are rarely used for major structural applications. The most common applications for the 3xxx series alloys are cooking utensils, radiators, air-conditioning condensers, evaporators, heat exchangers, beverage containers, residential siding, and handling and storage equipment.

**Silicon (Si) 4xxx.** The addition of silicon to aluminum reduces melting temperature and improves fluidity. Silicon alone in aluminum produces a non-heat-treatable alloy; however, in combination with magnesium, it produces a precipitation hardening heat-treatable alloy. Consequently, there are both heat-treatable and non-heat-treatable alloys within the 4xxx series. The most common application for silicon additions to aluminum is the manufacturing of aluminum castings. The most common applications for the 4xxx series alloys are welding wires for fusion welding, and brazing of aluminum.

**Magnesium and Silicon (Mg, Si) 6xxx.** The addition of magnesium and silicon to aluminum produces the compound magnesium-silicide (Mg2Si). The formation of this compound provides the 6xxx series the ability to be heat treated. These alloys extrude easily and economically. For this reason, they are most often found in an extensive selection of extruded shapes. These alloys form an important complementary system with the 5xxx series alloys. The 5xxx series alloys used in the form of plate and the 6xxx series used in an extruded form are often joined to the plate. Some common applications for the 6xxx series alloys are handrails, drive shafts, automotive frame sections, bicycle frames, tubular lawn furniture, scaffolding, and stiffeners, and braces used on trucks, boats, and many other structural fabrications.

**Zinc (Zn) 7xxx.** The addition of zinc to aluminum (in conjunction with some other elements, primarily magnesium and/or copper) produces heat-treatable aluminum alloys of the highest strength. These zinc substantially increases strength and permits precipitation hardening.

---

**Table 1 — The Aluminum Alloy Series Used for Wrought Alloys**

<table>
<thead>
<tr>
<th>Series</th>
<th>Primary Alloying Element</th>
</tr>
</thead>
<tbody>
<tr>
<td>1xxx</td>
<td>Aluminum ≥ 99.00%</td>
</tr>
<tr>
<td>2xxx</td>
<td>Copper</td>
</tr>
<tr>
<td>3xxx</td>
<td>Magnesium</td>
</tr>
<tr>
<td>4xxx</td>
<td>Silicon</td>
</tr>
<tr>
<td>5xxx</td>
<td>Magnesium</td>
</tr>
<tr>
<td>6xxx</td>
<td>Magnesium and Silicon</td>
</tr>
<tr>
<td>7xxx</td>
<td>Zinc</td>
</tr>
</tbody>
</table>

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TONY ANDERSON (tanderson@esab.com) is Corporate Technical Training Manager for ESAB North America, Florence, S.C., and past Technical Director of AlcoTec Wire Corp., Traverse City, Mich.
Some of these alloys can be susceptible to stress corrosion cracking and for this reason are not usually fusion welded, while others within this series are often fusion welded with excellent results. Some of the common applications of the 7xxx series are not usually fusion welded, while others within this series are often fusion welded with excellent results. Some of the common applications of the 7xxx series include aerospace, armored vehicles, baseball bats, and bicycle frames.

How Aluminum Alloys Obtain Their Strength

As mentioned previously, aluminum alloys consist of both heat-treatable and non-heat-treatable types. The addition of alloying elements to aluminum is the principal method used to produce a selection of different materials used in a wide assortment of applications. The principal reason for adding the major alloying elements is to facilitate an improvement in the alloys’ physical and/or mechanical characteristics. Typically, the purpose for adding primary alloying elements to aluminum is to provide improvement in work hardening and/or precipitation hardening characteristics.

Work Hardening

Work hardening — used extensively to produce the strain-hardened tempers in the non-heat-treatable aluminum alloys — is an important process that increases the strength of materials that heat treatment cannot strengthen. This process involves a change of shape brought about by the input of mechanical energy. As deformation proceeds, the material becomes stronger, but harder and less ductile. For example, the strain-hardened temper of H18, full-hard material, is obtainable with a cold work equal to about a 75% reduction in area. The H16, H14, and H12 tempers obtained with lesser amounts of cold working represent three-quarter-hard, half-hard, and quarter-hard conditions, respectively.

Precipitation Hardening

Precipitation heat treatment precedes solution heat treating. Solution heat treating is achieved by heating a material to a suitable temperature, holding at that temperature for a long enough time to allow constituents to enter into solid solution, then cooling rapidly to hold the constituents in solution. Usually, precipitation hardening, or what is also termed artificial aging, follows. This is achieved by reheating the alloy to a lower temperature and holding it at that temperature for a prescribed period. The result is to produce a metallurgical structure within the material that provides superior mechanical properties. If, during heat treatment, the material is held at temperature for too long or the temperature used is too high, the material will become overaged, resulting in a decrease in tensile strength. It is important to recognize that the precipitation hardening process is both time and temperature controlled.

Non-Heat-Treatable Alloys

What is important from a HAZ perspective is that annealing can restore aluminum alloys strengthened by strain hardening to a full soft, ductile condition. Annealing eliminates strain hardening, as well as the microstructure that is developed because of cooled working. The heating of the HAZ, which takes place during the arc welding operation, is sufficient to anneal the base metal within the HAZ area. For this reason, the minimum tensile strength requirements for as-welded, non-heat-treatable alloys are based on the annealed strength of the base alloy. Typical tensile strengths of heating and cooling during the welding operation, arc welding on materials that have been strengthened by work hardening or precipitation hardening will change their properties. The properties of the HAZ may be extremely different than that of the original base alloy and the unaffected area of the base material — Figs. 1, 2.

The Effect of Arc Welding on the Heat-Affected Zone

In order to make a welded joint in an aluminum structure using arc welding, melting of the base metal must occur. During the melting operation, heat transfers through conduction into the base metal adjacent the weld. Typically, the completed weldment is divided into three distinct areas: the weld metal, the heat-affected zone adjacent the weld, and the base material beyond the HAZ that the welding operation has not affected. Because the HAZ experiences cycles of
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### Table 3 — Typical Tensile Strength Properties of Groove Welds in Heat-Treatable Alloys

<table>
<thead>
<tr>
<th>Base Alloy &amp; Temper</th>
<th>Base Alloy Tensile Strength (ksi)</th>
<th>As-Welded Tensile Strength (ksi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6063-T6</td>
<td>31</td>
<td>19</td>
</tr>
<tr>
<td>6061-T6</td>
<td>45</td>
<td>27</td>
</tr>
<tr>
<td>6061-T4</td>
<td>35</td>
<td>27</td>
</tr>
<tr>
<td>2219-T81</td>
<td>66</td>
<td>35</td>
</tr>
<tr>
<td>2014-T6</td>
<td>70</td>
<td>34</td>
</tr>
<tr>
<td>7005-T33</td>
<td>57</td>
<td>43</td>
</tr>
</tbody>
</table>

---

non-heat-treatable alloys in their tempered condition and as-welded are shown in Table 2.

### Heat-Treatable Alloys

In the case of the heat-treatable alloys, the HAZ will not be fully annealed. Typically, the HAZ is not maintained at an adequate temperature for a sufficient period to fully anneal the HAZ. This does not suggest that experiences in a reduction in strength in the HAZ will not occur. The effect on the HAZ of a heat-treatable alloy that is welded in the solution heat-treated and artificially aged condition is typically one of partially annealed and overaged. This condition is affected by the heat input during the welding operation. The general rule is, the higher the heat input, the lower the as-welded strength. Typical tensile strengths of some of the heat-treatable alloys in their temper condition and as-welded are shown in Table 3.

### Summary

Depending on the particular aluminum alloy type and its temper, there are often significant differences between the tensile strength of the HAZ and that of the unaffected area of the welded component. The reduction in tensile strength of the HAZ under controlled conditions, particularly with the non-heat-treatable alloys, can be somewhat predictable. The reduction in HAZ tensile strength in the heat-treatable alloys is more susceptible to welding conditions and can be reduced below the required minimum requirement if excessive heating occurs during the welding operation.

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Understanding Stainless Steel Heat-Affected Zones

By C. Meadows and J. D. Fritz

The HAZ properties are discussed as a function of microstructure.

The structural changes that occur in the heat-affected zone (HAZ) of stainless steel weldments can potentially degrade strength, toughness, and corrosion resistance. Therefore, it is important to understand which grades of stainless steel are susceptible and the kinds of degradation that can occur. The potential problems associated with stainless steel HAZs include excessive grain growth, chromium carbide precipitation, precipitation of intermetallic compounds, and improper phase balance.

Stainless steels can be divided into families characterized by the crystal structure of predominant phase or phases that are present in the microstructure. The nature of the HAZ and the possible problems that can occur in the HAZ often depend on the stainless steel family.

The “austenitic” family of stainless steels has an austenitic or face-centered cubic crystal structure. The grades in this family are by far the most widely used of any of the stainless steels. The austenitic family includes the commodity grades such as 304/304L and 316/316L stainless steel, as well as more highly alloyed grades such as 904L and 6%Mo grades like 254 SMO® (UNS S31254).

The “ferritic” family is the second most widely used group of stainless steels. These grades have a crystal structure that is primarily composed of the ferrite phase, which has a body-centered cubic crystal structure. This family includes common grades such as 409, 430, 436, 444, and the more highly alloyed grades such as Sea-Cure® (UNS S4466) and AL 29-4C® (UNS S44735).

The duplex stainless steels have a microstructure that consists of a combination of ferrite and austenite. Most commercial duplex grades have a structure that consists of approximately 50% austenite and 50% ferrite. In this family, the most widely used grade is 2205 duplex stainless steel (UNS S32205).

Other families of stainless steel include the “martensitic” grades such as 410, 420, and 440, and the “precipitation hardened” grades such as 15-5PH, 17-4PH, and 17-7PH. These steels can be hardened by heat treatment, which adds another dimension to the welding of these grades. In most cases, welding of these grades would require postweld heat treatment to restore toughness and achieve matching mechanical properties in the weld and base metal. Because of the need for postweld heat treatment, these grades are not discussed in this paper.
Potential Problems with Stainless Steel HAZs

Excessive Grain Growth

With all steels, it is desirable to avoid excessive grain growth because the strength and toughness of the steel will decrease as the grain size increases. Grain growth in the weld HAZ is usually not a problem with most stainless steels. However, grain growth can be an issue with ferritic stainless steels. The ferritic structure is much more prone to rapid grain growth than the austenitic and duplex structures. This, combined with the fact that the ferritic grades have relatively low toughness, make the ferritic grades vulnerable to embrittlement in the HAZ.

Figure 1 shows the kind of grain growth that routinely occurs in the HAZ of ferritic stainless steels. The grains in the HAZ show substantial growth compared to the grains in the base metal. As the grains increase in size, the toughness decreases and the ductile-to-brittle transition temperature increases. Because of this, it is important to verify the strength and toughness of ferritic weldments.

Reducing the heat input can minimize excessive grain growth. Another option is to choose a stabilized grade containing Ti and/or Nb additions, for example, Type 439 (Ti stabilized) instead of 430. The resulting Ti and Nb carbides and/or nitrides in the microstructure tend to pin grain boundaries slowing grain growth during welding.

Chromium Carbide Precipitation

Austenitic Stainless Steels. In these stainless steels, chromium carbides can precipitate on the grain boundaries if the steel is held for sufficient time in the temperature range of 800°-1500°F. This can be a factor because some region of the HAZ will be in this temperature range during the welding process. Chromium carbides by themselves do not lower the corrosion resistance. However, the Cr-depleted region immediately adjacent the carbides will reduce the corrosion resistance. By definition, this condition is termed “sensitization,” and when sensitization is caused by the heat input from welding, it is termed “weld decay.”

Sensitization occurs when Cr and C atoms diffuse to the grain boundaries where Cr carbides (CrC) precipitate and grow. As the carbides grow, a narrow region in the vicinity of the grain boundaries becomes depleted in Cr. As shown in Fig. 2, this condition can cause a susceptibility to intergranular attack (IGA).

During welding, there will be a volume of metal within the HAZ that is exposed to the sensitizing temperature range. If the time of this temperature excursion is long enough, sensitization will occur. As shown in Fig. 3, the sensitized zones associated with austenitic stainless steel welds tend to be slightly removed from the actual weld.

The kinetics of sensitization are a function of time, temperature, and carbon content of the stainless steel. Figure 4 shows the time-temperature regions that produce sensitization for 304 stainless steel with varying levels of carbon. Note that at 0.062% carbon, the 304 grade will suffer sensitization within a matter of minutes at 1200° to 1400°F, while a carbon content of 0.03% would require about an hour before the onset of sensitization.

Sensitization in the HAZ of austenitic stainless steels can be controlled by various means. Reduced heat input will result in less time in the sensitized temperature range and will lower the likelihood of carbide precipitation. For example, sensitization seldom occurs during welding of thin sheet material, which requires low heat input.

Low-carbon grades or L-grades limit the carbon content to 0.03% maximum. This reduced carbon level provides sufficient time for welding without the onset of sensitization. Common grades that use this approach include 304L and 316L.

An alternate approach is to use a stabilized grade such as Type 347 or 321. Stabilized grades use additions of Ti or Nb to provide resistance to sensitization. At temperatures above 1450°F, Nb and Ti have a stronger affinity for carbon than chromium. This results in the formation of Ti and Nb carbides, which removes available carbon, thus minimizing chromium carbide precipitation at lower temperatures.

If sensitization does occur, the carbides can be dissolved and the corrosion properties restored by a solution anneal heat treatment. A typical anneal cycle for 300 series stainless steel is 1900°F followed by a rapid cool. Although this approach is very effective, it is not practical to heat-treat large components such as tanks, vessels, and piping systems.

Ferritic Stainless Steels. Sensitization in ferritic stainless steel is slightly different than that in austenitic stainless. The difference is due to the lower solubility of N in the ferrite structure, which results in the precipitation of chromium nitrides (CrN) in addition to the chromium carbides (CrC). Both of these precipitates can cause sensitization and a loss of corrosion resistance in ferritic stainless steels.

Sensitization of ferritic stainless steels occurs when the alloy is cooled from a temperature above the carbide and nitride solubility temperatures (about 1700°F). Hence, a much higher temperature excursion is required to sensitize the ferritic
grades compared to the austenitic grades.

Diffusion is more rapid in the ferritic grades compared to the austenitic grades. Hence, unstabilized ferritic grades cannot be cooled fast enough using typical industrial processes to avoid carbide and nitride precipitation. Also, with standard production processing, it is not cost effective to reduce the C and N to levels that will prevent carbide and nitride formation. Because of this, most commercial ferritic grades rely on a combination of reduced C and N contents and additions of Ti and/or Nb to prevent sensitization.

Figure 5 shows IGA of a sensitized ferritic stainless steel weld. Note that the attack occurs in the weld and in the HAZ immediately adjacent the weld. This is because these are regions that reach the required 1700°F temperature to initiate sensitization. This is different than the austenitic grades where sensitization occurs in the temperature range of 800°-1500°F.

Reduced heat input during welding cannot be used to avoid sensitization with ferritic grades of stainless steel. Sensitization of ferritic stainless steels is usually avoided by selecting an adequately stabilized grade. Many of the commercial ferritic grades such as 409, 439, and 444 mandate sufficient Ti and/or Nb content to allow normal welding operations. With unstabilized grades such as Type 430, a postweld heat treatment can be used to restore corrosion resistance. This heat treatment consists of holding the steel in a temperature range of about 1000°F-1200°F for a long enough time for Cr to diffuse back into the Cr-depleted regions restoring the corrosion properties.

**Duplex Stainless Steels.** The duplex stainless steels and most of the more highly alloyed austenitic stainless steels such as 904L and the 6%Mo grades have carbon contents below 0.03%. These grades are essentially low-carbon grades and sensitization during welding is typically not a concern.

**Intermetallic Compounds**

An intermetallic compound is a phase that is formed from two or more metals.

With stainless steels, intermetallic compounds are formed from alloying elements such as chromium and molybdenum, which removes these elements from their role of providing corrosion resistance. There are several intermetallic compounds possible in stainless steel, but the most common are sigma phase and to a lesser extent chi phase. Both of these intermetallic compounds form over the same temperature range (1050° to 1900°F). It is common to refer to all intermetallic compounds that form in this temperature range as sigma phase even though sigma may be only one of several intermetallic compounds that are present.

The formation of sigma reduces the corrosion resistance of stainless steel. Even worse is that the presence of sigma embrittles the stainless steel. Sigma formation can occur in austenitic, ferritic, and duplex stainless steels, and occurs more readily in grades that have higher levels of Cr and Mo.

The kinetics of the sigma and chi transformations depends on the alloy composition. Higher chromium and molybde-
Intermetallic Precipitation in Austenitic Stainless Steels. Figure 6 shows the time-temperature-precipitation diagram for sigma formation in some common austenitic stainless steels. For the more highly alloyed grades, the precipitation kinetics can be quite rapid in the 1450°F to 1650°F temperature range. For example, with the 6%Mo grade, 254 SMO®, sigma will form in less than a minute at 1450°F to 1650°F. Because of this rapid precipitation, heat input during welding must be minimized to prevent sigma formation in the HAZ.

The impact of sigma formation on the corrosion resistance of a 6%Mo austenitic stainless steel is shown in Fig. 7. The critical temperature required to produce pitting can decrease substantially when sigma is precipitated.

Intermetallic Precipitation in Ferritic Stainless Steels. Sigma and chi phases can precipitate in the HAZ of ferritic stainless steels, particularly in the higher Mo-bearing grades. In addition to sigma and chi formation, ferritic stainless steels are also susceptible to alpha prime formation, which can embrittle the alloy. Alpha prime occurs in the range of 500°F to 1000°F and is often termed “885 embrittlement.” The time-temperature-precipitation diagram in Fig. 8 shows the regions of sigma and alpha prime formation in 26%Cr-4%Mo ferritic stainless steels. Because of the long times required to form the alpha prime phase, 885 embrittlement is generally not a problem during welding.

As with the austenitic grades, intermetallic precipitates reduce the toughness and corrosion resistance of ferritic stainless steels. Figure 9 shows the influence of time and temperature on brittle fracture in a 29%Cr-4%Mo ferritic stainless steel.

Intermetallic Precipitation in Duplex Stainless Steels. The time-temperature-precipitation curves for the formation of intermetallic compounds in various du-
The austenite transformation to proceed. If the cooling rate is too rapid, there is not sufficient time for forms to austenite. If the cooling rate is reached where some of the ferrite transforms to austenite, a transformation temperature is mended to maintain 30 to 70% volume fraction of the austenite.

Improper Phase Balance

The properties of duplex stainless steels depend on maintaining a proper volume fraction of austenite and ferrite. Most commercial grades have a target of 50% austenite and 50% ferrite. A volume fraction of ferrite of more than about 70% can lead to a loss of toughness. Similarly, if the HAZ becomes too enriched in the ferrite phase, there could be a reduced resistance to stress corrosion cracking. Because of this, it is generally recommended to maintain 30 to 70% volume fraction of the austenite.

At temperatures above approximately 2550°F, duplex stainless steels have a structure that is completely ferrite. Upon cooling, a transformation temperature is reached where some of the ferrite transforms to austenite. If the cooling rate is too rapid, there is not sufficient time for the austenite transformation to proceed, and the structure will be enriched in the ferrite phase.

When welding a duplex stainless steel there is a balance between too much heat input, which can result in sigma formation, and too little heat input, which can result in a high volume fraction of ferrite. Actually it is not the low heat input but the very rapid cooling rates that occur with low heat inputs that enriches the structure in ferrite.

The nitrogen in a duplex stainless steel is a strong austenite former and it causes austenite to form quickly, at a high temperature. With the high nitrogen levels in today's duplex stainless steels, it is possible to do most routine welding and still achieve adequate austenite levels in the HAZ. As shown in Fig. 12, welds that have very high cooling rates are prone to excessive ferrite levels in the HAZ. Problem applications include tube-to-tube sheet welding, thin sheet linings on plate structures, and resistance welds. When welding these types of applications, it is possible to increase the austenite volume fraction by preheating the metal to 200°F before welding. When using preheat, care must be taken to maintain the temperature of the metal below 500°F or alpha prime precipitation can occur.

Heat Tint

The presence of heat tint on the weld and HAZ of any stainless steel will lower the corrosion resistance (Ref. 5). Heat tint on stainless steels is primarily composed of chromium oxide, and when it forms, it depletes the underlying metal surface of chromium. When left intact, heat tint will make the surface more susceptible to pitting and crevice corrosion. Heat tint and the underlying chromium-depleted layer should be removed using either a chemical cleaning method or a combination of mechanical cleaning such as brushing, grinding, or blasting followed by chemical cleaning. Chemical cleaning typically consists of either immersion in a nitric/hydrofluoric acid pickling bath or applying a pickling paste to the affected surface. For guidance on cleaning heat tint from stainless steel see Refs. 7, 8.

Conclusions

Depending on the stainless steel family and the weld procedure, a loss of corrosion resistance, strength, and toughness can occur in the HAZ. An understanding of the various types of degradation mechanisms and which stainless steels are susceptible is helpful in avoiding problems. Proper selection of stainless steel base material and weld procedures will ensure minimal loss of properties in the HAZ of stainless steels.

Table 1 — The Effects of Sigma Formation on 2205 Duplex Stainless Steel

<table>
<thead>
<tr>
<th>Condition</th>
<th>CVN Impact Energy (ft-lb at -40°F)</th>
<th>Critical Pitting Temp (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mill Annealed</td>
<td>Mill Annealed</td>
<td></td>
</tr>
<tr>
<td>1950°F + water quench</td>
<td>185</td>
<td>35</td>
</tr>
<tr>
<td>Plus 5 minutes at 1550°F</td>
<td>196</td>
<td>25</td>
</tr>
<tr>
<td>Plus 10 minutes at 1550°F</td>
<td>25</td>
<td>15</td>
</tr>
<tr>
<td>Plus 15 minutes at 1550°F</td>
<td>32</td>
<td>10</td>
</tr>
<tr>
<td>Plus 20 minutes at 1550°F</td>
<td>21</td>
<td>9</td>
</tr>
</tbody>
</table>

References

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American Welding Society
Founded in 1919 to advance the science, technology and application of welding and allied processes including joining, brazing, soldering, cutting and thermal spray.
Resistance spot welding (RSW) is one of the welding processes that involves the joining of two or more metal parts together in a localized area by applying heat and pressure (Ref. 2). For applications such as medical devices and electronic components, the welded parts are thinner and smaller compared to common RSW applications. Therefore, the authors refer to this process as “Small Scale” RSW (SSRSW) (Refs. 1, 5).

Studies of the SSRSW have shown that 20% of the welding quality issues are welding schedule or power supply related (Refs. 3–5). Therefore, the study of different weld schedules and control schemes will contribute to weld quality improvement. This article presents the design and development of a novel power supply, which can provide a testing bench for these studies, and at the end implement the final results of the studies.

This power supply uses pulse width modulation technique, with low cost MOSFETs, to convert the power of a 12-V battery to the weld current up to 800 A. Microprocessor/controller technology is used in the novel design, which provides the flexibility for the application of different control schemes. The operation of the proposed power supply has been simulated, and the simulation results agreed with the experiments very well. Based on the experimental data, the weld quality and the stability of three different control modes have been analyzed, and the results indicated that the constant power control achieved the best weld quality.

System Description

Figure 1 shows the system diagram of a SSRSW system, which consists of a micro welding machine, a DC power supply, and a 12-V battery.

The designed power supply consists of the following three major sections: the power section, the control electronics, and the microcontroller. Figure 2 illustrates the system block diagram.

The power section is a DC/DC converter, which converts the input power from the 12-V battery to an appropriate output voltage to feed the welding machine. Power MOSFETs are used as the switching components, which switch at a frequency of 20 kHz. Filter capacitors are used to assist the ripple current required during the high-frequency switching. An output inductor is used to filter the output current.

The control electronics section includes the driver circuits for the MOSFETs, the sensing circuits for voltage and current, and other electronics circuit for the control purpose.

The microcontroller is the central control unit of the system, which includes both the hardware and software. Based on the given reference and feedback signals, the microcontroller implements the control schemes and provides the PWM signal to drive the MOSFETs in the power section. An 8-bit microcontroller, PIC16F73 from Microchip, Inc., was selected as the CPU of the system.

Control Schemes

The following four control modes are set in this power supply:
1) Voltage control mode;
2) Current control mode;
3) Power control mode; and
4) Generic control mode.

The voltage control mode is to control the output voltage as constant; the current control mode is to control the output current as constant; the power control mode is to control the output power as constant; and the generic control mode is to control the output voltage, current, and power as constant.
rent and power applied at the welding machine tips change along with the load resistance. In the current control mode, the load current is kept as constant. The voltage needs to be adjusted according to load resistance, and the power changes accordingly. In the power control mode, the voltage is adjusted to keep the power constant. Consequently, the current changes as well.

A generic control scheme is discussed, which covers all three control modes above. Figure 3 presents the block diagram of the generic control scheme.

A variable called equivalent power \( P_e \) is defined as \( P_e = V^\alpha \times (I^{1-\alpha}) \), where \( \alpha \) is a control index, which has the range between 0 and 1. The reference \( \text{Peref} \) and feedback \( \text{Peo} \) are all based on this definition. The PI controller takes the error signal \( e \) and calculates the duty ratio \( D \) of the PWM applied to the power supply.

The generic control scheme can represent all three control schemes discussed above by using a different control index \( \alpha \). When \( \alpha = 0 \), the equivalent power \( P_e \) equals to the current \( I \); therefore the generic control scheme is equivalent to the current control. When \( \alpha = 1 \), the equivalent power is the voltage, and the generic control scheme represents the voltage control. When \( \alpha = 0.5 \), the equivalent power is defined as the square root of the output power, and the generic control scheme is the same as the power control.

### System Simulation

The operation of the DC power supply is studied through simulation. Figure 4 shows the simulation model for the closed-loop constant current control mode of the SSRSW system.

The load-dynamic resistance is the key component in this model. The load is the welding machine, and its impedance consists of the following components:
1. Resistance of the electrodes;
2. Bulk resistance of the workpieces;
3. Contact resistance between the electrode and workpiece;
4. Contact resistance between pieces; and
5. Resistance of the cables.

An equivalent RL component should be an adequate representation for the load. However, to simplify the simulation, components 1 and 5 are considered in the miscellaneous loss resistance, and the cable inductance is lumped in with the battery inductance. Therefore, in the simulation model, the load only represents the components 2, 3, and 4, which will be changing during the welding process.

That's why it is also called a dynamic resistance.

In reality, the dynamic resistance is a complicated function of different variables like current, voltage, and temperature. To simplify the study, the following assumptions are made:
1) The welding process takes 20 ms; and
2) A single resistance curve can be used regardless of power supplied.

According to these assumptions, the dynamic resistance is described as a function of time. Figure 5 gives an example waveform of this function taken from Ref. 7. Based on the experimental data from the prototype, an analytical expression for the dynamic resistance is obtained as Equation 1

\[
R_{\text{welder}} = (1.1433^t - 0.8867) \cdot (u(t) - u(t-1)) + (0.7937(t+5.4253) + 0.03) \cdot 0.025 \\
(1)
\]

where \( R_{\text{welder}} \) is the dynamic resistance in m\(\Omega \), \( t \) is the time in ms, and \( u(t) \) is the unit step function.

Figure 6 shows the simulated load voltage and current, battery current, and capacitor voltage during switching. The simulation results are verified by the later experimental results.
Experimental Results

Experimental Setup

The experimental setup includes a SSRSW machine, the developed DC power supply, current and voltage sensors, a data acquisition system, and a personal computer (PC). Figure 7 shows the block diagram of the setup.

The SSRSW machine is a Model 80 Series from Unitek Peco. The welding force can be adjusted by selecting a trigger point within a range of 2 to 20 lb. When the force reaches the trigger point, a trigger signal is sent to the DC power supply, which controls the welding current flowing through the electrodes and the workpieces. A voltage sensor and a current meter are used to measure the electrodes’ output tip voltage and welding current, which are transmitted to the PC through the data acquisition system.

The data acquisition system is a Single-Board Simulator from DSpace, Inc., which includes a connector panel, PPC controller board, and the software. The connector panel samples the measured signals, and the PPC controller board is inserted into the computer and communicates between the PC and the connector panel. The software does the job of signal processing. A Tektronix TDS 2014 oscilloscope is used to monitor some critical signals during the welding process.

Experimental Results

Parameters obtained from the lobe tests were implemented in welding tests for the three control modes. The welding test results provide the data for further analysis and comparison of the three control modes.

Figure 8A–C shows the output waveforms under different control modes. The experimental results show that the novel power supply can provide sufficient power and control the welding process successfully.

Experimental Data Analysis

Based on the experimental data from the welding tests, further statistic analysis has been performed. The effects of the three control modes are compared according to the statistic analysis results.

The variance of the nugget size is used to evaluate the general effect of the control mode on the welding quality. The smaller the variance, the less the dispersion of the samples, and the more consistent the weld quality. The repeatability of the system is used to check that the change in consistency of the weld nuggets is due to the mode of the power supply and not a result of the implementation of the control modes.

The measured nugget sizes under the three control modes are presented in Fig. 9. Note that the open loop or voltage control has least repeatability and, hence, requires loose set points.

The variance of nugget size is expressed as the following:

\[ \sigma^2_d = \frac{1}{n} \sum_{i=1}^{n} (D_i - \bar{D})^2 \]  

where \( D_i \) is the diameter of the nugget sample, \( \bar{D} \) is the average of the nugget diameters, and \( \sigma^2_d \) is the variance of the nugget size.

The variances of nugget size under the three control modes have been calculated and the results are illustrated in Fig. 10. It is obvious that the variance for the power control is the smallest, and then the current control mode, followed by the voltage control mode. The analysis results indicate that the power control mode achieves the best welding quality for the material of workpieces used in the study.

The variables used to measure repeatability for the three control modes are listed in Table 1. For the open-loop mode, the control variable is the duty cycle, which is
Fig. 8 — A — Output waveforms under open-loop voltage control; B — constant current control; and C — constant power control modes.

Fig. 9 — Nugget diameters under different control modes.

Fig. 10 — Comparison of variances of nugget size for three control modes.

Fig. 11 — Tip voltage waveforms under voltage control mode.

not an appropriate variable for testing repeatability of the controller implementation. However, control of the duty cycle, theoretically, is a form of voltage control. Hence, we have used tip voltage to measure repeatability for this mode. Figures 11 through 13 show the measured waveforms of the repeatability variables from the repeated experiments under the three control modes, respectively.

In order to compare the three control modes, the normalized values are used in the definition of the variance of the repeatability variable. The variance of the repeatability variable at time moment $t$ is defined as:

$$\sigma^2_c(t) = \frac{1}{n} \sum_{i=1}^{n} \left( \frac{C_i(t)}{C(t)} - 1 \right)^2$$

(3)

where $\sigma^2_c(t)$ is the variance of the repeatability variable at time moment $t$, $n$ is the number of samples, $C_i(t)$ is the repeatability variable at time moment $t$, and $C(t)$ is the average of the repeatability variable at time moment $t$.

Figure 14 shows the variances of repeatability variables as functions of time for three control modes.

The variance of the repeatability variable over the whole welding process is defined as:

$$\sigma_c = \frac{1}{N} \sum_{i=1}^{N} \sigma_c(i)$$

(4)

Figure 15 shows the variances of
repeatability variables over the whole welding process under the three control modes. From small to large variances, the control modes are the current control, the power control, and the open-loop voltage control. The analysis results indicate that among the three control modes under study, the current control mode is the most stable.

The figure also shows that the variances of all three-control modes are getting larger at the end of a welding period, and it indicates that the preset welding length 20 ms may be too long for the tested materials.

**Conclusion**

A low cost, highly flexible welding power supply has been built. This power supply is ideal for testing new control parameters. It has been determined that constant power control mode produces more consistent sized nuggets. The implemented three control modes, voltage control, current control, and power control modes can be seen as three special points in the generic power control mode. The V-shaped nature of our existing results suggests that α for the generic control has not yet been determined.

**References**


With this welding technique, tight control over subsequent weld beads is used to control the properties of previously deposited beads and the heat-affected zone.

**BY WALTER J. SPERKO**

For many years, metallurgists have recognized that welding can have both positive and negative effects on the properties of the base metals being joined, as well as on previously deposited weld metal. Historically, one way of ameliorating some of the deleterious effects was postweld heat treatment of welds. Postweld heat treatment was sometimes known as stress relieving because it lowered residual stress in welds from yield-point order of magnitude to about one-third of yield. For high-carbon steels or low-alloy steels, postweld heat treatment also tempered hard microstructures containing martensite, improving resistance to cracking by improving the toughness of the weld metal or heat-affected zone (HAZ).

Modern steels have changed much of this. Postweld heat treatment is no longer a universal good as it was when steel properties were controlled by solution strengthening mechanisms. In fact, many high-performance steels are designed to be used in the as-welded condition. Microalloyed steels, particularly those containing vanadium, will lose toughness if postweld heat treated.

To optimize the properties of welds in modern steels where postweld heat treatment is not performed, or to optimize properties of steels where postweld heat treatment might be desirable but is not practical, special welding techniques are used. Foremost among these is temper bead welding.

The 2004 edition of the ASME Boiler and Pressure Vessel Code, Section IX: Welding and Brazing Qualifications, added requirements for qualification when using temper bead welding. It defines temper bead welding as the following: “A weld bead placed at a specific location in or at the surface of a weld for the purpose of affecting the metallurgical properties of the heat-affected zone or previously deposited weld metal.”

The purpose of depositing a temper bead, then, is to affect the properties of the HAZ or the weld metal beneath that...
bead that is being placed at a specific location. What the definition implies, but does not say, is that the temper bead improves the properties of the HAZ or the weld metal located under the temper bead. To understand how this happens and how to optimize the effect, a little metallurgy is necessary.

Figure 1 shows a segment of the iron-carbon equilibrium phase diagram and the locations on the diagram that mark transition points in the HAZ. Keeping it simple, any portion of the HAZ that is heated above the lower transformation temperature ($A_T$) is subject to changes in microstructure and mechanical properties upon cooling. Those changes can vary from minimal for a low-carbon steel that cools slowly to extreme hardening and embrittlement for a mid-carbon steel containing a few percent chromium, molybdenum, or just a little vanadium.

The factors that determine exactly what microstructures exist in the HAZ after a weld bead is deposited depend mostly on two factors.

1. The chemical composition of the base metal. This is usually expressed using a carbon equivalent (CE) formula such as that published by the International Institute of Welding (IIW): $CE = C + \frac{Mn}{6} + \frac{(Cr + Mo + V)}{5} + \frac{(Ni + Cu)}{15}$. The higher the CE, the more hardenable the steel is, and the easier it is to damage during welding. (Note that temper bead techniques normally only apply to carbon and alloy steels. Temper bead welding is not done to austenitic stainless steel, aluminum, copper, nickel, or titanium alloys.)

2. The cooling rate. Faster cooling rates cause harder and more brittle microstructures in higher CE materials. Thicker materials cool faster than thin ones. Welds made with lower heat input cool more rapidly than those made with high heat input. Welds made on cooler base metals cool more rapidly than welds made on hotter base metals.

Other areas of the HAZ are also affected during welding. The portion of the HAZ that sees temperatures above $1900^\circ F$ experiences grain growth forming the coarse grain region — Fig. 1. The longer this region stays above the grain growth temperature, the more grain growth there is. The larger these grains become, the more the toughness of that region deteriorates.

What factors affect the amount of grain coarsening that occurs? The same ones that affect the cooling rate: Rapid cooling results in a smaller HAZ and less loss of toughness in the HAZ. Slow cooling results in more loss of toughness.

**Optimizing Temper Bead Welding Parameters**

Going back to the definition, a temper bead is a weld bead placed at a specific location for the purpose of affecting the metallurgical properties of the HAZ or previously deposited weld metal. Once one deposits the first bead, the properties of that bead and its associated HAZ can be changed by weld beads that are deposited next to that bead; the energy flowing from the weld pool raises the temperature of the previously deposited weld and HAZ to “temper” it.

As shown in Fig. 2, a portion of the weld metal and HAZ of the first bead is remelted by the heat from the second bead. If the second bead overlaps the first bead a lot, much of the weld metal and HAZ of the first bead is gone, as shown in the figure; if it only overlaps a little as the third bead overlaps the second, little of the HAZ of the second bead will be affected.

Obviously, the successive beads cannot completely overlap the earlier beads because that would result in a lump of weld metal that would not be very useful; tempering occurs when successive weld beads overlap previous weld beads by 30 to 70%, the optimum being 50%. This is most easily done by having the welder run a stringer bead or a small weave with the electrode pointed at the toe of the previously deposited weld bead. It is also important to make the beads consistent in width and thickness to ensure uniformity of tempering by the next bead and next layer of weld metal.

Once the first layer of weld metal has been deposited over an area, the second layer is deposited. The energy from each bead of the second layer not only affects neighboring beads just like in the first layer, but that energy penetrates into the weld layer below the second layer where it further tempers that weld metal and some of the HAZ beneath the layer — see Fig. 3. Note how the second layer HAZ overlaps the coarse-grain regions of the first layer completely as well as a large portion of the fine-grain regions. Multiple thinner layers provide more uniform tempering than a couple of thick layers.

In the old days, the effectiveness of the second layer on tempering the first layer was enhanced by grinding off part of the first layer — the so-called “half-bead technique.” The difficulty with this technique was accurately controlling removal of the first layer weld metal. One could not easily tell if enough or too much of the first
layer was removed. Later research showed that one could optimize the effectiveness of the second layer by only grinding enough to clean and slightly smooth the first layer, then depositing the second layer using heat input that was about 30 to 70% greater than the heat input used on the first layer. This resulted in optimum overlap of the second layer HAZs over those of the first layer without the labor, aggravation, and uncertainty of grinding off a lot of otherwise perfectly good weld metal. For shielded metal arc welding (SMAW), increasing the electrode size by one size while keeping the same welding technique generally accomplishes this.

Once the second weld layer has been deposited, controlling subsequent weld layers remains critical to control the HAZ properties until at least 3/16 in. (5 mm) of weld metal has been deposited over the base metal.

### Measuring Heat Input

Heat input can be measured three ways. First is the classic heat input formula

\[
\text{Heat input} = \frac{\text{Volts} \times \text{Amps} \times 60}{\text{Travel speed}}
\]

In this formula, heat input is measured in Joules/inch (J/in.) or Joules/mm (J/mm) depending on whether the travel speed is measured in inches per minute or millimeters per minute. Because the numbers are large, this product is usually divided by 1000 and expressed in kilojoules per unit length (i.e., kJ/in. or kJ/mm).

The second way to measure heat input is by the length of weld deposit per unit length of electrode consumed. This method is particularly easy to use with SMAW because it does not require the welder to measure the amperage, voltage, or travel speed when making production welds. The basis for this method is simply that it takes a certain amount of energy (Joules) to melt a given length of electrode. It does not matter whether the amperage used was at the high end of the electrode's operating range or the low end — the amount of energy consumed is the same at both extremes for all practical purposes. If that energy is spread out over a given length as a weld bead, and that length is divided into measurement units, the energy per unit length will be constant. For example, if it took 120 kJ of energy to melt a 3/16-in. (3.2-mm) electrode from a 14 in. length to a 2-in. stub, and that energy was spread out over a 4-in. length, the equivalent heat input would be 30 kilojoules per inch of weld length. If that energy were spread out over a 3-in. length, the heat input would be 40 kilojoules per inch of weld length. One does not need to calculate the energy that it takes to melt the electrode when using this method; one only needs to measure the length of weld beads deposited for each unit length of electrode consumed. Heat inputs qualified using this method are valid for only the size electrode used, although by measuring both deposit length per unit length electrode and the heat input using the formula for various electrode sizes, one can easily develop correlations between different electrode sizes.

The third method of measuring heat input is by the size of the weld bead. A larger bead will contain more energy and automatically have a higher heat input per unit length than a smaller bead. Weld bead size should be measured as width x thickness for each bead, and the product recorded as the bead area.

To measure the heat input, one simply records the heat input by any of the three methods for each pass on the first layer, then selects a representative value to record on the procedure qualification record (POR) for that layer. This process is repeated for subsequent layers until the test coupon is welded out.

### Specifying Heat Input in the WPS

When writing the welding procedure specification (WPS), the heat input for each weld layer recorded on the POR becomes the basis for the heat input limits specified on the WPS. While it is not necessary to use the same heat input in production as was used on the test coupon, the ratio of heat input between layers must remain constant as shown in Table 1.

For production welding, if the welder selected a heat input for layer 1 (the layer against the base metal) of 60 kJ/in., the nominal heat input for the next layer is required to be 90 kJ/in. For P-1 metals, section IX sets a tolerance of ±20%, so the heat input for the second layer can be from 72 to 108 kJ/in.

One might ask if this is technically sound. Doesn’t increasing the heat input against the base metal increase the size of the HAZ? Yes, that does, but by increasing the heat input in the next layer proportionally, that layer’s HAZ is also increased proportionally. Imagine making the weld beads in Fig. 3 twice as large as they are on the figure; the HAZ of each bead increases proportionally, and the figure does not look any different with beads twice as large — except that it is larger.

A WPS that specifies that “the heat input for the second layer shall be between 72 and 108 kJ/in.” is adequate unless the welder has been trained how to calculate the heat input based on the amps, volts, and travel speed that he or she will be using. This means that the welder would have to have a calculator and a stop watch, and understand the math. In the author’s opinion, heat input should be controlled in the WPS by appropriate nomographs or by tables showing the amperage and corresponding travel speeds for a given heat input. For example, a heat input showing 72 to 108 kJ/in. at 28 V is detailed in Table 2.

By this table, if the welder chooses to weld at 225 A, he or she has to be within the range of 3.5 to 5.2 in./min travel speed. All WPSs that specify heat input controls should provide the heat input parameters in such a manner that the welder and the QC inspector do not have to calculate anything — they just look it up and use the required parameters. This includes specifying heat input by deposit length per unit length of electrode (which would simply be a minimum and maximum deposit length per unit length of electrode) or a bead width range assuming some typical weld bead thickness.

### Table 1 — Example of Calculating Heat Input Ratios between Weld Layers

<table>
<thead>
<tr>
<th>Layer Number</th>
<th>PQR Heat Input*</th>
<th>Ratio</th>
<th>WPS Heat Input 1</th>
<th>WPS Heat Input 2</th>
<th>WPS Heat Input 3</th>
<th>WPS Heat Input 4</th>
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</thead>
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<tr>
<td>1</td>
<td>30</td>
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<td>25</td>
<td>30</td>
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<tr>
<td>2</td>
<td>45</td>
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<td>1.22</td>
<td>45.8</td>
<td>55</td>
<td>73.3</td>
<td>110</td>
</tr>
</tbody>
</table>

*All heat inputs shown are in kJ/in., but could be expressed as bead size or deposit length per unit length of electrode.

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Table 2 — Travel Speed Range for Various Amperages at 72 and 108 kJ/in. at 28 V

<table>
<thead>
<tr>
<th>Amps</th>
<th>Minimum Travel Speed(a) (in./min)</th>
<th>Maximum Travel Speed(b) (in./min)</th>
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<tr>
<td>300</td>
<td>4.7</td>
<td>7.0</td>
</tr>
</tbody>
</table>

(a) Based on 108 kJ/in. heat input.
(b) Based on 72 kJ/in. heat input.

Heat Input for Fill Layers

Fill layers are those that complete the weld joint after the layers affecting the HAZ have been deposited. Because these layers are weld metal being deposited over weld metal, the welding engineer can choose appropriate filler metals to ensure that the weld metal has appropriate properties. If the basis for temper bead qualification is impact testing, the normal supplementary essential variable QW-409.1 applies. In this case, the heat input may not exceed that qualified for the fill layers. If the basis for qualification is hardness limits, the heat input may not be less than 20% below the heat input qualified.

Optimizing Properties at the Toe of a Completed Weld

After completing a weld using the temper bead technique, there is still one region where no tempering of the HAZ has occurred. That is at the toe of the weld as shown in Fig. 3. In addition, there is weld metal that is also not tempered. If necessary to obtain the desired properties, one may have to add an additional layer of weld metal to the completed weld — and then grind it off. This results in tempering of the remaining untempered weld metal and HAZ. One does, however, have to be careful when approaching the edge of the weld not to let this extra tempering layer get too close to the toe of the weld. If it does, it will create a new untempered HAZ. The trick in optimizing the properties at the toe of the weld is to place the tempering bead a short distance from the toe, typically 3/8 to 5/8 in. This allows the heat from the tempering bead to penetrate the weld metal and the HAZ at the weld toe, tempering both. Often, just tempering the weld toe is adequate to achieve the required properties, avoiding the extra work of overlaying the entire weld surface and then grinding it off — see Fig. 4.

ARE YOU UP TO STANDARD?

www.aws.org/catalogs
Troy, Ohioans, and visitors nationwide convened May 14 to celebrate the 75th anniversary of the founding of what has evolved into the Hobart Institute of Welding Technology (HIWT) (see lead photo), and the rededication of the Unity of Man fountain (Fig. 1) gracing the main entrance to the facility.

With such an impressive legacy to celebrate, HIWT Chairman and President André A. Odermatt joined with numerous local and national dignitaries, including HIWT past president and current AWS Executive Director Ray Shook, for the event — Fig. 2.

Presentation of the AWS Plaque

Shook said it was his privilege to have worked for Hobart Brothers for 23 years and to serve as the school’s president for two years. Shook noted, “The rededication of the Unity of Man fountain is the ideal venue to highlight the unity that exists between HIWT and AWS. The cornerstone of this unity,” Shook added, “is the AWS Certified Welding Inspector (CWI) program.” Shook noted HIWT has ten CWIs on staff and is the first non-AWS location to administer the CWI exam without an AWS proctor. The Institute is also an AWS Authorized Testing Facility (ATF), which means HIWT can offer welder certifications to AWS specifications. Shook concluded by presenting President Odermatt with a plaque engraved as follows:

_in the Beginning

William Hobart, Sr., recognized in 1930 a need to teach people about the welding processes if welding was to become an accepted way to join metals. Beginning with four welding booths in a corner of the factory to train customers, the school soon expanded to 15 booths. In 1937, the school was moved to a self-contained area within the factory featuring 30 welding booths. Training was offered to anyone able to pay the $10 tuition for a full week of instruction. On May 3, 1940, the school was incorporated as a nonprofit corporation named Hobart Trade School.

The War Years

Later, during the WWII years, the school went to two-shift operation to train large classes of women students enrolled to learn defense production welding. After the war, the school was kept at operating capacity with male students who took advan-
tage of the training benefits afforded by the G.I. Bill of Rights. Men accounted for about 90% of the students. At that time, the complete training program lasted only 16 weeks, and the school was selling its 516-page welder training manual for $2.

In early 1941, the school moved to a new, modern, all-welded steel building housing 52 arc welding booths and 12 gas welding stations.

The 1950s and ’60s

The 1950s saw the introduction of shorter one- and two-week-long courses, and in 1958, a modern 80,000-sq-ft facility was built on Trade Square East in Troy, under the direction of Howard Cary and Ray Dunlavy.

The early 1960s prompted a need to provide technical information and training in addition to the skills training. Technical workshops and seminars were started at the school.

Also, gas metal arc welding was becoming more widely used in industry, necessitating that this course be added to the program in 1963. A $5 deposit was required to enroll.

In 1964, Hobart initiated what has since become one of the nation’s largest libraries dedicated to welding. Located on the second floor, the John H. Blankenbuehler Library currently offers more than 4000 references, texts, publications, and standards, both foreign and domestic. The facility is open, by appointment, to the public.

The Unity of Man Fountain

Hobart’s landmark Unity of Man fountain, created by the late famed sculptor George Tsutakawa, was installed in 1967 to commemorate Hobart Brothers Co.’s 50th anniversary. Nearly 20 ft high, the 2700-lb tower spews plumes of water in all directions from 45 jets concealed by five silicon bronze spheres (welded with the gas tungsten arc process).

David Niland, professor of architecture at the University of Cincinnati, designed the raised concrete stage, reflecting pool, and gardens. Over time, the fountain’s concrete stage, plumbing, pumps, and electrical wiring had deteriorated beyond repair. In 2004, after two years’ of herculean efforts, the fountain was replaced and the fountain reassembled to full operating condition, justifying its rededication at the 75th anniversary ceremonies. The Unity of Man commemorative plaque, introduced by Peter Cahill Hobart, vice president international, Hobart Brothers Co., reads:

Dedicated as a symbol of the
Beauty — Strength — Flexibility
available from good craftsmanship in the art of welding

The Roaring Seventies

On February 4, 1971, the Hobart Trade School was renamed Hobart School of Welding Technology, and became the first welding school approved by the Ohio State Board of Schools and College Registration. In the summer of 1991, under the direction of then-President Ray Shook, the school took its present name, Hobart Institute of Welding Technology.

Three shifts were taught around the clock with enrollment at an all-time high in 1976. As a result, ground was broken in 1978 to expand the facility by 50,000 sq ft for new air-conditioned classrooms and state-of-the-art workstations — Fig. 3.
More Recent Events

In 1990, the HIWT offered two associate degree options through cooperation with Sinclair Community College in nearby Dayton, Ohio.

The World of Welding

Hobart’s quarterly publication, *The World of Welding*, began with the Spring 1990 issue. Following a several-year hiatus, the magazine was revived, redesigned, and expanded in content under the editorship of Martha (Marty) Baker — Fig. 4. Finally, 1990 was notable for the introduction of the Pipe Layout for Fitters and Welders course.

Today, HIWT’s complete welding program lasts 9 months. Students work with purchased-to-order, precleaned metals in well-ventilated booths equipped with the latest power sources.

The Hobarts Look to the Future

Peter C. Hobart said at the ceremonies, “Welding has always played an essential role in man’s endeavors, from the basic tool of industry for developing countries to the strategic technological role in war and peace for America and all nations.”

William H. Hobart, retired chairman of the board and CEO of Hobart Brothers Co., stated, “The philosophy of the institute is to help individuals to develop marketable welding skills through quality training at minimum cost. According to the U.S. Dept. of Labor, there is a shortage of trained welders and this labor supply shortage is projected to increase in the next 20 years. The challenge is to attract more young people to become welders, and Hobart Institute is well positioned to meet this challenge and to continue to help young people to create earning power for themselves and to fill the needs of the welding industry.”

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Standardization in Welding

Are today's standards different from those of the past and can they ever be globally relevant?

BY JEAN-PAUL GOURMELON

If you look for a definition of standardization in a dictionary from early in the 20th century, you would not find one. At most, you will find “standard” defined as “principle used as a rule.” The concept of standard, as we understand it now, appeared around 1920 with the definition “formula defining a type of thing, a product, a technical process in order to simplify and rationalize its production.” As for “standardization,” it was more recently defined as “a set of technical rules resulting from an agreement between producers and users, and leading to specify, unify, and simplify for a better output in all fields of human activity.”

This definition of standardization is already 20 years old and does not correspond with today’s reality. Obviously, the basic rule remains but, in addition to an agreement on technical content, a standard is also a marketing and economic tool. The current ISO definition for standard is “a document, established by consensus and approved by a recognized body, that provides, for common and repeated use, rules, guidelines, or characteristics for activities or their results, aimed at the achievement of the optimum degree of order in a given context.”

Looking back, we see that the first published international standards were mainly about products, tests, or measuring systems.

Sixty years ago, the necessity appeared for speaking about the same things with the same language, dealing with the same characteristics of products. The aim was that a part coming from one country should match another part coming from another country and all points were well defined in standards such as those concerning mechanical fasteners.

Year after year, other types of international standards were written, containing more general specifications, but, from the view of today’s definitions, they could be considered more as guidelines than as requirements.

Concurrently, national standards were developed, corresponding to national practices, knowledge, and regulations. The result was that, for the same activity, the general scheme could be identical but the details widely different.

Then, strong, fast development of European standardization occurred, directly governed by establishment of the Common Market, the European Economic Community, and, eventually, the European Union. Changes were made to national standards, sometimes painfully, and the consensus was not always the rule, but progress came from discussions.

That was one step. The next was the World Trade Organization Agreement that underlined the importance of international standards. The document, which was signed on April 15, 1994, in Marrakech, includes in its Annex A1 an “agreement on technical barriers to trade.” Its content makes strong references to international standards and encloses a code of good practice for the preparation, adoption, and application of standards.

That new context was clearly explained in a paper, “Welding Standards Together,” published in the ISO Bulletin, May 1997, by David Shackleton and Glenn Ziegennfuss, respectively, chairman and standardization officer in the IIW Select Committee “Standardization.”

Use of Standards in Contracts

It appeared that standards should be able to be referred to in contracts. Thus, they need to contain clear, precise re-

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This is a condensed version of the Thomas Medal Lecture presented April 27 at the AWS Welding Show and Convention, Dallas, Tex.
requirements so as to avoid any ambiguity in the relation between contractors. In some cases that implies a major change. A good example can be given with welding quality management.

In 1988, an ISO/DIS was circulated in order to revise the 1978 version of ISO 3834, "Welding — Quality Assurance Requirements for Welded Structures." That was a short standard (a little bit more than two pages) and, when reading it we notice some interesting points, but the specifications remained at a general level and could not be directly applied. That was, in fact, not so easy, welding being a technique that can be used in various fields with various levels of requirements.

In an annex, reference was made to the ISO 9000 standards developed by ISO/TC 176, but no link was underlined between the two standards. Almost at the same time, under regulation pressure, the need appeared to develop a standard with specific requirements on the European level and EN 729 was written. That standard, "Quality Requirements for Welding — Fusion Welding of Metallic Materials," contained four parts: Part 1, "Guidelines for selection and use," and three others dealing with comprehensive, standard, or elementary quality requirements.

Unlike the ISO/DIS mentioned previously, the specifications were precise and could theoretically be applied directly but, in fact, in some fields of application it was not so easy, the problem of requirement diversity being the same, and this standard being obviously under the influence of pressure vessel techniques and practices. Additionally, a link was clearly made with ISO 9000 standards and some countries or contractors intended to use it for the purpose of certification. A few years after being issued at the European level, this standard was adopted as a revision of ISO 3834.

With the revision of ISO 9000, this standard needed to be updated. This is currently under way and a fifth part will be added: "Normative references for the requirements of ISO 3834-2, ISO 3834-3, and ISO 3834-4," so as to make its implementation easier around the world.

This need for contractual references, illustrated by this example, is applied at the European level with stringent conditions, national standards being replaced by European standards in order to dismantle technical-economic barriers to trade. Such conditions are not yet applied to ISO standards, but it is clear that standards are now considered economic tools more than technical ones. That was proved when business plans for standardization were introduced, in which the ISO Technical Management Board (TMB) specified, "Business plans are intended to ensure that the work program of ISO technical committees are derived from and justified on the basis of clearly identified market needs...."

Involving the User

What does that mean? It means on the one hand that standards should not be written only for the pleasure of some experts, and on the other hand that they shall take into account the needs of all actors in the market.

They should be written in close cooperation with all participants in relevant fields, sometimes with other technical committees, and not only in close circles of technical experts, even if they are the best in their fields.

Participation of users is one of the major points in this standardization process. They should be able to give their points of view from the early stage of writing. If that is not the case, the standard could be, perhaps, the best technically speaking but the worst economically.

Coming back to the World Trade Organization Agreement and its annex, it would be too long to detail all provisions made in those documents, but their analysis could be titled: "Use and misuse of technical rules and standards." As the Greek fabulist Aesop said about the tongue, it can be "the best thing as well as the worst."

• The best: If they are tools in order to facilitate exchanges and improve knowledge between countries.

• The worst: If they are weapons in order to protect a market or if they represent one country's opinion or one partner's (producer, user, authority) point of view.

There is only one way to reach the best and avoid the worst: to work together, to examine arguments of every interested party, whatever they are, and try to find a common agreement, probably not the best for everybody but surely not the worst for anybody.

The Case for Global Relevance

 Might that be a good definition for "global relevance"?

The official ISO definition is "the required characteristic of an International Standard that can be used/implemented as broadly as possible by affected industries and other stakeholders around the world."

This seems to be easy for a general standard such as ISO 9000, but when you deal with technical items needing precise details, this would be more difficult. It is one thing to agree with the work item and its usefulness, another to agree on all correlative technical details.

The ISO/TMB policy and principles' statement on global relevance of standards specifies that "given existing and legitimate marked differences, an International Standard may pass through an evolutionary process, with the ultimate objective being to publish, at a later point, an International Standard that presents one unique international solution in all of its provisions."

This solution was used in the field of welding consumables where comparison between International and European Standards was the occasion of hard discussions. To begin with, there were essential differences concerning the reference mechanical characteristics and the impact resistance values and temperatures. Then, standards such as ISO 2560, Welding Consumables — Covered Electrodes for Manual Arc Welding of Nonalloy and Fine-Grain Steels — Classification, and ISO 14344, Welding Consumables — Wire Electrodes, Wires, and Rods for Arc Welding of Stainless and Heat-Resisting Steels — Classification, were developed as "cohabitation standards" containing options with the displayed objective to reach a unique classification within five to ten years. However, this solution shall not be used without proper judgment and be considered as an easy way out.

Welding is not a field where essential differences in markets around the world should be addressed permanently, that is, factors that are not expected to change over time, such as embedded technological infrastructures, climatic, geographical, or anthropological differences.

However, ISO/TMB policy draws attention to the fact that committees can only ensure the global relevance of the International Standards they produce if they are aware of all the factors that may affect a particular standard's relevance. One of them is the way in which standards are applied; the same requirement may give different results depending on the country — the cultural factor.

We can try to get a quick overview of the current corpus of standards in the field of welding. Could they be used tomorrow, meaning used worldwide? In other words, do they have any chance to be "globally relevant"?

Types of Standards

We can distinguish three categories of standards:

• Product standards;
• Process standards;
• Quality management and test standards.

Product standards are mainly the field of producers, who need to ensure the qual-
Participation of users is one of the major points in this standardization process.

An analysis of published standards related to quality management shows that the backbone of the system is ISO 3834, which was mentioned earlier. As an application to welding of ISO 9000, which is the most globally relevant standard, it is globally relevant in itself; it provides options to users and the last remaining problem of normative references will be solved with the new part five.

Using ISO 3834 implies a good knowledge and use of standards dealing with each particular point in the quality process. Going into detail, we find two types of standards: those covering all welding processes and materials and those dedicated to a specific welding process. One of the latter is ISO 14555, Arc Stud Welding of Metallic Materials. Under revision, it is now at ISO/DIS stage. The new text was fully rearranged so as to follow the general scheme of ISO 3834 and offers all necessary options for applications. Among the others, those dealing with specification and qualification of welding processes, recently underwent a major change. Existing standards are to be replaced by the new series ISO 15607 to ISO 15614. Those are a real toolbox covering all welding processes and materials and offering several types of qualification (tested welding consumables, previous welding experience, standard welding procedure, preproduction welding test, or welding procedure test). As it is true that you can’t require the same quality level for an offshore platform, a pressure vessel, a bridge, a two-story building, or a bike shed, you can find there the right procedure able to reconcile two apparently conflicting objectives: safety and economy. If well used, that series is in a position to cover any situation anywhere, that is to be globally relevant as a whole.

Who Are the Users?

We spoke from the beginning about the “users,” mysterious persons who are at the end of the chain, take decisions, and have to use standards. Who are they? There are many, so diverse are the practices depending on the applications and countries. They might be consulting engineers, manufacturers, constructors, and fabricators well aware of the welding technique; they might be architects, private clients knowing nothing about welding; they might be standardizers writing application standards who need the right references to be referred to. How could so many different people find their way? The global relevance should also take into account such diversity. A solution to improve the dissemination of welding standards could be to write an informative document explaining their organization, their flowcharts, a kind of instruction guide: “How to write welding standards.” This could take the shape of an ISO technical report.

Finally, the challenge for welding standards is

• To be high quality technical;
• To cover all fields of application;
• To offer several economic solutions;
• To be varied, but precise;
• To be understandable by any concerned person.

We can’t ensure that all those items are fulfilled but, looking to the work done over the last ten years, we can say that we are on the right track. Welding standards are not standards from yesterday that gave the “state of art”; they are definitely standards for tomorrow, bases for contracts as broad as possible.
Solid-State Inverters

An inverter is a circuit that uses solid-state devices called metal oxide semiconductor field effect transistors (MOSFETs), or integrated gate bipolar transistors (IGBTs), to convert direct current (DC) into high-frequency alternating current (AC), usually in the range of 20 to 100 kHz. Conventional welding power sources use transformers operating from a line frequency of 50 or 60 Hz.

Since transformer size is inversely proportional to line or applied frequency, reductions of up to 75% in power source size and weight are possible using inverter circuits. Inverter power sources are smaller and more compact than conventional welding power sources. They offer a faster response time and less electrical loss.

The primary contributors to weight or mass in any power source are the magnetic components, which consist of the main transformer and the filter inductor. Manufacturers have made various efforts to reduce the size and weight of power sources such as by substituting aluminum windings for copper.

Inverter circuits control the output power using the principle of time-ratio control (TRC), also referred to as pulse-width modulation. The solid-state devices (semiconductors) in an inverter act as switches; they are either switched on and conducting, or switched off and blocking. Time-ratio control is the regulation of the on and off times of the switches to control the output. Figure 1 illustrates a simplified TRC circuit that controls the output to a load such as a welding arc.

Another method of inverter control, frequency-modulation TRC, varies the frequency. Both frequency modulation and pulse-width modulation are used in commercially available welding inverters.

Figure 2 shows a block diagram of an inverter used for direct-current welding. A full-wave rectifier converts incoming three-phase or single-phase 50- or 60-Hz power to direct current. This direct current is applied to the inverter, which converts it into high-frequency square-wave alternating current using semiconductor switches. In another variation used for welding, the inverter produces sine waves in a resonant technology with frequency-modulation control. The switching of the semiconductors takes place between 1 and 50 kHz, depending on the component used and method of control.

This high-frequency voltage allows the use of a smaller step-down transformer. After being transformed, the alternating current is rectified to direct current for welding. Solid-state controls enable the operator to select either constant-current or constant-voltage output, and with appropriate options these sources can also provide pulsed outputs.

The capabilities of the semiconductors and the particular circuit switching determine the response time and switching frequency. Faster output response times are generally associated with the higher switching and control frequencies, resulting in more stable arcs and superior arc performance. However, other variables, such as the length of the weld cables, must be considered because they may affect the performance of the power source. Table 1 compares inverter switching devices and the frequency applied to the transformer.

Inverter technology can be used to enhance the performance of AC welding power sources and can also be applied to DC constant-current power sources used for plasma arc cutting.

Table 1 — Types of Inverter Switching Devices and Frequency Ranges Applied to the Transformer

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<td>SCR devices</td>
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<tr>
<td>Transistor devices</td>
<td>10–100 kHz</td>
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Metalform Mexico 2005. Sept. 28–30, Monterrey, Mexico. Contact Graylin Presbury at graylin.presbury@mail.doc.gov.

5th Int'l Forum on Aluminum Ships. Oct. 11–13, Zenkyoren Bldg. Tokyo, Japan. All business conducted in English. Contact The Society of Naval Architects of Japan, alumni@congre.co.jp.


### AWS 2005 Schedule

**CWI/CWE Prep Courses and Exams**

Exam applications must be submitted six weeks before the exam date. For exam information and an application, contact the AWS Certification Dept., (800) 443-9353, ext. 273. For exam prep course information, contact the AWS Education Dept., (800) 443-9353, ext. 229.

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<th>City</th>
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<td>Albuquerque, N.Mex.</td>
<td>July 31-Aug. 5 (API 1104 Clinic also offered)</td>
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<tr>
<td>Anchorage, Alaska</td>
<td>EXAM ONLY</td>
<td>Sept. 24</td>
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<tr>
<td>Atlanta, Ga.</td>
<td>Oct. 23-28 (API 1104 Clinic also offered)</td>
<td>Oct. 29</td>
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<tr>
<td>Baltimore, Md.</td>
<td>Oct. 30-Nov. 4 (API 1104 Clinic also offered)</td>
<td>Nov. 5</td>
</tr>
<tr>
<td>Beaumont, Tex.</td>
<td>Nov. 6-11 (API 1104 Clinic also offered)</td>
<td>Nov. 12</td>
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<td>Charlotte, N.C.</td>
<td>Aug. 21-26 (API 1104 Clinic also offered)</td>
<td>Aug. 27</td>
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<tr>
<td>Chicago, Ill.</td>
<td>Oct. 23-28 (API 1104 Clinic also offered)</td>
<td>Oct. 29</td>
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<tr>
<td>Columbus, Ohio</td>
<td>Aug. 8-12 (MBBPVI)</td>
<td>Aug. 13</td>
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<tr>
<td>Columbus, Ohio</td>
<td>Dec. 5-9 (MBBPVI)</td>
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<td>Corpus Christi, Tex.</td>
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<td>Dallas, Tex.</td>
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<td>Denver, Colo.</td>
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<td>Detroit, Mich.</td>
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<td>Seattle, Wash.</td>
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<td>Sept. 24</td>
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<td>Sioux Falls, S.Dak.</td>
<td>Nov. 13-18</td>
<td>Nov. 19</td>
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<td>Syracuse, N.Y.</td>
<td>Sept. 11-16</td>
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<td>Tulsa, Okla.</td>
<td>Oct. 16-21</td>
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<td>York, Pa.</td>
<td>July 31-Aug. 5</td>
<td>Aug. 6</td>
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<td>(API 1104 Clinic also offered)</td>
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### INTERNATIONAL COURSES

The Mexico training and testing location is DALUS, S.A. de C.V., Monterrey, N.L. Contact: Lorena Garza at info@dalus.com. DALUS is an AWS-accredited training and testing facility. It employs the S.E.N.S.E. (Schools Excelling Through Skill Standards Education) programs.

- **Monterrey, Mex.** July 11-15
- **Monterrey, Mex.** Nov. 7-11

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Welding Industry’s High Achievers Celebrated at Dallas Show

COMFORT A. ADAMS LECTURE AWARD
Fukuhisa Matsuda

Fukuhisa Matsuda received his Ph.D. in 1965 from Osaka University. In 1967, he joined the university’s faculty as an associate professor in the Welding Engineering Department and the Japan Welding Research Institute (JWRI). In 1976, he was promoted to professor. He served the university and JWRI as a professor until his retirement in 1996. He currently holds the title Professor Emeritus. From 1959 to 1967, he was with National Research Institute for Metals (NRIM). His research subjects included electron beam welding, welding of nonferrous metals, and solidification and hot cracking. From 1965 to 1966, he was a research fellow under Prof. Warren F. Savage at Rensselaer Polytechnic Institute. As a professor at Osaka University and JWRI, his research included electron- and laser-beam weldability, weldability of aluminum alloys and refractory metals, toughness of the heat-affected zones of high-strength and pressure-vessel steels, and the SCC properties of steels in nuclear power plants. From 1996 to 2001, as general director, Tarasaki R&D Center, Japan Power Engineering and Inspector Corporation (JAPCIC), he conducted national welding technology research projects for nuclear power plants. Matsuda has authored more than 400 technical papers. On two occasions he received the Excellent Paper Prize from the Japan Welding Society. He received the J. Chabelka Medal from Slovakia WRI, Honorable D.Sc. from the University of Kosice, Slovakia, was named Honorable Professor by Tianjin University, China, among other institute and Japanese-government recognitions.

ADAMS MEMORIAL MEMBERSHIP AWARD
YuMing Zhang

YuMing Zhang received his Ph.D. degree in mechanical engineering/welding from Harbin Institute of Technology, China. Since 1991, he has been with the University of Kentucky, where he is currently the director of welding and applied sensing/control research program in the Center for Manufacturing, and an associate professor and the director of graduate studies in the department of Electrical and Computer Engineering. Zhang’s research interest lies in sensors, control systems, and arc welding processes. He holds five U.S. patents for his double-sided arc welding, metal transfer control, three-dimensional weld pool surface measurement, and joint-tracking techniques. His research has been documented in 90 papers and peer-reviewed journals. Zhang has been an AWS member since 1992. He is a senior member of IEEE and SME, and a member of ASME.

AWS Standards Writers on the Job

The D8 Committee on Automotive Welding held its spring meeting April 12 in Romulus, Mich. Shown are (from left) Secretary Harold Ellison, Chair John Bohr, Bill Qualls, Bill Brafford, Jim Dolfi, Jim Osborne, Dave Kelly, Bernie Bastian, Glen Armstrong, Ted Coon, and Murali Tumuluru.

The A2 Committee on Definitions and Symbols held its May meeting in Miami, Fla. Shown at AWS Headquarters are (from left) J. P. Christein, Dick Holdren, Jerry Warren, David Beneteau, Larry Barley, Pat Newhouse, Peter Howe, Lou Siy, Rick McGuire, Secretary Cynthia Jenney, and Chuck Ford.
Nominations are sought for the 2006 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 the science and technology of materials joining through research and development.

The candidate must be 40 years old or younger, and may live anywhere in the world. The candidate need not be an American Welding Society member.

The nomination package should be prepared by someone familiar with the research background of the candidate. It should include a résumé and three to five letters of recommendation from researchers familiar with the candidate. The résumé should include a summary statement of the candidate’s research interests and accomplishments, educational background, professional experience, publications, honors, and awards.

The award was established to recognize Prof. Masubuchi for his contributions to the advancement of the science and technology of welding, especially marine and outer space structures.

December 1, 2005, is the deadline. Submit your nomination to Prof. John DuPont at jmd1@lehigh.edu.
Alan S. Beckett
Alan S. Beckett earned a B.S. degree in welding engineering from LeTourneau University, Longview, Tex. He currently serves as the Welding Program Steward for the Alyeska Pipeline Service Co. In this position, he is responsible for welding and materials used in maintenance and construction on the 800-mile Trans-Alaska Pipeline (TAPS) that transports crude oil from the North Slope of Alaska to the marine terminal in Valdez, Alaska, as well as the 148-mile natural gas transmission pipeline that supplies fuel to operate Pump Stations 1–4.

John N. DuPont
John N. DuPont earned Ph.D. in materials science and engineering from Lehigh University. He served as a research scientist and associate director of the Energy Liaison Program at Lehigh University until 1999. He joined Lutron Electronics in 2002, where he is a senior operations project engineer. Kusko served as a research assistant at Lehigh from 1997 to 2002. In 1999, he received an AWS Navy Joining Center Fellowship. He has served as a consultant to industry research projects and has taught metallurgical courses.

Structure Design
"The Influence of Microstructure on Fatigue Crack Propagation Behavior of Stainless Steel Welds"
Chad S. Kusko
Chad S. Kusko received his M.B.A. and Ph.D. in materials science and engineering from Lehigh University in 2002. His research theses included a fundamental investigation of martensite formation adjacent to the weld interface of austenitic/ferritic dissimilar metal welds, and fatigue crack propagation behavior of stainless steel welds. He joined Lutron Electronics in 2002, where he is a senior operations project engineer. Kusko served as a research assistant at Lehigh from 1997 to 2002. In 1999, he received an AWS Navy Joining Center Fellowship. He has served as a consultant to industry research projects and has taught metallurgical courses.

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New Standards and Bundles of Standards Announced

AWS D16.4M/D16.4:2005, Specification for the Qualification of Robotic Arc Welding Personnel, has been released and is available for purchase from Global Engineering Documents online at www.global.ihs.com, or call (800) 854-7179.

The document contains 20 pages, 2 annexes, three figures, and four tables. Price is $28, $21 for AWS members.

The standard is the basis for the AWS Certification of Robotic Arc Welding Personnel (CRAW) program. It provides requirements for the qualification of robotic arc welding support personnel at three levels: CRAW-L1, CRAW-O, and CRAW-T. The revisions align education and experience requirements more realistically with those in industry.

AWS D14.6/D14.6M:2005, Specification for Welding of Rotating Elements of Equipment. This standard establishes material and workmanship standards for manufacturers, fabricators, repair organizations, purchasers, and owners and operators ofrotating equipment fabricated or repaired by welding. Included are sections defining process qualifications, operator qualifications, quality control, inspection requirements, and repair requirements. It has 282 pages, 18 tables, and 42 charts and figures. Price is $60, $45 for AWS members.

The specification may be purchased from Global Engineering Documents online at www.global.ihs.com, or call (800) 854-7179.

AWS offers its most popular Structural Welding Codes collected in “bundles,” in five combinations, at prices significantly lower than purchasing the documents individually. Plus, AWS members received an additional 25% discount off the bundle list price. The five bundles are detailed and priced on page 5 of the AWS 2005 Product Catalog. The catalog is viewable and downloadable at www.aws.org/catalogs.

For example, Bundle A — AISC Steel Building Structures, includes AWS D1.1, Structural Welding Code — Steel, AWS A2.4, Standard Symbols for Welding, Brazing, and Nondestructive Examination, and AWS A3.0, Standard Welding Terms and Definitions. These three documents individually cost $624 list/$468 for AWS members. Purchased as Bundle A, the three documents cost $532 list/$399 for AWS members.

The other four bundles offered in the catalog are titled: Bundle B — D1 All; Bundle C — AISC Conventional and Complex Steel Building Structures; Bundle D — AISC Simple and Major Steel Bridges; and Bundle E — Structural Aluminum.
DuPont’s research interests cover processing-microstructure-property relations in solidification and joining of materials, laser engineered net shaping, and alloy development. He has published more than 140 technical articles, edited four books, and has been granted one patent. He has organized four international conferences. He is currently the principal or coprincipal investigator on nine research programs that support a research group including two postdoctoral students, two Ph.D. students, and six M.S. students.

DuPont was an ASM scholar in 1990, and received an AWS National Fellowship Award in 1995. He received the AWS Charles H. Jennings Memorial Award in 1996 and 2000, and the AWS William Spraragen Memorial Award in 1999 and 2000. He received the A.F. Davis Silver Medal Award from AWS in 2001, 2002, and 2004, and the Warren F. Savage Memorial Award in 2004. In 1999, he was awarded the AWS Prof. Koichi Masubuchi Award. In 2000, he received a Young Investigator Award from the Office of Naval Research for work on laser beam welding and surface treatment of superaustenitic stainless steels in advanced double-hull combatant ships, and a CAREER award from the National Science Foundation for research on Laser Engineered Net Shaping. In 2000, DuPont received the National Science Foundation Presidential Early Career Award for Scientists and Engineers (PECASE) from President Clinton. In 2002, he received the AWS Adams Memorial Membership Award, and in 2003 was awarded the Lehigh University College of Engineering Teaching Excellence Award. DuPont is currently a Principal Peer Reviewer for the Welding Journal and is a reviewer for the Journal of Materials Engineering and Performance. He is on the AWS Research and Development Committee, Welding Handbook Committee, Conference Committee, Technical Papers Committee, and the Edison Welding Institute Navy Joining Center Technical Advisory Board. He has served as a consultant to industry and government research laboratories; and has developed and taught industrial short courses in the areas of welding, failure analysis, metallurgy for the nonmetallurgist, and heat treating.

Arnold R. Marder
Arnold R. Marder received his Ph.D. in metallurgy and materials science from Lehigh University in 1968. Currently, he is professor in the Department of Materials Science and Engineering, and associate director of the Energy Research Center at Lehigh University. Earlier, he worked for the General Electric Company, and was employed by the Geometry Research Laboratories of the Bethlehem Steel Corp. for more than 20 years. Marder’s present research interests include processing-structure-property relationships of materials, including coatings and alloys for ambient and high-temperature environments regarding erosion, oxidation, and sulfidation. He also works on the physical metallurgy of steel for weld overlay coating of superalloys and iron alloys into intermetallics, as well as weldability studies of Cr-Mo steels.

Marder has published more than 200 technical papers, edited three books, and has been granted 20 U.S. and foreign patents. Among his honors, he won first-place in an AWS Professional Poster Competition. In 1996, he received the Charles H. Jennings Memorial Award, and in 1998 the William Spraragen Memorial Award. He received the A.F. Davis Silver Medal Award in Structure Design in 2001 and 2002. In 1990, he was elected a Fellow of ASM International, Lehigh Valley Chapter.

Dalton E. Hamilton Memorial CWI of the Year Award
James P. Hennessy
James P. Hennessy has been a welding consultant and quality control field inspection specialist with more than 33 years of industrial equipment and heavy steel construction experience. This includes plant maintenance work in the paper, petrochemical, and commercial electric power industries.

William H. Hobart Memorial Award
“Microstructure-Property Relationships in HAZ of New 13% Cr Martensitic Stainless Steels”
Odd M. Akselsen
Since 1981, Odd M. Akselsen has been with SINTEF, working with materials subjected to welding and joining. He received his Ph.D. in physical metallurgy in welding in 1988. He was appointed group leader of the welding metallurgy research group in 1985, and was named research manager in 1994. From 1999 to 2004, he served as research manager for the Department of Corrosion and Joining. Today, he is a senior scientist working with welding and weldability of low-alloy and stainless steels. During the past ten years, he has been involved in the qualification of supermartensitic 13% Cr stainless steels for subsea pipelines. He is also involved in joining of specialty materials such as shape memory alloys and intermetallics, and metal coatings to improve wear resistance. Akselsen has authored more than 170 publications, including articles in international journals, international conference proceedings, and technical reports. In 1993, he won the AWS Arsham Amirikian Memorial Maritime Welding Award.

Gisle Rørvik
In 1984, Gisle Rørvik received his B.Sc. in metallurgy and materials tech-
nology. Rørvik worked as an engineer and research scientist in SINTEF Materials Technology — Steel and Welding Group for 14 years. Since 1998, he has been with the Norwegian Oil Company Statoil ASA as a staff engineer and, most recently, as an advisor in metallic materials. His main fields of expertise include structural and stainless steels, physical and welding metallurgy, metallography, fractography, and failure analysis. He has authored or coauthored more than 50 international scientific publications. In 1993, he received the AWS Arsham Amirikian Memorial Maritime Welding Award. In 1997, he won a first-prize award for Artistic Microscopy — Color Only Class, in the International Metallographic Contest presented by The International Metallographic Society and ASM International.

Per Egil Kvaale

Per Egil Kvaale studied physical metallurgy at the Norwegian University of Science and Technology, Trondheim, Norway. Following graduation in 1974, he worked at the Norwegian Steel Mill’s laboratory until 1980. From 1980 to 1985 he worked at SINTEF, researching welding of steels for offshore construction. In 1985, Kvaale joined the Norwegian Oil Co. Statoil ASA where he has held various positions, including head of the material department and chief engineer. Today, he is a special advisor for materials technology. His main activities at Statoil have been the qualification of pipeline materials and welding. He is a pioneer in the field of supermartensitic 13%Cr stainless steels.

Casper van der Eijk

Casper van der Eijk received his M.S. in materials science and technology from Delft University of Technology in the Netherlands in 1994. His thesis concerned the production of intermetallic alloys using powder metallurgy technology. After completing his military service in 1995, he emigrated to Norway. In 1999, he completed his Ph.D. in physical metallurgy at the Norwegian University of Science and Technology. His dissertation was the weldability of Ti-deoxidized steels. He has been employed as a research scientist at SINTEF in Norway since 1999. He is working with steel weldability, inclusion engineering in steels, joining of intermetallics, powder metallurgy, and shape memory alloys. He has published more than 30 conference and journal papers.

HONORARY MEMBERSHIP AWARD
Louis DeFreitas

Louis DeFreitas received his M.A. degree in education administration from San Francisco State University. He received his teacher training from the University of California at Berkeley, and holds a Standard Designated Subjects Teaching Credential in welding, and a Community College Supervisor’s Credential from the state of California. He has been in the welding industry for more than 50 years, working as a welding engineer in the military, job shops, and the aircraft and electronics industries. DeFreitas has served more than 30 years as a professor and chair of the Welding Technology Department at the College of San Mateo in California. For the past nine years, he has been the director of the Arc Gas Training Institute in San Jose, Calif. DeFreitas is a member of the American Welding Society, and served as chairman of the Santa Clara Valley Section 1994–1995.

Glen R. Edwards

Glen R. Edwards holds a Ph.D. in materials science and engineering from Stanford University. Early in his career, he worked for ACF Industries and Los Alamos National Laboratory, then served with the Naval Postgraduate School in Monterey, Calif. He joined the faculty of Colorado School of Mines (CSM) in 1976. Edwards served as professor of metallurgical and materials engineering for CSM until 2003. From 1984 to 2003, he was director of the CSM Center for Welding, Joining, and Coatings Research. He has advised more than 50 students, and contributing more than 200 papers to the technical literature. In 2003, CSM awarded him his honorary designation, University Emeritus Professor, for his distinguished service to the institution. Edwards has served on numerous national committees of professional societies and has been a key reviewer for major research journals. He currently serves as U.S. Delegate for Commission IX of the International Institute of Welding. The American Welding Society has awarded him the Warren F. Savage Memorial Award, R. D. Thomas Memorial Award, Adams Memorial Membership Award, William Irrgang Memorial Award, and the Comfort A. Adams Lecture Award. During the 2004 ASM International Conference on Joining of Advanced and Specialty Materials, he was honored with a special session in his name. He is a Fellow of both ASM International and the American Welding Society.

INTERNATIONAL MERITORIOUS CERTIFICATE AWARD
Bertil Pekkari

Bertil Pekkari holds a M.Sc. degree and a university degree in economics. He started his professional career in 1964 as a development engineer for electrical drives and battery chargers at ESAB in Laxå, Sweden. Later, he was involved in the development of welding equipment when ESAB sold off its industrial equipment business. Since then, he has worked in many positions at ESAB, including research and development manager, production manager, plant manager, and business area director for Welding and Cutting Automation. He was the group vice president and technical director for 17 years, having responsibility for research and development, and quality and environmental affairs. He was instrumental in introducing new technologies and businesses such as welding robotics, inverters, friction stir welding, laser processing, knowledge-based systems, and working environment strategies. He retired in 2004 after 40 years of service. Presently he runs his own consulting company BePe Konsult. He serves as chairman of the Swedish Welding Commission, chairman of the Swedish Welding Research Council, nonexecutive director at The Welding Institute, and president of the International Institute of Welding. Pekkari is also an elected member of the Royal Swedish Academy of Engineering Sciences.

Shinsuke Tsutsumi

Shinsuke Tsutsumi is a senior research engineer in the standards department at the Japanese Standards Assn. in Tokyo. He received his master’s degree in metallurgical engineering from Yokohama National University in 1975. That year he joined Kobe Steel, Ltd., where he worked as a research engineer in the Welding division. He served as manager in the QA section for welding consumables from 1991 to 2001. He has been a member of the IIW Subcommission II-E and ISO/TC44/SC3. He proposed at an ISO meeting a “cohabitation idea” for two systems to “live together” for ISO welding consumables. In 1999, ISO accepted his idea and has prepared the cohabitation drafts of ISO standards for welding consumables. Tsutsumi served as chair of the Subcommittee on ISO Standardization, Technical Committee,
Welding Consumables Div., the Japan Welding Engineering Society, 1998–2004. This Subcommittee has prepared many cohabitation drafts of ISO standards for welding consumables for arc welding of steels. In 2003, Tsutsumi was awarded the IWI Thomas Medal for contributions to the IIW/ISO international standards activities. He received the 2004 FY Award for the promotion of industrial standardization from the Ministry of Economy, Trade, and Industry of Japan.

WILLIAM IRRGANG MEMORIAL AWARD
Lee G. Kvidahl
Lee Kvidahl, an AWS past president (1993–1994), is a graduate of Stevens Institute of Technology. He is the section manager of welding engineering for Northrop Grumman Ship Systems, responsible for all welding engineering activities at the Pascagoula and Gulfport, Miss., and the New Orleans and Tallulah, La., sites. He has served as the AWS Pascagoula Section chair, and District 9 director. He has chaired several AWS standing committees, including Executive, Compensation, National Nominating, Honorary-Meritorious Awards, and Roles and Missions. He has served on the AWS Technical Activities, Technical Papers, and Counselors Committees. Presently, he chairs the AWS Membership Committee, and is a member of the D3 Committee on Welding in Marine Construction, and the A5 Committee on Filler Metals and Allied Materials. Kvidahl served as vice chair of the AWS Foundation 1992–2004. He chairs the National Shipbuilding Research Program Welding Technology Panel. He also is the chair of the Navy Joining Center Steering Committee and is a member of its Technical Advisory Board. He is a member of the American Bureau of Shipping Special Committee on Materials and Welding, and is a member of ASM International and SNAME.

CHARLES H. JENNINGS MEMORIAL AWARD
"An Investigation of Ductility-Dip Cracking in Nickel-based Weld Metals — Part III"

MATTHEW G. COLLINS
Matthew Collins is a staff mechanical/welding engineer for ConocoPhillips Alaska, Inc., with 14 years of experience in the oil and gas industry. Much of his work experience has been on the North Slope of Alaska working at the Prudhoe Bay, Kuparuk, and Alpine oil field assets as a facility engineer, corrosion engineer, and a mechanical/piping/welding engineer. He is the ConocoPhillips Alaska, Inc., technical authority for piping, valves, welding, hot-tapping, and in-service welding standards and specifications. Collins earned a M.S. degree in welding engineering, with a major in welding metallurgy, from the Ohio State University, working under the advisement of Dr. John C. Lippold. His graduate thesis is titled An Investigation of Ductility-Dip Cracking in Nickel-Based Filler Materials. He is a registered Professional Mechanical Engineer in the states of Alaska and Ohio. He also is a licensed mechanical administrator in the state of Alaska. Currently, he holds a National Board Owner/User Inspector Certification, and API-510, API-570, and API-653 Certifications. Further, he holds certifications as an AWS CWE, CWI, and an IWI Welding Engineer diploma. He is a member of AWS, ASME, and ASM International. Collins has published five technical papers on ductility dip cracking in nickel-based filler metals and will soon publish two papers on root pass welding of duplex stainless steel pipeline girth welds using the SMA process without the use of backing gas.

ANTONIO JOSE RAMIREZ
Antonio Jose Ramirez received his Ph.D. degree in materials science from the University of Sao Paulo, Brazil, and a mechanical engineering degree from the National University of Colombia, in materials characterization and electron microscopy. He was a research associate at The Ohio State University. Currently, he is manager and a researcher in the industrial research program at the Brazilian Synchrotron Light Laboratory, Sao Paulo. He is an Invited Professor at University of Campinas and University of Sao Paulo.

MCKAY-HELM AWARD
“Yttrium Hydrogen Trapping to Manage Hydrogen in HSLA Steel Welds”

CHAD A. LENSENSING
Chad A. Lensing received his Ph.D. in metallurgy and metallurgical engineering from the Colorado School of Mines in 2001. Following graduation, he joined BP America. Currently he is with its Integrity Management Team in Houston, Tex., as a specialist in corrosion, materials, and welding. Previously, he served as a member of the Offshore Systems Team, and a member of the Topsides Construction division.

John C. Lippold
John Lippold received his Ph.D. degree in materials engineering from Rensselaer Polytechnic Institute. He worked for seven years on the technical staff at Sandia National Laboratories, specializing in weldability of stainless steels and high alloys. From 1985 to 1995, Lippold was employed by Edison Welding Institute where he served as materials department leader and manager of research. In 1995, he joined the faculty of the welding engineering program at The Ohio State University. In 2004, he began a one-year term as Interim Chair of Industrial, Welding, and Systems Engineering at the university. Over the past 25 years, Lippold has been involved in research of welding metallurgy and properties of engineering materials. His research has involved both fundamental and applied topics with a high degree of industrial relevance. Lippold has published more than 150 technical papers and reports, and delivered more than 300 technical presentations. He is recognized internationally in the field of stainless steel and high-alloy welding metallurgy, and weldability testing. Lippold has earned several AWS-sponsored awards including the Charles H. Jennings Memorial Award (1977, 1980), William Spraragen Memorial Award (1979, 1992), Warren F. Savage Memorial Award (1993, 1996), McKay-Helm Award (1994), Lincoln Gold Medal (1983), F. Davis Silver Medal (2000), Irrgang Award (2002), and Plummer Memorial Educational Lecture Award (2002). He has received the Buehler Technical Paper Merit Award (1985, 1989) from the International Metallographic Society. In 1997, he presented the Comfort A. Adams Memorial Lecture at the AWS Annual Convention in Los Angeles. In 1994, Lippold was elected a Fellow of ASM International, and in 1996 was inducted as a Fellow of the American Welding Society.

MATTHEW G. COLLINS
Matthew Collins is a staff mechanical/welding engineer for ConocoPhillips Alaska, Inc., with 14 years of experience in the oil and gas industry. Much of his work experience has been on the North Slope of Alaska working at the Prudhoe Bay, Kuparuk, and Alpine oil field assets as a facility engineer, corrosion engineer, and a mechanical/piping/welding engineer. He is the ConocoPhillips Alaska, Inc., technical authority for piping, valves, welding, hot-tapping, and in-service welding standards and specifications. Collins earned a M.S. degree in welding engineering, with a major in welding metallurgy, from the Ohio State University, working under the advisement of Dr. John C. Lippold. His graduate thesis is titled An Investigation of Ductility-Dip Cracking in Nickel-Based Filler Materials. He is a registered Professional Mechanical Engineer in the states of Alaska and Ohio. He also is a licensed mechanical administrator in the state of Alaska. Currently, he holds a National Board Owner/User Inspector Certification, and API-510, API-570, and API-653 Certifications. Further, he holds certifications as an AWS CWE, CWI, and an IWI Welding Engineer diploma. He is a member of AWS, ASME, and ASM International. Collins has published five technical papers on ductility dip cracking in nickel-based filler metals and will soon publish two papers on root pass welding of duplex stainless steel pipeline girth welds using the SMA process without the use of backing gas.

ANTONIO JOSE RAMIREZ
Antonio Jose Ramirez received his Ph.D. degree in materials science from the University of Sao Paulo, Brazil, and a mechanical engineering degree from the National University of Colombia, in materials characterization and electron microscopy. He was a research associate at The Ohio State University. Currently, he is manager and a researcher in the industrial research program at the Brazilian Synchrotron Light Laboratory, Sao Paulo. He is an Invited Professor at University of Campinas and University of Sao Paulo.
Yeong-Do Park
Yeong-Do Park received his Ph.D. in metallurgical and materials engineering from the Colorado School of Mines (CSM) in 2003. Yeong-Do is currently a senior research engineer, Materials Research Team in the Advanced Technology Center of Hyundai Motor Co. in Korea. From 2003 to 2005, he served on the CSM research faculty and as a guest researcher at National Institute of Standards and Technology. While earning his advanced degrees, he was a CSM graduate research assistant. His work focused on the management of hydrogen in high-strength steel welds, and measurement of diffusible hydrogen content using the Seebeck effect, and electronic measurements for evaluating metallurgical and microstructural phase stability. He has received the Korea Maritime University’s Excellent Grade Scholarships, 1990–1996, and the AWS William Spraragen Memorial Award in 2003.

Iman Soerjadrama Maroef
Iman Soerjadrama Maroef joined the Welding Cluster at the Netherlands Institute of Metals Research (NIMR) in 2003. His research involves metallurgical studies for metals joined with arc welding, with primary focus on the welding of dissimilar metals. Maroef received his Ph.D. in metallurgical and materials engineering from the Colorado School of Mines (CSM). Prior to joining the NIMR, he continued his involvement at CSM in various aspects of metallurgy, including welding, steel processing, electrochemistry, and failure analysis.

David L. Olson
David L. Olson is the John Henry Moore Distinguished Professor of Physical Metallurgy, and a professor of metallurgical engineering, at the Colorado School of Mines (CSM). He is a licensed Professional Engineer in the state of Colorado. He received a Ph.D. in materials science from Cornell University in 1970. He did postdoctoral studies at The Ohio State University (1970–72), with sabbatical studies taken at Norwegian Institute of Technology (1979). Olson has been a CSM faculty member since 1972. He served as director of the Center for Welding (1981–85), and dean of research and vice president of research and development (1986–89). He is a LANL University Affiliate. He has published numerous papers, holds several patents, and has authored, coauthored, or edited numerous books. He has advised 34 Ph.D., and 62 M.Sc. students. Olson is a Fellow of AWS and ASM International. He is a Foreign Member of the National Academy of Science of Ukraine. He has received AWS technical paper awards, ANSI paper awards, the ASM Bradley Stoughton Award (1976), 1999 TTCP Achievement Award (DOD), and the 2001 Arata Medal (IIW). He is an international lecturer and has been an American Council Delegate to IIW.

PROF. KOICHI MASUBUCHI AWARD
Ernst Kozeschnik
Ernst Kozeschnik studied physics at the Graz University of Technology, Austria, and received his Doctor of Technical Sciences degree in 1997. Under an Erwin Schrodinger fellowship, he carried out a one-year research project at Oak Ridge National Laboratory. From 1999 to 2001, he was a research assistant at the Institute for Materials Science, Welding and Forming (IWS) at Graz University of Technology, Austria. From 2000 to 2004, he was the operative project leader at the Materials Center Leoben (MCL) in Austria. He has been an assistant professor at IWS, and since 2004 has served as a key researcher at MCL. Kozeschnik has more than 40 publications on weld phenomena subjects, is a key reader for Metallurgical and Materials Transactions, has organized international conferences on numerical analysis of weldability, is a coauthor of the book, Mathematical Modeling of Weld Phenomena 7, and has given numerous talks addressing thermodynamics and superalloys.

SAMUEL WYLIE MILLER MEMORIAL MEDAL AWARD
Conway E. “Whitey” Grubbs

Grubbs chaired the Chapter Committee on Underwater Welding and Cutting for the AWS Welding Handbook, 8th edition, vol. 3; served on the D3 Committee on Welding in Marine Construction, founded and chaired the D3B Committee on Welding in Marine Construction: founded and chaired the D3B Subcommittee on Underwater Welding and Cutting; served on the executive committee on Safety and Health; was a member of the American Council of the IIW; and was technical representative for the AWS District 9 Academia Section. Grubbs was a member of the IIW Commission VIII on Hygiene and Safety; the Select Committee on Underwater Welding; and Commission II, Arc Welding. He chaired Work Group D, Commission VIII, Safety in Underwater Welding and Cutting, and was a delegate in the American Council to the Select Committee on Underwater Welding. For the U.S. National Research Council, he was a member of the Materials Advisory Group of the Committee on Marine Structures. Technical Advisory Committee to the Ship Structure Committee on Project SR-1283, Performance of Underwater Weldments, and served on the Panel on Undersea Facilities. He was a consultant for the Marine Board Panels on Underwater Electrical Safe Practices, and Certification of Offshore Structures.

Mr. Grubbs was a consultant for the U.S. Department of the Interior, Mineral Management Service, Technology Assessment and Research Branch. He chaired the Executive Committee for the Joint Industry Underwater Welding Development Program. He authored more than 40 technical papers on underwater welding, including 15 international presentations. He is listed in Who's Who in Science and Engineering (1998 and 2002) for his contributions to the science of underwater welding.
Grubbs received two AWS Meritorious Certificate Awards for his outstanding achievements in the science of welding in 1987, and the other for serving as founder and chair (1975–1988) of the D3B Subcommittee on Underwater Welding. He was granted three U.S. patents. Grubbs patented a method for underwater welding using pressurized welding electrode transfer capsule and dry welding electrode in situ storage; another patent covered a viewing scope for turbid environments and use in underwater welding; and the third patent concerned a unique method of underwater welding using a viewing scope.

NATIONAL MERITORIOUS AWARD

Harvey R. Castner

Harvey R. Castner received his M.B.A. from Kent State University. He has more than 30 years of experience in the welding field with extensive experience in manufacturing, problem solving, and engineering management. In 1994, Castner joined, and currently directs, the Government Programs Office at Edison Welding Institute (EWI), including the Navy Joining Center (NJC). He is responsible for overall direction and management of welding-related R&D programs that develop and implement welding technology to improve the quality and cost-effectiveness of manufacturing and repair operations of the U.S. Navy, Dept. of Defense, and other government agencies. Prior to joining EWI, Castner was vice president of engineering at Hartman Materials Handling Systems, Inc. He also served as manager of manufacturing automation technology at the Allis Chalmers Corp.’s Advanced Technologies Center. Castner received the James F. Lincoln Gold Medal Award and the Arsham Amirkhan Memorial Maritime Welding Award. He is a registered professional engineer in the state of Ohio, an AWS Life member, and an AWS director at large. He is a member of various AWS committees including the Welding Handbook Committee, SHI Safety and Health Subcommittee on Fumes and Gases, Conference Committee, and chairs the Product Development Committee.

James R. “Rusty” Franklin

Rusty Franklin has served the welding industry for almost 30 years. He has a B.S. degree in accounting from Central State University, Edmond, Okla. He is currently vice president of Sellstrom Mfg. Co., a manufacturer of welding helmets and other personal protective equipment. He was formerly executive vice president and coowner of Sooner Supplies, Inc., a large independent welding supply distributor in Oklahoma. Franklin has been active in AWS for many years. He has served on its board of directors for two three-year terms, was a member of the Executive Committee for three years, a member of the Roles and Missions for three years, vice chair of the Manufacturers Committee, first chair of WEMCO, and a member of WEMCO’s Executive Committee for six years, a member of various AWS councils and committees and served on several AWS Presidential Task Groups.

PLUMMER MEMORIAL EDUCATION LECTURE AWARD

Ernest D. Levert, Sr.

Ernest Levert received his degree in welding engineering from The Ohio State University. He is employed as a senior staff manufacturing engineer for Lockheed Martin Missiles and Fire Control in Dallas, Tex. He has led efforts on the Patriot Advance Capability (PAC-3) Missile. Line-of-Sight Missile (LOSAT), Joint Strike Fighter (JSF-F22), International Space Station, Army Tactical Missile System (ATACS), and the Multiple-Launch Rocket System (MLRS) Advanced Missile Programs. Previously, Levert worked for General Dynamics, Convair Div., in San Diego, Calif., as a welding engineer supporting the Atlas space vehicle, Tomahawk cruise missile, and ground-launched cruise missile programs. He has worked more than 35 years in welding, supporting the aerospace and defense industries. Levert has presented several papers on aerospace applications of welding with emphasis on the electron beam process. He is a registered professional engineer in the state of Texas. He has earned certifications in high-pressure pipe welding, pressure hull welding, and aluminum structure welding. Levert was also chairman of the VICA Chapter at Max Hayes Vocational High School in Cleveland, Ohio.

PRIVATE SECTOR INSTRUCTOR MEMBERSHIP AWARD

Jay J. Jones

Jay Jones received his associate degree in applied arts and science for welding technology from Eastfield College, Mesquite, Tex., and his state teaching certificate and B.S. degree in Education from Texas A&M University. Since 2001, Jones has been with Thermadyne Industries, Inc. Currently, he is senior trainer for Thermadyne Victor Equipment Co. Prior to joining Thermadyne, he was an adjunct welding instructor for 18 years for the Dallas County Community College District; a welding shop foreman with Smith’s Welding Works, Garland, Tex.; a welding technician with Texas Instruments; and a full-time high school welding instructor for five years in the Garland Independent School District. At Thermadyne, he is involved with oxyfuel processes, developing programs and audits for end users, and demonstrating welding applications to assist end users with production. He also develops and presents product training to manufacturers’ and distributors’ sales personnel. Other subjects he teaches include arc welding, plasma cutting, arc gouging, and slice torch techniques. Jones has authored instructor guides for oxyfuel welding and cutting, shielded metal arc welding, gas metal arc welding, gas tungsten arc welding, and flux cored arc welding. He was a technical contributor to the oxyfuel portion of Welding Principles and Application, first and fifth editions, by Larry Jeffus. He has authored publications and articles for various industry magazines, and was a contributing author to the oxyfuel sections of the 2004 AWS Welding Handbook, 9th edition. He has delivered numerous technical presentations and training sessions nationwide to employees of shipyards, railroads, airlines, utility contractors, the Alaska pipeline, trade schools, and colleges. He has received special meritorious recognitions from the Garland Independent School District, Eastfield College, the Texas Parks and Wildlife Chairman’s Award for Public Services, and awards from AWS District 17. He has held all of the officer positions in the AWS North Texas Section.

ROBOTIC AND AUTOMATIC ARC WELDING AWARD

Chester L. Woodman, Jr.

Chester Woodman received his MBA from Pepperdine University in 1957. He joined Ingersoll-Rand Co.
John N. DuPont
Dr. DuPont’s biography appears under the A. F. Davis Silver Medal Award.

Charles V. Robino
Charles Robino received his Ph.D. in materials science and engineering from Lehigh University. From 1988 to 2002, he was a principal member of the technical staff at Sandia National Laboratories, and was promoted to distinguished member of the technical staff in 2002. His research includes fabrication and service weldability, solidification, and phase transformations. He also performs materials selection, weld reliability, and weld processing studies relating to Department of Energy programs in the defense and energy sectors. Robino has authored or coauthored more than 140 papers in the areas of welding, solidification, kinetics, and heat treatment. He has extensive experience in the welding behavior of steels, refractory metals, stainless steels, and nickel alloys. In 1997, he was awarded the AWS Koichi Masubuchi/Shinsho Corporation Award. In 1998 and 1999, he received the William Sprarragen Memorial Award. He received the McKay-Helm Award, the ISS/AISI Memorial Award. He received the A. F. Davis Silver Medal in 2001. He is a member of AWS and ASM International.

Joseph R. Michael
Joseph Michael received his Ph.D. degree at Lehigh University. He is a member of the technical staff in the Materials Characterization Department of Sandia National Laboratories. His primary interest is in the application of advanced characterization techniques to the study of materials. His recent research involved the application of electron backscatter diffraction and focused ion beam techniques to materials science. Prior to joining Sandia, Michael was a senior research engineer at the Bethlehem Steel Homer Research Laboratory where he worked with the physical metallurgy of new HSLA steels with improved properties. Michael has served as president and director of the Microbeam Analysis Society. He has received the McKay-Helm Award, Charles H. Jennings Memorial Award, and Warren F. Savage Memorial Award. He also received the Burton Medal from the Microbeam Analysis Society, and the ASM Grossman Award. In 1998, he received an R&D 100 Award. Michael has published more than 100 papers about materials science and the application of materials characterization techniques.

Ronald E. Mizia
Ronald Mizia received his M.S. degree in metallurgical engineering from Michigan Technological University in 1976. He is a senior consulting engineer at the Idaho National Laboratory. He has more than 30 years of experience in metallurgical and corrosion engineering in the areas of nickel-based alloy development, corrosion testing of metallic and nonmetallic materials, welding engineering materials for nuclear fuel reprocessing and waste storage, and materials for new reactor concepts. Mizia’s recent work concerns the development of a patented gadolinium-containing nickel-based alloy as a fixed neutron absorber. Mizia has another patent pending in the area of neutron-absorbing, corrosion-resistant metallic coatings. His recent publications describe work in the development of the Ni-Cr-Mo-Gd alloys, underground corrosion, electrochemical noise monitoring of corrosion in nuclear waste tanks, and innovative corrosion-measurement techniques. He is on the editorial review board for the Journal of Failure Analysis and Prevention, and is the vice chair for the NACE Intl’ Nuclear Systems Corrosion Technical Exchange Group.

David B. Williams
David Williams is the Harold Chambers Senior Professor of Materials Science and Engineering and vice provost for Research at Lehigh University. He obtained his Ph.D. and Sc.D. from Cambridge University. From 1974 to 1976, he was a science research council fellow in the Department of Metallurgy and Materials Science at Cambridge. In 1976, Williams moved to Lehigh as an assistant professor, becoming associate professor in 1979, and professor in 1983. He directed the Electron Optical Laboratory at Lehigh from 1980 to 1998, and chaired the Department of Materials Science and Engineering from 1992 to 2000. Williams has coauthored and

SAFETY AND HEALTH AWARD
Harvey R. Castner
Mr. Castner’s biography appears under the National Meritorious Award.

WARREN F. SAVAGE MEMORIAL AWARD
“Physical and Welding Metallurgy of Gd-Enriched Austenitic Alloys for Spent Nuclear Fuel Applications — Part II: Nickel-Based Alloys”
edited 11 textbooks and conference proceedings, and has published 200 journal papers, and 190 abstracts and conference proceedings in the general areas of analytical and transmission electron microscopy and the application of these techniques to studies of precipitation and segregation. Williams has given 250 invited presentations at universities, conferences, and research laboratories in 25 countries. He is a Fellow of TMS, ASM International, and the Royal Microscopical Society (U.K.), editor of Acta Materialia, and a past president of the International Union of Microbeam Analysis Societies.

**WILLIAM SPRARAGEN MEMORIAL AWARD**

"Direct Observations of Austenite, Bainite, and Martensite Formation during Arc Welding of 1045 Steel Using Time-Resolved X-Ray Diffraction"

**John W. Elmer**

John Elmer received his Sc.D. in metallurgy from Massachusetts Institute of Technology in 1988. From 1982 to 1984, he worked as a welding metallurgist at Lawrence Livermore National Laboratories (LLNL) for a variety of defense-related programs. He returned to LLNL in 1989, where he is currently deputy program element leader for Stockpile Metallurgy and Joining, in the Materials Science and Technology division, and serves as adjunct professor at the Pennsylvania State University. He is a Fellow of the American Welding Society and ASM International. He has received the Prof. Masubuchi-Shinsho Corporation Award, William Spraragen Award, A. F. Davis Silver Medal, Warren Savage Memorial Award, and the Samuel Wiley Miller Award. He serves as a member of numerous professional committees for AWS and ASM International, has published more than 90 articles and reports, and has been granted eight U.S. patents for his work in the field of welding. Elmer is renowned for his understanding of solidification and the kinetics of phase transformations during welding, high-energy-density beam-material interactions, and the application of synchrotron radiation for real-time observations of phase transformations during welding.

**Todd A. Palmer**

Todd Palmer received his Ph.D. in materials science and engineering from The Pennsylvania State University, where he studied under Prof. DebRoy. Since 2000, he has worked at Lawrence Livermore National Laboratory where he started as a postdoctoral technical associate, and currently is a metallurgist in the Materials Science and Technology division in the Chemistry and Materials Science Directorate. Presently, he is vice chair of the C7B Subcommittee on Electron Beam Welding and Cutting, and is a member of the Welding Journal Peer Review Panel, the editorial board of the journal, Science and Technology of Welding and Joining, and is a Key Reader for Metallurgical and Materials Transactions. He received the Geoffrey Belton Award from The Iron and Steel Society in 2000, and won the ASM International Graduate Student Paper Competition in 1999. From 1995 to 1998, he held an AWS Graduate Research Fellowship. He is the author or coauthor of more than 25 articles and reports. His current research interests involve the characterization of phase transformations in structural materials using synchrotron based in situ x-ray diffraction techniques, high-energy-density electron beam and laser beam welding and joining processes, and electron beam welding diagnostics.

**Sudarsanan Suresh Babu**

Sudarsanan Suresh Babu obtained his Ph.D. in materials science and metallurgy at the University of Cambridge, U.K. From 1992 to 1993, he worked as a research associate at Tohoku University, Japan. Babu joined Oak Ridge National Laboratory (ORNL) in 1993 as a postdoctoral research scholar, then joined its research staff in 1997. He is currently a senior research and development staff member at ORNL. Babu's expertise lies in the areas of phase transformations, welding metallurgy, and computational models for welding. 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 authored or coauthored 215 papers on welding and modeling of various other materials processing operations. DebRoy has received the Kenneth Easterling Award for the International Institute of Welding and Technical University of Graz, and the Adams Memorial Membership Award, McKay-Heilm Award, Charles H. Jennings Memorial Award, Warren F. Savage Memorial Award, Comfort A. Adams Lecture Award, William Spraragen Memorial Award, and the Honorary Membership Award. He is also the re-

**Wei Zhang**

Wei Zhang received his Ph.D. in materials science and engineering from the Pennsylvania State University in 2004. After graduation, he joined the Edison Welding Institute where he is currently an applications engineer. Zhang's research interests include the computational modeling of transport phenomena, welding metallurgy, welding stress and distortion. He has synthesized the numerical tools from several disciplines to study a wide range of welding processes and welded materials. Zhang received an AWS Graduate Fellowship to support his doctoral research studies at Pennsylvania State. He coauthored a paper winning the Kenneth Easterling Best Paper Award.

**Tarasankar DebRoy**

Tarasankar DebRoy is professor of materials science and engineering at the Pennsylvania State University. He received his Ph.D. from the Indian Institute of Science, in Bangalore, India. He did his postdoctoral work at the Imperial college of Science and Technology, London, U.K., 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 authored or coauthored 215 papers on welding and modeling of various other materials processing operations. DebRoy has received the Kenneth Easterling Award for the International Institute of Welding and Technical University of Graz, and the Adams Memorial Membership Award, McKay-Heilm Award, Charles H. Jennings Memorial Award, Warren F. Savage Memorial Award, Comfort A. Adams Lecture Award, William Spraragen Memorial Award, and the Honorary Membership Award. He is also the re-

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Fellows and Counselors Announced at AWS Welding Show

Six AWS Fellows and six AWS Counselors were announced at the Dallas AWS Welding Show.

Robert Hofman was cited for his contributions to fusion welding, and defining the complex phenomena occurring in the GMAW processes.

Robert Hofman attended Grand Rapids Community College, Michigan State University, and Aquinas College, where he majored in business administration. In 1958, he joined Kirkhof Manufacturing where he worked in various production positions, progressing to sales engineer. For five years he was a sales manager for the Transformer division. In 1980, he became vice president and cofounder of RoMan Manufacturing, Inc., a producer of resistance welding power sources. Hofman has served as chair of the AWS Western Michigan Section, and served as District 11 director (1977–1980), and an AWS director-at-large (1980–1983). He was involved with the Resistance Welder Manufacturers’ Association, ultimately serving as its president in 1991. He also served on the advisory board at Ferris State University for its welding engineering technology program.

GEORGE E. WILLIS AWARD

Kohuske Horikawa

Kohuske Horikawa received his Ph.D. in engineering from the University of Tokyo in 1967 after which, he joined the university as an assistant professor. In 1978, he joined the Welding Research Institute, Osaka University, as associate professor. In 1987, he served as a full professor until his retirement in 2002, when he was given the title Professor Emeritus. During his career, he conducted fundamental research and practical coordination for design, fabrication, and rehabilitation of heavy welded steel constructions, quality management in welded construction, and international standardization of welding and allied processes.

He has held the position of Head of Japanese Delegation to ISO/TC44, ISO Official Representative to CEN/TC121, chairman of Asian Welding Standardization Forum, IIW vice chairman of Select Committee Standardization, and IIW vice chairman of Commission XV. Horikawa is a Life Member and a Fellow of ASCE, and a 30-year member of AWS. He is the recipient of the Tanaka Prize, JSCE, for “Repair Welding under Service Conditions,” and the IIW Gurrenera Medal for “Welding Coordination for Akashi Bridge.”

Pingsha Dong received his Ph.D. in computational mechanics from the University of Michigan at Ann Arbor. He is currently with Battelle Memorial Institute. As technical director, Center for Welded Structures Research, his interests include design and analysis methods for welded structures, advanced computational procedures for welding/joining process simulations, fatigue/fracture behavior of welded structures, and residual stress and distortion mitigation techniques. Dong has published more than 180 papers in various peer-reviewed journals and conference proceedings and has received numerous awards, including Dr. Rene Wasserman Award, ASME’s G.E. Widera Literature Award, and SAE’s Henry Ford II Distinguished Award for Excellence in Automotive Engineering. He serves as associate editor for ASME Transactions Journal of Offshore Mechanics and Arctic Engineering, and the Journal of Science and Technology of Welding and Joining. He is also a Principal Reviewer for peer-reviewed papers published in Welding Journal. Since 1994, he has served as a U.S. Delegate to International Institute of Welding Commissions X on Fracture Avoidance of Welded Structures, and has served since 2003 as chairman of Subcommission XE on Defect Assessment.

ELIHU THOMSON RESISTANCE WELDING AWARD

Robert S. Hofman

Robert Hofman attended Grand Rapids Community College, Michigan State University, and Aquinas College, where he majored in business administration. In 1958, he joined Kirkhof Manufacturing where he worked in various production positions, progressing to sales engineer. For five years he was a sales manager for the Transformer division. In 1980, he became vice president and cofounder of RoMan Manufacturing, Inc., a producer of resistance welding power sources. Hofman has served as chair of the AWS Western Michigan Section, and served as District 11 director (1977–1980), and an AWS director-at-large (1980–1983). He was involved with the Resistance Welder Manufacturers’ Association, ultimately serving as its president in 1991. He also served on the advisory board at Ferris State University for its welding engineering technology program.

Six AWS Fellows and six AWS Counselors were appointed at the Dallas AWS Welding Show.

Appointed to AWS Fellow status were Harvey R. Castner, William H. King, Ravi Menon, Suck-Joo Na, Raymond George Thompson, and Thomas Zacharia.

Appointed to AWS Counselor status were Warren G. Alexander, Lee G. Kvidahl, Ernest D. Levert, Sr., Glenn M. Nally, Nancy C. Porter, and Amos O. Winsand.

Castner was cited for his development of fluxes for the GTAW process, and an analytical approach to determining crack-resistant weld compositions.

King was noted for his extensive work in the aerospace welding industry and welding of superalloys.

Menon was recognized for his work on flux cored wires, and developing the first all-position nickel-based flux cored wires in industry.

Suck-Joo Na was honored for his contributions to fusion welding, and defining the complex phenomena occurring in the GMAW processes.

Thompson was named for his research in the theory of weld HAZ microstructure evolution, microfissuring and grain boundary migration.

Zacharia was honored for his research in weld pool modeling and enhancements to resistance spot welds for the automobile industry.

Alexander was cited for his work in bridge fabrication quality standards and his successful efforts to coauthor and publish the AASHTO/AWS D1.5 Bridge Welding Code.

Kvidahl was recognized for his distinguished service in the shipbuilding industry.

Levert was cited for his significant contributions to major welding programs, including Atlas and Centaur space boosters and Space Shuttle and International Space Station.

Nally was recognized for his outstanding communications, advertising, trade show, and public relations skills.

Porter was honored for her work at Edison Welding Institute and involvement with welding engineering students, fundraising, and job placement assistance to further the Image of Welding.

Winsand was cited for his numerous achievements, innovative ideas to improve the performance of multipass resistance welding used for automotive bodies.
TECHNICAL COMMITTEE MEETINGS

AWS technical committee meetings are open to the public. If you want to attend a meeting, contact the staff secretary of the committee as listed below at AWS, 550 NW LeJeune Rd., Miami, FL 33126; telephone (800/305) 443-9353.


Aug. 11, Technical Activities Committee. Columbus, Ohio. General meeting. Staff Contact: P. Howe, ext. 309.

Aug. 30, D15 Committee on Railroad Welding. St. Louis, Mo. Standards preparation meeting. Staff Contact: R. Hancock, ext. 226.

Aug. 30, D15A Subcommittee on Freight Cars and Their Materials. St. Louis, Mo. Standards preparation meeting. Staff Contact: R. Hancock, ext. 226.

Standards for Public Review

AWS was approved as an accredited standards-preparing organization by the American National Standards Institute (ANSI) in 1979. AWS rules, as approved by ANSI, require that all standards be open to public review for comment during the approval process. This column also advises ANSI approval of documents. The following standards are submitted for public review. Draft copies may be obtained from Rosalinda O'Neill, 550 NW LeJeune Rd., Miami, FL 33126; (800/305) 443-9353, ext. 451, ronell@aws.org.


ERRATA IN D15.1


P. 23, Table C2, under column titled “Base Metal Thickness of …”, last entry, change “3/4” Т” to “3/4 < Т”.

P. 53, Table C5, for Preheat Category C row, under column titled “Thickness of Thickest Part…”, second entry, change “over 3/4 through 1-1/2”. P. 126, Fig. F2(A), for callouts, change “d = d-2t” to “d = d-t”, and “d = 07d-15t” to “d = 0.7d-1.5t”.

P. 126, Fig. F2(B), for the callout, change “d = 07d-15t” to “d = 0.7d-1.5t”.

P. 129, 26.1.5.2(3), first sentence, change “Figure F2” to “Figure F10”.

Page 139, 29.3.2, second sentence, change “50°F (10°C)” to “50°F (10°C)”.

OPPORTUNITIES

Ship and Boatbuilding

The D3A Committee seeks volunteers to help revise D3.7, Guide for Aluminum Hull Welding, and D3.5, Guide for Steel Hull Welding. Topics include design, cutting, qualification, construction practices, inspection, and welding processes and equipment. Contact Brian McGrath, (800) 443-9353, ext. 311, bmcgrath@aws.org.

Iron Castings

The D11 Committee seeks volunteers to help revise D11.2-89, Guide for Welding Iron Castings. Experts in the welding of iron castings as well as users of iron castings are urged to participate in this important work. Contact John Gayler, (800) 443-9353, ext. 472; gayler@aws.org.

Inspection

The B1 Committee on Methods of Inspection seeks volunteers to help revise AWS B1.10:1999, Guide for the Nondestructive Examination of Welds, and AWS B1.11:2000, Guide for the Visual Examination of Welds. Meetings will be held using the Internet, teleconferences, and e-mail. A face-to-face meeting may be held during the next AWS Welding Show, Nov. 13–16, 2005, in Chicago. Contact Brian McGrath, (800) 443-9353, ext. 311, bmcgrath@aws.org.

DUES UPDATE

Effective June 1, 2005, the following rates for annual membership dues went into effect.

Individual Member $80
Educational Institution $240
Supporting Company $400
AWS Student $15

The two-year membership for new subscribers is $135, a savings of $25.

Note that $4 of membership dues goes to the AWS Foundation to support its scholarship programs; $18.75 pays for the subscription to the Welding Journal. For complete information, visit www.aws.org/membership, or call (800) 443-9353, ext. 480.
Stanley Takes the Gold in U.S. Open Weld Trials

Joel Stanley II, 22, was judged the official winner of the U.S. Open Weld Trials held at the AWS Welding Show in Dallas, Texas, in April. There, he competed against six U.S. welders plus contenders from Australia, Canada, Ireland, the Netherlands, Thailand, and the U.K.

A student at Northern Penobscot Tech Region III and Eastern Maine Community College, he spent an entire year practicing on weekends, and nights after working full-time as a welder at Fastco Corp. in Lincoln, Maine.

As he left Lincoln for Dallas, he said, “I think it’s going to be a tough competition, but I am looking forward to it. I feel pretty laid-back and confident about competing.”

He discovered that the Dallas contest was tough. It required using detailed welding blueprints to build four constructs of steel, stainless steel, aluminum, and a pressure vessel of mixed metals that contest judges tested with X rays.

The Dallas win earned him a $40,000 scholarship presented by Miller Electric Co., plus the opportunity to compete in the WorldSkills welding competition held the last week of May in Helsinki, Finland.

Stanley used those few weeks between contests to scrutinize his Dallas weld projects to learn where he lost points, and how to improve his performance. Stanley’s welding instructor, David Hartley, who accompanied him to Finland, said, “Joel really knows how welding works, how amperage and voltage affect the weld pool and how to apply that knowledge.”

At Helsinki, Stanley competed well against 24 of the world’s best welders. His work took fifth place after the entries of Korea, Australia, Thailand, and Chinese Taipei. The competition was so close the top three contestants each received a gold medal.

Experienced and even headed, Stanley flatly states it is virtually impossible to be perfect in welding all the time, and even the best welder can misjudge tolerances or have a weld crack.

As for his future, Stanley said, “I plan to use the Miller $40,000 scholarship, but I haven’t decided what course to follow yet. I prefer hands-on work, but haven’t ruled out an engineering career either. I will take the time to look at the schools to see what they have to offer.

WEMCO Presents Its 2005 Image of Welding Awards

The AWS Welding Equipment Manufacturers Committee (WEMCO) named seven professionals to receive its third annual Image of Welding Award at the Dallas AWS Welding Show.

Tom Morrissett was cited for the Individual Award.

William Adams, Clovis Community College, Clovis, N.Mex., accepted the Educator Award.

Mahany Welding Supply, Rochester, N.Y., received the Distributor Award.

LeTourneau University, Longview, Tex., and Ferris State University, Big Rapids, Mich., tied for the Educational Facility Award.

Dana Corp., Toledo, Ohio, took the Large Business Award honors.

Detroit Section received recognition for the AWS Section Award.

WEMCO is a standing committee of the American Welding Society. Executives from welding industry suppliers formed the committee as a forum to promote their understanding of the welding equipment market through customized plans and programs. Enhancing the image of welding as a skill crucial to industry has been identified as a top-priority program.

Nominations for the 2006 Image of Welding Awards are being accepted now. For information, contact Maggie Alvarez-Miranda, AWS public relations manager, at malvarez@aws.org.

For complete information on WEMCO membership and benefits, visit the committee’s Web site at www.aws.org/wemco.

Five Sections Cited by AWS Board of Directors

On April 28, 2005, after due consideration of the recommendations by Districts Council, the AWS Board of Directors approved the disbandment of the AWS Puerto Rico Section, District 5, and the AWS Southwest Idaho Section, District 20.

The name of the AWS Eastern Idaho/Montana Section, District 20, was changed to Idaho/Montana, and the name of the AWS Maryland Section, District 3, was changed to Baltimore.

The AWS Richmond Section, District 4, was placed on Inactive Status.
New AWS Supporters

New Sustaining Companies

**Daily's 4 G. Welders**  
6541 125th Ave. NE  
Kirkland, WA 98033  
Representative: Charles Lee Daily

My father, Chuck Daily, first started welder training in 1939. He has taught his two sons, two grandsons, two great-grandsons, and many others how to weld and inspect each weld to a qualified procedure and job specifications. The company is pleased to be welding partners, advisors, and consultants supporting the AWS Student Chapters, AWS scholarship programs, and working with AWS District 19, the Puget Sound Section, local welding schools, instructors, students, and industry.

**Lake Murray Steel Inspection, Inc.**  
PO Box 508  
Prosperity, SC 29127  
Representative: Richard C. Bannister

Lake Murray Steel Inspection, Inc., is a full-service quality assurance inspection agency. We are capable of providing all of your construction and maintenance inspection needs. Do your welders or inspectors need training? Our staff is qualified to meet your certification needs for personnel and fabrication facilities. We provide consulting and inspection services in-house or at your site.

**Manitowoc Crane Group**  
1565 Buchanan Trail East  
Shady Grove, PA 17256  
Representative: Gary Martens

The Manitowoc Crane Group companies compose one of the world’s broadest and most comprehensive families of lifting products, including Manitowoc Cranes, Potain, Grove, and National Crane. The Manitowoc Crane Group is a wholly owned subsidiary of The Manitowoc Co., which also includes a food service segment and a marine division.

Educational Institutions

- **Amarillo College**  
  1201 I Ave.  
  Amarillo, TX 79111

- **Gateway Regional High School**  
  12 Littleville Rd.  
  Huntington, MA 01050

- **Oak Ridge High School**  
  127 Providence Rd.  
  Oak Ridge, TN 37830

- **Oklahoma Dept. of Career Tech**  
  1500 W. 7th Ave.  
  Stillwater, OK 74074

- **Prosper School of Technology**  
  4202 Charlestown Rd.  
  New Albany, IN 47150

- **Tusla Technology Center**  
  3420 S. Memorial Dr.  
  Tulsa, OK 74145

- **Instituto Mexicano del Petróleo**  
  Eje Central Lázaro Cárdenas No. 152  
  Mexico, D.F. 07730, Mexico

New Affiliate Companies

- **Aaron’s Technical Services**  
  4101 S Longfellow Ave., Ste. E  
  Tucson, AZ 85714

- **Accurate Steel and Pipe Fabricators**  
  106 W. 1st St., PO Box 217  
  Kennard, NE 68034

- **Bozankaya, LLC**  
  81210 Siena Ave.  
  Sacramento, CA 95828

- **Dynamic Creations**  
  4641 Emory  
  El Paso, TX 79907

- **Equipos Inoxidables del Norte, SA de CV**  
  Piedras Negras #330  
  Parque Industrial Laguna  
  Gomez Palacio, Durango, 35070, Mexico

- **House of Weiss, LLC**  
  587 Wallingford Rd., Unit 48  
  Durham, CT 06422

- **Industrial Construction & Welding, Inc.**  
  PO Box 227  
  Lithia, FL 33547

Membership Counts

<table>
<thead>
<tr>
<th>Grades</th>
<th>As of 6/1/05</th>
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<tbody>
<tr>
<td>Sustaining companies</td>
<td>420</td>
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<td>Supporting companies</td>
<td>210</td>
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<td>Educational institutions</td>
<td>347</td>
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<td>Affiliate companies</td>
<td>305</td>
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<tr>
<td>Welding distributor companies</td>
<td>51</td>
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<td>Total corporate members</td>
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<tr>
<td>Individual members</td>
<td>43,499</td>
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<tr>
<td>Student + transitional members</td>
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<tr>
<td>Total members</td>
<td>48,256</td>
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</table>
RECRUIT NEW MEMBERS... WIN GREAT PRIZES

A simple way to give back to your profession, strengthen AWS and win great prizes is by participating in the 2005-2006 Member-Get-A-Member Campaign. By recruiting new members to AWS, you’re adding to the resources necessary to expand your benefits as an AWS Member. Plus, you become part of an exclusive group of AWS Members who get involved. Year round, you’ll have the opportunity to recruit new members and be eligible to win special contests and prizes. Referrals are our most successful member recruitment tool. Our Members know first-hand how useful AWS Membership is. Who better than you to encourage someone to join AWS?

AWS MEMBER BENEFITS CHECKLIST:

- Annual subscription to the Welding Journal.
- A 25% discount on hundreds of first-rate AWS technical publications and 140+ industry codes.
- Deep discounts on 120+ technical training events every year.
- Access to widely recognized AWS Certification programs.
- New Members can save nearly 90% off an AWS publication. Choose from four of our most popular titles (see reverse).
- AWS Membership Certificate and Card.
- Networking opportunities through local Section meetings, the AWS Welding Show and an online bulletin board on the AWS website at <www.aws.org>.
- Members-only discounts on auto insurance, car rentals, credit cards and more.
- Connection to career opportunities through AWS JobFind – at www.awsjobfind.com
- The American Welder section of the WJ geared toward front-line welders.
- And much more!

GET INVOLVED TODAY, AND WIN!

PRIZE CATEGORIES

President’s Honor Roll:
Recruit 1-5 new Individual Members and receive a welding ball cap.

President’s Club:
Recruit 6-10 new Individual Members and receive an American Welder™ polo shirt.

President’s Roundtable:
Recruit 11-19 new Individual Members and receive an American Welder™ polo shirt, American Welder™ T-shirt and a welding ball cap.

President’s Guild:
Recruit 20 or more new Individual Members and receive an American Welder™ watch, a one-year free AWS Membership, the “Shelton Ritter Member Proposer Award” Certificate and membership in the Winner’s Circle.

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

SPECIAL PRIZES

Participants will also be eligible to win prizes in specialized categories. Prizes will be awarded at the close of the campaign (June 2006).

Sponsor of the Year:
The individual who sponsors the greatest number of new Individual Members during the campaign will receive a plaque, a trip to the 2006 FABTECH International and The AWS Welding Show, and recognition at the AWS Awards Luncheon at the Show.

Student Sponsor Prize:
AWS Members who sponsor two or more Student Members will receive a welding ball cap.

The AWS Member who sponsors the most Student Members will receive a free, one-year AWS Membership and an American Welder™ polo shirt.

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

LUCK OF THE DRAW
For every new member you sponsor, your name is entered into a quarterly drawing. The more new members you sponsor, the greater your chances of winning. Prizes will be awarded in November 2005, as well as in February and June 2006.

Prizes Include:
- American Welder™ T-shirt
- one-page, black/white ad in the Welding Journal
- Complimentary AWS Membership renewal
- American Welder™ polo shirt
- American Welder™ baseball cap

SUPER SECTION CHALLENGE
The AWS Section in each District that achieves the highest net percentage increase in new Individual Members before the June 2006 deadline will receive special recognition in the Welding Journal.

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

American Welding Society
550 N.W. LeJeune Rd. • Miami, Fl 33126
Visit our website http://www.aws.org
AWS STUDENT MEMBERSHIP

Domestic (Canada & Mexico incl.) $15

TOTAL PAYMENT $135

If yes, add one-time initiation fee of $25

TWO-YEAR AWS INDIVIDUAL MEMBERSHIP $135 (a $25 savings)

NEW MEMBER REOQuest

BOOK/CD-ROM SELECTION

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

NEW MEMBER RENEWAL

A free local Section Membership is included with all AWS Memberships

Section Affiliation Preference (if known):

Type of Business (Check ONE only)

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

Job Classification (Check ONE only)

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

Technical Interests (Check all that apply)

A Ferrous metals
B Nonferrous metals except aluminum
C Advanced materials/intemetallics
D Ceramics
E High energy beam processes
F Arc welding
G Brazing and soldering
H Resistance welding
J Thermal spray
K Cutting
L NDT
M Safety and health
N Bending and shear
O Roll forming
P Stamping and punching
Q Aerospace
R Automotive
S Machinery
T Marine
U Piping and tubing
V Pressure vessels and tanks
W Sheet metal
X Structures
Y Other
Z Automation
1 Robotics
2 Computerization of Welding
DISTRICT 1
Director: Russ Norris
Phone: (603) 433-0855

BOSTON
April 18
Activity: Stuart Olsen, materials manager, and Jim Laverdiere, president, led the Section members on a tour of the KleenLine Engineered Conveyor Systems facility in Newburyport, Mass. The plant fabricates custom stainless steel conveying products for the food and pharmaceutical industries.

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

DISTRICT 3
Director: Alan J. Badeaux, Sr.
Phone: (301) 934-9061

LANCASTER
April 5
Activity: The meeting was held at Symposium Restaurant in Lancaster, Pa. In attendance were AWS President Jim Greer and District 3 Director Alan Badeaux. Greer presented Chairman John Ament with a certificate of appreciation for serving as Section chair.

READING
March 19
Activity: The Section hosted its annual Vo-Tech welding competition at Berks County Vocational and Technological Career Center in Reading, Pa.

April 21
Activity: The Reading Section hosted an awards-presentation banquet to honor the participants in its March welding competition. The event was held at Berks County Career and Technology Center West in Reading, Pa.

AWS President Jim Greer (left) presents John Ament with a certificate of appreciation at the Lancaster Section program in April.

Shown during the Boston Section's tour of KleenLine Engineered Conveyor Systems are (from left) Jim Laverdiere, president; Stuart Olsen, materials manager; and Section Chair Gary Hylan.

Shown at the Reading Section's sponsored welding competition held last March are the contestants, judges, and instructors.

Attendees posed for a photograph during the Reading Section's awards-presentation banquet held in April.
Bill Rhodes (left), Southeast Virginia Section chair, accepts an appreciation award from Ted Alberts, District 4 director.

Shown at the York-Central Pa. car show are (from left) Chair George Bottenfield, John Lengel, and Tim Anderson.

Shown (from left) are George Bottenfield, Mike Bunnell, and Larry Smith during the York-Central Pa. car show in April.

YORK-CENTRAL PA. and York County School of Technology Student Chapter
APRIL 16
Activity: The York-Central Pennsylvania Section and its Student Chapter participated in a car show featuring hot rods, classics, antique, custom-mades, trucks, motorcycles, stock, and muscle cars. The event was held at the school grounds featuring more than 180 vehicles on display. The ESAB trailer presented welding and plasma arc demonstrations. The Section's booth was manned by Mike Bunnell and George Bottenfield.

DISTRICT 4
Director: Ted Alberts
Phone: (540) 674-3600, ext. 4314

SOUTHWEST VIRGINIA
APRIL 13
Activity: The Section hosted its Students' Night program for 86 attendees. District 4 Director Ted Alberts presented Mike Bryant (Dabney S. Lancaster C.C.) the Section Educator Award, and the Section Appreciation Award to Chairman Bill Rhodes. Welding instructors in attendance included

Shown at the Southwest Virginia Section Students' Night awards-presentation program are (from left) Chair Bill Rhodes, Matthew Vanderkooy, David Williams, Layne Harmon, and Ted Alberts, District 4 director.

Shown are the students who participated in the Southwest Virginia welding competition.
Sandra Johnston (Patrick Henry H.S.), James Stump (Guiles Tech Center), Chris Overfelt (Arnold R. Burton Tech Center), Charlie Overfelt (Wm. Fleming H.S.), Bruce Hunt (Botetourt Tech Education Center), Doug Thompson (Floyd County H.S.), and Jamie Huffman (Jackson River Tech Center).

DISTRICT 5
Director: Leonard P. Connor
Phone: (954) 981-3977

PALM BEACH
January 19
Speaker: Vergie Y. Bain, compliance specialist
Affiliation: U.S. Dept. of Labor, OSHA
Topic: OSHA regulations for oxyacetylene welding and cutting
Activity: Len Connor, District 5 director, attended this program, held at the Olive Garden Restaurant in Boynton Beach, Fla.

SOUTH CAROLINA
April 28
Speakers: Marvin Tallent, QC/QA manager, Palmetto Bridge Constructors; and Richard Grumbine, ASNT Level II inspector, Soil Consultants, Inc.
Topics: Tallent discussed weld quality and workmanship; Grumbine presented a talk on nondestructive testing.
Activity: The program was held at the Palmetto Bridge Constructors facility.

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

NIAGARA FRONTIER
April 21
Speaker: Jim Orndorff, CWI, CWE
Affiliation: Quality Inspection Services
Topic: Discontinuities in weld and base metal
Activity: The program was held at Quality Inspection Services in Buffalo, N.Y.

DISTRICT 7
Director: Don Howard
Phone: (814) 269-2895

JOHNSTOWN/ALTOONA
November 10, 2004
Speaker: Fred Raco, president
Affiliation: RNDT, Inc.
Topic: Nondestructive testing methods

December 9, 2004
Speaker: Bart Sickles, Division chair
Speaker Brad Shaw (far left) is shown with a few of the welding students present at the March meeting of the Johnstown/Altoona Division.

Honored at the Western Area Career & Tech Center Student Chapter meeting in May are (from left) Joe Bianchin, Carl Cosentino, Brian Birdsall, Brandon Wiei, Chapter Advisor Tony Reis, and Dave Kelly. Max Davis missed getting into the photo.

Affiliation: Concurrent Technologies
Topic: Explosion welding and testing
Activity: District 7 Director Don Howard discussed national AWS activities for the Johnstown/Altoona Division members.

FEBRUARY 9
Speaker: Robert Wertz, senior project engineer
Affiliation: Concurrent Technologies
Topic: Fuel cell testing and evaluation
Activity: This Johnstown/Altoona Division program attracted 48 attendees.

MARCH 9
Speaker: Paul Brad Shaw, senior project engineer
Affiliation: Maglev, Inc.
Topic: The Pennsylvania high-speed Maglev transportation project
Activity: This Johnstown/Altoona Division event was held in Johnstown, Pa.

Western Area Career & Tech Center Student Chapter
MAY 4
Activity: Six students from the AWS Student Chapter were inducted into the National Technical Honor Society.

Honored were Joe Bianchin, Carl Cosentino, Brian Birdsall, Brandon Wiei, Dave Kelly, and Max Davis.

DISTRICT 8
Director: Wallace E. Honey
Phone: (256) 332-3366

DISTRICT 9
Director: John Bruskotter
Phone: (504) 394-0812

DISTRICT 10
Director: Richard A. Harris
Phone: (440) 338-5921

NORTHEASTERN PA.
APRIL 12
Speaker: Richard Harris, contributing editor
Affiliation: Penton Publishing Co.
Topic: The value of reading welding trade magazines
Activity: The program was held at Tri State Welding Lab in Erie, Pa.

DISTRICT 11
Director: Efthihios Siradakis
Phone: (989) 894-4101

DETROIT
May 6
Activity: The Section hosted its annual Ladies’ Night event at Cobo Center in downtown Detroit. The event was attended by 420 members and guests. Special guests at the program were Jeff Weber, AWS associate executive director, and his wife, Linda.

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

LAKESHORE
April 14
Activity: The Section members toured the Burger Boat facility in Manitowoc, Wis., to study its yacht-building techniques. Following the tour, the meeting was held at Lighthouse Inn where John Brodtke received his Silver Membership Award for 25 years of membership in the Society. The award was presented by John Zielona, Section chairman.

MILWAUKEE
April 21
Speaker: William Bong
Affiliation: Arcmatic Integrated Systems
Topic: Improved electroslag welding
Activity: William Bong, Bob Shuster, and James Priestly demonstrated the narrow gap improved electroslag welding system to join two heavy plates in less than nine minutes that would have taken hours to weld by hand. The dinner was held at Thunder Bay Grille in Pewaukee, Wis. Sean P. Moran, incoming District 12 director, was introduced to the attendees.
DISTRICT 13
Director: Jesse L. Hunter
Phone: (309) 359-3063

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

INDIANA
April 18
Activity: The Section held its awards-presentation and officer elections program at Jonathon Byrd’s Cafeteria near Indianapolis.

LEXINGTON
April 12
Activity: The Section rallied to assist Herbert Harrison who lost everything when his home burned down. Jim Lamirande, Section chair, presented Harrison with a $500 check.

ST. LOUIS
February 17
Speaker: Gailyn Cornell, a trainer for the retail division
Affiliation: The Lincoln Electric Co.
Topic: Welder training
Activity: The Section held its annual Students’ Night program to award its scholarships and recognize the outstanding student members.

March 31
Activity: The St. Louis Section toured the Seyer Industries plant to study the building of parts and products used for maintenance of military helicopters, planes, and ships. Chris Seyer, president, conducted the tour for 37 members and guests.

Gailyn Cornell discussed welder training at the St. Louis Section Students’ Night program in February.

Shown at the Indiana Section program in April are (front, from left) J. R. Hollers, Gene Poe, and Gary Dugger. Top, from left, are Mike Anderson, Steven Meckstroth, and Bob Richwine.

The proud instructors and their award-winning students posed at the St. Louis program in February.

Shown at Busch Stadium during the St. Louis Section’s Past Chairmen’s outing are (from left) Chuck Gulash, Don Kimbrell, Mark Anderson, Larry Ingram, Jerry Simpson, Kevin Corgan, Norm Helton, and District 14 Director Tully Parker.
Chris Seyer (left) accepts an appreciation gift from Brian Muenchau, St. Louis Section publicity chair, following the Section’s March tour of Seyer Industries.

John Crook (left), Westside High School principal, accepts a $2500 donation from Monty Rogers, Nebraska Section chairman.

May 7
Activity: The St. Louis Section hosted its annual Past Chairmen’s Night program at Busch Stadium in St. Louis, Mo., to watch the Cardinals play against the Padres. Past chairs in attendance were Chuck Gulash, Don Kimbrell, Mark Anderson, Larry Ingram, Jerry Simpson, Kevin Corgan, Norm Helton, and District 14 Director Tully Parker.

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

Dist 16
Director: Charles F. Burg
Phone: (515) 233-1333

Dist 17
Director: Oren P. Reich
Phone: (254) 867-2203

Shown at the Nebraska Section presentation ceremony at Westside High School are (from left) Mike Fraser, secretary; Steve Nell, vice chair; John Bombac, welding instructor; Karl Fogleman, awards chair; John Crook, school principal; Monty Rogers, Section chair; and Gregg Ratliff, welding instructor.

Winners on the Oklahoma City Section’s Aqua Canyon course were (from left) Dan Andrews, Dean Evans, Rick Lawson, and John Francis.

Winners on the Oklahoma City Section’s Cimarron course were (from left) Dave Quentero, Randy Wilkerson, Cary Reeves, and Tim Kerse.

Mid Plains
April 27
Activity: The Section toured the Baldwin Filter Plant in Gothenburg. Neb. David Haynes, plant operations manager, conducted the tour.

Dist 16
Director: Charles F. Burg
Phone: (515) 233-1333

Dist 17
Director: Oren P. Reich
Phone: (254) 867-2203

Neb.
April
Activity: The Section presented Westside High School welding hoods, jackets, pliers, safety glasses, wire tips, welding wire, gloves, and other valuable welding-related items worth $2500. John Crook, school principal, accepted the donation from Section Chair Monty Rogers.
EAST TEXAS  
APRIL 29  
Speaker: Jeff Ding, welding engineer  
Affiliation: NASA  
Topic: Welding development at Marshall Space Flight Center  
Activity: The Section held its election of officers for the 2005-2006 term in Berry Auditorium at LeTourneau University, Longview, Tex.

OKLAHOMA CITY  
MAY 16  
Activity: The Section hosted its annual golf tournament fundraiser event at Cimarron National Golf Course in Guthrie, Okla. One hundred fifty entered the event. The big winners included Dan Andrews, Dean Evans, Rick Lawson, John Francis, Dave Quentero, Randy Wilkerson, Cary Reeves, and Tim Kerce.

TULSA  
JANUARY 25  
Speaker: Bob Ball, manager of economic research  
Affiliation: Tulsa Metro Chamber of Commerce  
Topic: The economic outlook for Tulsa’s heavy manufacturing in 2005  
Activity: The meeting was held at Tulsa Technology Center, Lemly Campus.

FEBRUARY 12  
Activity: The Tulsa Section hosted its annual Ladies’ Night Out with Sweethearts dinner, followed by bingo. District 17 Director Oren Reich presented appreciation awards to Jan Todd and Jane Morgan for their contributions to the Section’s activities.

MARCH 22  
Activity: The Tulsa Section toured the Airgas Mid South, Inc., facility in Tulsa, Okla., to study the operations performed at this manufacturing and distribution center. Vice Chair Mark Davidson presented the Manufacturer’s Appreciation Award to Mike Duvall, president.

DISTRICT 18  
Director: John L. Mendoza  
Phone: (210) 353-3679

LAKE CHARLES  
APRIL 20  
Activity: The Section hosted its annual crawfish boil and awards night program. On hand for the event were R. W. “Tac” Edwards, Drew Fontenot, James Bobo, District 18 Director John Mendoza, David Savoy, Ronnie Hebert, Andy Davis, Kermit Babaz, and Jimmy Veillon.

SABINE  
APRIL 19  
Speaker: Ron Theiss, nondestructive evaluation program coordinator  
Affiliation: North Harris College in Houston, Tex.  
Topic: Radiographic film interpretation of welds  
Activity: The program was held at Team Cooperheat in Beaumont, Tex.

MAY 17  
Speakers: James Phillips and Randy Veillon  
Affiliation: Car-Ber Testing Services  
Topic: Hydrostatic testing  
Activity: The incoming officers were introduced: Grady Hatton, chairman; Glynn Savage and James Amy, vice chairs; Mark Clark, secretary; and Ruel Riggs, treasurer.
Shown at the District 18 conference are (from left) AWS representative Vicki Pinsky, Raul Robles, Morris Weeks, James Amy, Drew Fontenot, Dennis Eck, John Mendoza, Jr., Al Marin, and Ruel Riggs.

Shown are most of the 35 delegates and guests who attended the District 18 conference in San Antonio, Tex.

Shown working the AWS Foundation's booth during the Welding Show are (from left) Nora Mendoza, John Mendoza, Jr., and Mayra Medina.

Speakers James Phillips (left) and Randy Veillon (far right) receive the Sabine Section's Texas plaque from Morris Weeks, vice chair.

Topic: Distortion control when welding aluminum hull submarine sections
Activity: The incoming Section officers were introduced: Chris Sundberg, chairman; Ken Johnson, vice chair; Terri Tovey, secretary; Tim Jackson, treasurer; and Steve Pollard, technical representative.

DISTRICT 20
Director: Nancy M. Carlson
Phone: (208) 526-6302

ALBUQUERQUE
CALENDAR
Contact: Mike Thomas, (505) 239-6295 yahtayhey@aol.com

October meeting: A research scientist from Los Alamos National Laboratories will give a presentation on flux core welding.

November meeting: An OSHA representative will present updates on compliance in the workplace.

December meeting: The holiday social will be held at Sandia Casino.

IDAHO/MONTANA
JANUARY
Activity: The Section toured RAVE TDC (Rocky Mountain Agile Virtual Enterprise Technical Development Center) in Butte, Mont. RAVE provides hands-on technical education and manufacturing prototyping. It houses a robotic GMA welding machine, a GTAW system donated by Edwards AFB, and a Hass CNC lathe and a vertical mini mill.

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

DISTRICT 22
Director: Kent S. Baucher
Phone: (559) 276-9311

FRESNO
MARCH 17
Activity: The Section toured Pelco, Inc., in Covis, Calif., to study its manufacture of security camera systems led by Nealdey Foster, director, and Brandon Greene, security officer. CWI Brad Bosworth, secretary, presented the Chairman Appreciation Certificate to Tim Youngberg.
The incoming Puget Sound Section officers are (from left) Steve Pollard, Terri Tovey, Chris Sundberg, Ken Johnson, and Tim Jackson.

Some of the Idaho/Montana Section members are shown during their tour of the RAVE facility in Butte, Mont.

Brandon Greene (left) is shown with Tim Youngberg, Fresno Section chair, at the March 17 program.

Fresno Section Secretary Brad Bosworth (left) presents the Chairman Appreciation Award to Tim Youngberg.

Fresno Section members pose for a photo with Pelco director Neadly Foster (center-front).
Listed are the participants in the 2004–2005 Campaign. See page 65 for campaign rules and prize list. Call Membership Dept. (800) 443-9353, ext. 480, for more information.

**Winner’s Circle**

(AWS Members who have sponsored 20 or more new Individual Members, per year, since June 1, 1999.)*

J. Compton, San Fernando Valley
C. Reeves, Oklahoma City
G. Euliano, Northwestern Pennsylvania
B. Breeden, Santa Clara Valley
W. Shreve, Fox Valley
R. Olson, Siouxland
H. Hughes, Mahoning Valley
D. Tipton, Southeast Nebraska
K. Langdon, Johnny Appleseed
R. Halvorsen, Idaho/Montana
T. Baldwin, Arrowhead
M. Batchelor, Boston
A. Baughman, Stark Central
A. Burton, Chicago
J. Campbell, Milwaukee
J. Cantlin, Southern Colorado
J. Carew, Western Michigan
K. Carter, Tri-River
C. Daily, Puget Sound
M. Darnell, San Antonio
M. Davidson, Tulsa
J. Emmerson, Connecticut
G. Erickson, Florida West Coast
G. Fudala, Philadelphia
G. Garrison, Michigan
P. Harper, Baton Rouge
J. Jaskolosi, Western Michigan
D. Kensrue, Long Beach/Orange County
T. Krall, Dayton
P. Layola, International
R. Nielsen, Utah
R. Olson, Siouxland
H. Riviere, South Florida
R. Robles, Corpus Christi
D. Russell, Chattanooga
S. Salamon, New Jersey
W. Scarince, Northwest
G. Schroeter, Puget Sound
O. Templet, Baton Rouge

**President’s Guild**

(AWS Members sponsoring 11–19 new Individual Members between June 1, 2004, and May 31, 2005.)

G. Euliano, Northwestern Pennsylvania
D. Hatfield, Tulsa
G. Taylor, Pascagoula
W Shreve, Fox Valley
J. Compton, San Fernando Valley
J. Daily, Puget Sound
M. Darnell, San Antonio
M. Davidson, Tulsa
J. Emmerson, Connecticut
G. Erickson, Florida West Coast
G. Fudala, Philadelphia
G. Garrison, Michigan
P. Harper, Baton Rouge
J. Jaskolosi, Western Michigan
D. Kensrue, Long Beach/Orange County
T. Krall, Dayton
P. Layola, International
R. Nielsen, Utah
R. Olson, Siouxland
H. Riviere, South Florida
R. Robles, Corpus Christi
D. Russell, Chattanooga
S. Salamon, New Jersey
W. Scarince, Northwest
G. Schroeter, Puget Sound
O. Templet, Baton Rouge

**President’s Roundtable**

(AWS Members sponsoring 6–10 new Individual Members between June 1, 2004, and May 31, 2005.)

J. Bobo, Atlanta
J. McCarty, St. Louis
R. Culbert, Inland Empire

**President’s Club**

(AWS Members sponsoring 1–5 new Individual Members between June 1, 2004, and May 31, 2005. Only those sponsoring 2 or more Members are listed.)

O. Baker, Olympia
J. Jaeger, Kansas
M. Tryon, Utah
B. Breeden, Santa Clara Valley
G. Euliano, Northwestern Pennsylvania
D. Guthrie, Tulsa
C. Reeves, Oklahoma City
T. Shirk, Tidewater
H. Shore, Tulsa
D. Wright, Kansas City
B. Franklin, Mobile
E. Levert, North Texas
G. Navas, Washington, D.C.
T. Neubauer, Sangamon Valley
N. Ramersdor, International
T. Baldwin, Arrowhead
M. Batchelor, Boston
A. Baughman, Stark Central
A. Burton, Chicago
J. Campbell, Milwaukee
J. Cantlin, Southern Colorado
J. Carew, Western Michigan
K. Carter, Tri-River
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D. Harrison, Cleveland
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D. Ketter, Willamette Valley
D. Scott, Peoria
A. Baughman, Stark Central
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J. Pelsier, Southeast Nebraska
T. Buchanan, Mid-Ohio
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O. Templet, Baton Rouge

**Member-Get-a-Member Campaign**

Superscript denotes number of times the Member achieved Winner’s Circle status. Status will be awarded at the close of each membership campaign year.
aws president
Damian J. Kotecki
Damian_Kotecki@lincolnelectric.com
The Lincoln Electric Co.
22801 St. Clair Ave. Cleveland, OH 44117-1199

jeff weber
associate executive director

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

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.

jeffrey r. hufsey
associate executive director

Marketing

Bob Bishops.. bbishop@aws.org ... (213)
Senior Manager, Marketing
Linda Henderson.. lindah@aws.org ... (298)
Marketing Communications
Senior Manager
George Leposky.. glep@aws.org ... (416)
Manager, Public Relations
Magda Alvarez-Miranda.. alz@aws.org ... (308)
Plans and coordinates marketing of AWS products and services.

member services

Associate 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.

education services

Managing Director
Richard J. DePue.. rd@aws.org ... (237)
Educational Product Development Director
Christopher Pollock.. cpollock@aws.org ... (219)
Responsible for tracking the effectiveness of programs and development of new products and services. Coordinates in-plant seminars and workshops. Administers the S.E.N.S.E. program. Acts as Government Liaison Committee with advocacy efforts. Works with Education Committees to disseminate information on careers, national education, and training trends and schools that offer welding training, certificates or degrees.

conferences and seminars

Director
Giselle I. Hufsey.. giselle@aws.org ... (278)
Responsible for conferences, exhibitions, and seminars on topics ranging from the basics to the leading edge of technology. Organizes CWI, SCWI, and 9-Year Renewal certification-driven seminars.

CERTIFICATION OPERATIONS

department

Managing Director
Andrew R. Davis.. adavis@aws.org ... (466)
International Standards Activities, American Council of the International Institute of Welding (AWI)

Technical Publications
Senior Manager
Rosalinda O’Neill.. ronell@aws.org ... (451)
AWS publishes more than 200 technical standards and publications widely used in the welding industry.

Technical Committee Secretaries
Harold R. Ellison.. ellen@aws.org ... (299)

Structural Welding, Welding Iron Castings
Rakesh Gupta.. rakesh@aws.org ... (301)

Ross Hancock.. rhancock@aws.org ... (226)
Welding Qualification, Friction Welding, Railroad Welding, Joining of Metals and Alloys.

Cynthia Jenney.. cyj@aws.org ... (304)
Definitions and Symbols, Brazing and Soldering, Brazing Filler Metals and Fluxes, Technical Editing.

Brian McGrath.. bmcgrath@aws.org ... (311)

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.

web site administration
Director
Keith Thompson.. keiko@aws.org ... (414)
Nominees for National Office

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

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

To be considered a candidate for positions of president, vice president, treasurer, or director-at-large, the following qualifications and conditions apply:

President: To be eligible to hold the office of president, an individual must have served as a vice president for at least one year.

Vice President: To be eligible to hold the office of vice president, an individual must have served at least one year as a director, other than executive director and secretary.

Treasurer: To be eligible to hold the office of treasurer, an individual must be a member of the Society, other than a Student Member, must be frequently available to the national office, and should be of executive status in business or industry with experience in financial affairs.

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

Interested parties are to send a letter stating which particular office they are seeking, including a statement of qualifications, their willingness and ability to serve if nominated and elected, and 20 copies of their biographical sketch.

This material should be sent to Thomas M. Mustaleski, Chairman, National Nominating Committee, American Welding Society, 550 NW LeJeune Rd., Miami, FL 33126.

The next meeting of the National Nominating Committee is scheduled for October 2006. The term of office for candidates nominated at this meeting will commence January 1, 2008.

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 AWS Exposition and Convention held each spring. The deadline for submissions is July 1 prior to the year of awards presentations. Send candidate materials to Wendy Sue Reeve, Secretary, Honorary-Meritorious Awards Committee, 550 NW LeJeune Rd., Miami, FL 33126. A description of the awards follow.

National Meritorious Certificate Award: This award is given in recognition of the candidate’s council, 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 to enhance the American Welding Society’s goal of advancing the science and technology of welding over the past five-year period.

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.

International Meritorious Certificate Award: This award is given in recognition of the candidate’s significant contributions to the worldwide welding industry. This award should reflect “Service to the International Welding Community” in the broadest terms. The awardee is not required to be a member of the American Welding Society. Multiple awards can be given per year as the situation dictates. The award consists of a certificate to be presented at the awards luncheon or at another time as appropriate in conjunction with the AWS President’s travel itinerary, and, if appropriate, a one-year membership in the American Welding Society.

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 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 Damian J. Kotecki as listed on the previous page.
10th AWS/AA Aluminum Welding Conference & Exhibition
October 24–26
Orlando, Fla.
Grosvenor Resort in the Walt Disney World Resort

Welding the High-Performance Stainless Conference
November 14, 15
FABTECH International & The AWS Welding Show
Chicago, Ill.

This two-day conference will focus both on conventional stainless steels as well as the new high-performance grades such as duplex stainless, the superaustenitics, the superferritics, and the supermartensitic stainless steels. Dr. Ralph Davison will present an overview of the high-performance stainless steels, while Donald Tillack will provide helpful guidelines for the welding of the conventional grades. Other topics on the program will include the welding of dissimilar metals and the use of ferrite numbers. A presentation on the use of the hosts of shielding gases for stainless steels will be given by Kevin Lyttle.

For more information please contact the AWS Conferences and Seminars Business Unit at (800) 443-9353, ext. 223. You can also visit the Conference Department at www.aws.org for upcoming conferences and registration information.

Friction Stir Welding Conference
November 16
FABTECH International & The AWS Welding Show
Chicago, Ill.

The most interesting new welding process in years — friction stir welding — will be the subject of this one-day conference. The speakers will be ready to answer many of the questions that are on the minds of welding engineers. Presentations will be delivered on the various types of equipment available, the tooling used to make the welds, case studies, and cost. Considerable time will also be spent on the use of this process in various industries, including aerospace and automotive. There will also be a great deal of coverage on the use of friction stir welding for aluminum. Also highlighted will be some of the progress being made on such materials as titanium and steel.

Radiographic Interpreters

AWS announces a new program to train and certify AWS Radiographic Interpreters. If your job responsibilities include reading and interpreting weld radiographs, this program is for you. Seminars and exams are scheduled throughout the rest of the year in various U.S. cities. Call the AWS Certification Department, 800-443-9353, ext. 273, or visit www.aws.org/certification/RI for more information.
NJC Exploring New Techniques for Virginia Class Sub Construction

The Navy Joining Center (NJC) is currently leading a project to develop novel design-for-manufacturing methods (DFM) and welding automation to support product-centered structural fabrication at General Dynamics Electric Boat (GDEB). The project team is combining the welding process and automation expertise of Edison Welding Institute (EWI) and the manufacturing systems design expertise of the Institute for Manufacturing and Sustainment Technology (iMAST) to assist GDEB in planning a new state-of-the-art fabrication facility that will feature product-centered manufacturing.

Early in development activity, the project team identified a family of tank components in the Virginia Class submarine (Fig. 1) as a candidate for DFM principles. The result was a flexible fixture design for the feed water, bilge water, and lube oil tanks.

As a direct result of the success of that project, a second-phase effort has been initiated to identify an additional family of tank components from the Virginia Class submarine. The new family of tanks selected for fixtures is the auxiliary tanks and their associated wing tanks. These tanks are more complex than the tanks addressed earlier in the project.

State-of-the-art welding automation technologies will be evaluated for GDEB production welding operations. Additionally, the most appropriate welding process and portable automation solutions will be determined and functional requirements will be established for a comprehensive flexible fixture design.

The primary purpose of any welding fixture is to 1) assist in the accurate positioning of components for production welding and 2) provide minimal interference to the welder (or automated device) as the welds are deposited.

Even with an optimum fixture, the ability to produce a final component meeting all of the dimensional requirements will be limited unless consideration is given to the sequence in which individual pieces or subassemblies are introduced and included in the final welded structure. Toward that end, the project team is selecting automation methods and developing new fixtureing technology. Fixtures are being designed to accommodate the access and positioning requirements dictated by optimized welding procedures and automated welding systems.

A Welding Procedure Estimator™ was developed in Phase I of the project to accurately predict welding fabrication time. This tool is being optimized to assist in making production work assignments and to enable GDEB to easily compare the economic benefits of multiple welding processes, and to compare the pros and cons of semiautomatic vs. automated deployment of a single welding process.

The key to exploiting product-centered manufacturing is to improve productivity across production operations. GDEB has achieved significant advancements in cutting, forming, marking, and surface-preparation processes. Without developing the requisite infrastructure to support product-centered manufacturing, the potential of these enhanced capabilities will not be fully realized.

The first year’s efforts have shown successes and will continue in the next year to apply flexible fixture approaches employing DFM principles for the fabrication of foundation tanks in the Virginia Class submarine. For more information, contact Nancy Porter, Navy Joining Center, (614) 688-5194, e-mail nancy_porter@ewi.org.

Two NJC Fellowships Awarded at AWS Welding Show

The Navy Joining Center each year supports two graduate fellowships as part of its commitment to further technical education and the advancement of materials-joining technology. These fellowships are awarded through the American Welding Society Foundation to support graduate students whose research topics address materials-joining topics of interest to the Navy.

The two NJC graduate fellowships for the 2005–2006 academic year were announced at the AWS Welding Show held in Dallas, Texas, in April. The NJC Fellowships for the upcoming academic year have been awarded to Timothy Anderson, Lehigh University, and Morgan Gallagher, The Ohio State University.

Anderson is pursuing master's and doctorate degrees in material science and engineering with studies in “Alloy Development of a Robust Filler Metal for the Superaustenitic Stainless Steel AL-6XN®.” Gallagher is pursuing his Ph.D. in welding engineering with studies in “An Investigation of Hot Cracking in Hastelloy® Alloy C-22®.”

For more information on the requirements for receiving graduate fellowships, contact the AWS Foundation at (800) 443-9353, ext. 689.

The Navy Joining Center
1250 Arther E. Adams Dr.
Columbus, OH 43221
Phone: (614) 688-5010
FAX: (614) 688-5001
e-mail: NJC@ewi.org
www: http://www.ewi.org
Contact: Larry Brown

Fig. 1 — The Virginia Class submarine. (Photo by Chris Oxley, Northrop Grumman Corp.)
Northrop Grumman Appoints Four Vice Presidents

Northrop Grumman, Newport News, Va., has named Robert L. Gunter, sector vice president of operations; Matthew J. Mulherin, sector vice president of programs; Ken Mahler, vice president for aircraft carrier overhauls; and Mike Shawcross, vice president of the CVN 21 program. Prior to this appointment, Gunter was vice president for aircraft carrier programs and vice president of engineering. Mulherin most recently served as vice president for the CVN 21 program. Prior to their promotions, Mahler served as program director responsible for completion of the USS Ronald Reagan, and Shawcross served as CVN 21 propulsion plant program director.

Linde Gas Announces Management Changes

Linde Gas, Cleveland, Ohio, has named Howard Hubert to succeed Cliff Caldwell who was recently promoted to global specialty gas manager for Linde AG. Chris Ebeling has been named marketing director for gas and welding; and David Browning appointed manager, marketing communications and hardware product management. The Gas and Welding-North sales team was restructured under senior vice president Jack Brull. Scott Latta was promoted to lead the Midwest region, and Scott Snyder joined the company to head the Eastern region. Named as regional zone managers were Shane Dillman (Wisconsin), Ken Ishman (Michigan), Don Speight (Chicago area), and Heath Wells (central Illinois and Missouri), Joel Lewandowski (NE Ohio and western Pennsylvania), Hal Mager (Cincinnati area, Kentucky, West Virginia, and northern Tennessee), and Jim Simpson (central Indiana and Ohio). In the Gas and Welding-South division, under Vice President Dave Carter, Paul Smith has been named manager, Georgia region, replacing Bob Slagle, who was recently promoted to manager, regional operations south.

MG Systems and Welding Hires Sales Manager

MG Systems and Welding, Menomonee — continued on page 83

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Circle No. 9 on Reader Info-Card
Industrial Plastic Products Displayed

A colorful 88-page catalog illustrates and describes the company’s wide assortment of products for industrial use. Shown are plastic bins, containers, tubing, gloves, stretch film wraps, aprons, rainwear, coveralls, shoe covers, and Tyvek® clothing products. Other items include siphons and rotary hand pumps, poly and steel drums up to 55-gal, vials, and bags-on-rolls.

Consolidated Plastics Co., Inc. 115
8181 Darrow Rd., Twinsburg, OH 44087

Powder Metallurgy Publications Detailed

A 20-page catalog describes dozens of textbooks, manuals, standards, publications, conference proceedings, and videos detailing every aspect of powder metallurgy and particulate materials. General topics include ferrous powder metallurgy, aluminum and light alloys, cemented carbides, metal and ceramic injection molding, tungsten and refractory metals, mechanical alloying, sintering, nanotechnology, and metallography.

Metal Powder Industries Federation 116
185 College Rd. E., Princeton, NJ 08540-6692

Pneumatic Cylinders and Actuators Pictured

The 700-page SC-Master catalog offers technical and ordering details regarding industrial pneumatic cylinders and actuators. Among the 23 product lines listed are TaskMaster® aluminum profile, PowerMaster® NFPA steel tie rod, Easy-2-Combine modular handling system, grippers, rotary actuators and modules, micro, guided, twin-rod, clamping devices, and NCT noncontact transfer units. Also detailed are right-angle flow controls as accessories.

Bosch Rexroth Corp. 117
5150 Prairie Stone Pkwy., Hoffman Estates, IL 60192

Welding Course Catalog

The 44-page course catalog details the school’s history, types of training, training methods, facilities, and detailed course contents, and schedules. Complete information is presented on costs, financial aid, loans, and grants. Included are descriptions of new seminars on laser welding and processing, and robotic arc welding. Information is presented on opportunities for in-plant training at the customer’s site, and other specialized training services.

Hobart Institute of Welding Technology 118
400 Trade Square East, Troy, OH 45373

Surface Prep Supplies for Contractors Showcased

A brochure details the company’s supplies, equipment, service, and solutions for a wide range of surface preparation applications. Shown are air blast abrasives, mass finishing, and coated and bonded abrasives. Other topics covered include service and training, air tools, dust collector cartridges, parts processing labs, industrial safety products, and wheel blast equipment and parts.

International Surface Preparation 119
663 Park Point Dr., Ste. 200, Golden, CO 80401
MEMBER MILESTONE

John L. Mendoza Elected to SkillsUSA Board

John L. Mendoza has been elected to the board of directors for the SkillsUSA Texas College/Postsecondary Division. The body is responsible for setting policy for SkillsUSA activities in the state of Texas. Mendoza is currently the AWS District 18 director. He is an AWS Certified Welding Inspector and a Certified Welding Educator.

Airgas Names Senior VP

Airgas, Inc., Radnor, Pa., has named Michael Rohde to the new position of senior vice president, distributions operations. Previously, Rohde served as regional company president of Airgas South for the past five years.

OBITUARY

David J. Crawford

David J. Crawford, 53, died April 15. Mr. Crawford was involved in all aspects of distribution and finance at Atlas Welding Accessories, Inc., with locations in Michigan and New York. He was active in AWS District 11, and Detroit Section events, and participated in the preparations for the AWS Welding Shows. Among his favorite activities were playing golf and basketball, and sports coaching. He is survived by his wife and three daughters.

Battelle Honors Scientist for Welding Breakthrough

Battelle Memorial Institute researcher Pingsha Dong was awarded the Aerospace 2004 Laurels Award from Aviation Week and Space Technology for his breakthrough method of predicting the fatigue life of welded structures. Dong’s Verity™ mesh-insensitive structural stress method, experts say, could save billions of dollars in aerospace, automotive, and other engineering fields by allowing companies to reduce expensive testing practices and over-engineering of designs.

FKI Logistex Appoints Two Canadian Representatives

FKI Logistex, St. Louis, Mo., has appointed Glen Chambers as regional director, and Paul Swietlinski as business development manager, for the Canadian operations of its North American manufacturing systems unit. Prior to joining the company, Chambers held positions with General Conveyor and Matthews Conveyor. Swietlinski, who now reports to Chambers, previously worked for General Conveyor, Comptrol, and Chronos/Howe Richardson.

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INTERNATIONAL STANDARDS DEVELOPMENT - MIAMI, FL

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Requires a University degree, preferably in engineering or equivalent (experience in welding or manufacturing desirable), standards development experience, especially ISO procedures (either as a committee member or from a standards development organization), excellent verbal and written English skills. Must be computer literate, proficient in MS Windows/PC environment and have good e-mail and internet skills (for web-based standards development).

Interested parties should send a resume and salary range along with a cover letter outlining interest to American Welding Society
550 N.W. LeJeune Rd.
Miami, FL 33126
Attn.: Andrew Davis
Technical Services
adavis@aws.org
AWS – An Equal Oppotunity Employer
Visit our Website at www.aws.org

NDT TECHNICIAN

Must be qualified at Level 2, Radiographic inspections, Ultrasonic testing, Magnetic Particle testing. An AWS CWI certification would be a plus. All certifications must be traceable to a recognized industrial standard, i.e., SNT-TC-1A and/or ANSI/ASNT.

MT, RT, UT certification required.

High familiarity of QC standards and procedures is essential. A good working knowledge of welding and heavy metal fabrication is essential. Ability to communicate (written and verbal) required.

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The AWS Certification Committee

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For further information, contact:

Joseph P. Kane
631-265-3422 (office)
516-658-7571 (cell)
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AWS Certification Committee

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Reliable Calculations of Heat and Fluid Flow during Conduction Mode Laser Welding through Optimization of Uncertain Parameters

A deterministic approach is proposed to improve reliability of heat transfer and fluid flow calculations

BY A. DE AND T. DebROY

ABSTRACT. During conduction mode laser beam welding, the quality of numerical simulation of heat transfer and fluid flow in the weld pool is significantly affected by the uncertainty in the values of absorptivity, effective thermal conductivity, and effective viscosity that cannot be easily prescribed from fundamental principles. Traditionally, values of these parameters are either prescribed based on experience or adjusted by trial and error. This paper proposes a deterministic approach to improve reliability of heat transfer and fluid flow calculations. The approach involves evaluation of the optimized values of absorptivity, effective thermal conductivity, and effective viscosity during conduction mode laser beam welding from a limited volume of experimental data utilizing an iterative multi-variable optimization scheme and a numerical heat transfer and fluid flow model. The optimization technique minimizes the error between the predicted and the measured weld dimensions by considering the sensitivity of weld dimensions with respect to absorptivity, effective thermal conductivity, and effective viscosity. Five sets of measured weld pool dimensions corresponding to five different welding conditions were utilized for the optimization. However, the procedure could identify the optimized values of the three uncertain parameters even with only three sets of measured weld pool dimensions.

Introduction

Since the temperature and velocity fields in the weld pool are difficult to measure experimentally (Refs. 1-7), these important variables are often estimated by numerically solving the equations of conservation of mass, momentum, and energy. In recent years, the numerically computed temperature fields have been utilized to estimate weld pool dimensions (Refs. 4-7) and understand weld metal phase composition (Refs. 8-11), grain structure (Refs. 10, 11), inclusion structure (Refs. 12-14), and weld metal composition changes owing to both vaporization of alloying elements (Refs. 15, 16) and dissolution of gases (Refs. 17, 18).

The transport phenomena-based numerical models have been continually updated to include more detailed and realistic descriptions of component physical processes for simple (Refs. 19-22) as well as for complex weld joint geometries (Ref. 23). In recent years, these models have become relatively easy to use because of advances in computational hardware and software. However, these powerful numerical heat transfer and fluid flow models have not found widespread use in manufacturing or design applications. An important difficulty is the uncertainty involved in specifying some of the necessary input variables such as absorptivity, effective thermal conductivity, and effective viscosity. Although the time-tested physical laws such as the equations of conservation of mass, momentum, and energy provide a reliable phenomenological framework for calculations, the reliability of the numerical process models greatly depends on the accuracy of several input parameters.

Many input parameters necessary for the numerical simulation of heat transfer and fluid flow in conduction-mode linear laser beam welding can be readily specified. These include welding speed, beam power, beam diameter, and thermophysical properties of the material being welded (Refs. 19, 24). However, the values of absorptivity, effective thermal conductivity and effective viscosity cannot be specified from fundamental principles (Refs. 2, 24-30). For example, absorptivity depends on the chemical composition of the substrate, the surface finish, laser mode, and the prevailing temperature distribution on the weld pool. As a result, the absorption coefficient cannot be estimated theoretically with high reliability. However, an accurate value of absorptivity is critical for the dependable estimation of the rate of heat absorption. Similarly, appropriate values of effective thermal conductivity and effective viscosity are needed for the reliable modeling of the high rates of transport of heat, mass, and momentum in weld pools with strong fluctuating velocities (Ref. 25). Enhanced values of liquid thermal conductivity and viscosity have been frequently used to take into account the effects of the fluctuating...
components of velocities in the weld pool. In some cases, the two-equation k-ε turbulence model has also been used in estimating the effective viscosity and effective thermal conductivity in the weld pool (Refs. 26-28). However, the two-equation k-ε turbulence model contains several empirical constants that were originally estimated from parabolic fluid flow data in large systems. As a result, its applicability for the recirculating flow in small scale systems has not been adequately tested. Since the effective thermal conductivity and viscosity depend on the turbulent kinetic energy and other properties of convection, these parameters are system properties (Refs. 1, 2, 24-30) and their values depend on welding conditions, particularly the heat input.

The values of effective viscosity and thermal conductivity have been determined in this work as a function of heat input from a limited volume of measured weld pool dimensions for conduction mode linear laser beam welding (Ref. 24) utilizing an optimization algorithm and a numerical heat transfer and fluid flow model. In contrast with the effective viscosity or the effective thermal conductivity, the laser beam absorptivity coefficient is a materials property. Although it varies with temperature, the extent of the variation is normally much smaller than those of the effective thermal conductivity or the effective viscosity. It has been taken as a constant in this work for simplicity. The optimization algorithm minimizes the error between the predicted and the experimentally observed penetrations and the weld widths by considering the sensitivity of the computed weld pool dimensions with respect to the absorptivity, effective thermal conductivity, and effective viscosity. The sensitivity terms are calculated by running the heat transfer and fluid flow model several times for each measurement considering small changes in the absorptivity, effective thermal conductivity, and effective viscosity (Refs. 29, 30).

The approach determines the values of absorptivity, effective viscosity and thermal conductivity in an iterative manner starting from a set of their initial guessed values. In order to include the effects of laser power, spot diameter, and welding speed into one convenient variable during optimization, a nondimensional heat input variable, \( N_{HI} \), is defined as

\[
N_{HI} = \frac{P}{\rho C_p V (T_L - T_a) + \rho L}
\]

where \( P \) is the laser power (W), \( r_s \) the spot radius (m), \( v \) the welding velocity (m/s), \( C_p \) the specific heat of the solid metal (J/kg*K^-1), \( p \) the density (kg/m^3), \( L \) the latent heat of fusion (J/kg^-1) and \( T_L \) and \( T_a \) are the liquidus and ambient temperatures (K), respectively. In Equation 1, the numerator represents the available laser power per unit volume and the denominator depicts the enthalpy required to heat a unit volume of metal from ambient temperature to liquidus temperature. The numerator in Equation 1 when multiplied by the absorptivity, \( \eta \), provides the absorbed heat per unit volume. The optimization approach identifies a single value of absorptivity and a linear trend of effective thermal conductivity and effective viscosity with \( N_{HI} \) from a limited volume of measurements.

The work presented in this manuscript represents a significant improvement over the previous (Refs. 31-35) reverse model-
ing work in welding reported in the literature. First, unlike the previous efforts, a well-tested, three-dimensional numerical heat transfer and fluid flow model is used to compute the weld pool geometry. This is significant, because previous research has shown the importance of convective heat transfer in the weld pool. Second, the model input and the computed weld pool geometry are related by a rigorous phenomenological framework of the conservation of mass, momentum, and energy used in the optimization algorithm. The optimized values of absorptivity, effective thermal conductivity, and effective viscosity were tested by comparing the computed weld dimensions with the corresponding experimentally determined values (Ref. 4).

The effect of volume of data on the outcome of the optimization was examined. First, the optimization was done using five sets of measured weld pool dimensions. Second, the optimization was also carried out with only three measured data sets of weld pool dimensions. The optimized values of the uncertain variables were almost identical in both cases.

**Heat Transfer and Fluid Flow Simulation**

Table 1 depicts five sets of measurements of weld dimensions and the corresponding welding parameters that have been used in the present investigation. The chemical compositions of the steels used are presented in Tables 2 and 3. The steel compositions conform to two different grades of high-speed steel (Ref. 24). The thermophysical properties of these steels are given in Tables 4 and 5. The flow of liquid metal in the weld pool in a three-dimensional cartesian coordinate system is represented by the following momentum conservation equation (Refs. 4, 21, 22, 36):

\[
\rho \frac{\partial u_i}{\partial t} + \rho \frac{\partial (\mu u_i u_j)}{\partial x_j} = \frac{\partial}{\partial x_j} \left( \mu \frac{\partial u_i}{\partial x_j} \right) + S_i
\]  

(2)

where \( \rho \) is the density, \( t \) is the time, \( x_i \) is the distance along the \( i = 1, 2 \) and 3 directions, \( u_i \) is the velocity component along the \( j \) direction, \( \mu \) is the effective viscosity, and \( S_i \) is the source term for the \( i \)th momentum equation and is given as (Refs. 21, 22):

\[
S_i = -\frac{\partial p}{\partial x_j} + \frac{\partial}{\partial x_j} \left( \frac{\mu u_i}{\partial x_j} \right) - C \left( \frac{1-f_L}{f_L} \right)^2 u_i - \rho \frac{\partial u_i}{\partial x_j} + S_{b_i}
\]  

(3)

where \( p \) is the pressure, \( f_L \) is the liquid fraction, \( B \) is a constant introduced to avoid division by zero, \( C (=1.6 \times 10^4) \) is a constant that takes into account mushy zone morphology and \( S_{b_i} \) represents both the electromagnetic and buoyancy source terms. The third term on the right-hand side (RHS) represents the frictional dissipation in the mushy zone according to the Carman-Kozeny equation for flow through a porous media (Refs. 37, 38). The pressure field was obtained by solving the following continuity equation simultaneously with the momentum equation

\[
\frac{\partial (\rho u_i)}{\partial x_j} = 0
\]

(4)
The total enthalpy $H$ is represented by a sum of sensible heat $h$ and latent heat content $\Delta H$, i.e., $H = h + \Delta H$ where $h = \epsilon C_p$ $dT$, $C_p$ is the specific heat, $T$ is the temperature, $\Delta H = f_L L$, $L$ is the latent heat of fusion and the liquid fraction $f_L$ is assumed to vary linearly with temperature in the mushy zone (Ref. 4).

$$f_L = \begin{cases} \frac{1}{T_L-T_S} & T_L \leq T \leq T_S \\ \frac{T-T_L}{T_S-T_L} & T < T_L \end{cases}$$

where $T_L$ and $T_S$ are the liquidus and solidus temperature, respectively. The thermal energy transport in the weld workpiece can be expressed by the following modified energy equation (Refs. 4, 21):

$$\rho \frac{\partial h}{\partial t} + \rho \frac{\partial (\mu \Delta H)}{\partial x_i} = \frac{\partial}{\partial x_i} \left( k \frac{\partial h}{\partial x_i} \right)$$

$$-\rho \frac{\partial F L}{\partial t} - \rho \frac{\partial (\mu \Delta H)}{\partial x_i} - \rho U \frac{\partial h}{\partial x_i}$$

$$\frac{\partial \Delta H}{\partial x_i}$$

where $k$ is the thermal conductivity. The effective thermal conductivity in the liquid weld pool is also a property of the specific welding system and not a fundamental property of the liquid metal. Therefore, the value of the effective thermal conductivity is not known. Since the weld is symmetrical about the weld centerline only half of the workpiece is considered. The weld top surface is assumed to be flat. The velocity boundary condition is given as (Ref. 4)

$$u = 0$$

where $u$, $v$, and $w$ are the velocity components along the x, y, and z directions, re-
sively, γ is the surface tension, and T is the temperature. The w velocity is zero, since the liquid metal is not transported across the weld pool top surface. The heat flux at the top surface is given as

\[ q_s = n_s \frac{dT}{dz} \]

where \( n_s \) is the Stefan-Boltzmann constant, \( T \) is the ambient temperature, \( T_a \) is the heat transfer coefficient, and \( T_f \) is the temperature of the solid material at room temperature, viscosity of molten iron at 1823 K, and absorptivity, respectively. Assuming that \( O(f) \) is continuous and has a minimum value, the LM method tries to obtain the optimum values of \( f_1, f_2 \), and \( f_3 \) by minimizing \( O(f) \) with respect to them. In other words, Equation 11 is differentiated with respect to \( f_1, f_2 \), and \( f_3 \), and each derivative is made equal to zero.

**Levenberg-Marquardt (LM) Method**

In the LM method, the search for the optimized values follows the direction of the objective function gradient with step size modification by an adjustable damping parameter after each iteration. In the CG method, the direction of optimization is a conjunction of objective function gradient direction and the previous iteration objective function gradient direction and the previous iteration gradient direction. The LM method tries to obtain the optimum values of \( f_1, f_2, \) and \( f_3 \) by minimizing \( O(f) \) with respect to them. The values of the sensitivity terms are numerically calculated. For example, the sensitivity of \( p_m \) with respect to \( f_1 \) is calculated as

\[ \frac{\partial O(f)}{\partial f_1} = 0 \]

where \( f_i \) represents \( k^*, \mu^* \), or \( \eta \). The variables \( p_m \) and \( w_m \) in Equation 13 are obtained from the numerical heat transfer and fluid flow calculations for a certain set of \( f_1, f_2, \) and \( f_3 \), i.e., \( k^*, \mu^* \), and \( \eta \). The partial derivatives in Equation 13 are referred as sensitivity of the computed weld width and penetration with respect to the unknown parameters. The values of the sensitivity terms are numerically calculated.

### Optimization Procedure

Both the Levenberg-Marquardt (LM) and the conjugate gradient (CG) methods have been described in the literature (Refs. 39-42) and only the special features of their application are described here. The optimization of the absorptivity, effective thermal conductivity, and effective viscosity begins with the construction of an objective function that depicts the difference between the computed and the measured values of weld dimensions.

**Levenberg-Marquardt (LM) Method**

In the LM method, the search for the optimized values follows the direction of the objective function gradient with step size modification by an adjustable damping parameter after each iteration. In the CG method, the direction of optimization is a conjunction of objective function gradient direction and the previous iteration direction (Refs. 39-42). The objective function, \( O(f) \), is defined as

\[ O(f) = \sum_{m=1}^{M} \left( \frac{p_m - p_{m,\text{obs}}}{p_{m,\text{obs}}} \right)^2 + \sum_{m=1}^{M} \left( \frac{w_m - w_{m,\text{obs}}}{w_{m,\text{obs}}} \right)^2 \]

where \( p_m \) and \( w_m \) are the penetration and the width of the weld pool, respectively, and \( p_{m,\text{obs}} \) and \( w_{m,\text{obs}} \) are the corresponding measurements at similar welding conditions. The subscripts \( p_m \) and \( w_m \) are nondimensional and indicate the extent of over or underprediction of penetration and weld width, respectively. In Equation 11, the subscript \( m \) refers to a specific weld in a series of \( M \) number of total welds and the outlet of the welds is assumed as zero as (Refs. 4, 21)

\[ \frac{\partial u}{\partial y} = 0, \quad \frac{\partial v}{\partial y} = 0 \]

At all other surfaces, temperatures are taken as ambient temperature and the velocities are set to zero.

### Optimization Procedure

Both the Levenberg-Marquardt (LM) and the conjugate gradient (CG) methods have been described in the literature (Refs. 39-42) and only the special features of their application are described here. The optimization of the absorptivity, effective thermal conductivity, and effective viscosity begins with the construction of an objective function that depicts the difference between the computed and the measured values of weld dimensions.
where \( \delta f_1 \) is very small compared with \( f_1 \). The solution of Equation 13 is achieved when both \( p_n \) and \( w_m \) becomes close to one. In other words, the calculated values of \( p_n \) and \( w_m \) should be close to the corresponding measured values of \( p_{mn} \) and \( w_{km} \) for all M welds. Since \( f_1, f_2, \) and \( f_3 \) do not explicitly appear in Equation 13, this equation needs to be rearranged so that it can serve as a basis for an iterative scheme to evaluate the optimum values of \( f_1, f_2, \) and \( f_3 \). The procedure is explained in Appendix 1. The final form of equations to be solved is

\[
[S][\Delta f^k] = -[S^*]
\]

where, \( \{f_i^k\} = \{f_i^*\} + \{\Delta f_i^k\} \) for \( i = 1,3 \) and \( \{f_i^{k+1}\} \) refers to the three unknown increments after \((k+1)^{th}\) iteration. Equation 15 provides the solution of the three unknown increments, \( \{\Delta f_i\} \) corresponding to the three unknown parameters.

**Conjugate Gradient (CG) Method**

In the conjugate gradient technique, the unknown parameters are iteratively searched in the following sequence (Refs. 40-42):

\[
f_i^{k+1} = f_i^k - \beta^k d_i^k \quad \text{for} \quad i = 1,3
\]

where \( f_i^{k+1} \) represents the values of the three unknowns after \((k+1)^{th}\) iteration, indicates the directions of search at the end of \( k^{th}\) iteration corresponding to the unknowns \( f_1, f_2, \) and \( f_3 \), and \( \beta^k \) is the size of the search step. Both \( d_i^k \) and \( \beta^k \) are calculated for every iteration or step. The variable \( \beta^k \) tends to adjust the extent of increment in unknown parameters between successive iterations and logically should assume a value that will facilitate the condition of objective function minimum. Thus, \( \beta^k \) is calculated by minimizing the residual objective function \( O(f)^{k+1} \).

The directions of search, \( d_1^k, d_2^k, \) and \( d_3^k \), at the end of \( k^{th}\) iteration are calculated as a linear conjugation of the corresponding directions of search at the end of \((k-1)^{th}\) iteration and the respective residual gradient of the objective function, \( O(f) \), after \( k^{th}\) iteration as

\[
\frac{\partial O(f)}{\partial \beta^k} = 0 ; \beta^k \geq 0
\]

The solutions of search, \( d_1^k, d_2^k, \) and \( d_3^k \), at the end of \( k^{th}\) iteration are calculated as a linear conjugation of the corresponding directions of search at the end of \((k-1)^{th}\) iteration and the respective residual gradient of the objective function, \( O(f) \), after \( k^{th}\) iteration as

\[
d_1^k = \nabla O(f_1^k) + \gamma^k d_1^{k-1}
\]

\[
d_2^k = \nabla O(f_2^k) + \gamma^k d_2^{k-1}
\]

\[
d_3^k = \nabla O(f_3^k) + \gamma^k d_3^{k-1}
\]

where \( \gamma^k \) is a conjugation coefficient at the end of \( k^{th}\) iteration. The coefficient \( \gamma^k \) is obtained either by Equation 20a using Polak-Ribiére's (CGPR) modification or by Equation 20b using Fletcher-Reeve's modification (CGFR)

\[
\gamma^k = \frac{\sum_{i=1}^{3} [\nabla O(f_i^k)]^2}{\sum_{i=1}^{3} [\nabla O(f_i^{k-1})]^2}
\]

for \( k = 1,2,... \) and \( \gamma^0 = 0 \) (20a)

\[
\gamma^k = \frac{\sum_{i=1}^{3} [\nabla O(f_i^k)] [\nabla O(f_i^k) - \nabla O(f_i^{k-1})]}{\sum_{i=1}^{3} [\nabla O(f_i^{k-1})]^2}
\]

for \( k = 1,2,... \) and \( \gamma^0 = 0 \) (20b)
Further details of these two approaches are given in Appendix 2. In the CG methods, the direction of search is important, since the solution may diverge if the direction of search loses sight of the optimal solution. In the LM method, a manual damping factor is used that continually tracks the search step (or increment) so that the optimal solution cannot move away from the last computed minimum value of the objective function.

There are two main limitations in finding property data by the coupled heat and fluid flow and optimization procedure described in this manuscript. They are 1) the accuracy of measured depth and width and 2) how strongly the depth and the width vary with the uncertain parameter (sensitivity).

Results and Discussion

The sensitivity of the computed weld pool dimensions with respect to the effective thermal conductivity, effective viscosity, and absorptivity were determined by several heat transfer and fluid flow calculations. Figures 1A and B depict a number of isocontours of the dimensionless penetration, \( p_\text{s} \), and the dimensionless width, \( w_\text{m} \), as a function of \( k^* \) and \( \mu^* \) for data set Nos. 3 and 4 in Table 1. It is observed from Fig. 1A that the dimensionless penetration, \( p_\text{s} \), increases with \( k^* \) or \( \mu^* \). However, the dimensionless width, \( w_\text{m} \), decreases with \( k^* \) or \( \mu^* \) as shown in Fig. 1B. For \( k^* \) values above 7.0, both \( p_\text{s} \) and \( w_\text{m} \) become fairly insensitive to \( \mu^* \). Furthermore, both \( p_\text{s} \) and \( w_\text{m} \) approached a value of unity at high values of \( k^* \) and \( \mu^* \). When both \( p_\text{s} \) and \( w_\text{m} \) are 1, \( p_\text{s} \) equals \( p_\text{m} \) and \( w_\text{m} \) equals \( w_\text{m} \) and the calculated results agree with the corresponding measured values.

The effects of \( k^* \) and \( \mu^* \) on the computed weld pool dimensions are explained as follows:

The dimensionless weld penetration, \( p_\text{s} \), increases with \( k^* \) since high values of thermal conductivity facilitate rapid heat transport in the downward direction. However, the higher thermal conductivity also reduces the surface temperature gradient and the radial convective heat transport and, consequently, decreases. Higher values of \( \mu^* \) lowers radial convection and the convective heat flux resulting in both lower weld width and slightly higher peak temperature. The higher peak temperature enhances downward heat conduction and increases penetration. Furthermore, as \( k^* \) is progressively increased, conduction becomes the dominant mechanism of heat transfer and changes in \( \mu^* \) do not significantly alter either the peak temperature or the convective heat transfer rate. Thus, the weld pool dimensions do not change significantly with \( \mu^* \) at high values of \( k^* \) as observed in Fig. 1A and B.

It is quite apparent that in addition to the variation in \( k^* \) or \( \mu^* \), any change in the value of absorptivity will further influence the results presented in Fig. 1A and B. Although it has been reported that \( \eta \) depends on laser power (Ref. 43), the absorptivity is a material property, and its exact value depends on factors such as the surface temperature. An increase in the value of absorptivity implies an enhancement in the heat absorption rate that leads to higher peak temperature, greater temperature gradient and larger computed weld pool dimensions for a specific set of \( k^* \) and \( \mu^* \). In contrast, a decrease in the value of absorptivity leads to smaller values of computed weld pool dimensions for a specific set of \( k^* \) and \( \mu^* \). Such a behavior was also demonstrated in the case of a GTA weld pool (Ref. 29). To keep the problem tractable, a single optimized value of absorptivity \( (\eta) \) for all the welding conditions considered in the present work is assumed.

Figure 2 shows that high values of \( k^* \) and \( \mu^* \) are necessary to achieve good agreement between the computed and the experimental weld pool geometry, i.e., low values of objective function for data set Nos. 3 and 4 in Table 1. In contrast, Fig. 3 indicates that low values of both \( k^* \) and \( \mu^* \) are necessary to reduce the objective function for data set No. 2 in Table 1. These apparently contrasting results are achieved for welds with different heat input indexes \( (N_{\text{HI}}) \) of 21.90 and 14.97 for data set Nos. 2 and 3, respectively. The results in Figs. 2 and 3 are consistent with the fact that \( k^* \) and \( \mu^* \) are not materials properties and their optimum values depend on \( N_{\text{HI}} \). To account for the same in the procedure of optimization of \( k^* \) and \( \mu^* \) in a simplified manner, the following linear relationships are assumed for simplicity:

\[
k^* = C_1 + C_2 N_{\text{HI}}
\]

\[
\mu^* = C_3 + C_4 N_{\text{HI}}
\]

where \( C_1 \) and \( C_3 \) are the minimum values of the effective conductivity and effective viscosity, respectively, and \( C_2 \) and \( C_4 \) are constants. Since \( k^* \) and \( \mu^* \) equal 1 at low values of \( N_{\text{HI}} \), the values of both \( C_1 \) and \( C_3 \) are taken to be one. Thus, the optimization routine is used to estimate the values of \( C_2 \) and \( C_4 \) for each \( N_{\text{HI}} \).

Results in Figs. 2 and 3 also indicate that several combinations of \( k^* \) and \( \mu^* \) may result in low values of \( f \) for a given \( N_{\text{HI}} \). In order to seek optimum values for \( k^* \) and \( \mu^* \) for a particular \( N_{\text{HI}} \), an additional constraint is useful to achieve a physically realistic solution. Since \( k^* \) and \( \mu^* \) are related by the turbulent Prandtl number, \( Pr_T \), its value \( (0.9) \) provides a useful constraint. In other words, out of many possible solutions, the specific combination of \( k^* \) and \( \mu^* \) nearest to the line corresponding to \( Pr_T = 0.9 \) will be chosen as the final solution. \( Pr_T \) is defined as

\[
Pr_T = \frac{\mu_T C_P}{k_T}
\]

where \( \mu_T \) and \( k_T \) are the turbulent viscosity and thermal conductivity, respectively, and \( C_P \) and \( k_T \) are the viscosity and thermal conductivity of the liquid, respectively. Finally, Equation 12 is modified as

\[
\{f\} = \{f_1 f_2 f_3\} = \{C_2 C_4 \eta\}
\]

A set of initial values of \( C_2, C_4 \) and \( \eta \) is necessary to start the optimization calculations by all three methods indicated in Appendixes 1 and 2. It is apparent from
Figs. 1 through 3 that the expression \( \frac{\partial O(f)}{\partial t} = \frac{\partial O(f)}{\partial t} \) does not conform to a continuous, convex, or concave-type function and the solution of Equation 13 involves multiple local minima in the objective function. To address this difficulty, the optimization calculations have been performed with a number of initial values in the ranges of 0.10 to 0.50 for \( C_2 \) and \( C_4 \), and 0.10 to 0.50 for \( \eta \). The initial values for \( C_2 \) and \( C_4 \) and \( \eta \) were the same as those obtained with the CGPR and CGFR routines. The effectiveness of the optimization process is evident from the fact that all three optimization methods resulted in nearly similar sets of the optimum values of \( k^* \), \( p^* \), and \( \eta \). The optimization methods. In the LM method, the minimum value of \( O(f) \) was obtained when the \( 1^\text{st} \) and \( 2^\text{nd} \) set of initial values (Table 6) were used (Figs. 4i) while the \( 3^\text{rd} \) and \( 4^\text{th} \) set of initial values resulted in values of \( O(f) \) as 0.219 and 0.837, respectively. In both the CGPR and CGFR methods, a minimum value of \( O(f) = 0.129 \) was achieved when the \( 2^\text{nd} \) set of initial values (Table 6) were used (Figs. 4ii and 4iii). The value of \( O(f) \) could not be reduced below 0.129 with various other sets of initial guesses used all three optimization procedures. The final optimum solutions of \( C_2 \), \( C_4 \), and \( \eta \) corresponding to \( O(f) = 0.129 \) were the same regardless of the initial guessed values of \( C_2 \), \( C_4 \), and \( \eta \). For example, a set of initial values of \( C_2 \), \( C_4 \), and \( \eta \) equal to 1.0, 1.0, and 0.3, respectively, yielded nearly similar values of \( O(f) \) and the optimized solution of \( C_2 \), \( C_4 \), and \( \eta \) were the same as those obtained with the \( 2^\text{nd} \) set of initial values (Table 6). Although a reduction in the value of \( O(f) \) from 0.166 in the LM method to 0.129 in the CG method appears to be small, it should be noted that \( O(f) \) departs from the square of the summation of the actual errors representing the discrepancy between \( p_m \) and \( p_m^* \) and \( w_m \). Figure 6 shows that both \( k^* \) and \( p^* \) increase significantly with \( N_{HI} \) consistent with Equation 24. This behavior is expected since higher heat input leads to more rapid transport of momentum and heat. The computed values of \( p_m \) and \( w_m \) using the optimized values of \( k^* \) and \( p^* \) are plotted in Fig. 6 for all values of \( N_{HI} \). A fairly satisfactory agreement is obtained between the computed and measured weld dimensions. The slight discrepancy between the computed and the experimental values can be attributed, at least in part, to the experimental errors.

Typical computed temperature and velocity fields are shown in Fig. 7. The results show that the liquid metal is transported from the middle of the pool outward due to a negative temperature coefficient of surface tension. The features of the computed temperature and velocity fields are typical of the Marangoni convection dominated laser melted pools and have been discussed in the literature (Refs. 16, 19, 20, 24, 26, 27).

A test for the effectiveness of the proposed deterministic model is to check if the values of the uncertain parameters can be evaluated from a relatively small volume of experimental data. For this purpose, the values of \( C_2 \), \( C_4 \), and \( \eta \) were determined from the experimental data for three welds with \( N_{HI} = 14.97, 32.90, \) and \( 34.53 \) in Table 1. Figures 8f) through (iii) show the variation of the objective function with number of iterations for four sets of initial guesses presented in Table 6 using all three optimization methods. It is observed that the LM method can provide an approximate minimum value of \( O(f) \) of 0.089 when the 1st and 2nd set of initial values (Table 6) are used — Fig. 8i. Both CGPR and CGFR routines could reach the minimum values of \( O(f) \) only when the 2nd set of initial values (Table 6) is used — Figs. 8ii and 8iii. The minimum value of \( O(f) \) could be reached within ten iterations using the LM routine and around 90 iterations in both CGPR and CGFR methods. The values of \( C_2 \), \( C_4 \), and \( \eta \) were found to be 0.252, 1.115, and 0.253, respectively, corresponding to the minimum value of \( O(f) \) following CG methods.

Following the LM method, the optimized values of \( C_2 \), \( C_4 \), and \( \eta \) were found to be 0.265, 1.138, and 0.228, respectively, when only three sets of experimental data were used in the optimization process. The optimized values of these parameters did not change significantly when all five sets of experimental data were used for optimization.

The values of \( k^* \) and \( p^* \) estimated in the present work are within the range of enhancement factors reported in the literature. For example, values in the range of 30 to 400 for both \( k^* \) and \( p^* \) were estimated through trial and error to achieve good agreement between the computed and the measured weld dimensions (Ref. 27). When the \( k\)-e turbulence model with a spatially variable effective viscosity was used, a maximum value of 16 for \( \mu^* \) was reported for a stationary GTA weld pool (Ref. 26). Although the value of \( \eta \) and the relationships between \( N_{HI} \) and \( k^* \), and \( \mu^* \) are valid for the specific conditions of welding considered here, a similar approach can be adopted for other welding conditions (Refs. 29, 30). Since \( \eta \), \( k^* \), and \( \mu^* \) are linked with \( p_m \) and \( w_m \) through the equations of conservation of mass, momentum and energy rather than through a straightforward polynomial function, local minima should be avoided by repeating the procedure with several sets of initial values. The intensive computational work needed to determine the uncertain parameters results in enhanced reliability of the numerical modeling of heat transfer and fluid flow in the weld pool.

Summary and Conclusions

Reliability of numerical heat transfer and fluid flow calculations in the weld pool can be significantly enhanced by determining the optimized values of effective thermal conductivity, effective viscosity, and absorptivity from a limited volume of measured weld dimensions. Three versions of gradient-based optimization techniques could produce low values of an objective function and determine the three aforementioned parameters. Although the values of these parameters were independent of the optimization process, the volume of the calculations needed and the manner in which the optimized values were obtained depended on both the opti-
mization method selected and the initial guessed values of the parameters. The values of effective thermal conductivity and effective viscosity were found to be much higher than their corresponding molecular values and also depended on heat input. Correlations are proposed to determine these parameters from welding conditions. The use of the optimized values of absorptivity, effective thermal conductivity and effective viscosity, determined from a limited volume of experimental data and the proposed model, resulted in good agreement between the computed and the experimentally determined fusion zone geometry without the need to adjust these parameters by trial and error.

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References


Appendix 1

In order to explain the basic concept of the LM method, a simplified system involving three unknown parameters, f1, f2, and f3, and one dependent variable, p_m measured under five welding conditions is considered first. Equation 13 can be written for f1, f2, and f3 as:
The values of the three unknowns, \( f_1, f_2, \) and \( f_3 \) cannot be directly obtained from the above equations since they do not appear explicitly in these equations. The symbols \( f_1, f_2, \) and \( f_3 \) resemble \( k^*, \mu^*, \) and \( \eta \) (absorptivity), respectively. So, the dependent variable \( p^* \) is expanded using the Taylor's series expansion to explicitly contain values of increments and \( f_1, f_2, \) and \( f_3. \) Considering two successive iterations of \( p^*_m \) and taking only the first order terms

\[
(p_m^*)^{k+1} = (p_m^*)^k + \frac{\partial (p_m^*)^k}{\partial f_1} \Delta f_1^k + \frac{\partial (p_m^*)^k}{\partial f_2} \Delta f_2^k + \frac{\partial (p_m^*)^k}{\partial f_3} \Delta f_3^k
\]

(A4)

where \( \Delta f_1, \Delta f_2, \) and \( \Delta f_3 \) are three unknown increments corresponding to \( f_1, f_2, \) and \( f_3 \) as

\[
f_1^{k+1} = f_1^k + \Delta f_1^k \\
f_2^{k+1} = f_2^k + \Delta f_2^k \\
f_3^{k+1} = f_3^k + \Delta f_3^k
\]

(A5)

and \( p^{*+1}, f^{*+1}, \) and \( f^{*+1} \) correspond to the values of three unknowns after \( (k+1) \) th iteration. Except \( \Delta f_1, \Delta f_2, \) and \( \Delta f_3, \) all other terms on the right hand side of Equation A4 are considered to be known. To solve for \( \Delta f_1, \Delta f_2, \) and \( \Delta f_3, \) Equations A1, A2, and A3 are first rewritten replacing \( p^*_m \) by \( (p_m^*)^{k+1} \) as

\[
\sum_{m=1}^{5} \left[ (p_m^*)^{k+1} - (p_m^*)^k \right] \frac{\partial (p_m^*)^k}{\partial f_1} = 0;
\]

\[
\sum_{m=1}^{5} \left[ (p_m^*)^{k+1} - (p_m^*)^k \right] \frac{\partial (p_m^*)^k}{\partial f_2} = 0;
\]

\[
\sum_{m=1}^{5} \left[ (p_m^*)^{k+1} - (p_m^*)^k \right] \frac{\partial (p_m^*)^k}{\partial f_3} = 0
\]

(A6, A7, A8)

However, \( p_m^* \) equals to \( p_m^*/p_m^* \) and although \( p_m^*/p_m^* \) is a known measured value, \( p_m^* \) is to be computed using the numerical heat transfer and fluid flow calculation for a set of \( f_1, f_2, f_3 \) and other known parameters. So, \( (p_m^*)^{k+1} \) that is the value of \( p_m^* \) after \( (k+1) \) th iteration is unknown since \( \Delta f_1, \Delta f_2, \) and \( \Delta f_3 \) are unknown. Next, substituting right hand side of Equation A4 in the place of \( (p_m^*)^{k+1} \), Equations A6, A7, and A8 are rewritten as:

\[
\sum_{m=1}^{5} \left[ (p_m^*)^k \frac{\partial (p_m^*)^k}{\partial f_1} \Delta f_1^k + \frac{\partial (p_m^*)^k}{\partial f_2} \Delta f_2^k + \frac{\partial (p_m^*)^k}{\partial f_3} \Delta f_3^k \right] = 0
\]

(A9)

Equations A9, A10, and A11 are further simplified as:

\[
\sum_{m=1}^{5} \left[ \frac{\partial (p_m^*)^k}{\partial f_1} \Delta f_1^k \right] = 0
\]

\[
\sum_{m=1}^{5} \left[ \frac{\partial (p_m^*)^k}{\partial f_2} \Delta f_2^k \right] = 0
\]

\[
\sum_{m=1}^{5} \left[ \frac{\partial (p_m^*)^k}{\partial f_3} \Delta f_3^k \right] = 0
\]

(A12)

(A13)

(A14)

Equations A12, A13, and A14 are next rearranged as

\[
\sum_{m=1}^{5} \left[ \frac{\partial (p_m^*)^k}{\partial f_1} \right] \Delta f_1^k = 0
\]

\[
\sum_{m=1}^{5} \left[ \frac{\partial (p_m^*)^k}{\partial f_2} \right] \Delta f_2^k = 0
\]

\[
\sum_{m=1}^{5} \left[ \frac{\partial (p_m^*)^k}{\partial f_3} \right] \Delta f_3^k = 0
\]

(A15)

Neglecting higher order differentials e.g.

\[
\frac{\partial}{\partial f_1} \left( \frac{\partial (p_m^*)^k}{p_m^*} \right) \Delta f_1^k \]

etc., Equations A9, A10
Equations A15, A16, and A17 can be expressed in matrix form as
\[
[S] \{ \Delta f^k \} = - \{ S^* \} \quad \text{(A18)}
\]

where

\[
[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix}
\]

\[
\sum_{m=1}^{3} \frac{\partial (p_m^*)^k}{\partial f_i} \frac{\partial (w_m^*)^k}{\partial f_j} \Delta f_{ij}^k + \sum_{m=1}^{3} \frac{\partial (p_m^*)^k}{\partial f_i} \frac{\partial (p_m^*)^k}{\partial f_j} \Delta f_{ij}^k
\]

(A19)

Thus, Equations A1, A2, and A3 are modified to Equation A18 where the three unknown incremental terms \( \Delta f_1, \Delta f_2, \) and \( \Delta f_3 \) are explicitly defined in terms of the known quantities. The solution of \( \Delta f_1, \Delta f_2, \) and \( \Delta f_3 \) are used next to obtain \( f^{k+1} \), \( f_2^{k+1} \), and \( f_3^{k+1} \) (expression A5) that are employed to compute \( p_c^{k+1} \) using the numerical heat transfer and fluid flow model. Next, \( O(f)^{k+1} \) is calculated as
\[
O(f)^{k+1} = \sum_{m=1}^{3} \left( (p_m^*)^{k+1} - 1 \right)^2
\]

(A22)

Values of \( f_1, f_2, \) and \( f_3 \) are assumed to reach optimum when the calculated value of \( O(f)^{k+1} \) is smaller than a predefined small number. For the two dependent variables \( p_m^* \) and \( w_m^* \), Equation A19 is modified as
\[
[S] = \begin{bmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{bmatrix}
\]

(A23)

where

\[
S_{ij} = \sum_{m=1}^{3} \frac{\partial (p_m^*)^k}{\partial f_i} \frac{\partial (p_m^*)^k}{\partial f_j} + \sum_{m=1}^{3} \frac{\partial (p_m^*)^k}{\partial f_i} \frac{\partial (w_m^*)^k}{\partial f_j}
\]

for \( i, j = 1 \) to \( 3 \)

(A24)

The product \( \lambda I \) in Equation A26 ensures that the left-hand term in Equation A26 will remain nonzero even if the determinant of the matrix \( [S] \) is zero. The value of \( \lambda \) is usually increased or decreased by a factor of ten as the value of the objective function in subsequent iterations increases or decreases. This, in effect, ensures the reduction or enhancement in step size as the solution respectively tends to diverge or converge. The algorithm of the complete procedure using the LM method can be presented as follows:

Step 1. Guess initial values (e.g., \( k^{th} \)) of unknown variables set, \( \{ f \} \) for \( i = 1, 3 \) from Equation 12.

Step 2. Choose initial value of damping factor \( \lambda \).

Step 3. Compute the value of the objective function, \( O(f) \) from Equation 11.

Step 4. Solve for the set of unknown in-
Considering two dependent variables, and \( p_m^*, w_m^* \),

\[
\alpha(f^k - \beta^k d_1^k f_2 - \beta^k d_2^k f_3 - \beta^k d_3^k)
\]

can be expressed further as

\[
\alpha(f^k - \beta^k d_1^k f_2 - \beta^k d_2^k f_3 - \beta^k d_3^k)
\]

Substituting Equation A30 in Equation A29 and using Taylor’s expansion, Equation A31 can be substantially rearranged to give \( \beta^k \) as (Refs. 41, 42)

Equations 20a and 20b can respectively be rewritten as

\[
\sum_{m=1}^{3} \sum_{i=1}^{5} \left( \left( p_m^* - 1 \right) \frac{\partial p_m}{\partial f_1^i} + \left( w_m^* - 1 \right) \frac{\partial w_m}{\partial f_1^i} \right)^2 \]

for \( k = 1, 2 \) and, \( \gamma = 0 \). Apart from the calculation of conjugate coefficient, \( \gamma \), both CGPR and CGFR methods are the same.

### Appendix 2

Considering the objective function defined in Equation 11 with two dependent variables, \( f_1, f_2, \) and \( f_3, \) Equation 17 can be written as

\[
f_1^{k+1} = f_1 - \beta^k d_1^k
f_2^{k+1} = f_2 - \beta^k d_2^k
f_3^{k+1} = f_3 - \beta^k d_3^k
\]

(A28)

where \( f_1^{k+1}, f_2^{k+1}, d_1^k, \) and \( d_3^k \) and \( \beta \) confirm to their definitions presented previously. In Equation 18, as \( O(f_1^{k+1}) \) contains \( (p_1^*)^{k+1} \) and \( (w_1^*)^{k+1} \) obtained from numerical heat transfer and fluid flow code using values of \( f_1^{k+1}, f_2^{k+1}, \) and \( f_3^{k+1} \), and \( O(f_1^{k+1}) \) depends on \( f_1^{k+1}, f_2^{k+1}, \) and \( f_3^{k+1} \), and, thus, replacing \( f_1^{k+1} \) by \( f_1^{k+1}, f_1^{k+1}, \) and \( f_1^{k+1}, \) and substituting the right-hand side of Equation A28 in place of them, Equation 18 can be rewritten as

\[
\frac{\partial O(f^k - \beta^k d_1^k f_2 - \beta^k d_2^k f_3 - \beta^k d_3^k)}{\partial \beta^k} = 0; \beta^k \geq 0
\]

(A29)

Furthermore, following Equation 13,

\[
\beta^k = \left( \left( \sum_{m=1}^{3} \sum_{i=1}^{5} \left( \left( p_m^* - 1 \right) \frac{\partial p_m}{\partial f_1^i} + \left( w_m^* - 1 \right) \frac{\partial w_m}{\partial f_1^i} \right)^2 \right)^{-1} \right)^{-1} \]

(A31)

### Call For Papers

**The 6th European Conference on Welding, Joining, and Cutting**

Santiago de Compostela, Spain, June 28-30, 2006

The 6th European Conference on Welding, Joining, and Cutting, sponsored by the European Federation for Joining, Welding, and Cutting (EWF), in association with the Spanish Association of Welding and Joining Technologies (CESOL), and the Metallurgical Research Association of the Northwest (AIMEN), has issued a call for papers and posters.

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Send your intention to participate, including title and abstract of the work to be presented, to CESOL, Gabino Jimeno 5B, 28026 Madrid, Spain; FAX: +34 91 500 53 77; cesol@cesol.es, by September 30, 2005.
ABSTRACT. Evaluation of heat-affected zone (HAZ) properties after postweld heat treatment (PWHT) is important not only for selection of suitable chemical composition of microalloyed steel pipes, but also for development of welding procedures, including PWHT, for sour service. In this study, coarse-grained heat-affected zones (CGHAZ) were induced in V-microalloyed X60 steel pipe specimens using a Gleeble weld thermal simulation. Cooling rates from 5 to 80°C/s were used to represent a broad range of welding conditions. The CGHAZ specimens were subjected to PWHT at temperatures from 635 to 670°C (1175 to 1238°F) for 3 to 15 hours. Microhardness and microstructure of the CGHAZ were evaluated in the simulated "as-welded" and PWHT condition as functions of weld cooling rate and PWHT schedule. The tensile properties and sulfide stress cracking resistance (SSC) of CGHAZ with selected hardness level were determined as well. The maximum hardness of the CGHAZ increases from 233 to 392 HV-10, and its microstructure changes from ferrite with aligned second phases to martensite by increasing the cooling rate from 5 to 80°C/s.

None of the PWHT schedules used in this study induced hardening of the CGHAZ of the microalloyed steel. However, the rate of softening may have been retarded because of VC secondary hardening. For a holding time between 3 and 15 hours, the softening effect induced by the PWHT can be described by the Larson-Miller tempering parameter. The apparent activation energy for tempering in the different softening regimes observed during PWHT was determined. The behavior of the CGHAZ during tensile testing depends on the degree of overmatching between the CGHAZ and the base material. Coarse-grained heat-affected zones with a maximum hardness of 264 HV did not crack during exposure to sour testing according to procedure specified in standard NACE TM0177 (Method A).

Introduction

During welding, the HAZ of base metals is subjected to thermal cycles, which produces a change in both its microstructure and mechanical properties. In addition to chemical composition, rate of cooling through the temperature range within which transformation of austenite occurs to martensite, bainite, ferrite plus pearlite, or mixtures of these microstructural constituents, has a marked influence on the hardness achieved for a particular composition. The cooling time \( \Delta t_{45} \) through the range 800° to 500°C, as descriptive of a given weld, has been widely adopted in the welding community as an important index. The temperature of 800°C, in most steels, approximately represents the \( A_3 \) transformation temperature and the \( y/\alpha \) transformation takes place through the 800° to 500°C temperature range.

For single-pass welds in C-Mn and low-carbon microalloyed steels, four microstructural regions can be distinguished in the HAZ as indicated in Fig. 1. The microstructure in each region of the HAZ is related to the temperature cycle experienced during welding. The four general regions and their corresponding temperature ranges are as follows:

- **Coarse-grained HAZ (CGHAZ)** - 1100°C to melting point
- **Fine-grained HAZ (FGHAZ)** — \( A_c_3 - 1100°C \)
- **Intercritical HAZ (ICHAZ)** — \( A_c_1 - A_c_3 \)
- **Subcritical HAZ (SC-HAZ)** — Below \( A_c_1 \)

In multipass welds in C-Mn steels, each of the HAZ regions can experience multiple temperature excursions that can further alter the microstructure in the HAZ. For convenience, these regions can be categorized into six basic types as compared to four in single-pass welding. The two extra basic regions are as follows: intercritically reheated CGHAZ (IC-CGHAZ) and subcritically reheated CGHAZ (SC-CGHAZ). The mechanical properties vary across the different subzones. Among the HAZ subzones, the CGHAZ, which experiences the most severe thermal cycle, usually possesses the maximum hardness. As such, this region is usually given the most attention regarding alloy design and welding procedure, including PWHT.

Postweld heat treatment is commonly applied to welded steel construction for three main reasons. First, it may be deemed necessary to improve the mechanical properties, in particular the toughness, across the welds (Ref. 1). Second, heat treatment is applied to reduce the high level of residual stresses that are induced along and across weldments (Ref. 1, 2). Third, PWHT is used to decrease the hardness across the weldment to avoid the risk to stress corrosion cracking (SCC) (Ref. 1), for example, hardness level below 22 HRC in sour service. According to the provisions established in the NACE material recommendations for sour service (MR0175) (Ref. 3), a maximum hardness of 22 HRC (248 HVN) is recommended to avoid the risk to sulfide stress cracking. The changes in strength, hardness, and toughness during PWHT are the net re-

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KEYWORDS

- Heat-Affected Zone (HAZ)
- Postweld Heat Treatment (PWHT)
- Coarse-Grained Heat-Affected Zones (CGHAZ)
- Sulfide Stress Cracking Resistance (SSC)
- V-Microalloyed X60 Steel Pipe
- Larson-Miller Tempering Parameter

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HAZ in V/Nb bearing steels sometimes subcritical thermal cycles or during cooling can precipitate during subsequent service. During the weld thermal cycle, vanadium and niobium carbonitrides are dissolved in austenite at high peak temperatures during the weld thermal cycle. Particles that do not reprecipitate upon cooling can precipitate during subsequent subcritical thermal cycles or during PWHT. Therefore, the hardness of the HAZ in V/Nb bearing steels sometimes increases following PWHT due to V/Nb carbonitride precipitation. Because the solution temperature of vanadium carbonitrides is lower than that of niobium carbonitrides, and because niobium is more likely than vanadium to precipitate in the austenite during cooling, it would be expected that vanadium steels would be more susceptible than niobium steel to PWHT hardening (Ref. 2, 4, 5). Therefore, it is important to determine the effect of PWHT on the HAZ of microalloyed steels in a case by case approach.

Gleeble weld thermal simulation is an inexpensive, simple, and rapid test method to investigate fundamental phenomena that take place in the HAZ of a welded joint using a large number of specimens. It is used to simulate the weld thermal cycle under laboratory conditions in order to obtain information about microstructural and property changes in the HAZ. Although, in principle, these changes can be observed and measured from real welds, in practice it is more convenient to work with test pieces representative of one, not a range, of microstructures and grain sizes.

In this experimental work, the effect of weld cooling rates representing a broad range of welding conditions and PWHT schedules, different holding temperatures and holding times, on the microstructure and hardness of Gleeble-simulated CGHAZ of a V-microalloyed X60 steel pipe were evaluated. Additionally, tensile properties and resistance to SSC of CGHAZ with selected hardness levels were determined as well.

### Experimental Procedures

#### Materials

The material specimens were machined from a 12.75-in. OD x 64-mm (2.5-in.) wall thickness V-microalloyed seamless X60 steel pipe. Figure 2A and B show a general view of the V-microalloyed X60 steel pipe section used for the experimen-
thermal work, and the relative through-thickness location of the test specimens, respectively. The chemical composition reported in the mill test report (MTR) of the V-microalloyed seamless X60 steel pipe is shown in Table 1.

Gleeble Weld Thermal Cycle Simulation

Single CGHAZ thermal cycles were simulated on 10-×10-×5-mm specimens. The thermal cycles were measured using fine k-type thermocouples. The thermocouples were percussion welded to the samples. After the thermocouples were attached, the specimens were clamped between water-cooled jaws of a Gleeble machine, which, in addition to serving as grips to hold the samples, provide a means for introducing the current to the specimen during heating and ensuring a rapid cooling when the current flow is interrupted. Coarse-grained heat-affected zones thermal cycles with a peak temperature of 1320°C (2408°F) and cooling rates ranging from 5 to 80°C/s through the temperature range of 800° to 500°C were imposed on the V-microalloyed X60 steel pipe specimens using the Gleeble simulator.

Postweld Heat Treatment

Following HAZ simulation, CGHAZ samples with a nominal "as-welded" hardness of 280, 300, 325, and 350 HVN-10 were subjected to the specified PWHT cycles listed in Table 2. During PWHT, the heating and cooling rates above 427°C (800°F) were maintained under and close to 400°F/h and 500°F/h, respectively. The furnace used to run the PWHT allowed a close temperature control (±5°C or less) during the PWHT cycles. Figure 3 shows a thermal cycle representing one of the PWHT schedules used during this study.

Microstructure and Microhardness Evaluation

After HAZ simulation or PWHT, the samples were cross sectioned, mounted, polished, and etched for microstructural evaluation and microhardness testing. Five microhardness readings were obtained from the cross section of each sample.

Tensile Testing of Simulated CGHAZ

Tensile tests were conducted in selected CGHAZ samples in the simulated "as-welded" and in the PWHT condition. The CGHAZ tensile samples were tested have an average hardness of 300 HV-10 in the simulated "as-welded" condition and an average hardness of 250 HV-10 after being PWHT at 635°C for 6 hours. For the tensile specimens, single CGHAZ thermal cycles were simulated on 10-×10-×110-mm specimens. Tensile subsize specimens with a gauge of 0.25 in. (6.35 mm) in diameter and 1 in. (25.4 mm) in length were used.

SSC Testing of a Simulated CGHAZ

Specimens representing a CGHAZ in the PWHT condition were tested in a sour environment according to the procedure specified in NACE TM0177 (Method A). The simulated "as-welded" CGHAZ samples exhibited an average hardness of 300 HV-10. The average and maximum hardness of the samples after being subjected to a PWHT at 635°C for 6 hours was 250 and 264 HV-10, respectively. The specimens for SSC were prepared by imposing CGHAZ thermal cycles on 11-×11-×110-mm samples. After PWHT, round cross-section test specimens were manufactured from the square bars. The specimens had a gage diameter of 0.250 in. and a gage length of 1.0 in., as shown in Fig. 4A.

The specimens were stressed to 90% (54 ksi) of the specified minimum yield strength (60 ksi) of the steel pipe using a proof ring setup. Figure 4B shows a general view of the setup of the proof ring. The proof rings were calibrated. The stress level was determined by measuring the deflection of the proof rings. Immediately after applying the stress, the specimens were exposed to a test solution of 5.0 wt% NaCl and 0.5 wt% glacial acetic acid in deionized water for 30 days. The solution was deaerated and purged with H₂S gas in accordance with NACE TM0177 (Method A). The pH of the solution at the end of the test was measured as between 3 and 4, which is within the specification of TM0177 (Method A).

After 30 days, both specimens were removed from the test cells. The external surface of the samples was evaluated for presence of cracks using a binocular microscope at magnification of up to 30X.

Experimental Results and Discussions

Effect of Cooling Rate on CGHAZ Hardness and Microstructure

The resulting CGHAZ microhardness was measured first by making indentations

---

**Fig. 3 — Thermal cycle representing one of the PWHT schedules.**

**Fig. 4 — A — Round-bar specimen for proof-ring testing in sour environment; B — general view of the proof-ring setup.**
Fig. 5 — Average HAZ hardness as function of cooling rate (data obtained from different specimen preparations).

Fig. 6 — HAZ hardness as a function of cooling rate (data obtained from the cross-section of the HAZ specimens after complete metallographic preparation).

Table 3 — Average and Maximum CGHAZ Hardness as Function of Cooling Rate

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Cooling from 800° to 500°C °C/s</th>
<th>Average Hardness (HVN-10 kgf)</th>
<th>Maximum Hardness (HVN-10 kgf)</th>
<th>Yurioka Method Prediction</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>5.1</td>
<td>230</td>
<td>233</td>
<td>229</td>
</tr>
<tr>
<td>1</td>
<td>10.5</td>
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<td>277</td>
<td>246</td>
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<tr>
<td>37</td>
<td>15.6</td>
<td>286</td>
<td>294</td>
<td>262</td>
</tr>
<tr>
<td>11</td>
<td>15.7</td>
<td>280</td>
<td>292</td>
<td>262</td>
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<tr>
<td>6</td>
<td>19.7</td>
<td>298</td>
<td>304</td>
<td>275</td>
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<td>3</td>
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<td>9</td>
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<td>4</td>
<td>80.2</td>
<td>385</td>
<td>392</td>
<td>368</td>
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Table 4 — Average HAZ Hardness and HAZ Hardness Range Obtained with Selected Cooling Rates

<table>
<thead>
<tr>
<th>HAZ Cooling from 800° to 500°C HVN-10 kgf</th>
<th>Sample</th>
<th>Hardness Range, HVN-10 kgf</th>
<th>Average HAZ Hardness, HVN-10 kgf</th>
<th>Target HAZ Hardness, HVN-10 kgf</th>
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<tbody>
<tr>
<td>°C/s</td>
<td>θ&lt;sub&gt;85&lt;/sub&gt; (s)</td>
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<td>19.1</td>
<td>11</td>
<td>272-292</td>
<td>280</td>
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<td>19.7</td>
<td>15.2</td>
<td>6</td>
<td>292-304</td>
<td>298</td>
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<tr>
<td>30.5</td>
<td>9.8</td>
<td>2</td>
<td>318-333</td>
<td>325</td>
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<tr>
<td>48.8</td>
<td>6.1</td>
<td>3</td>
<td>343-363</td>
<td>353</td>
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<td>None</td>
<td>Base Metal</td>
<td>206-206.5</td>
<td>206</td>
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</table>

It was observed that the hardness data obtained from the cross section of the specimens present a lower level of scattering than the data obtained from the side of the samples. This result is the result of a better and smoother surface condition of the samples that were cross sectioned, mounted, polished, and etched. Additionally, the average hardness obtained from the cross sections is higher than the average hardness obtained from the side of the specimens as shown in Fig. 5. This can be explained based on the roughness of the samples. For a given hardness, as the roughness of the samples increases, the size of the indentation will increase. This
will result in a lower apparent hardness of the material. The average and maximum CGHAZ hardnesses as functions of the cooling rate from the data obtained from the cross section of the samples are listed in Table 3.

One of the most popular empirical equations that has been developed to predict maximum HAZ hardness as function of composition and cooling rates through the transformation temperature range is the Yurioka method (Ref. 7). The maximum HAZ hardness predicted by the Yurioka method is included in Table 3. It was noted that the measured maximum CGHAZ hardness is generally greater than the predicted maximum hardness. Therefore, the predictions of the Yurioka method are unconservative for the specific V-microalloyed steel used in this study.

A correlation between CGHAZ cooling rate and CGHAZ microhardness, HVN-10, obtained from the cross section of the samples was determined as shown in Fig. 6. It was observed that the maximum hardness of the CGHAZ increases from 233 to 392 HVN-10 as the cooling rates through the temperature range of 800° to 500°C increases from 5° to 80°C/s. The change of hardness as function of cooling rate is the result of the expected change of the CGHAZ microstructure as a function of the cooling rate. The microstructure of CGHAZ was observed to change from mainly a mixture of grain boundary ferrite and ferrite with aligned second phases with a small fraction of upper and lower bainite resulting from cooling rates in the range of 5° to 30°C/s to a microstructure with an increasing fraction of martensite and decreasing fraction of Ferrite, resulting from cooling rates in the range of 40° to 80°C/s. Figure 7A–D shows representative microstructures observed in the CGHAZ of the V-microalloyed seamless X60 steel pipe at different cooling rates through the temperature range of 800° to 500°C.

Response of Gleeble-Simulated CGHAZ to PWHT

In order to evaluate the response of Gleeble simulated CGHAZ to PWHT, HAZ cooling rates of 15.7, 19.7, 30.5, and 48.8°C/s were used to induce nominal CGHAZ hardness of 280, 300, 325, and 350 HVN-10, respectively. The average and HAZ hardness ranges obtained in the CGHAZ with these cooling rates are listed in Table 4. The hardness of the base metal is included in Table 4 as a reference.

The microhardness of the CGHAZ as a function of original hardness, PWHT, temperature, and holding time are shown in Figs. 8–10. The average and maximum hardness of each one of the tested samples are also listed in listed in Table 5.

None of the PWHT schedules used in
WELDING RESEARCH

Fig. 10 — Microhardness of simulated HAZ as function of original CGHAZ hardness and PWHT holding time at 670°C.

Fig. 11 — Change of the CGHAZ hardness, tempering effect, as function of the as-welded hardness and the Larson-Miller tempering parameter.

Fig. 12 — Hardness of the CGHAZ as function of the as-welded hardness and the Larson-Miller tempering parameter.

Fig. 13 — Comparison of predicted CGHAZ hardness with actual CGHAZ hardness of the V-microalloyed X60 steel pipe after PWHT.

this study induced any apparent hardening on the CGHAZ of the V-microalloyed X60 steel pipe tested. Age hardening may occur during PWHT and a net increase in hardness will be seen only if precipitation hardening is great enough to offset the microstructural softening that occurs simultaneously during aging. In a PWHT process, recovery of ferrite, decrease in dislocation density, coarsening and spheroidization of cementite, and the microstructural changes in other constituents such as martensite and bainite may also take place, contributing to softening of the material. The net hardness changes in the CGHAZ during PWHT result from the contribution of all the softening and hardening mechanisms and their interplay. The relative magnitude of such changes is, of course, dependent on the steel type tested.

As shown in Figs. 8-10, the change of hardness as a function of time at a given holding temperature indicates a higher softening rate, slope, for holding times shorter than 3 hours than the softening rate observed for holding times between 3 to 15 hours. This may result from different hardening and softening mechanisms interacting and being operative at short and long holding times, as discussed in the following sections.

Figure 11 shows the change of hardness in the CGHAZ in the V-microalloyed X60 steel pipe as a function of the Larson-Miller tempering parameter. The tempering effect or change of hardness in the CGHAZ during PWHT depends not only in temperature and time, but also on the original hardness of the CGHAZ. The tempering effect of a given PWHT increases with an increase in the as-welded hardness of the CGHAZ. However, in Figs. 8-10, it is observed that most of the decrease in hardness happens relatively early in the PWHT, holding times equal or less than 3 hours. At low tempering parameter values, the tempering effect of a given PWHT increases with an increase in the as-welded hardness of the CGHAZ. This behavior may be related to tempering of an increasing martensite/bainite volume fraction present in the CGHAZ as the “as-welded” hardness increases. Additionally, a harder “as-welded” CGHAZ resulting from faster cooling rate is expected to have a higher dislocation density and a higher thermodynamic driving force for tempering.

On the other hand, the PWHTs with holding times between 3 and 15 hours resulted in roughly similar slopes of hardness change per unit of tempering parameter change, e.g., nearly parallel lines, independent of the original CGHAZ hardness, as seen in Fig. 11. It is generally
expected that faster cooling rates would result in higher vanadium supersaturation of the CGHAZ. Therefore, CGHAZ induced with faster cooling rates should exhibit stronger secondary hardening. However, no obvious secondary hardening was observed in any of the CGHAZ evaluated. Had hardness changes during tempering been dominated by secondary hardening from vanadium carbide precipitates, a nonlinear curve would be expected.

As shown in Figs. 11 and 12, for PWHT times between 3 and 15 hours, the interaction of time and temperature in reducing the hardness of the CGHAZ during PWHT can be described by the Larson-Miller tempering parameter, \( P \), given by the following equation:

\[
P = T\left(C + \log t\right) \times 10^{-3}
\]

where \( T \) is the absolute temperature of PWHT in degree Kelvin, \( t \) is the PWHT time in hours, and \( C \) is a constant equal approximately to 20. The Larson-Miller tempering parameter of each PWHT is listed in Table 6. The Larson-Miller tempering parameter was originally devised as an indicator of the tempering behavior via a single reaction (Refs. 8, 9). Therefore, in the present case, there is clearly an indication that the tempering behavior of the CGHAZ in the V-microalloyed seamless X60 steel pipe at the holding temperatures used in this study and for holding times between 3 and 15 hours is controlled by a single metallurgical reaction. This may indi-
that at long holding times, the softening mechanism becomes independent of starting hardness and microstructure. In this condition, tempering of the CGHAZ may be approaching a purely carbide coarsening dominated mechanism as observed in the last stages of tempering of a martensitic microstructure.

Different methods have been developed to predict the effect of PWHT on HAZ hardness. One of these methods is the Okumura method, which has been developed to combine martensite softening with hardening caused by V, Nb, and Mo as a function of tempering parameter, martensite fraction, and composition (Refs. 5, 10).

A comparison between the prediction of the Okumura methods and observed CGHAZ hardness is shown in Fig. 13. In this case, the effect of PWHT at 650°C for 3, 6, 12, and 15 hours on the CGHAZ hardness of samples with simulated "as-welded" hardness of 325HV is compared to the hardness values predicted by the Okumura method. Results show actual CGHAZ hardness being significantly below the predicted value; however, the difference narrows as tempering parameter increases. These results indicate that for the specific X60 material tested in this study, the Okumura equation significantly over predicts hardness at a given tempering parameter. The slope of the predicted value curve which includes the combined effect of martensite softening and precipitation hardening is much steeper than the actual data. Additionally, the actual CGHAZ hardness data follows a similar trend that the prediction for tempering controlled by martensite softening only. This also confirms the absence of secondary hardening as major reaction during the tempering process of the CGHAZ of the V-microalloyed steel pipe. However, the actual data presents a slope that is steeper than pure martensite softening, but not as steep as that predicted by the Okumura equation, which may indicate retardation of softening of the CGHAZ due to minor precipitation reaction.

Figure 12 shows the hardness of the CGHAZ in the V-microalloyed X60 steel pipe as function of the Larson-Miller tempering parameter. As indicated in Fig. 12, PWHT with a characteristic Larson-Miller tempering parameter of about 18.47, 18.96, and 19.16 is needed to decrease the hardness of the CGHAZ in the V-microalloyed X60 steel pipe from an as-welded hardness of 300, 325, and 350 HVN-10, respectively, to a hardness of about 248 HVN10. The maximum hardness of 248 HVN-10 (22 RC) recommended by NACE to avoid risk to SSC is included in Fig. 12 as a reference. These results have significant implications for the required control over welding procedure variables. These tempering conditions require much longer holding times during PWHT than the holding time normally required in different industry codes, which are a function of thickness only.
CGHAZ Microstructure

Figure 14A–F shows microstructures representative of the CGHAZ induced at different cooling rates and after being subjected to different PWHT. Metallographic examinations showed a small dependence of microstructure on PWHT time, although a stronger effect of temperature was observed, in which the degree of dispersion of the carbides was temperature dependent.

As previously described, the microstructure of the CGHAZ can be regarded as composed mainly of ferrite with aligned second phases and an increasing fraction of bainite/martensite constituents as the cooling rate is increased. Based on optical microscopic observation, the strongest effect of varying heat treatment temperature was on the morphology of the ferrite with aligned second phases. With increasing temperature, the packets of second phases spheroidize, eventually forming a small number of globular precipitates to minimize the interfacial energy. The elongated constituent would be expected to have a high interfacial energy because of the higher surface area to volume ratio. It seems that during heat treatment, carbon diffusion enables the second phase to dissolve and form smaller packets, as observed by other workers on both base metal (Ref. 11) and weld metal (Ref. 12). At the same time, the low angle boundaries between the ferrite laths became less pronounced.

As PWHT temperature was increased, the intragranular microstructure became less defined. The grain and colony boundaries were more pronounced after PWHT, compared to the “as-welded” condition. From the optical examination, this seemed to be accompanied by carbide formation at colony and possibly prior austenite grain boundaries. This effect has been noted in weld metals (Ref. 13) and, indeed, high angle boundaries are known to be preferred sites for carbide formation both because of a higher carbon diffusion rate along such boundaries and because the high vacancy level more readily accommodates the volume difference between cementite and the ferrite matrix.

Additional fine scale microstructural variations during PWHT, such as martensite decomposition, annealing of dislocations, and V/Nb carbide precipitation that are embodied in the variation in the HAZ hardness data, are beyond the resolution capabilities of optical microscopy.

Metallurgical Reactions Controlling Tempering of CGHAZ

The fact that time and temperature have corresponding effects on tempering of steels as shown in Figs. 8–12 has been known for a long time. The observed time-temperature relation is based on the well known theory of rate processes, which states that the rate at which certain processes progress is related to temperature by activation or Arrhenius-type laws. Therefore, the apparent activation energy of tempering observed in the CGHAZ was also determined in the present work. The logarithmic form of equation 2 is \( \log \left( \frac{dH}{dt} \right) = \log A - \frac{m}{T} \) (3) where \( \frac{dH}{dt} \) is the softening rate and \( m = \frac{Q}{2.3R} \).

The apparent activation energy for tempering of the CGHAZ during short holding times, less than 3 hours, and during long holding times, 3 to 15 hours, was evaluated by plotting \( \log \left( \frac{dH}{dt} \right) \) as function of \( 1/T \) in the form of an Arrhenius plot (Figs. 15, 16). The determined values of the apparent activation energy are listed in Table 7.

As expected, the apparent activation energy for tempering of the CGHAZ during short holding times depends on the original microstructure and associated hardness of the CGHAZ. The average apparent activation energy for tempering of CGHAZs that consist of mainly ferrite with aligned second phases was determined to be equal to 16,376 cal/mol. On the other hand, for CGHAZs with a mainly martensitic microstructure, the apparent activation energy for tempering was determined to be equal to 9853 cal/mol. Tempering at temperatures between 635° and 670°C and holding times less than 3 hours are expected to induce different thermally activated metallurgical reactions. These reactions include recovery of dislocations in the ferrite lath boundaries, recrystallization of ferrite grains, transformation of low-carbon martensite to ferrite by losing both its carbon and tetragonality, precipitation of cementite, and coarsening of the second phases. Therefore, it is difficult to associate the apparent activation energy with a specific physical phenomenon or reaction.
On the other hand, it was observed that the apparent activation energy for tempering of the CGHAZ during holding times between 3 and 15 hours was independent of the original microstructure and associated hardness of the CGHAZ. The average apparent activation energy for tempering of CGHAZ during long holding times was determined to be equal to 11,636 cal/mol. This makes sense taking into account that after 3 hours of tempering, the microstructure is expected to be an aggregate of ferrite containing a large number of spheroidal carbide and second-phase particles independent of the original microstructure. The coarsening of cementite and second-phase particles is considered to be the primary metallurgical reaction controlling the softening of the CGHAZ during late stages of tempering.

The growth rate of carbide particles in iron-carbon alloys is diffusion-controlled (Ref. 14). The activation energy for the transfer of carbon atoms from cementite to alpha iron is 9700 cal/mol (Ref. 15). The activation energy for the diffusion of carbon atoms in alpha iron is 20,100 cal/mol (Refs. 16, 17). Therefore, it seems that the transfer of carbon atoms from cementite to ferrite is the main controlling mechanism of tempering of the CGHAZ during the late stages of tempering. However, further experimental work is needed to support this statement.

### Tensile Properties and SSC Resistance of CGHAZ

#### Tensile Properties

The results of the tensile tests are reported in Table 8. All the samples seem to have failed in the base metal very close to the interface with the simulated HAZ as shown in Fig. 17. Therefore, the results are not representative of the intrinsic mechanical properties of the simulated CGHAZ. The fracture of all samples has a “cup-cone” feature characteristic of ductile failure. The lower tensile properties of the samples in the as-simulated condition may be due to the normal variance of properties of the base metal from sample to sample and due to the clearly overmatched condition of the HAZ as compared to the base metal. A highly overmatched condition would induce localized deformation in the base metal, which causes the point of instability to be controlled by the properties of the base metal. On the other hand, a lower overmatched condition of the PWHT samples will cause a more homogeneous distribution of the plastic deformation and the point of stability being controlled by the strain hardening behavior of both the HAZ and the base metal. Sample 75 failed at or near a gauge mark, which may have resulted in a stress concentrator and the observed low percent elongation.

#### SSC Resistance

The PWHT CGHAZ specimens with an average and maximum hardness of 250 and 264 HV-10, respectively, did not rupture in the H₂S environment after 30 days.
of testing. The specimens had a smooth, black, shiny appearance — Fig. 18. No cracks were visible on the external surface of the gauge length at magnifications up to 30X.

Conclusions

1. The maximum hardness in the CGHAZ of the V-microalloyed X60 steel pipe increases from 233 to 392 HV-10 by increasing the CGHAZ cooling rate through the 800° to 500°C temperature range from 5° to 80°C/s.

2. The microstructure of CGHAZ changes from a mixture of grain boundary ferrite and ferrite with aligned second phases resulting at cooling rates from 5° to 30°C/s to a microstructure with an increasing fraction of martensite at cooling rates from 40° to 80°C/s.

3. CGHAZ cooling rates of 15.7, 19.7, 30.5, and 48.8°C/s induced an average CGHAZ hardness of 280, 300, 325, and 350 HVN-10, respectively.

4. None of the PWHT schedules used in this study induced any apparent hardening on the CGHAZ of the V-microalloyed X60 steel pipe tested.

5. The softening rate of the CGHAZ or tempering effect of PWHT decreases after 3 hours at a given PWHT temperature used in this study.

6. The tempering effect of PWHT on the CGHAZ for holding times between 3 and 15 hours is described by the Larson-Miller parameter. Therefore, the tempering behavior of the CGHAZ is controlled mainly by a single metallurgical reaction.

7. Coarse-grained heat-affected zones in the V-microalloyed X60 steel pipe with an as-welded hardness of 300, 325, and 350 HVN-10 need to be subjected to a PWHT with a characteristic Larson-Miller tempering parameter of about 18.47, 18.96, and 19.16, respectively, to decrease the hardness to 248 HVN10. This can have significant impacts on welding procedure qualification requirements.

8. The Yurioka and Okamura methods were not adequate to calculate and predict as-welded hardness and hardness after PWHT for the CGHAZ of the V-microalloyed steel pipe evaluated.

9. The apparent activation energy for tempering of the CGHAZ during short holding times depends on the original microstructure and associated hardness of the CGHAZ. The apparent activation energy for tempering of CGHAZ that consists of ferrite with aligned second phases was equal to 16,376 cal/mol. The apparent activation energy for tempering for CGHAZ with a martensitic microstructure was equal to 9853 cal/mol.

10. The apparent activation energy for tempering of the CGHAZ during holding times between 3 and 15 hours was independent of the original microstructure and associated hardness of the CGHAZ. The average apparent activation energy for tempering of CGHAZ during long holding times was 11,636 cal/mol.

11. The tensile test results were dependent on the degree of overmatching between the CGHAZ and the base metal.

12. The PWHT V-microalloyed X60 steel CGHAZ with an average and maximum hardness of 250 and 264 HV-10, respectively, were resistant to SSC.

Table 8 — Tensile Test Results of Simulated “As-Welded” and PWHT CGHAZ in V-Microalloyed X60 Steel Pipe

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Nominal Hardness, HV-10</th>
<th>UTS ksi</th>
<th>0.2 Yield Strength ksi</th>
<th>Elongation (%)</th>
<th>Reduction of Area (%)</th>
</tr>
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<tbody>
<tr>
<td>74</td>
<td>300</td>
<td>603.4</td>
<td>466.2</td>
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<td>75</td>
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<td>615.9</td>
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<tr>
<td>68 (PWHT)</td>
<td>250</td>
<td>628.3</td>
<td>520.7</td>
<td>26.1</td>
<td>76.2</td>
</tr>
<tr>
<td>69 (PWHT)</td>
<td>250</td>
<td>626.9</td>
<td>534.5</td>
<td>26.4</td>
<td>76.6</td>
</tr>
</tbody>
</table>

Sample failed at or very near a gauge mark.

References

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<thead>
<tr>
<th>Item</th>
<th>Category</th>
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<td>2</td>
<td>2. Product Management</td>
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</tr>
<tr>
<td>3</td>
<td>3. Engineer</td>
<td>100 to 499</td>
</tr>
<tr>
<td>4</td>
<td>4. Welding or Cutting Op.</td>
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<td>5</td>
<td>5. Quality Control</td>
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<td>6</td>
<td>6. Sales</td>
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<td>7</td>
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<td>9</td>
<td>9. Other</td>
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<td>6. Miscellaneous</td>
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<th>PURCHASING AUTHORITY</th>
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<td>2. Specify</td>
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<td>3. Approve</td>
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<td>General Information</td>
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- Item 306: Information on AWS Membership

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<td>Construction</td>
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<td>Engineer</td>
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<td>Welding or Cutting Oper.</td>
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<td>Quality Control</td>
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<td>Total</td>
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