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Reducing Shrinkage Voids in Resistance Spot Welds
A study was conducted to help develop practical techniques to reduce shrinkage voids and decrease the potential for interfacial fracture in resistance spot welds
A. Joaquin et al.

New AWS D1.8 Seismic Welding Supplement Outlined
This new supplement to AWS D1.1 strives to help buildings resist earthquake damage
R. O. Hamburger et al.

Making Resistance Spot Welding Safer
Practical solutions are proposed to help operators avoid injuries from spot welding machines
R. B. Hirsch

Inspecting RSW Electrodes and Welds with Laser-Based Imaging
The use of various types of optical sensors for inspecting RSW electrodes and welds was studied
C. Reichert and W. Peterson

Reducing Resistance Welding Costs
An organized approach and detailed analysis are needed to achieve real resistance welding cost savings
N. Scotchmer

A Methodology for Prediction of Fusion Zone Shape
A methodology was developed to predict fusion depth and width in gas metal arc welding
N. Okui et al.

A New Proposal of HAZ Toughness Evaluation Method: Part 2 — HAZ Toughness Formulation by Chemical Compositions
Weld joints in structural steels were examined to determine HAZ toughness, then correlated to the steels’ chemical composition
H. Furuya et al.

Technical Note: Martensite Formation in Austenitic/Ferritic Dissimilar Alloy Welds
Concentration gradients were used to explain the differences in martensite layer widths in the partially mixed zone of dissimilar welds
J. N. DuPont and C. S. Kusko
Labor Department Sets Its Agenda for 2007

The U.S. Department of Labor has released its regulatory plans for the first half of 2007. This “agenda” identifies the regulations that the agency intends to focus on, whether in final, proposed, or other stage of development.

As usual, the most significant activities are those of the Occupational Safety and Health Administration, within Labor, and among its priorities are rulemakings on cranes and derricks, global harmonization of chemical labeling, and silica. A rule that would require employers to pay for employee personal protective equipment is also slated for action by May 2007.

Other activities on the regulatory agenda include as follows:
• A final rule on electrical protective equipment;
• A proposed rule for general working conditions for shipyard employment;
• A proposed rule for walking and working surfaces and personal fall-protection systems;
• A review of comments on a proposed rule that would incorporate by reference updated National Fire Protection Association standards in standards in shipyard protection by December 2006;
• A request for information for personal continuous dust monitors; and
• A final rule establishing a new asbestos exposure limit.

House Education Committee Chairman Announces Agenda

The new chairman of the U.S. House Education and Workforce Committee, George Miller (D-Calif.), has announced the committee’s priorities for 2007. These include the following:
• Increasing workforce competitiveness;
• Reducing student loan interest rates;
• Reauthorizing the No Child Left Behind Act, Head Start, and the Higher Education Acts;
• Raising the maximum Pell grant scholarship; and
• Containing tuition costs.

Representative Miller has also said that he will schedule hearings to address what he refers to as middle class issues, such as the security of retirement funds.

New House Science Chairman Hopes to Implement NAS Recommendations

Representative Bart Gordon (D-Tenn.), the new chairman of the House Science Committee, has pledged to pursue legislation to implement many of the recommendations of the recent National Academy of Sciences’ report Rising Above the Gathering Storm.

This document expresses grave concern that U.S. economic competitiveness is being harmed by inferior education in areas of math, engineering, and science. The report calls for a renewed investment in K–12 education, greater investment in basic research, incentives to improve higher education, and incentives to advance innovation.

The following are among the specific steps proposed:
• Recruitment of 10,000 new science and math teachers annually;
• Increasing federal investment in research by 10% per year over the next seven years, with primary attention devoted to the physical sciences, engineering, mathematics, and information sciences;
• Providing research grants to early career researchers;
• Allocating at least 8% of the existing budgets of federal research agencies to discretionary funding under the control of local laboratory directors;
• Creation of an Advanced Research Projects Agency — Energy (ARPA-E), modeled after DARPA in the Department of Defense, reporting to the Department of Energy Undersecretary for Science;
• Establish a Presidential Innovation Award to recognize and stimulate scientific and engineering achievements;
• Establishing 25,000 competitive science, mathematics, engineering, and technology undergraduate scholarships and 5000 graduate fellowships in areas of national need for U.S. citizens pursuing study at U.S. universities;
• Providing a federal tax credit to employers to encourage their support of continuing education;
• Instituting a skill-based, preferential immigration option;
• Increasing the R&D tax credit from the current 20% to 40%, and making the credit permanent; and
• Providing permanent tax incentives for U.S.-based innovation to encourage long-term innovation-related investments.

Congress Expected to Focus on Climate Change

The new chairs of three key U.S. Senate committees have announced their intentions to make climate change a subject of both hearings and legislation in 2007.

Senators Barbara Boxer (D-Calif.), Jeff Bingaman (D-N.Mex.), and Joseph Lieberman (D-Conn.) sent a formal letter to President George W. Bush asking him to commit to working with the new Congress on this issue in 2007. Senators Boxer, Bingaman, and Lieberman are, respectively, the chairs of the Senate Environment and Public Works Committee, the Senate Energy and Natural Resources Committee, and the Senate Homeland Security and Governmental Affairs Committee, all of which have jurisdiction over global warming concerns.

All three have pledged to work to pass “mandatory limits on greenhouse gases.” Senator Boxer also has announced that her committee will hold a series of “intensive hearings” on climate change.

China Second Only to U.S. in R&D

China spent more on research and development in 2006 than any other nation except the United States, according to a study by the Organisation for Economic Cooperation and Development (OECD). The OECD is comprised of the 30 leading market democracies in the world, including the United States.

China is estimated to have spent $136 billion on R&D in 2006, compared to $230 by the European Union and $130 billion by Japan. The United States spent $330 billion.

This report is intended to send a warning to market democracies to make their research and innovation systems more efficient and find new ways to stimulate innovation in the increasingly competitive global economy. ♦
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Circle No. 20 on Reader Info-Card
Youth and Industry to Benefit from Promotion of Skills through the Alignment of IIW and WorldSkills International

The International Institute of Welding (IIW) and WorldSkills International are working together to ensure that the memorandum of understanding (MOU) recently signed between the two global organizations is a success, with benefits for young people and industry worldwide.

Both organizations recognize that, with globalization and an increasingly competitive global labor market, there will be a greater focus on the principle of “life-long learning” for individuals. They also believe that vocational education and training will play a critical role if any real, lasting progress is to be made toward sustainable global development and economic progress.

Through this MOU, both organizations mutually recognize and support their respective missions and objectives. Additionally, they agree that the MOU is a significant strategic milestone with key objectives being to share information, knowledge, and networks; cooperate in the establishment of standards for vocational education and training; promote both organizations and the benefits of the relationship on a worldwide basis; and consider joint projects in promoting vocational education and training.

Chris Smallbone, IIW president, said that the signing of the MOU forms a key element in a new IIW project “to optimize the global quality of life by optimum use of welding technology” and will be instrumental in coordinating efforts around the world to support a culture of respect for skills and an improved image of welding.

Kodak to Sell Health Group to Onex for Up to $2.55 Billion

Eastman Kodak Co. has entered into an agreement to sell its Health Group, which includes the Non-Destructive Testing Group, to Onex Healthcare Holdings, Inc., a subsidiary of Onex Corp.

Under terms of the agreement, the company will sell its Health Group to Onex for up to $2.55 billion. The price is composed of $2.35 billion in cash at closing, plus up to $200 million in additional future payments if Onex achieves certain returns with respect to its investment. Also, if Onex Healthcare investors realize an internal rate of return in excess of 25% on their investment, Kodak will receive payment equal to 25% of the excess return, up to $200 million.

Following the closing, about 800 employees associated with the Health Group will continue with the business. Included in the sale are manufacturing operations focused on the production of health imaging products, as well as an office building in Rochester, N.Y.

Subject to regulatory and other approvals, it is anticipated that the sale will close in the first half of this year.

NASA Grants Delphi Nearly $1 Million to Develop Deformation Resistance Welding

The National Aeronautics and Space Administration (NASA) and the Michigan Research Institute will grant Delphi Corp., Troy, Mich., an additional $950,000 to help fund the continuing development of deformation resistance welding (DRW) in cooperation with the Edison Welding Institute and SpaceForm, Inc. Planned projects will develop the technology in the areas of ferrous and nonferrous materials, dissimilar material joints, lean tubular structures, and concepts for future manufacturing cells.

The first two grants for DRW, totaling $2.17 million, were used to perfect existing welding techniques, to create new ones, and to find new innovative ways to use DRW on suspension subframes.

NASA plans to use what is learned from the company’s work with DRW as part of its Space Power Development Programs. Advanced welding of dissimilar metal joints for integrating titanium-based cooling loops with power conversion systems utilizing stainless steel structures is of specific interest.
EWI Performs Weld Development in Oxide Dispersion Strengthened Alloys

Edison Welding Institute (EWI) and team partners Foster Wheeler Development Corp., University of California — San Diego, Special Metals Corp., and Oak Ridge National Laboratory are investigating the use of oxide dispersion strengthened (ODS) alloys for a high-temperature heat exchanger under a contract through the Department of Energy (DOE). The DOE, National Energy Technology Laboratory (NETL), has initiated a strategic plan for the development of advanced technologies needed to design and build fossil fuel plants with very high efficiency and environmental performance. These plants will produce electricity, chemicals, fuels, or a combination of these products, and possibly secondary products such as steam/heat for industrial use. In addition, this program will achieve radical improvements in the performance of existing power technologies and seek to virtually eliminate the environmental concerns associated with the use of fossil fuels. The successful implementation of new technologies requires the development of a durable coal-fired heat exchanger.

The project development activities are focused on:

a) development of an innovative ODS heat exchanger tube capable of operating at temperatures greater than 2000°F
b) development of at least one method for welding ODS tubes, and
c) generate the necessary tube property data required for the design of a heat exchanger made from an ODS alloy.

The prime candidate material being selected for the heat exchanger is ODS Alloy MA956. This alloy was primarily developed for the aerospace industry. It has found use in advanced military gas turbine engines for next-generation aircraft.

The alloy can be used in applications requiring excellent strength and oxidation resistance for prolonged exposures up to 2400°F. MA956 is an iron-chromium-aluminum alloy that is yttrium oxide dispersion strengthened; however, there are gaps in the data required to commit to the use of this alloy in a full-size fossil fuel plant. This project will develop a MA956 alloy tube that will lead to the design and fabrication of a full-scale tube heat exchanger.

Oxide dispersion strengthened materials typically do not lend themselves to conventional arc welding practices due to the inherent oxides in the alloy that promote cracking in the fusion zone of the weld.

EWI has initiated joining development with friction and flash butt welding processes — Fig. 1.

Friction welding is accomplished by the use of relative mechanical motion between the two pieces (rotary or linear) under an applied force. This application of motion and force generate enough heat to plastically deform material at the interface of the two materials to create a weld.

Flash butt welding is a resistance welding process that produces coalescence of materials by a flashing action and the application of pressure after heating is completed. The flashing action, created by high current densities at small contact points between faying surfaces, forcibly expels material from the joint as the surfaces are being moved slowly together. The weld is completed by rapidly upsetting the materials to create a solid-state bond.

Edison Welding Institute has successfully demonstrated joining the MA956 ODS material with both welding processes. Test specimens have been produced that exhibit exceptional tensile and creep properties at elevated temperatures being considered for operation of the proposed heat exchanger.

It has been noted that the creep performance of the friction welded joints compare favorably to that of the base material. Weld development will continue with additional mechanical and environmental tests to validate the use of the joining processes.

The designers and manufacturers for both government and commercial industry sectors will have more options available to them for fabricating ODS structures. Such nonfusion joining techniques are deemed to be a viable approach for weld fabrication in ODS-type materials.

For more information contact Larry Brown, lbrown@ewi.org, (614) 688-5080; or David Workman, dworkman@ewi.org, (614) 688-5244.
Good news — the Welding Journal is going electronic, all 85 years. A project to capture the Welding Journals on DVD was initiated last year, and we will enjoy its benefits in the first quarter of 2007. I am talking about a stack of 1020 journals with an estimated count of 114,000 pages. Up to ten years can be stored on a single DVD. This electronic archive will contain the Journal in its entirety just as it was printed throughout the years, including advertising, Society news, and industry happenings. It promises not only to be a treasure trove of technical information, but also a complete historical reference source of the Society. In fact, the whole project grew from a concern that the two complete sets of bound volumes of Welding Journals that reside at AWS headquarters presented a fragile and vulnerable record of the Society’s history. If misfortune, such as fire or water damage, would ever befall them, this unique record would be gone forever. The electronic capture of these Journals will ensure their posterity. In addition to being securely stored as a historical archive of the Society, the DVDs will also be reproduced in quantity and be available for purchase or through a licensing agreement. Each DVD is indexed and searchable, making it a very usable reference source.

The Society began publishing a journal on a monthly basis in January 1922. In that issue it was stated, “…like other societies we should have our own proceedings, which should be complete and issued monthly in convenient form. In addition to technical papers it should include news items and reports of the Society, local Sections, the American Bureau of Welding, and of the industry. Moreover, certain sections should be devoted to editorials, employment services, bibliography of current welding literature, etc.” The Welding Journal has remained true to that core mission, but it has greatly expanded the information provided to AWS members. That 1922 issue contained 44 pages. The present-day Journal averages about 120 pages an issue.

Actually, the issue printed in 1922 was not the first. A single issue of Journal of the American Welding Society was printed in October 1919, the first year of existence for the Society. It was discontinued after that single issue because of the expense to sustain a continuous journal. In 1920, an arrangement was made with the journal Welding Engineer to publish the Society’s proceedings in that publication, but it proved unsatisfactory with the AWS members because it was not possible to include the news of the Society, and this publication was not exclusive to the Society’s members.

Unfortunately, that first issue in 1919 has gotten away from AWS headquarters. It can’t be included in our archiving efforts unless someone has knowledge of where one might exist and is willing to help AWS secure it. It was thin, maybe 25–35 pages, and had on the cover a picture of what appeared to be an offshore structure on stilts. If anyone knows where a copy of that issue might exist, or can offer a lead to its possible whereabouts, please let me know at cullison@aws.org. I would like to make the collection complete.

I am excited about this project, and I eagerly await its completion. I think it is an excellent way to retain the rich and varied history of the American Welding Society and to make that history available to future generations.
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Circle No. 36 on Reader Info-Card
The Louisiana Technical College (LTC) Region 4 recently began offering a free welding program. It is hoped that at least 150 new welders will be trained by June 30.

This short-term welding program offers day, evening, and customized classes that will be taught at all seven campuses in LTC’s Region 4 — Acadian, Lafayette, T. H. Harris, Gulf Area, Evangeline, Teche Area, and Charles B. Coreil — as long as ten or more students enroll in the training. Any Louisiana resident is eligible.

The programs are designed for students who desire employment in the field of welding and welding engineering technology. Graduates will also have the opportunity to pursue careers such as welding technician, welding supervisor, inspector, and sales engineer, qualifying for technician-level positions involved in testing and improving welding processes, procedures, and equipment.

In addition, graduates of the welding technology degree program have the option of transferring to four-year institutions offering a bachelor’s degree in welding engineering technology.

“Jamestown Community College (JCC) welding technology student practices welding pipe in the 5G position. The JCC students learn basic and advanced welding practices and welding positions.”

Degree and certificate programs in welding technology have recently been approved by the New York State Department of Education and the State University of New York for Jamestown Community College’s (JCC) Jamestown Campus.

Jamestown Community College now offers a 63-credit associate in applied science degree and a 32-credit certificate program in welding, with much of the instruction conducted at the college’s Manufacturing Technology Institute. The facilities feature a fully equipped machine shop, specialized welding equipment, and physics and materials testing labs.

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In addition, graduates of the welding technology degree program have the option of transferring to four-year institutions offering a bachelor’s degree in welding engineering technology.

“The efforts of JCC to move this program through the local and state approval process is to be commended,” said Todd Tranum, executive director of the Manufacturers Association and Manufacturing Technology Institute. “We are fortunate to have a community college that is responsive to the needs of manufacturers in the region.”

Louisiana Technical College Region 4
Offers Free Welder Training

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There are nine welding instructors in the LTC Region 4. As for what will be taught, in some cases campuses will use the National Center for Construction Education and Research (NCCER) Level 1, and special projects are also being developed to meet the needs of business and industry in the area. Additionally, the program is working with companies to provide customized welding programs to meet their specific training needs.

Funding is provided by the Pathways to Construction Employment Initiative given to the Louisiana Community & Technical College System (LCTCS) through a $15 million allocation from the governor’s office.

“The Louisiana Technical College Region 4 has received $1.3 million dollars to train 695 new construction and construction-related workers by June 30, 2007,” said Debbie L. Burkheiser, dean, Workforce Development, Louisiana Technical College, Greater Acadiana Region. “An opportunity to provide training for this many workers at no cost does not come along often.”

The program serves an important purpose because it will provide Louisiana employers the skilled workforce they need.
Thermadyne Teams with Arizona Western College and ‘Welders without Borders’

Thermadyne District Sales Manager Jeff Shively (left) and Professor Sam Colton are pictured at an Arizona Western College (AWC) welding class in 2006. Thermadyne is partnering with AWC’s Institute of Welding Technology and Colton, founder of the “Welders without Borders” program, to recruit and train future welders.

One of the efforts being undertaken by Thermadyne Industries, Inc., St. Louis, Mo., to help prevent a critical shortfall of skilled welders in the future is a partnership with Arizona Western College’s (AWC) Institute of Welding Technology and Professor Samuel Colton Sr., founder of the “Welders without Borders” program.

Founded in 2000, “Welders without Borders” enlists the help of
professionals from education, industry, and government to create extraordinary educational programs for students of welding. These programs highlight the many educational and academic opportunities available in the welding industry.

“One of the goals of our program is to encourage welding professionals from around the world to share their knowledge and experience,” said Colton. “Welding serves mankind because it is knowledge that improves lives, builds nations, and gives hope to millions.”

Ohio Supercomputer Center Partners with Edison Welding Institute

The Ohio Supercomputer Center (OSC) and the Edison Welding Institute (EWI) recently announced a partnership agreement. As part of its Blue Collar Computing initiative, a cooperative effort to help small- and medium-sized companies gain access to supercomputing technology at a more affordable cost, OSC will provide remote portal access of high-performance computing (HPC) systems and software to EWI welding applications. This cost-saving resource will reach engineers at more than 200 companies.

Through OSC’s HPC application interface, engineers will easily be able to input product dimensions, welding process parameters, and other specifications to conduct complete online simulations of welding procedures to determine the strength and viability of its prototypes.

TRUMPF Breaks Ground on New Laser Building in Connecticut

TRUMPF Inc., Farmington, Conn., recently broke ground on a research and manufacturing facility that will be used to further develop new lasers and expand the company’s production of laser resonators. The high-tech facility will add 83,000 sq ft to the company’s existing campus.

The building will feature a new production hall designed for the manufacture of different types of CO₂ and solid-state laser resonators, as well as a laser research lab and laser development department. Also, it will house the company’s laser marking ap-
Application and sales group and give the information technologies department a larger area for a state-of-the-art server room.

Construction of the building is expected to be completed by the end of this year. It is estimated to cost more than $20 million. In early 2008, the company hopes to open the building.

**Airgas Acquires Southern Welding and Alpena Supply**

Airgas, Inc., Radnor, Pa., has acquired the assets and operations of Southern Welding Supply, Inc., based in northern Alabama, and Alpena Supply Co., headquartered in Alpena, Mich.

Southern Welding Supply, an industrial gas and welding supply distributor with locations in Tarrant, Pelham, Decatur, and Tuscaloosa, Ala., generated $15 million in revenues in the 12 months ended June 30, 2006. The operations have been integrated into Airgas South.

In the Michigan acquisition, Airgas Great Lakes will integrate four locations in Alpena, Gaylord, Charlevoix, and Petoskey, Mich., constituting the Welding Division of Alpena Supply Co. and its Northern Michigan Welding Supply affiliate, which collectively totaled more than $4 million in annual revenues.

**Lincoln Electric Opens New Concept Distribution and Training Center in Georgia**

*The Lincoln Electric Co. has opened a new concept regional distribution and training center in Atlanta, Ga. The facility combines sales, distribution, training, and demonstrations of advanced arc welding products under one roof. The 100,000-sq-ft center also allows customers to learn about and select equipment with hands-on training and demonstrations.*

**Industry Notes**

- Dominic Stekly, president of Welding Alloys USA Inc., Florence, Ky., recently announced the expansion of the company’s facilities with the purchase of a new wire mill to increase capacity and for producing the TETRA series of small-diameter (0.035) stainless steel flux and metal cored wires.

- Ultra Machine & Fabrication, Inc., a precision fabricator of welded armored subassemblies for military contractors, will expand its manufacturing facility in Shelby, N.C., creating 63 jobs and investing $6 million during the next three years. Also, the company will receive a $108,000 One North Carolina Fund grant.

- August Mack, an Indianapolis, Ind., based environmental and engineering firm, has been honored as the winner of the 2006 Blue Chip Business Award for its innovative development of its eCAPSM (Compliance Assurance Program) environmental and safety management program.

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Circle No. 35 on Reader Info-Card
Q: There is a product on the market called aluminum and steel bimetal plate. This plate has aluminum on one side and steel on the other, and assists with the arc welding of aluminum to steel. Can you please provide some information about how this plate is made, what procedures are used when welding it, and in general, how it is used in industry?

A: The type of plate that you are referring to is, as you say, a bimetal plate made from two different metals. It is used to assist with the arc welding of aluminum to other metals such as stainless steel, carbon steel, copper, and titanium. This product is available in both plate and pipe, and is essential if you need to use the arc welding process as the principal joining method between components manufactured from these dissimilar materials.

Joining Aluminum to Other Metals

While adhesive bonding or mechanical fastening can join aluminum to most other metals relatively easily, arc welding is not a reliable method for joining aluminum to other materials such as steel. Very brittle intermetallic compounds form when metals such as steel, copper, or titanium are directly arc welded to aluminum.

To avoid the problems associated with arc welding these dissimilar materials, it is necessary to use special fabrication techniques to isolate the other metal from the molten aluminum during the arc welding process. The most common method of facilitating the joining of an aluminum component to a steel component by arc welding is by using the bimetallic transition insert.

Bimetallic Transition Inserts

Bimetallic transition inserts are available commercially in combinations of aluminum to such other materials as carbon steel, stainless steel, copper, and titanium. These inserts are sections of material that are comprised of one part aluminum with another material already joined to the aluminum. The methods used for joining these dissimilar materials together and thus forming the bimetallic transition are usually explosion welding, rolling, friction welding, flash welding, or hot pressure welding.

Explosion Welding of Aluminum to Other Materials

Explosion welding is a common method used for producing bimetallic transition inserts. This solid-state welding process produces a weld by high-velocity impact of the workpieces as a result of detonation. As the name suggests, this welding process uses an explosive force to create the weld. The explosion accelerates one of the materials to a speed at which a metallic bond will form between the two materials when they collide. In a fraction of a second, the weld is produced without the addition of filler metal. This is essentially a low-temperature process in that intense heating and melting of the workpiece does not occur. The faying surfaces, however, are heated to some extent by the energy of the collision, and welding is accomplished through plastic flow of the metal on those surfaces. Welding takes place progressively as the explosion and the force it creates advance from one end of the joint to the other creating the characteristic wavy profile as seen in Fig. 1. A typical arrangement of the components and setup for explosion welding are shown in the schematic — Fig. 2.

Typically, there are three components used in explosion welding — the backing plate, the cladding plate, and the explosive. The backing plate generally remains stationary, the cladding plate is usually positioned parallel to the backing plate, and a specified spacing, referred to as the standoff distance, separates the two. The explosion locally bends and accelerates the cladding plate across the standoff distance at a high velocity so that it collides at an angle with and welds to the backing plate. This angular collision and welding front progresses across the joint as the explosion takes place.

There are three important interrelated variables of the explosion welding process — collision velocity, collision angle, and cladding material velocity. The intense pressure necessary to make a weld generates at the point of collision. Pressure forces the two surfaces into intimate contact and causes localized plastic flow in the immediate area of the collision point. At the same time, a jet forms at the point of collision, as shown in Fig. 2. The jet sweeps away the original surface layer on each component, along with any contaminating film that might be present. This exposes clean underlying metal, which is required to make a strong metallurgical bond. Residual pressures within the system are maintained long enough after the collision to avoid release of the intimate contact of the metal components and to complete the weld.

Fig. 1 — A microetch of the characteristic wavy profile of an explosion welded joint. (Photograph courtesy of Dynamic Materials Corp.)

Fig. 2 — Schematic of the explosion welding process.
Welding of Bimetallic Transition Inserts

The arc welding of these steel-aluminum transition inserts in production can be performed by the normal arc welding methods such as gas metal arc welding or gas tungsten arc welding. One side of the insert is welded steel to steel and the other aluminum to aluminum. Care should be taken to avoid overheating the inserts during welding, which may cause growth of brittle intermetallic compounds at the steel-aluminum interface of the transition insert. It is good practice to perform the aluminum-to-aluminum weld first. Proceeding in this manner can provide a larger heat sink when the steel-to-steel welding is performed and help prevent the steel-aluminum interface from overheating.

Some manufacturers of these bimetallic inserts provide recommended procedures that suggest care should be taken to avoid heating the steel-aluminum bond zone above 600°F during welding. In addition, joint details are recommended for some applications that are designed to minimize the amount of heat directed toward the transition bond.

Principal Applications for Bimetallic Transition Inserts

Bimetallic transition inserts are offered in various thicknesses and are available in strip, plate, and tubular section — Fig. 3. The bimetallic transition insert is a popular method of joining aluminum to steel and is often used for producing welded connections of excellent quality within structural applications. One principal use is in the shipbuilding industry, where transition insert joints have become the standard means of welding aluminum superstructures and bulkheads to steel hulls, framing, and decks. This aluminum-to-steel weldability has given naval architects and shipbuilders the freedom to maximize the benefits of materials, the strength and economy of steel, combined with the lightweight and corrosion resistance of aluminum. Structural transition inserts for shipbuilding use are typically composed of 5xxx series aluminum bonded to low-carbon-manganese steel.

Bimetallic transition inserts are also available for use in other applications like tube sheets in heat exchangers that have aluminum tubing with steel or stainless steel tube sheets as well as for producing arc-welded joints between aluminum and stainless steel pipelines — Fig. 4.

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

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

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

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

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

For specifics on the nomination requirements, please contact Wendy Sue Reeve at AWS headquarters in Miami, or simply follow the instructions on the Counselor nomination form in this issue of the Welding Journal. The deadline for submission is July 1, 2007. The committee looks forward to receiving these nominations for 2008 consideration.

Sincerely,

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**PICO Chemical Corp.**
400 E. 16 St., Chicago Heights, IL 60411

**Disk Laser Processes Nearly Any Material**

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**TRUMPF Inc.**
111 Hyde Rd., Farmington, CT 06032

**Cutoff Machine Offers Chipless, Mill Length Thin-Wall Processing**

The company has developed a chipless rotary cutoff process where cam rollers act as chamfer tools, producing a finished edge on both ends of the tubing. This cutoff machine is based on the RC 60 rotary machine and processes mill-length 40-ft tubes with wall thickness up to 0.125 into drive shafts from 18 to 60 in. in length. Rotary cutoff wheels are used instead of carbide tooling. Additionally, the overhead bridge allows for 100% length inspection after cutoff. Primary lengths are placed on an angled runout table and roll down to a pair of bumpers that elevate the piece to a programmable position. Each tube is inspected and moved onto the next stage. Maximum utilization of the mill length tube is achieved by cutting secondary lengths from the remnant, which can then be processed in a future run.

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2300 S. Calhoun Rd., New Berlin, WI 53151

Thermite Tip Delivers Consistent Performance

The company’s thermite heating tip features a high tolerance machined design that helps operators heat rail ends consistently and evenly to ensure sound rail
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Smith Equipment
2601 Lockheed Ave., Watertown, SD 57201-5636

Beveler Features Variable Angle Adjustments

The Model 9000 Bevel-Mill produces bevels up to 1 1/2 in. Useful for weld preparation beveling, the unit uses standard carbide inserts in a milling cutting device for beveling most machinable materials. The machine is self-supporting on the workpiece and is hand fed by the user along the edge of the plate at up to 6 ft/min. It features variable angle adjustments from 15 to 45 deg as well.

Heck Industries, Inc.
PO Box 425, 1480 Old U.S. 23 S., Hartland, MI 48353

Rotary Hammer Powered by Lithium-Ion Technology

The 18-V BHA18 rotary hammer with its lithium-ion battery weighs 6.5 lb. Using SDS-plus carbide bits, it has 3/4 in. capacity in concrete with an optimum range of 3/8–5/8 in. The hammer is also equipped with electronic variable-speed control, a forward-reverse switch, the company’s Quick-change SDS chuck system, and an antivibration side handle. It features 1.6 joules of impact energy, a no-load speed of 0–1100 rpm, and no-load blows per minute of 0–4900 bpm.

Metabo
1231 Wilson Dr., West Chester, PA 19380

Metal-Cored Wire Improves Productivity

The Metalloy Vantage D2 (AWS E90C-D2) is a gas shielded metal cored wire for use with high-strength, low-alloy steels. It helps improve productivity by providing high deposition rates and fast travel speeds. Also, because the wire produces weld toe lines with minimal silicon deposits and spatter, it reduces the need for parts preparation and minimizes post-weld cleanup. When used with higher content argon shielding gas blends (90% Ar/10% CO2), it provides wet-in to help eliminate rework due to incomplete fusion or other weld discontinuities. The wire can be used for single- or multipass welding and is available in 0.045 and 0.052 in. wire diameters.

Hobart Brothers Co.
101 Trade Square East, Troy, OH, 45373

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Pro-Wash™ W is a paint marker that washes off easily with plain tap water. Pro-Wash™ D is a paint marker that washes off in a detergent bath with a pH 10 or more. Both formulas are available in six colors — red, black, white, yellow, blue, and green — and encased in an industrial-strength plastic barrel with a valve-actuated tip that releases paint on demand for smooth, continuous use. Fast drying and easy to remove, the product is useful for making temporary marks anywhere a removable mark is needed. Also, if left intact, the mark will not ghost or bleed through when painted over.

LA-CO Industries, Inc./Markal
1201 Pratt Blvd., Elk Grove Village, IL 60007
Reducing Shrinkage Voids in Resistance Spot Welds

Key factors that contribute to the formation of shrinkage voids in resistance spot welds of advanced high-strength steels were investigated.

By Armando Joaquin, Adrian N. A. Elliott, and Chonghua Jiang

Advanced high-strength steels (AHSS) continue to play an increasing role in vehicle body design. In general, resistance spot welding remains the primary process for joining body sheet metal in the automotive industry. Understanding and managing the resistance spot weld characteristics of AHSS is critical to successful application. Shrinkage voids are one of the main causes of interfacial fracture (Refs. 1, 2). The objective of this study was to develop practical techniques to reduce shrinkage voids in order to decrease the potential or eliminate interfacial fracture in resistance spot welds of AHSS. In this study, the effect of the welding power source, electrode tip shape, welding current input, material type and thickness, and hold time on shrinkage voids were investigated for seven steels.

Materials Studied

The materials evaluated in this study were DP600, TRIP590, CP800, and boron steels, as shown in Table 1. For comparison purposes, mild steel was also tested.

Welding Procedure

The welding equipment used in this experiment involved two types of power sources, midfrequency direct current (MFDC), and alternating current (AC). General welding parameters for this study are shown in Table 1. Dimensions of the weld specimens are shown in Fig. 1. Previous AHSS resistance spot welding studies show that shrinkage voids play a significant role in formation of interfacial fracture of spot welds when the button size is close to minimum button size (4 √t rule). The welding parameters were set up to achieve a minimum button size for the test materials.

Shrinkage Voids Examination

The welded specimens were separated through a method that involved rotation of one piece of the specimen relative to the other, which was clamped in a vice, in order to shear the weld and reveal the interfacial area. Visual examination for the presence of shrinkage voids was then conducted.

Fig. 1 — Schematic of the resistance spot welding specimen.
Experiment Results

Typical shrinkage voids in this study are shown in Figs. 2–8. The severity of weld shrinkage voids for different steels are compared in Figs. 9, 10. The effects of material-related and welding-related factors on shrinkage voids are discussed below.

Effect of Weld Power Source on Shrinkage Voids

No significant impact of welding power source (AC vs. MFDC) on shrinkage voids was observed on the 2.0-mm HDGI DP600. Based on this result, all subsequent experiments, except for mild steel only, used the MFDC power source. It is believed that the welding power source can only affect the weld nugget formation and growth, not solidification.

Effect of Coating Condition on Shrinkage Voids

It was observed that coating condition did not have an impact on shrinkage voids for materials in this study. It is thought that shrinkage voids could only form during the solidification of the molten nugget, and by that time, it is not likely for any...
coating material to exist in the nugget (aluminized coating may be an exception).

**Effect of Steel Grade and Thickness on Shrinkage Voids**

No shrinkage voids were found for both 1.5-mm HDGI DP600 and 1.5-mm EG DP600. For 2-mm HDGI DP600, shrinkage voids were observed under different welding conditions, as shown in Figs. 2, 3. For 2-mm HDGI mild steel, no visible shrinkage voids were found even when the hold time was 5 cycles, as shown in Fig. 4. Similar to 2-mm HDGI DP600,

![Fig. 7 — Shrinkage voids in 2-mm shot blasted boron steel (heat treated), MFDC, truncated electrode, single pulse. A — Hold time: 5 cycles; B — hold time: 10 cycles.](image)

![Fig. 8 — Shrinkage voids in 1.5-mm TRIP590, MFDC, truncated electrode, single pulse. A — Hold time: 5 cycles; B — hold time: 15 cycles; C — hold time: 30 cycles.](image)
welds of both 1.9-mm EG CP800 and 2-mm shot-blasted boron steel also had shrinkage voids under different welding conditions, as shown in Figs. 5–7. Different from the 1.5-mm DP600, welds of 1.5-mm TRIP590 showed significant shrinkage voids, as shown in Fig. 8.

It appears that steel grade and thickness have an impact on molten nugget solidification characteristics resulting in different severities in shrinkage voids — Figs. 9, 10.

**Effect of Hold Time on Shrinkage Voids**

As shown in Figs. 2–8, it is clear that hold time is the most important welding parameter that affects the severity of shrinkage voids. Relative longer hold time for steels that have higher tendency in formation of shrinkage voids (either have richer chemistry, or heavier gauge, or both) at least helps reduce the tensile thermal stress in the weld nugget when the nugget is not totally solidified.

Hold times longer than 15 cycles do not seem to be effective in shrinkage voids reduction.

**Conclusions**

The following conclusions can be drawn from this study:

- The tendency to form shrinkage voids increases as the steels become thicker.
- Materials with richer chemistry also promote the formation of shrinkage voids.
- Formation of shrinkage voids is independent of coating conditions of steels.
- Hold time is the most important welding parameter affecting shrinkage voids in the weld. Longer hold times help to reduce shrinkage voids. However, for most steels in this study, hold times needed to be no longer than 15 cycles.

**References**

Strong earthquakes can cause extreme damage, but fortunately, such events are quite rare. Therefore, building codes specify design criteria to avoid structural collapse, while permitting extensive structural damage in design-level events. Engineers have adopted a capacity-design approach, in which structures are designed to sustain ductile yielding in predetermined regions, protecting the balance of the structure from more extreme damage. Welded steel moment frame structures were regarded as one of the best systems to achieve this, with yielding anticipated to occur in the form of ductile plastic hinging within beams, adjacent to the beam-column connection.

On January 17, 1994, the magnitude 6.7 Northridge earthquake struck the Los Angeles region and abruptly ended engineers’ understanding of the way these structures behave. After inspecting a few buildings, engineers discovered that many of the moment-resisting connections had fractured in a brittle manner, at the beam flange-to-column CJP weld. Soon, engineers began to inspect for damage in steel buildings throughout the greater Los Angeles area. Although actual earthquake-induced fractures were plainly visible (Fig. 1), a practice soon evolved of using ultrasonic testing (UT) to detect damage. Ultrasonic testing frequently revealed indications, often interpreted as “incipient” cracks at the root pass of the beam bottom flange-to-column CJP weld. Rumors spread that hundreds of steel frame buildings had been damaged by the earthquake.

Assessing the Damage

Ultimately, researchers determined that most of the reported incidents of damage were really not damage at all, but rather previously undetected construction defects, including slag inclusions and incomplete fusion. There were also many false UT indications. Real damage did occur, however, in perhaps a few dozen structures. Nearly always, the damage consisted of a fracture that initiated at the root of the CJP weld of the beam bottom flange to column flange, usually beneath the beam web. Once initiated, these fractures progressed in a variety of patterns, sometimes extending through the column flange (Fig. 1), sometimes debonding the beam flange from the column flange (Fig. 2) and sometimes resulting in the withdrawal of large divots of material from the column flange — Fig. 3.

Later examinations found similar damage, previously undiscovered, in buildings that had been affected by the 1989 Loma Prieta and other earthquakes. Interestingly, although the damage was not of the type anticipated by engineers, it was generally not life-threatening and was perhaps more economical to repair than would have been the case had the desired ductile plastic hinging occurred. Nevertheless, because the behavior was decidedly nonductile and because these structures could be subjected to earthquakes significantly stronger than Northridge or Loma Prieta in the future, the response resulted in the initiation of a major program of research, development, and ultimately substantial revision of the building codes.

Causes of the Damage

The program of research sponsored by the U.S. Federal Emergency Management Agency (FEMA) identified a large number of causes for the damage that had occurred. Perhaps the most significant of these was the basic connection geometry prescribed by the building code. In this detail, field welded CJP joints attached the beam flanges to the column flanges while the beam web was connected with...
a shear tab, shop welded to the column, and field bolted to the beam. Standard weld access holes were placed in the beam webs at the top and bottom flanges. Typically, welding of both beam flange joints was performed in the downhand position with steel backing placed at the underside of the beam flange, and left in place after joint completion.

In the typical design model for this connection, the CJP flange welds carried 100% of the bending moment while the shear tabs carried 100% of the shear. Beam flanges and the CJP welds were assumed to be uniformly stressed in axial tension or compression, and to yield uniformly across their depth and width. The building code required that frames be designed such that beams were weaker than columns so that inelastic behavior of the frames would consist of ductile plastic hinging in the beams at the beam-to-column joint.

Analytical and laboratory studies revealed that the stress distribution in the beam flanges was anything but uniform. Out-of-plane bending of the column flanges, under the forces delivered by the beam flanges, resulted in a concentration of stress and strain at the center of the beam flange. Further, at the connection, plane sections did not remain planar, as assumed in design, and as a result, the beam flanges carried substantial shear. This shear caused the beam flanges to bend as they spanned across the weld access holes in the beam web, producing large secondary stresses, and causing near-doubling of the stresses at the bottom beam flange bottom surface while substantially reducing stress at the top surface.

Yielding of the beam flange and welded joint often could not occur as anticipated. High variability in yield strengths of structural steel often resulted in a condition where the beam, though designed to be weaker than the column in flexure, was actually stronger. Further, because very large member sizes were often used in the construction of these frames, the center of the beam to- column flange joint was often a region of very high restraint in which near hydrostatic stress conditions could develop. As a result, stresses in this region could easily exceed nominal yield levels and approach ultimate levels.

Even had these conceptual problems in the connection design not existed, if yielding had occurred in the beam flange to column flange joint as anticipated, it is unlikely that it could have accommodated much ductility. Generally, plastic hinge zones in beams have significant length, often extending from one-half of beam depth to a full beam depth in length. However, because the beam flange was bolted rather than welded to the column and the area of the beam was further reduced by the weld access holes, the connection region was substantially weaker than the beam itself. If yielding had actually initiated in this region, it could not have progressed easily into the beam to permit ductile behavior to occur.

In any event, in many cases, yielding could not develop. Often, the CJP joint of the bottom beam flange to column flange was of inadequate quality. It was reported that welders rarely followed WPS requirements, and often, WPSs were not available to them or to inspectors. Many welds were made with overly high deposition rates and high heat inputs, resulting in very low toughness in the welded joint and heat-affected zones. Further, this bottom beam flange weld was often made from a “wildcat” position atop the beam top flange, with stops and starts of the multipass welds made at the center of the beam flange, under the beam web. This often led to incomplete fusion and large slag inclusions in the root pass, as well as generally poor weld quality in the weld near the beam web.

**Inspection Methods**

Inspection practice had come to rely too much on the use of UT to discover defects and flaws in these welds, while visual inspection during welding was rarely adequately performed. Post-Northridge research demonstrated that as a result of joint geometry, UT is unable to reliably detect flaws at the root of the beam bottom flange joint, particularly in the area of the beam web. Further, since backing was routinely left in place, this obscured visual observation of the quality of the weld root, which unfortunately, was often poor, but remained undetected.

**Fig. 1 — Fracture extending through the column flange.**

**Fig. 2 — Fracture debonding the beam flange from the column flange.**

**Fig. 3 — Fracture that resulted in large divots of material from the column flange.**
These combined factors of high stress concentrations, high restraint, large flaws, and low toughness material resulted in a condition made to order for fracture to initiate and progress, which in many cases it did. Interestingly, during later laboratory research, it was demonstrated that even if weld quality and toughness were improved, if connection geometry remained unchanged, fractures would still initiate under low levels of inelastic cycling due to low cycle fatigue at the region near the intersection of the weld access hole with the beam flange. This research led to many changes in design and construction practice including the use of new connection geometries, improved control over base material yield strength and toughness, requirements for use of weld filler metals with rated notch toughness, and greater care in the preparation of and adherence to WPSs during construction.

Changes to Construction Codes

With the newfound knowledge regarding the causes of fractured connections, there was a significant effort to update the seismic design provisions. The FEMA project culminated late in 2001 with the publication of design guidelines applicable to moment frame buildings located throughout the U.S. The project recommendations are contained in:
- FEMA 350 — Recommended Seismic Design Criteria for New Steel Moment Frame Buildings. (FEMA, 2000a)
- FEMA 351 — Recommended Seismic Evaluation and Upgrade Criteria for Existing Welded Steel Moment Frame Buildings. (FEMA, 2000b)
- FEMA 352 — Recommended Postearthquake Evaluation and Repair Criteria for Welded Steel Moment Frame Buildings. (FEMA, 2000c)
- FEMA 353 — Recommended Specifications and Quality Assurance Guidelines for Steel Moment Frame Construction for Seismic Applications. (FEMA, 2000d)

These publications constituted “recommendations,” not prescriptive code requirements. Further, these standards were not subject to the consensus approval process, typical of most construction standards.

FEMA 353 identified the need to change requirements that were contained in both AISC and AWS specifications. Issues such as the overall design and acceptable connection details were clearly in the purview of AISC. It was less clear, however, as to which organization should address issues such as connection details (e.g., where steel backing could or could not be left in place, acceptable weld access hole geometries, etc.). It was agreed upon by the consensus committees that AISC should address the “what” and “where” requirements, while AWS would address the “how” and “who” issues. AISC did this in AISC 343, Seismic Provisions for Steel Buildings, while AWS issued its AWS D1.8, Seismic Supplement to the D1.1 Structural Welding Code — Steel.

To illustrate, where steel backing is required to be removed was not specified in D1.8, but rather included in AISC documents. However, when backing is required to be removed, AWS D1.8 addresses the issues of how this is to be done, and the applicable workmanship provisions for such operations.

For many years, AISC has had the TC9 Seismic task committee that was responsible for the Seismic Provisions. More recently, an AISC Connection Prequalification and Review Panel was formed to determine what connection details should be permitted to be used without performing full-scale assembly testing. The AWS D1 Structural Welding Committee established a seismic subcommittee to consider the welding-related issues that needed to be incorporated into AWS standards.

The New AWS D1.8 Seismic Welding Supplement

In 2005, the first D1.8 Seismic Welding Supplement was approved by the AWS D1 Committee. As the title implies, D1.8 is not a standalone standard, but rather supplements AWS D1.1, Structural Welding Code — Steel. Moreover, D1.8 is expected to be used in conjunction with the AISC Seismic Provisions. While most of the design-related issues are covered in AISC standards, D1.8 addresses connection details, materials, workmanship, and inspection issues. These topics are covered in seven sections as follows:

Section 1 General Requirements
Section 2 Reference Documents
Section 3 Definitions
Section 4 Welded Connection Details
Section 5 Welder Qualification
Section 6 Fabrication
Section 7 Inspection

Following these sections are eight normative (e.g., mandatory) annexes as follows:

Annex A — WP Heat Input Envelope Testing of Filler Metals for Demand Critical Welds
Annex B — Interim CVN Testing of Filler Metal Combinations (where one of the filler metals is FCAW-S)
Annex C — Supplemental Welder Qualification for Restricted Access Welding

Annex D — Supplemental Testing for Extended Exposure Limits for FCAW Filler Metals
Annex E — Supplemental Ultrasonic Technician Testing
Annex F — Supplemental Magnetic Particle Testing Procedures
Annex G — Flaw Sizing by Ultrasonic Testing

Finally, concluding the document is an extensive commentary that provides background material and explains the intent behind many of the provisions.

Summary of Major Provisions of D1.8

The following is a summary of major provisions contained in D1.8. This summary is NOT comprehensive, and the reader should obtain a copy of D1.8 and review it in depth as not every provision is covered in this summary.

Welder Qualification

Section 5 and Annex C of D1.8 are devoted to welder qualification. In addition to meeting the welder qualification requirements of D1.1, welders performing work under D1.8 are required to take the Supplemental Welder Qualification for Restricted Access Welding Test, as prescribed in Annex C, when the production weld involves all of the following:

1. the weld is demand critical (as defined by AISC)
2. the weld joins the beam bottom flange to a column flange
3. the weld must be made through a weld access hole in the beam web.

Qualification of welders in accordance with Annex C is not required if all of the three preceding conditions are not part of the production weld. See D1.8, provision 5.1.1.

Two test configurations are described in Annex C, known as Option A and Option B. Option A is to be used when steel backing is specified on the WPS, while Option B is used for open root joints, or joints backed with ceramic, copper, or other nonsteel materials. The type of test to be taken is dependent on the type of backing (if any) that will be used in production, and as shown on the WPS. See D1.8, provision 5.1.3 and Annex C provisions C3.2, C3.3.

As is the case for D1.1, welders taking the Annex C test must qualify by welding a test weld of the process. In addition, the test plate must be welded with a deposition rate equal to or higher than that which will be used in production. It is wise, therefore, to use a slightly higher deposition rate in the...
Filler Metals — Demand Critical Welds

In addition to meeting the requirements above, filler metals used for making demand critical welds are required to meet even more stringent requirements. For example, D1.8 requires that the filler metals to be used in production first be evaluated in tests run at high and low levels of heat input, that is, under slow and fast cooling rates. Production welding WPSs are then permitted to use a wide range of variables, providing the calculated heat input levels are within the range of tested values. See D1.8, provision 6.3.5 and Annex A.

The Seismic Welding Supplement provides two means by which the high and low heat input tests can be conducted. The first approach is detailed in Annex A of D1.8. Suggested heat input levels are provided, but alternative values may be used as well. The second approach applies to FCAW electrodes, and uses the new supplemental designator “D.” Filler metals with this supplemental designator are required to be tested at a prescribed high and low heat input level, as well as tested according to the standard A5 classification test.

Filler metals for demand critical welds, when tested at high and low heat input levels, must meet all the requirements for a minimum CVN toughness value of 20 ft-lb (27 J) at 0°F (-18°C), as measured in a standard AWS A5 filler metal classification test, as previously discussed. Additionally, filler metals for demand critical welds, when tested at high and low heat input levels, are required to deliver a minimum CVN toughness value of 40 ft-lb (54 J) at 70°F (20°C), when tested at high and low heat input levels, assuming the structure is subject to service temperatures of at least 50°F (10°C). If not, other requirements may apply. The strength and ductility requirements for the electrode classification must also be achieved. See D1.8, Table 6.2 and provision 6.3.6.

E7018, E7018-X, E7018-C3L, and E8018-C3 are exempted from the hi/lo heat input testing, as are solid GMAW electrodes. See D1.8, provision 6.3.5(1) and (2).

Filler metals to be used in making demand critical welds must also comply with one or more of the methods offered by D1.8 to ensure lot-to-lot consistency. Three methods are provided. First, each lot of material can be tested. Secondly, manufacturers who are audited and approved by various third-party agencies can supply untested product, providing at least three lots of material for each filler metal trade name and diameter have been tested, and such a test is repeated on a frequency not to exceed every three years. Finally, SMAW electrodes of the classification E7018, E7018-X, E7018-C3L, and E8018-C3, as well as solid GMAW electrodes, are exempt from lot testing, providing the certificate of conformance shows a minimum of 20 ft-lb (27 J) at 0°F (-18°C). See D1.8, provision 6.3.8.

Techniques

The sequence of depositing the half-length weld beads associated with making demand critical welds in beam bottom flange-to-column flange welds, where the welds are made through a weld access hole, is detailed. Welds should not be started or stopped directly under the web, and each layer must be completed on both sides of the beam web before a new layer can be started. Finally, weld starts and stops are to be staggered, layer to layer, on opposite sides of the beam web. See D1.8, provision 6.14.

The protected zone is the region within the structural member in which plastic hinging is expected to occur during seismic events. In order to facilitate this inelastic deformation (instead of initiating fracture), the protected zone must be kept free of notches and gouges, as well as miscellaneous attachments that may impede the desired behavior of the member. With the exception of arc spot welds used to hold steel decking in place, unauthorized welds and attachments should not be made in the protected zone. This would include, but is not limited to, welded studs, erection aids, and attachments for nonstructural members (such as sprinkler system supports). See D1.8, provision 6.15.

Conclusions

The Northridge earthquake provided an opportunity for engineers to increase their understanding of the behavior of steel structures during major seismic events. Through the effort of conscientious and knowledgeable volunteers, new consensus standards have been developed, codifying this knowledge into new or revised standards. The AWS D1.8 Seismic Welding Supplement, when specified and properly implemented, and when used with the AISC Seismic Provisions, is expected to significantly improve the performance of steel buildings and reduce or possibly eliminate the type of damage that was observed in steel structures after the Northridge earthquake.
Making Resistance Spot Welding Safer

Areas of potential injury on spot welding machines are detailed, and practical solutions are presented.

BY ROGER B. HIRSCH

Fig. 1 — Metal expulsion typically caused by low electrode force.

The potential dangers involved with operating punch presses or press brakes are quite obvious. But most people do not realize that an unprotected or improperly installed spot welding machine can potentially cause serious injury to the operator. According to the Bureau of Labor Statistics, 3,974,700 accidents involving industrial welding were reported in 2005. Of these, 2,148,800 resulted in lost days of work. Spot welding safety should be as important to the manufacturer as are safety concerns for presses and other industrial machinery.

Metal Expulsion Injury

It is not unusual to see a shower of sparks (expulsion) coming from the electrodes on a spot welding machine — Fig. 1. Many companies assume that this is a normal condition. Some believe that the expulsion is actually hot oil or grease. The truth is that these sparks are droplets of molten metal coming from under the electrode or from between the parts being welded.

Because metal expulsion can cause permanent eye damage, it is imperative that operators wear approved safety glasses that have side shields — Fig. 2. It is equally important to understand that a properly set spot welding machine should not create any major expulsion under any circumstances. This surprises many long-time users and gets to the heart of the resistance welding process.

Cause of Expulsion

When a spot weld is being made, the metal heats up to molten temperatures. At the same time, the metal molecules are all po-

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polarized in the same way at any one instant of time. This causes an extremely strong magnetic repulsion between these molten droplets to literally launch them away from the part. You see this as expulsion. In extreme cases, metal expulsion can travel 10 ft or more to potentially injure other personnel in the area. It can also set fire to gloves, clothing, and other flammable material in the area.

Elimination of Expulsion

The solution is to use a proper welding schedule for the material being welded. Selection of the proper electrode force will create a mechanical barrier around the molten metal to keep the material within the nugget area and eliminate expulsion. It will also reduce the electrical resistance between the face of the electrode where it touches the outer sheet to lower surface heating under the electrode and keep it from reaching the molten state. However, if the electrode force is too high, the amount of heat created in the nugget zone will be reduced to compromise the weld strength or, in extreme cases, totally eliminate fusion. The RWMA Resistance Welding Manual, Edition 4 (available at www.rwma.org), includes a collection of welding schedules for most metal alloys to provide high-strength welds while eliminating major metal expulsion.

Welding at Metal Edge

Placing a spot weld too close to the edge of a part can also cause metal expulsion. In this case, even use of proper electrode force will not keep the molten metal from flying out of the metal edge. The RWMA handbook recommends minimum edge distances to minimize expulsion. However, where the part design forces a weld location too close to an edge, use of pulsation in the welding schedule can be applied to minimize metal expulsion while maintaining weld strength. For most metals being joined, divide the weld time shown on the welding chart by three (round up), and install three impulses of this time with two cycles of cool time between impulses. This will minimize expulsion and form a nugget with acceptable penetration.

Pinch Point Injury

where there is a possibility of the operator’s fingers being under the point of operation, shall be effectively guarded by the use of a device such as an electronic eye safety circuit, two hand controls, or protection similar to that prescribed for punch press operation...” Unfortunately, most spot welding machines are operated without safeguards to protect the operator from serious finger injury — Fig. 3.

**Magnitude of Force**

It is important to appreciate the magnitude of force between electrodes. For example, a welding machine with a ¼-in. electrode face set with 600 lb of electrode force will develop 12,230 lb/in². This can cause major crushing damage to the operator’s finger if caught at this pinch point.

**Two-Hand Antitiedown Initiation**

Where the part and fixture design allows for welding without the operator holding the part, use of two-hand antitiedown initiation will keep the operator’s fingers out of the electrode pinch point zone during welding — Fig. 4. The initiation buttons should be located at least 18 in. apart and far enough away from the electrodes so that no part of the hand can be in the weld zone while pushing the initiation buttons. Operation of the welding machine should only happen if both switches are pushed within less than one second of time. If the switch on either side is permanently closed, closing of the other switch will not cause the welding machine to operate (antitiedown function). If the space between the electrodes exceeds ¼ in., the control should be set so that releasing either of the initiation switches before the electrodes close will cause the electrodes to immediately retract.

**Light Curtains**

Light curtains are rarely practical with hand-fed welding operations since the operator’s hands will normally be in the welding electrode zone. Also, light curtains cannot usually handle parts that have flanges that are in the same area as the operator’s hands. However, light curtains can be used effectively for automatic and semiautomatic welding systems when installed so that no mechanical movement can take place if the light curtain beam is broken — Fig. 5. In this case, once the welding sequence has started, breaking of the light curtain beam should automatically cause any moving components to retract to a safe position, and then require reinitiating of the welding machine after the beam has been cleared.

**Continuity Monitoring**

This type of system measures electrical continuity between the electrodes to verify they are actually touching the part to be welded — Fig. 6A. If anything, such as the operator’s finger, blocks the movement of the electrode, this system will not detect continuity. The continuity signal is picked up from points on the welding transformer secondary pads. This eliminates the need for wire connections at the electrodes — 6B.

In operation, the electrodes are closed under low force that is accomplished by a modified pneumatic valve system. A group of precision pressure regulators in a pad-
A locked box provides pressure needed to counterbalance heavy welding rams to less than 50 lb of force at the electrodes. The same components, arranged differently, can be used to furnish low pressure for operating welding machines with lightweight rams, or for operation of rocker arm or transgun welding machines — 6C. If continuity is detected before a maximum time has been reached, the electrodes are brought to full welding force. However, if continuity is not detected before that time, the electrodes are retracted and will not come forward until the initiation switch has been released and closed again.

This type of safety system does not have any operator-set components and does not require any adjustment when new setups are made. If designed properly, the continuity system cannot be overridden and is in place at all times that the welding machine is under power. Because this is a fully passive process, it can be used as the primary pinch point safety system for a spot welding machine.

**Ring Guards**

These devices typically utilize a rod with a horizontal ring installed at one end that encircles the moving electrode. A limit switch in this system is adjusted every time a new setup is made on the welding machine so that it closes if the rod travels to a position less than ¼ in. from the part being welded. When the welding machine is initiated, the rod lowers before the electrode starts movement. If the limit switch closes within a timer setting, the rod retracts while allowing the electrode to travel forward for the weld.

This type of system is not usable where the parts being welded are not flat in the area of the weld. More importantly, the fact that the level of safety is determined by how the limit switch is adjusted during each setup makes this process nonpassive and, therefore, ring guards should not be used as the primary safety system for a spot welding machine.

**Ram Limit Switches**

With this system, a limit switch is installed on the frame, and a cam moves with the ram. The limit switch cam is adjusted to close when the electrode is at a position less than ⅛ in. from the metal surface. The welding machine’s pneumatic system is designed to lower the electrodes under less than welding force until the limit switch has been closed, and retract the electrodes if this switch is not closed within a timer setting. Like the ring guards, this type of guarding requires adjustment every time a new setup is made and is, therefore, not passive. All safety of the welding machine is controlled by the actions of the last person who adjusted the limit switch cam. Therefore, this type of system cannot be considered as the primary guarding method.

**Barrier Guards**

On automatic or semiautomatic welding machines, systems can be installed that will automatically close a mechanical barrier at the start of each sequence. The moving barrier contains an interlocking limit switch to prevent electrode movement if the barrier is not fully closed. The mechanical barrier should be designed to preclude any ability for the operator to reach into the electrode area when it is in place. Closing force for the barrier should be selected to prevent injury to the operator from the moving barrier.

**Interlocked Cage Doors**

Systems, such as robotic welding cells, should have a cage installed to prevent movement within the cell when an entry...
Incoming Ground Wire

Proper grounding of all types of welding machines depends on the quality of the incoming ground wire to the machine.

Floor- or bench-mounted welding machines are normally manufactured with the stationary arm bolted to the transformer secondary pad and also connected to the frame. The frame is grounded to complete the path from secondary to ground. The movable arm of the welding machine is not grounded.

Press and Rocker Arm Welding Machines

Floor- or bench-mounted welding machines are normally manufactured with the stationary arm bolted to the transformer secondary pad and also connected to the frame. The frame is grounded to complete the path from secondary to ground. The movable arm of the welding machine is not grounded.

Portable Gun Welding Machines

Welding machines that use a permanently mounted transformer that connects to a portable welding gun by a long kickless cable require a ground strap to connect either side of the transformer secondary to the transformer frame. With the transformer frame properly connected to a ground wire, the path from the portable welding gun to ground is fully established.

Grounding Integrity

The RWMA standard requires that “the welding gun transformer case and secondary shell be grounded and protected by fail safe circuitry designed to immediately disconnect line voltage from the transgun via a circuit breaker with under-voltage trip. The combined clearing time shall not exceed 60 ms. A sensed value of grounding conductor resistance in excess of 1 Ω by the ground integrity system.

Laser Measurement Systems

In this type of guard, a laser beam is aimed alongside the electrode at the part being welded. When the welding machine is initiated, the laser measurement system checks to verify that the distance being measured is no less than ¼ in. from the top of the metal being welded before allowing any movement of the electrode. Like the ring guards, this type of guarding requires adjustment every time a new setup is made. Laser beam measurement systems are not passive and therefore should not be used as the primary safety system.

Electrical Shock Injury

By design, a resistance welding machine uses low voltage at the electrodes to produce an intrinsically safe process. However, an incorrectly grounded welding machine can pose a serious shock danger to the operator. A potentially fatal shock can occur if the primary winding of the welding transformer shorts to the transformer frame, or if a line voltage connection comes loose and shorts to the body. If a proper ground is in place on the welding machine, the line voltage will have a good path to ground and clear the control’s circuit breaker, line fuses, or main power circuit breaker.

Grounding a welding machine using the conduit or BX cable is not an acceptable method. The separate ground wire should enter the welding control enclosure and be connected to a properly bonded ground stud — Fig. 7. Wire size should be in line with NEC250.122 standards.

Transformer Secondary Grounding

OSHA Standard 1910.255(b)(9) covers grounding as follows: “Where technically practical, the secondary of all welding transformers used in multispot, projection and seam welding machines shall be grounded. This may be done by permanently grounding one side of the welding secondary current circuit. Where not technically practical, a center tapped grounding reactor connected across the secondary....”

Portable Transguns

This type of welding machine includes in one package a welding transformer and arms typically suspended by a counterbalanced mount and positioned by an operator. A flexible cable enters into the transformer carrying line voltage from the control. Because this portable device cannot be hard-connected to a suitable ground, the ground wire comes into the welding machine in the same flexible cable that contains the line voltage wires.

While many older transguns were supplied simply with a double-pole contactor between the control and the transgun, this form of protection is not adequate for personnel protection and can expose the operator to potentially fatal electrical shock even when the welding machine is under power but not being operated.

The RWMA bulletin 5, section 5-015.68.04, covers the special requirements for portable transgun grounding. Because the transgun is not hard-grounded, safety of the operator depends on the presence of a reliable ground path. However, since the ground path comes from a long flexible wire, there are additional requirements for this type of welding machine that monitor ground wire integrity and ground fault leakage current.

Fig. 7 — A separate, properly sized incoming ground wire is required to protect from electrical shock.

Fig. 8 — On a dual secondary welding transformer, one grounding reactor is required for each secondary. The center tap from both devices is connected to the building ground.
monitor would be considered an inadequate ground.”

**Ground Fault Current Relay**

If the transformer primary shorts to the secondary, line voltage will be present on the case of the transgun. With the operator maneuvering the transgun while holding parts of the welding machine case, this voltage can find a path through the operator and to ground. This leakage through the operator reduces current returning to the control and can be measured by a ground fault relay. The RWMA standard continues: “A sensitive, fail safe, ground fault relay with a maximum trip point of 15 mA must be used to provide protection against ground fault leakage currents. The ground fault relay must immediately disconnect line voltage from the Portable Transgun via a circuit breaker with shunt trip or a circuit breaker with undervoltage trip. The combined clearing time shall not exceed 60 ms.”

If purchasing a new transgun for handheld application, verify that the welding control contains systems to match the above requirements. If operating an existing handheld transgun, check to be sure that the welding control includes this full protection.

**Robotic Transguns**

Since the frame-grounding path to a robotically moved transgun is through hinge points, grounding must be done using a separate ground wire similar to that for the portable transgun above. Because it is possible for an operator to touch the frame of a transgun, the same type of grounding integrity and ground fault current relay applied to portable transguns should be used for robotic transguns.

**Fixture Transformers**

Welding machines that utilize multiple transformers on the same structure require special grounding. Connection of one side of the welding machine’s secondary on multiple transformers to the common ground causes ground paths through the metal being welded and through the fixture. These ground paths can easily weld or tack the metal parts to the fixture. There can also be electrical paths back through the metal being welded to other grounded electrodes to cause arcing throughout the system. For this application, a grounding reactor must be installed on the transformer secondary in place of a hard-wire ground.

This grounding reactor, containing an internal saturable coil, is connected across the weld transformer secondary with a center tap on the saturable coil connected to ground (Fig. 8). The coil has high impedance when voltage applied across it is less than the device’s rating (24–34 V). However, if the transformer secondary becomes connected to line voltage, the coil saturates and becomes a very low-impedance device. This drains the high voltage from the transformer secondary through the ground wire to produce high current that should trip the control’s circuit breaker or blow the line fuses. If the transformer has two secondary circuits, one grounding reactor must be installed on each circuit.

**Permanently Mounted Transguns**

These welding machines are structurally like the portable transguns discussed earlier, but are permanently mounted to a properly grounded steel pedestal. Either side of the machine’s transformer should be connected to the transformer frame to complete the ground path. Where multiple transguns are used in a system, or where arcing to the fixture is a potential problem, a grounding reactor, as presented above, should be used in place of a hard-wire ground connection.

**Conclusion**

Resistance welding can be one of the safest processes in the factory when proper personnel protection, correct equipment design, and appropriate electrical grounding are utilized. ♦

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Circle No. 31 on Reader Info-Card
Inspecting RSW Electrodes and Welds with Laser-Based Imaging

Studies demonstrated the feasibility of classifying and measuring weld size of spot weld fractures using laser vision profiles and surface topography

BY CONNIE REICHERT AND WARREN PETERSON

Optical sensors are commonly used for many types of applications in automotive production. Most of these are related to applications such as safety curtains and proximity measurements. However, optical sensing methods have not been used extensively to monitor the welding process.

Nondestructive inspection of resistance spot welding (RSW) process quality has largely concentrated on detecting spot weld formation, evaluating spot weld quality, and predicting the end of electrode life. However, several opportunities are available to monitor other aspects of the RSW process. Automation of these inspections is of particular importance in an automotive production environment. However, the production environment requires an inspection system to be significantly robust. In addition, the inspection system must provide an improvement in quality and/or productivity that is not currently available while not being cost prohibitive.

Optical inspection can be used for a large number of spot weld applications. This article provides two examples of inspections of the RSW process. The first example studies the feasibility of automating weld quality assessment during the spot weld teardown inspection using the weld fracture appearance classification system from AWS D8.1, Specification for Automotive Weld Quality and Resistance Spot Welding of Steel, and determining weld size information based on this assessment. The second example is contrasting the feasibility of determining the quality of electrode dressing operations using three different optical sensors.

Optical Inspection Methods

Types of Optical Sensors for Inspection

Laser Line Sensors. Laser-based vision incorporates optical geometry to measure a surface in 3D. A small laser sensor projects a laser stripe onto the surface of an object and a camera captures the image, much like a typical digital photograph. A computer is used to gather and process the digital image to extract only the important information. The image sent to the computer is made up of thousands of pixels, and each pixel represents a distance measurement from the sensor to the material or weld surface. By incrementally moving the laser in one dimension (1D), the distance measurements can be used to make a contour map of the surface. This map can then be used to measure surface features such as cracks that are fractions of a millimeter in size. The laser line sensor used in the examples has a resolution of 12 µm. The high resolution is needed to distinguish small differences in surface measurements.

Laser Spot Sensors. The laser spot sensor works in much the same way as the laser line sensor, except that it provides a single, high-resolution displacement measurement. By moving the laser, individual laser spots can be grouped together to form a single two-dimensional (2D) line containing width and height data or, if moved in 2D, measurements over a surface. This laser spot sensor is the most precise sensing method used in the examples, with a resolution of less than 2 µm. In addition, the simple continuous data output of the laser spot sensor enables data to be taken faster than the laser line sensors.

Digital Cameras. The digital camera uses a different measurement principle for surface inspection. Unfortunately, 3D measurements are not typically possible with a digital camera system. However, inspection of 3D objects is possible using inferred measurements. Since the field of view of the camera is known, the size of the objects or surface features can be cal-
culation by knowing frame of space. This inferred measurement method is the least precise of all of the methods evaluated in the examples.

**Software Requirements**

Each optical sensor requires software to retrieve the data from the sensor, transform it into discernable measurements, generate an image or topographical surface map, and possibly manipulate the sensor position or trigger the sensor to begin the inspection. Each sensor type requires different amounts of data manipulation for mapping.

**Laser Line Sensor.** The laser line sensor requires the largest amount of processing or software programming. The signal acquisition time depends mainly on computer speed for retrieving and processing the data. Motion control or coordinating software is required for moving the laser or the part in the travel or Y direction. Typically, a 1-×1-in. area can be automatically scanned and processed in less than 10 s.

**Laser Spot Sensor.** The laser spot sensor requires less processing or software programming to retrieve the data from the sensor. This is because the output is a simple voltage that is easy to gather at high rates of speed and with a wide variety of options. This technique requires the laser sensor to be moved in both the X and Y directions over the part so that a topographical map can be formed. Consequently, motion control or coordinating software is required. The time required to scan a 1-×1-in. area, producing the same topographical map as the laser line sensor and analyze the result, can be accomplished in under 30 s.

**Digital Color Camera.** The digital camera requires the least amount of processing or software programming primarily because the camera does not have to be moved to produce an image. Very little time is required to gather the digital image output from the camera. There are many software programs commercially available to do this. Less than 5 s is required to acquire and automatically analyze data from a 1-×1-in. area.

**Sensor Cost and Availability**

**Laser Line Sensor.** Laser line sensors are the most expensive technology for 3D inspection applications. These sensors range from $10,000 to $20,000, which may
Laser line technology has been used for about 20 years and a growing group of companies supplies sensors for inspection applications. Laser line sensors connect to computers by a variety of options, including IEEE 1394, RS-232 serial, and analog video.

**Laser Spot Sensor.** Laser spot sensors are more reasonably priced and range from a few hundred dollars to $1000 or more. They also have been used in industrial applications for more than 20 years. Sensors from many vendors with different spot resolutions are available off the shelf. They offer simple analog or digital outputs that easily connect to computer, PLC, robot, or other industrial I/O.

**Digital Color Camera.** The digital color camera market is flooded with applicable cameras capable of inspection applications. Prices range greatly from less than one hundred to thousands of dollars. Vendors are numerous and the resolution is constantly being improved. For inspection applications, a light source or backillumination may need to be considered. The digital camera is most often connected to a computer with IEEE 1394 or other digital medium.

**Sensor Resolution**

Resolution is a measure of the size of the smallest feature the camera or laser sensor can discern. Increasing the resolution makes the device more sensitive for detecting surface features and defects. Each of the optical techniques discussed differ in resolution. Laser spot sensors can provide the highest levels of resolution while digital color cameras tend to provide the least resolution for measurement.

**Ruggedness**

Laser line sensors were originally developed for arc weld joint tracking applications on robots. Because of this, they are designed for hazardous environments. They have protective glass or plastic lenses that can be easily cleaned/changed by the operator if they become dirty or damaged. Most of these laser sensors have air-cooling capability to keep the sensor cool if it is used on a welding torch. However, the sensor itself does not generate significant heat and therefore does not need to be cooled. Finally, the laser sensor was made to “see through” welding fumes. Because the laser beam is a specific wavelength, the detector inside the sensor rejects other wavelengths so other light sources (ambient light or glow from a spot weld) do not affect the measurement.

Laser line sensors have been industrially hardened and are extremely robust. However, spot sensors, though still rugged, do not usually offer protective techniques such as air cooling or positive air flow. Off-the-shelf digital cameras are the least robust and are generally not made for an industrial environment.
Portability and Adaptability

Laser sensors are about the size of a typical digital camera (4 × 1 × 1 in.). A protective casing can be used to make the sensor drop-proof. The laser sensors also weigh about the same as a typical digital camera. The laser sensors require a power source or, in some cases, a controller box. The size of the power supply depends on the laser manufacturer and can be as small as a laptop computer power supply. The controller boxes are usually the same size as the sensor.

Examples of NDE in RSW Production Applications

Following are two examples of how optical sensors are used for noncontact inspection on RSW applications. The objective of the first example is to determine the feasibility of using laser-based inspection to automatically classify weld fracture mode and make weld size measurements on resistance spot weld destruct samples. The objective of the second example is to contrast three types of optical sensors for inspection of electrode dress quality.

Example 1: Feasibility of Automated Advanced High-Strength Steel (AHSS) Fracture Characterization and Weld Size Inspection

DaimlerChrysler Corp. is using a new process standard that defines RSW quality for production applications for both low- and high-strength steels. This specification includes the same weld fracture mode classification system as detailed in AWS D8.1. Using the standard, destructive test results can be interpreted by an operator through comparison with a multi-page set of diagrams representing the range of failure modes possible. Further, determination of weld size is dependent on the fracture mode selected. A fast, objective, accurate, precise, and quantitative inspection method was investigated using laser-based vision inspection to determine the feasibility of automating the evaluation of RSW destruct weld tests. A laser vision system provides a fast, noncontact method of measuring the small surface features required for classifying and measuring weld size.
approach could potentially eliminate problems associated with user subjectivity and provide an electronic archival file.

**Setup for Line Laser Method of Postdestruct Test Spot Weld Inspection of AHSS.** Laser data were gathered for each weld and analyzed using a proprietary software program. In addition, the software also provided the motion control for the sensor. Both X and Y height profile data were converted into an easy-to-understand format. The software program displays the scanned image of the weld as well as the individual laser profiles as shown in Fig. 1. The 500 individual laser surface profiles represent actual surface contours and provide details of the surface characteristics.

**Sample Selection.** Thirty-five destructive test samples were selected to cover the eight different weld fracture types defined in a DaimlerChrysler process standard. These samples were taken from previous experiments performed on AHSS and provided a variety of fracture types with several unique features.

**Weld Fracture Type Classification Comparison.** The proprietary software displayed the image of the fractured weld area and provided high-resolution data for weld size measurements. Automatic processing of these data to distinguish between the different weld fracture types and automatic detection of features defining weld size was not done at the feasibility stage of this investigation, but could be done in the future. Table 1 lists the eight fracture modes and outlines the weld features that were distinguishable using the laser data.

The magnetic field data were gathered for each weld and analyzed using a proprietary software program. In addition, the software also provided the motion control for the sensor. Both X and Y height profile data were converted into an easy-to-understand format. The software program displays the scanned image of the weld as well as the individual laser profiles as shown in Fig. 1. The 500 individual laser surface profiles represent actual surface contours and provide details of the surface characteristics.

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### Table 1 — Fracture Mode Types

<table>
<thead>
<tr>
<th>Fracture Mode</th>
<th>Picture</th>
<th>Detectable Characteristics from Laser Scan Processing</th>
</tr>
</thead>
</table>
| Mode 1 Button Pull | ![Image](image1.png) | - Circular button area.  
- Uniform surface appearance.  
- Free from obvious surface defects.  
- Obvious single button visible and calculable in profile. |
| Mode 2 Partial Thickness with Button Pull | ![Image](image2.png) | - Change in surface texture in gray scale image.  
- Multiple changes in surface in single profile image.  
- Small button area in comparison to fusion zone boundary. |
| Mode 3 Partial Thickness | ![Image](image3.png) | - Nonuniform weld surface.  
- No obvious button in gray scale image.  
- Profile shows smooth “bump” rather than defined button shape. |
| Mode 4 Interfacial with Button Pull and Partial Thickness | ![Image](image4.png) | - Nonuniform weld surface.  
- Obvious button shape in single laser profile.  
- Distinct differences over entire weld surface in gray scale and single profile.  
- Obvious change in single laser profile indicating weld surface/height change.  
- Distinctive granular surface of interfacial fracture exhibited in one small area. |
| Mode 5 Interfacial with Button Pull | ![Image](image5.png) | - Obvious button of smaller size in comparison to weld fusion boundary.  
- Gray scale image indicates changes in surface texture across weld zone.  
- Distinctive granular surface of interfacial fracture inside weld zone boundary.  
- Single profile shows button clearly. |
| Mode 6 Interfacial with Partial Thickness | ![Image](image6.png) | - Nonuniform surface area.  
- No button visible in gray scale or single profile.  
- Smooth contour, bump in profile indicating possible partial thickness fracture.  
- Distinctive granular surface of interfacial fracture exhibited in weld zone area. |
| Mode 7 Interfacial | ![Image](image7.png) | - Nonuniform surface area.  
- No button visible.  
- No partial thickness fracture visible.  
- Somewhat “bumpy” laser profile indicating granular surface.  
- Distinctive granular surface of interfacial fracture exhibited over entire weld area. |
| Mode 8 No Fusion | ![Image](image8.png) | - Mostly uniform surface area.  
- No button visible.  
- No partial thickness fracture visible.  
- Flat laser profile indicating no height change on weld surface. |

**Fig. 13 — Surface topography profile created from laser spot sensor data of Electrode T.**
Table 2 — Manual and Laser-Based RSW Peel Test Diameter Measurements

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<th>Weld Fracture</th>
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Table 3 — Manual Caliper Measurements

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Table 4 — Scanning Line Measurements at Full Field of View

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scanned surface, detecting dresser defects, and determining out-of-tolerance dress quality conditions.

Setup for Dresser Quality Inspection System

Laser Line Sensor Setup. A high-resolution laser line sensor was mounted on a motorized linear slide that traversed each stationary electrode sample. The laser moved a total distance of 20 mm over the part and gathered about 500 individual laser surface profiles. The individual laser profiles were used to create an image using proprietary software. From these images, electrode diameter, electrode face diameter, and convexity were measured for each electrode. Figure 2 shows the system used to scan the electrodes with the laser line sensor. Figure 3 shows a close-up view of the laser line sensor just before scanning the electrode.

Laser Spot Sensor Setup. The laser spot sensor was also mounted on a motorized linear slide and continually gathered height data as it moved across the surface of the electrode. However, only one traverse over the electrode was made. This produced a single 2D contour of the electrode. The laser moved a total distance of 18 mm and gathered 25,000 individual displacement measurements per scan. Figure 4 shows the system used to scan the electrodes with the laser spot sensor.

Digital Camera Setup. The digital camera was mounted on a tripod and focused at the side of the electrode. The camera delivered a single, color, high-resolution image of the electrode. Proprietary software captured and analyzed the digital data in these experiments. The camera was attached to a computer using IEEE 1394 connection. Electrode diameter was measured at any point around the face from the bitmap image.

Sample Selection. Obara selected a set of 22 RSW electrodes with varying degrees of dress quality. The electrode selection included B- and E-nose electrodes. Before completing the image-based techniques, each electrode was measured manually with digital calipers (Table 3).

Scanning Laser Line Sensor Results. The laser line sensor provided measurements of electrode diameter, electrode face diameter, and convexity. The laser line sensor also enabled a histogram of the light intensity over the entire electrode face. For each electrode, about 5000 data points were taken that represent the entire scanned surface of the electrode. The measurements of electrode diameter and convexity using this technique can be found in Table 4. Figure 5 shows a screen shot from the software program.

Figure 5 uses callouts to describe the features displayed on the graph in all of the software screen shots. The red arrow points to a single line of raw laser data from the laser line sensor. The black arrows point to the movable cursors. The white arrow points to the image of the entire scan. The lower graph represents just one of the lines. The green arrow points to where the measurement of convexity is completed.

Table 5 — Laser Spot Sensor Measurements

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Table 6 — Digital Color Camera Measurements

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Laser Spot Sensor Results. The laser spot sensor also provided measurements of electrode diameter, electrode face diameter, and convexity from the individual laser spots forming a single 2D line. The measurements of electrode diameter and electrode face diameter are shown in Table 5. The laser sensor data were gathered and analyzed with EWI software. Figure 6 is a screen shot from the software program that shows the 2D plot and the measurement of convexity. A comparison of Figs. 5 and 6 shows that different measurements of convexity are made depending on the technique used to measure the face. The spot sensor provides many times better resolution than the line sensor.

Digital Camera Results. The color digital camera provided measurements of electrode diameter and electrode face diameter. Since the field of view of the camera is known, calculation of the electrode diameters in each picture is made by knowing the frame of space. It is important to note that this is an inferred measurement and is the least precise of all methods evaluated. The measurements of electrode diameter and electrode face diameter can be found in Table 6. Figure 7 shows a color image from the digital camera setup.

Summary and Conclusions

Feasibility of Lasers for RSW Fracture Mode-Type Inspection Applications

Laser sensing proved to be feasible for determining and distinguishing between types of weld fractures and measuring weld size. This was shown by distinguishing the differences between Types 7 and 8 fracture modes. Each set of laser scans provided a 3D image of the weld surface. While the image displays surface features in the same way a human operator would visually see them, the laser image can be rapidly analyzed by a computer. The analysis program can use a series of equations to make measurements or provide statistics. If a human eye can detect differences in the scanned images, an algorithm can likely be programmed to distinguish these differences automatically.

Feasibility of Lasers for Electrode Dressing Inspection Application

All three of the techniques researched in this study provided measurements that could be used to determine electrode dress quality. Due to the differences in the technologies, some techniques provided more information than others. Due to the range in resolution of the technologies, some provided more sensitivity.
than others. Depending on the conditions of the electrode that were considered improper or bad dressing, any one or more of these technologies can be used to determine dressing quality of B- and E-nose electrodes.

The laser line sensor was the most capable technique because it provided a full topographical map of the electrode surface. The laser spot sensor proved to be the next most capable technique. The limitation of this technique was not in the resolution, but in the limited data collected with only a single scanned line across the electrode surface. Dresser defects could still exist on portions of the electrode that were not scanned. Modifications of this approach include producing a few additional scans over the electrode face, or making perpendicular scans across the face. However, each additional scan increases the inspection and data-processing time.

The digital color camera provided the fastest data acquisition, but provided only 2D data. While this technique provided the least information from the three techniques researched, it can provide valuable information on electrode dress quality. The camera provides an overall picture of the side of the electrode all at once. Additionally, this technique provides color information used in the histogram analysis. 

**Conclusions**

The following conclusions were drawn from inspections of AHSS weld fracture surfaces:

1. The feasibility of classifying and measuring weld size of spot weld fractures using laser vision profiles and topography was demonstrated.

2. Measurement of RSW size using the laser profile data correlated well with the manual caliper measurements.

3. Different weld fracture modes were discernible using the laser data. This was illustrated by discerning differences between Types 7 and 8 fracture modes.

The following conclusions are drawn from inspections of electrode dress quality:

1. All three digital imaging techniques are feasible for determining electrode dressing quality. Not all of the techniques make the same types of measurements for determining electrode dress quality. One or a combination of techniques may be required, depending on the importance and number of features to be detected.

2. The most applicable and cost-effective method for measuring electrode face diameter and convexity appears to be the laser spot sensor.

3. The most applicable and cost-effective method for measuring gross surface quality (oxidation) appears to be the digital color camera.

**Acknowledgments**

Our thanks to Ilaria Accorsi of DaimlerChrysler Corp. and Obara Corp. for allowing publication of this work.

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Resistance welding is an inexpensive welding process, and its familiarity suggests there is nothing new to learn. Yet the mere fact that it is so common means that its costs, in aggregate, loom large and thus become targets for cost-savings initiatives. So, what can be done when your cost accountants come knocking for savings?

The most important topic of conversation in many automotive plants today is how to cut costs without reducing weld quality. This article presents a framework that can be used to effectively achieve lower costs. I believe that there is a plethora of buzzwords and “get results quick” schemes available today that neither reduce overall costs nor present a realistic approach to saving money. These schemes take a useful proven concept, such as “just in time” inventory management, and simplify and corrupt the approach, causing higher ancillary costs in related cost centers. Meanwhile, the consultants exit with fat checks, leaving behind upset, dedicated, and frustrated employees who are all too aware of the higher overall costs.

**What Not to Do**

Perhaps one of the best examples of such short-sighted and blind “cost-saving” plans is the large automotive corporation that decided that carrying a month’s supply of heavy (but cheap) copper electrodes was unnecessary and that a small amount of money would be saved in interest carrying costs if only a week’s supply of inventory was maintained. However, these electrodes were only made in one factory and shipped to many plants by truck. Therefore, it was decided that the supplier would hold the inventory and ship weekly. Shipping weekly meant using air freight. Thus, the average per-plant $500 cost of shipping monthly 25,000 50-cent electrodes suddenly became a $1500 per week cost for 6000 electrodes — and this cost ignored the increased shipping, delivery, NAFTA, customs, payables and payment paperwork required for each shipment. Yet the company’s consultants reported annual “savings” of $937.50 per plant based upon the reduction in amount of inventory carried. They also forgot to mention the many stock-outs that suddenly caused expensive emergency shipments and even bigger headaches for the maintenance and welding engineers. This farce continued for four years.

**Reducing Resistance Welding Costs**

*BY NIGEL SCOTCHMER*

An organized approach to cost reduction begins with establishing objectives and checklists, which then lead to a detailed analysis for implementation.

*Scotchmer  2007:Layout 1 1/9/07 1:55 PM Page 47*

*NIGEL SCOTCHMER* (nscotchmer@huysindustries.com) is with Huys Industries Ltd., Weston, Ont., Canada.
years, despite the grumblings of production and welding people. It is precisely this type of situation that makes it necessary for welding people to have a basic knowledge of cost saving and efficiency improvement plans, so that they can effectively contribute in the planning and implementation of cost-saving plans.

The Overview Checklist

Successful cost-reduction plans involve careful planning and common sense analysis. First, an overview of the entire situation should be obtained. An overview will highlight what is known, is not known, and what needs to be done next. Making checklists and matrix boxes are ideal ways to summarize important information and provide an organized approach. There is no need to have all the answers. Finding the correct questions is usually more important and useful than the answers.

The overview is essential as it provides the framework for the subsequent detailed analysis. The overview primarily considers the following:

1. The objectives — how large the savings are to be, how they are to be measured, and where they are to be sought;
2. The timelines in which the project is to be accomplished; and
3. The resources available to be used: the equipment, tools, and welding processes used, and the changes that can be considered; and the people available to do the work — their depth of knowledge, capabilities, and interest in creating and managing change.

Detailed Checklists

Each of the three items above is broken down to consider specific subtopics. For instance, what types of savings are paramount. Are they cash savings now, reduced depreciation charges, reductions of indirect overhead charges, or lower freight costs? How large a saving is sought? Is this a company or plant-wide program or is it to start on a line or an individual welding cell?

In terms of timelines, is this a multiyear project, or a one-time exercise to deal with a temporary slowdown in the market? What objective measures are to be used to gauge performance and track change? How involved is (are) the chosen measuring tool(s)?

The most difficult and time-consuming analysis concerns the resources available. The equipment in use is reviewed, and the labor force, generally speaking, is well-educated, highly motivated, and very capable of managing and reporting change.

A Case Study

One notable case was the transfer of small welded assemblies (such as hinges and brackets) from Germany to Hungary. Simpler tooling from less automation and lower labor costs reduced indirect costs by 10% and direct labor costs by 30%. Detailed and accurate accounting records allowed for the rapid scaling of production and early realization and reporting of cost savings.

In Japan, the analysis of detailed costs, and the allocation of indirect costs to individual welds per machine, or weld cell, or production line, reflects their underlying belief (well, a theoretical belief at least!) that every weld has to be a perfect weld. This is the concept of “cost per weld,” where all welding costs are allocated to individual welds.

There is the example of a major Japanese automaker that has the same cost per weld on similar production lines in Japan and in Western Europe. Similar detailed costs around the world would certainly suggest that costs are controlled in a format that is comparable. Innovation and originality may be stifled, but consistency has its own reward.

In North America there is a general belief that such detailed work is unnecessary and inordinately expensive; but perhaps such inattention to detail is yet another reason for the decline in our manufacturing?

For meaningful measurement of cost savings, there must be a simple yet effective method that management can use to track cost reductions. This number, or group of numbers, must be understood by the welding engineers and production people, and must track what is important to them and must be accurate and timely.
ordination between the welding department and accounting will allow both to learn each other’s roles and deepen each other’s understanding of the task — how to reduce costs. The easiest, and quickest, way this is achieved is with a series of checklists.

Suppose a single welding cell has been targeted for direct cost savings of 10% and indirect costs of 5%, to be realized within six months, using a modest capital budget of $10,000 on old equipment with a mature labor force. In the hands of diligent workers, completed checklists will provide the detailed analysis of what is discovered, what is tried, what works and what is achieved at the end of the process. In addition, documentation of the process will help on the next project.

Detailed checklists for this hypothetical robotic welding cell will cover such items as:

- description of cell, its type, manufacturer, age, and performance
- capital cost of the cell, its components, and tooling
- annual repair costs for the cell
- allocated overhead costs, with detailed breakdown (if available)
- maintenance, reliability and accuracy issues
- parts produced
- material being welded
- stack-ups
- historical production rates
- maintenance cycles/shift changes
- quality desired
- knowledge base of supervisory staff
- training of operating staff
- flexibility for innovation (change factor)
- how quality is measured
- consumables
- infrequent replacements (cables, shunts, adaptors, tip dresser blades, etc.)
- electrodes
- alloy
- geometry
- type (male, female, size, coating)
- maintenance — tip dressed, recycled, or end of life
- consumables costs
- optimization of weld cycle
- length and design of weld time
- length and design of heat
- length and design of force
- process control
- production rate
- maintenance
- quality inspection

Detailed analysis and open discussion of the completed checklists will present significant opportunities for “what if” scenarios. A change agent who is particularly knowledgeable about how others do welding will offer additional insights and possibilities for experimentation and follow-up. If new ideas are not tried, tested, and documented, then improvements will never be discovered and implemented.

**Conclusion**

Experience in both resistance welding and cost accounting is helpful to achieving overall, real, long-term cost savings. A full overview of the situation and a plan for execution is essential. An open mind to new initiatives and change is even more important. Persistence and determination are key for the effective recognition of opportunities for making savings. Clearly, any initiative requires the passion of a true leader who recognizes the challenges involved as well as the methods necessary to achieve them.

However, a simple, organized approach, based upon checklists and known objectives, starting from an overview and drilling down to details, will achieve greater long-term success in overall cost savings than a smaller, focused cost-saving plan that merely switches, say, from one brand of electrodes to another to get a cheaper brand, or switches from one commodity manager to another every three years.

---

**THE “W” STANDS FOR WELDING**

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**Design & Manufacturing**

Founded in 1945, Resistance Welder Corporation quickly became a world leader in the appliance and automotive industries, well known for practical welding solutions.

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In 1979, we changed our name to RWC, Inc. to better communicate our commitment to flexible automation systems and design, with a continued emphasis on welding as a specialty.

**Mash seam welder for dryer drum.**
Friends and Colleagues:

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

For specifics on the nomination requirements, please contact Wendy Sue Reeve at AWS headquarters in Miami, or simply follow the instructions on the Fellows nomination form in this issue of the *Welding Journal*. Please remember, we all benefit in the honoring of those who have made major contributions to our chosen profession and livelihood. The deadline for submission is July 1, 2007. The Committee looks forward to receiving numerous Fellow nominations for 2008 consideration.

Sincerely,

Nancy C. Cole
Chair, AWS Fellows Selection Committee
## Troubleshooting in Gas Metal Arc Welding

<table>
<thead>
<tr>
<th>Problem</th>
<th>Possible Cause</th>
<th>Remedy</th>
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</thead>
<tbody>
<tr>
<td>Difficult arc starting</td>
<td>Wrong polarity</td>
<td>Check polarity</td>
</tr>
<tr>
<td></td>
<td>Poor workpiece lead connection</td>
<td>Secure connection</td>
</tr>
<tr>
<td>Irregular wire feed and melt back</td>
<td>Insufficient drive roll pressure</td>
<td>Adjust</td>
</tr>
<tr>
<td></td>
<td>Contact tip plugged or worn</td>
<td>Clean or replace</td>
</tr>
<tr>
<td></td>
<td>Kinked welding wire</td>
<td>Cut out; replace spool</td>
</tr>
<tr>
<td></td>
<td>Coiled gun cable</td>
<td>Straighten cables; clean or replace contact tip</td>
</tr>
<tr>
<td></td>
<td>Conduit liner dirty or worn</td>
<td>Clean or replace</td>
</tr>
<tr>
<td></td>
<td>Conduit too long</td>
<td>Shorten; use push-pull drive system</td>
</tr>
<tr>
<td>Welding wire wraps around drive roll (birdnesting)</td>
<td>Excessive feed roll pressure</td>
<td>Adjust</td>
</tr>
<tr>
<td></td>
<td>Incorrect conduit liner or contact tip</td>
<td>Match liner and tip to electrode size</td>
</tr>
<tr>
<td></td>
<td>Misaligned drive rolls or wire guides</td>
<td>Check and align properly</td>
</tr>
<tr>
<td></td>
<td>Restriction in gun or gun cable</td>
<td>Remove restriction</td>
</tr>
<tr>
<td>Heavily oxidized weld deposit</td>
<td>Air/water leaks in gun or cables</td>
<td>Check for leaks and repair</td>
</tr>
<tr>
<td></td>
<td>Restricted shield gas flow</td>
<td>Check and clean nozzle</td>
</tr>
<tr>
<td></td>
<td>Defective gas solenoid valve</td>
<td>Repair or replace solenoid</td>
</tr>
<tr>
<td></td>
<td>Improper gun angle</td>
<td>Use 15-deg push or trail angle</td>
</tr>
<tr>
<td></td>
<td>Excessive nozzle-to-workpiece distance</td>
<td>Reduce distance to approximately 1/8 to 1/4 in.</td>
</tr>
<tr>
<td>Wire feeds but no gas flow</td>
<td>Gas cylinder is empty</td>
<td>Replace and purge lines</td>
</tr>
<tr>
<td></td>
<td>Gas cylinder valve closed</td>
<td>Open valve</td>
</tr>
<tr>
<td></td>
<td>Flow meter not adjusted</td>
<td>Adjust to specified flow</td>
</tr>
<tr>
<td></td>
<td>Restriction in gas line or nozzle</td>
<td>Check and clean</td>
</tr>
<tr>
<td>Welding gun overheats</td>
<td>Pinched or clogged coolant line</td>
<td>Check and correct</td>
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<tr>
<td></td>
<td>Low coolant level in pump reservoir</td>
<td>Add coolant</td>
</tr>
<tr>
<td></td>
<td>Water pump not functioning</td>
<td>Repair or replace</td>
</tr>
<tr>
<td>Porosity in weld bead</td>
<td>Dirty base metal</td>
<td>Remove scale, rust, oil</td>
</tr>
<tr>
<td></td>
<td>Excessive wire feed speed</td>
<td>Reduce</td>
</tr>
<tr>
<td></td>
<td>Moisture in shielding gas</td>
<td>Replace gas cylinder</td>
</tr>
<tr>
<td></td>
<td>Contaminated welding wire</td>
<td>Protect wire while using clean wire</td>
</tr>
<tr>
<td></td>
<td>Gas flow rate too high or low</td>
<td>Adjust</td>
</tr>
<tr>
<td>Excessive spatter</td>
<td>Excessive arc voltage</td>
<td>Reduce</td>
</tr>
<tr>
<td></td>
<td>Insufficient slope on power source (for short circuiting transfer)</td>
<td>Increase slope setting</td>
</tr>
<tr>
<td></td>
<td>Contact tip recessed too far in nozzle</td>
<td>Adjust or longer contact tip</td>
</tr>
<tr>
<td></td>
<td>Excessive gas flow rate</td>
<td>Adjust to recommendations</td>
</tr>
</tbody>
</table>

One of the most discussed topics and sources of misunderstanding involves joining dissimilar materials by welding. Vendors probably receive more phone calls with questions on this subject than any other. The traditional codes are nearly silent on the issue. Many design, shop, or field organizations do not have—or have lost—expertise in this area.

This conference will address issues including material properties, weld properties, preheat/post-weld heat treatment, corrosion, the use of transition joints, service conditions, and practical considerations.

Even the most difficult-to-weld of all material combinations—steel to aluminum—has been welded satisfactorily using such techniques as explosion welding and magnetic pulse welding. New chemistries are coming to the aid of existing filler metals, making them more amenable to dissimilar metals welding. Filler metals based on nickel-base superalloy chemistries are also meeting the challenge. Advances in brazing technology are taking care of a host of metallurgical problems as well.

The problems are there, but so are the solutions.

The conference keynote address will be presented by Dr. Thomas Eagar from MIT, a noted expert in this most difficult area of welding.

Keynote address:
Dealing with Diversity in the Joining of Dissimilar Metals
Thomas W. Eagar, Professor, MIT, Cambridge, MA

“As product life cycles increase, and the need for fuel-efficient lightweight structures increases, designers are specifying both higher strength metals, as well as a greater diversity of metals. Fabrication of these structures in an economically efficient manner poses significant challenges, as our favored fusion welding processes are simply not practical (or possible) for many of these combinations of metals. Meeting these challenges requires both greater expertise of the fabrication engineer but also earlier involvement in the product design process.”

Dissimilar Metal Weld Failures Involving Grade 91 Steel
Jeff Henry, Structural Integrity Associates, Inc., Chattanooga, TN

Advances in Friction Stir Welding and Application to Dissimilar Metal Joining
William J. Arbegast, NSAF Center for Friction Stir Processing, and Advanced Materials Processing and Joining Center, Rapid City, SD

Large-Area Soldering and Brazing of Dissimilar Materials with a Novel Heat Source
Dr. Timothy P. Weihs, Reactive NanoTechnologies, Inc., Hunt Valley, MD

CSC-Controlled Short Circuit Transfer – A New GMAW Process That Solves Old Weld Problems
Tom Rankin, ITW Jetline Engineering, Irvine, CA

Tensile Properties Evaluation of Dissimilar Welds in AL-6XN, DH-36, and A514 Gr. 2 Plate
Kim Tran, Surface Warfare Center Carderock Division (NSWC-CD), West Bethesda, MD

Magnetic Pulse Welding: Design and Analysis
Dr. James R. Dydo, Advanced Computational and Engineering Services, LCC (ACES), Gahanna, OH

Prediction of DMW Microstructures
Dr. Damian J. Kotecki, The Lincoln Electric Company, Cleveland, OH

Explosion Welding – A Highly Versatile Welding Technology
John G. Banker, DMC Clad Metal, Boulder, CO

Alternative Filler Materials for DMWs Involving P91 Materials
Kent Coleman, Electric Power Research Institute, Charlotte, NC

Ultrasonic Welding of Dissimilar Metals
Dr. Karl Graff, Edison Welding Institute, Columbus, OH

The Way We Were – NDE from the Beginning
Mike Turnbow, Tennessee Valley Authority, Chattanooga, TN

Applications of Dissimilar Joint Metallurgy in the Chemical Process Industry
David Oulton, NOVA Chemicals (Canada) Ltd, Ontario, Canada

Inertia Friction Welding
Al Wadleigh, Interface Welding, Carson, CA

To register or to receive a descriptive brochure, call (800) 443-9353 ext. 223, (outside North America, call 305-443-9353), or visit www.aws.org/conferences


### TECHNICAL TRAINING

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- Welding for the Non-Welder
  Apr 10-13 • Jun 25-28 • Aug 20-23
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  Mar 5-9 • Aug 6-10 • Nov 26-30
- Liquid Penetrant & Magnetic Particle Inspection
  Mar 12-16 • Jun 4-8 • Oct 1-5
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  Feb 5-16 • Mar 26-Apr 6 • May 7-18 • Jul 19-27 • Sep 10-21

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or visit us at www.welding.org for more information.

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14th Int’l Conf. on the Joining of Materials (JOM-14), and 5th Int’l Conf. on Education in Welding. April 29–May 2, at LO-Skolen, Helsingør, Denmark. For more information, contact: jom_aws@post10.tele.dk.


♦ FABTECH International & AWS Welding Show. Nov. 11–14, McCormick Place, Chicago, Ill. This show is the largest event in North America dedicated to showcasing a full spectrum of metal forming, fabricating, tube and pipe, and welding equipment and technology. Contact American Welding Society, call (800/305) 443-9353, ext. 462; or visit www.aws.org.
# AWS Certification Schedule

## Certification Seminars, Code Clinics and Examinations

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

### Certified Welding Inspector (CWI)

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<tr>
<th>Location</th>
<th>Seminar Date</th>
<th>Exam Date</th>
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<td>Boston, MA</td>
<td>Mar. 4-9</td>
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<td>Oct. 6</td>
</tr>
</tbody>
</table>

* Mail seminar registration and fees for Columbus seminars only to National Board of Boiler & Pressure Vessel Inspectors, 1055 Crupper Ave., Columbus, OH 43229-1183. Phone (614) 888-8320. Exam application and fees should be mailed to AWS.

### 9-Year Recertification for CWI and SCWI

<table>
<thead>
<tr>
<th>Location</th>
<th>Seminar Dates</th>
<th>Exam Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dallas, TX</td>
<td>Mar. 19-24</td>
<td>NO EXAM**</td>
</tr>
<tr>
<td>Sacramento, CA</td>
<td>Apr. 23-28</td>
<td>NO EXAM**</td>
</tr>
<tr>
<td>Pittsburgh, PA</td>
<td>Jun. 11-16</td>
<td>NO EXAM**</td>
</tr>
<tr>
<td>San Diego, CA</td>
<td>Aug. 13-18</td>
<td>NO EXAM**</td>
</tr>
<tr>
<td>Dallas, TX</td>
<td>Oct. 29-Nov 3</td>
<td>NO EXAM**</td>
</tr>
<tr>
<td>Orlando, FL</td>
<td>Dec. 3-8</td>
<td>NO EXAM**</td>
</tr>
</tbody>
</table>

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

### Certified Welding Supervisor (CWS)

<table>
<thead>
<tr>
<th>Location</th>
<th>Seminar Dates</th>
<th>Exam Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chicago, IL</td>
<td>Mar. 19-23</td>
<td>Mar. 24</td>
</tr>
<tr>
<td>Nashville, TN</td>
<td>Apr. 16-20</td>
<td>Apr. 21</td>
</tr>
<tr>
<td>Atlanta, GA</td>
<td>Apr. 23-27</td>
<td>Apr. 28</td>
</tr>
<tr>
<td>Columbus, OH</td>
<td>May 7-11</td>
<td>May 12</td>
</tr>
<tr>
<td>Minneapolis, MN</td>
<td>Jun. 11-15</td>
<td>Jun. 16</td>
</tr>
<tr>
<td>Philadelphia, PA</td>
<td>Jul. 16-20</td>
<td>Jul. 21</td>
</tr>
<tr>
<td>Atlanta, GA</td>
<td>Jul. 23-27</td>
<td>Jul. 28</td>
</tr>
<tr>
<td>Seattle, WA</td>
<td>Aug. 13-17</td>
<td>Aug. 18</td>
</tr>
</tbody>
</table>

CWS exams are also given at all CWI exam sites.

### Certified Radiographic Interpreter (RI)

<table>
<thead>
<tr>
<th>Location</th>
<th>Seminar Dates</th>
<th>Exam Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Houston, TX</td>
<td>Mar. 26-30</td>
<td>Mar. 31</td>
</tr>
<tr>
<td>Philadelphia, PA</td>
<td>Apr. 30-May 4</td>
<td>May 5</td>
</tr>
<tr>
<td>Nashville, TN</td>
<td>Apr. 4-8</td>
<td>Jun. 9</td>
</tr>
<tr>
<td>Manchester, NH</td>
<td>Jul. 23-27</td>
<td>Jul. 28</td>
</tr>
<tr>
<td>St. Louis, MO</td>
<td>Sept. 24-28</td>
<td>Sept. 29</td>
</tr>
<tr>
<td>Philadelphia, PA</td>
<td>Oct. 22-26</td>
<td>Oct. 27</td>
</tr>
<tr>
<td>Jacksonville, FL</td>
<td>Nov. 26-30</td>
<td>Dec. 1</td>
</tr>
</tbody>
</table>

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

### Certified Welding Educator (CWE)

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

### Senior Certified Welding Inspector (SCWI)

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

### Certified Welding Fabricator

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

### Code Clinics & Individual Prep Courses

The following workshops are offered at all sites where the CWI seminar is offered (code books not included with individual prep courses): Welding Inspection Technology (general knowledge and procedures, including brazing, soldering and thermal spraying).

### On-site Training and Examination

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

---

*For information on any of our seminars and certification programs, visit our website at www.aws.org or contact AWS at (800/305) 443-9353, Ext. 273 for Certification and Ext. 224 for Seminars.

Please apply early to save Fast Track fees. This schedule is subject to change without notice. Please verify the dates with the Certification Dept. and confirm your course status before making final travel plans.

© AWS 2007 CEB1324-02
C7B Committee Honors One of Its Own

Donald E. Powers holds his Silver Certificate of Appreciation presented to him for his 25 years of service to the C7 Committee on High Energy Beam Welding and Cutting.

Shown above are committee members (from left) Gordon Gibbs, Kenn Lachenberg, Committee Chairman Douglas D. Kautz, AWS Past President (2003–2004) Thomas M. Mustaleski, Donald E. Powers, AWS Past President (2002–2003) Ernest D. Levert, Ken Zacharias, Committee Secretary Annette Alonso, C7B Subcommittee Chairman Pat Hochanadel, and C7B Vice Chair Todd Palmer.

Powers is a founding member and a past officer of the C7 Committee, C7B Subcommittee on Electron Beam Welding and Cutting, and the C7X Executive Committee.

The award presentation was made during the committee meeting held at the recent FABTECH International & AWS Welding Show in Atlanta, Ga. The committee members met to work on the revisions for two documents: C7.1, Recommended Practices for Electron Beam Welding, and C7.3, Process Specification for Electron Beam Welding.

Kotecki Heads Numerous Events in India

Damian J. Kotecki, technical director for stainless and high-alloy product development at The Lincoln Electric Co., Cleveland, Ohio, and, at the time, AWS president, was a featured presenter at the Welding Seminar 2006 held Nov. 24–26 in Chennai, India, in addition to giving lectures to groups in seven Indian cities during a 16-day lecture tour.

On Nov. 23, Kotecki conducted the pre-conference tutorial program titled, Martensite Boundaries on the WRC-1992 Diagram. This event was held at the Radha Park Hotel, Chennai.

The next day, Kotecki opened the seminar with the keynote address. His IIW Chennai Medal Lecture was titled, How to Convert Good Austenitic Stainless Steel Filler Metal into Bad Welds. The lecture was held at the Chennai Trade Center, with 300 representatives from the industrial and scientific community in attendance. The event was organized by The Indian Institute of Welding.

Kotecki’s lecture tour was arranged for him to present a lecture of three to five hours duration, Welding of New Generation Stainless Steels, to groups in seven locations, including Chennai, Coimbatore, Kochi, Surat, Mumbai, Tiruchirappalli (also known as Trich), and Pune. More than 800 attended these events, organized by The Indian Institute of Welding, The Indian Welding Society, and Weldwell Specialty Pvt. Ltd., a welding consumables supplier in India. Each lecture was followed by a lively question-and-answer period.

This lecture series was the latest in a series of annual lecture tours supported by the American Welding Society and presented by various welding experts to share the latest trends and practices in the welding industry with the scientists, engineers and manufacturing personnel in India.
**Tech Topics**

### Technical Committee Meetings

All AWS technical committee meetings are open to the public. To attend a meeting, call the committee secretary listed with the meeting at (800/305) 443-9353 at the extension shown.

- **Feb. 22, 23, Technical Activities Committee. Miami, Fla. Contact: J. Gayler, ext. 472.**
  - March 6, 7, D17 Committee on Welding in the Aircraft and Aerospace Industry. Redondo Beach, Calif. Contact: A. Alonso, ext. 299.
  - March 8, 9, ASH Subcommittee on Filler Metals and Fluxes for Brazing. Orlando, Fla. Contact: S. Borrero, ext. 334.
- **March 8, 9, C3 Committee on Brazing and Soldering. Orlando, Fla. Contact: S. Borrero, ext. 334.**
- **March 8, 9, C3A Subcommittee on Brazing Handbook. Orlando, Fla. Contact: S. Borrero, ext. 334.**
  - March 8, 9, C3B Subcommittee on Soldering. Orlando, Fla. Contact: S. Borrero, ext. 334.
  - March 8, 9, C3C Subcommittee on Education and Safety. Orlando, Fla. Contact: S. Borrero, ext. 334.
- **March 8, 9, C3E Subcommittee on Brazing Conferences. Orlando, Fla. Contact: S. Borrero, ext. 334.**
  - March 13–16, D1 Committee on Structural Welding. Houston, Tex. Contact: J. Gayler, ext. 472.
  - March 19, 20, A5 Committee on Filler Metals and Allied Materials. Orlando, Fla. Contact: R. Gupta, ext. 301.
  - March 20, A5T Subcommittee on Filler Metal Procurement Guidelines. Orlando, Fla. Contact: R. Gupta, ext. 301.

### ISO Drafts for Public Review

Copies of these standards are available for review and comment through your national standards body, which in the United States is ANSI, 25 W. 43rd St., 4th Floor, New York, NY 10036; (212) 642-4900. Comments regarding ISO documents should be sent to your national standards body. In the United States, if you wish to participate in the development of international standards for welding, contact **Andrew Davis**, technical director, at adavis@aws.org, ext. 466.

- **ISO/DIS 15011-3, Health and safety in welding and allied processes — Laboratory method for sampling fume and gases — Part 3: Determination of ozone emission rate.**
- **ISO/DIS 15012-2, Health and safety in welding and allied processes — Requirements, testing, and marketing of equipment for air filtration — Part 2: Determination of the minimum air volume flow rate.**
- **ISO/DIS 15616-4, Acceptance tests for CO2 laser beam machines for high-quality welding and cutting — Part 4: Using 2D moving optics type.**

### Technical Inquiries

**Re: AWS A2.4-98, Standard Symbols for Welding, Brazing, and Nondestructive Examination.**

**Question 1:** A flare bevel welding symbol is provided without a weld size (E) or bevel dimension (S). Should the groove be filled to the top, or would any size of weld be okay? Alternately, is it considered an improper weld symbol and should the engineer be contacted for the proper weld size? The print requires the weldment to be inspected to AWS D1.1, Structural Welding Code — Steel.

**Response:** The symbol specifies a complete-joint-penetration weld from the point of tangency where the two pieces meet to the top of the flare of the attaching bar as shown above. However, as noted in AWS A2.4-98, Annex B4.2.10, “the concept of complete joint penetration...is not attainable in many flare groove welds...” because “the rate of curvature on one or both members is such that the actual obtainable weld size is usually only some fraction of the radius.”

The Subcommittee considers that there is reason to query the engineer to confirm the required size of the weld because the ability to achieve complete joint penetration using conventional welding practices is questionable. For additional information relating to sizing flare-groove welds, see Section 2 of AWS D1.1.

**Question 2:** In the figure below, is the symbol adequate in calling out welds at both edges of the girder flange?

**Response:** No. Using the “Typ” designation in the tail is intended as an alternate to repeating identical welding symbols many times on the same drawing. However, all applicable joints must be completely identified (AWS A2.4-98, Section 3.11.3).

This is not accomplished with the symbol shown in the figure above. ♦

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**ISO Drafts for Public Review**

Copies of these standards are available for review and comment through your national standards body, which in the United States is ANSI, 25 W. 43rd St., 4th Floor, New York, NY 10036; (212) 642-4900. Comments regarding ISO documents should be sent to your national standards body. In the United States, if you wish to participate in the development of international standards for welding, contact **Andrew Davis**, technical director, at adavis@aws.org, ext. 466.

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- **ISO/DIS 15616-4, Acceptance tests for CO2 laser beam machines for high-quality welding and cutting — Part 4: Using 2D moving optics type.**

### Resistance Welding Standard Scheduled for Release Soon

The following standard will be published soon and should be available in the next month or two:


The following standard was recently released and is available now:

- **AWS G2.4/2.4M: 2007, Guide for the Fusion Welding of Titanium and Titanium Alloys,** has 52 pages, 8 figures, and 20 tables. The list price is $60, $45 for AWS members. To order or preorder, contact World Engineering Exchange (WEX) Ltd., www.awspubs.com, or call toll-free (888) 935-3464 in U.S. and Canada; elsewhere (305) 824-1177, FAX (305) 826-6195.
Member-Get-A-Member Campaign

Listed are the members participating in the 2006–2007 Campaign for the period June 1, 2006, through May 31, 2007. See page 69 for rules and the prize list. Call the Membership Dept. (800/305) 443-9353, ext. 480, for information about your status as a member proposer. The following listings are for Dec. 21, 2006.

**Winner’s Circle**

AWS Members who have sponsored 20 or more new members, per year, since 6/1/1999. The superscript denotes the number of times Winners Circle status has been earned if more than once.

J. Compton, San Fernando Valley6
E. Ezell, Mobile4
G. Taylor, Pascagoula2
J. Merzthal, Peru2
B. Mikeska, Houston
R. Peaslee, Detroit
W. Shreve, Fox Valley
M. Karagoulis, Detroit
S. McGill, Northeast Tennessee
G. Lau, Cumberland Valley
T. White, Pittsburgh
M. Haggard, Inland Empire

Note: The superscript indicates the number of times an Individual Member has achieved Winner’s Circle status. Status awards will be determined at the close of each membership campaign year.

**President’s Guild**

AWS Members sponsoring 20 or more new Individual Members between June 1, 2006, and May 31, 2007.

L. Taylor, Pascagoula — 27
J. Compton, San Fernando Valley — 20

**President’s Roundtable**


M. Palko, Detroit — 16
R. Myers, L.A./Inland Empire — 10
R. Ellenbecker, Fox Valley — 9
L. Mathieu, International — 9

**President’s Club**


W. Shreve, Fox Valley — 8
R. Wilsdorf, Tulsa — 7
J. Bruskotter, New Orleans — 5
G. Taylor, Pascagoula — 5
B. Converse, Detroit — 4

T. Ferri, Boston — 4
H. Jackson, L.A./Inland Empire — 4
J. Leen, Chicago — 4
P. Zammit, Spokane — 4
S. Chuk, International — 3
J. Goldsberry Jr., SE Nebraska — 3
G. Lau, Cumberland Valley — 3
T. White, Pittsburgh — 3

L. Collins, Puget Sound — 11
A. Badeaux, Washington D.C. — 10
M. Koehler, Milwaukee — 10
G. Koza Jr., Houston — 10
S. Luis Jr., Calif. Central Coast — 10
J. Cox, Northern Plains — 9
L. Davis, New Orleans — 8
A. Mattox, Lexington — 8
G. Putnam, Green & White Mts. — 8
D. Newman, Ozark — 7
C. Schiner, Wyoming — 7
W. Younkins, Mid-Ohio Valley — 7
D. Combs, Santa Clara Valley — 6
G. Gammill, Northeast Mississippi — 6
R. Grays, Kern — 6
R. Hutchison, Long Beach/Or. Cty. — 6
C. Kipp, Lehigh Valley — 6
D. Kowalski, Pittsburgh — 6
G. Saari, Inland Empire — 6
J. Angelo, El Paso — 5
J. Carney, Western Michigan — 5
C. Chancy, Long Beach/Or. Cty. — 4
A. Dropik, Northern Plains — 4
C. Neichol, Houston — 4
M. Rahn, Iowa — 4
C. Schiner, Wyoming — 4
D. Wright, Kansas City — 4
C. Yeager, Northeastern Carolina — 4
D. Zabel, Southeast Nebraska — 4
T. Zablocki, Pittsburgh — 4
J. Boyer, Lancaster — 3
C. Bridwell, Ozark — 3
T. García, New Orleans — 3
F. Gorglione, Connecticut — 3
L. Gross, Milwaukee — 3
L. Ibarra, San Francisco — 3
T. Moore, New Orleans — 3
R. Richwine, Indiana — 3
M. Vann, South Carolina — 3
R. Vann, South Carolina — 3

**Student Member Sponsors**

AWS Members sponsoring 3 or more new AWS Student Members between June 1, 2006, and May 31, 2007.

C. Daily, Puget Sound — 196
D. Williams, North Texas — 63
A. Demarco, New Orleans — 45
G. Eugiano, Northwestern Penn. — 43
H. Jackson, L.A./Inland Empire — 41
H. Hughes, Mahoning Valley — 40
S. Burdge, Clark Central — 34
S. Sikski, Maine — 30
A. Zinn, Eastern Iowa — 24
T. Kienbaum, Colorado — 22
A. Reis, Pittsburgh — 22
B. Suckow, Northern Plains — 22
A. Dropik, Northern Plains — 22
E. Ezell, Mobile — 2
J. Dolan, New Jersey — 2
E. Ezell, Mobile — 2
D. Gillies, Green & White Mts. — 2
R. Gollihue, Tri-State — 2
D. Irvin, Mid-Ohio Valley — 2
M. Lamarre, Palm Beach — 2
E. Lamont, Detroit — 2
D. Lawrence, Peoria — 2
J. Little, British Columbia — 2
D. Malkiewicz, Niagara Frontier — 2
M. Rieb, Inland Empire — 2
D. Shackelford, L.A./Inland Empire — 2
R. Wright, San Antonio — 2

L. Collins, Puget Sound — 11
A. Badeaux, Washington D.C. — 10
M. Koehler, Milwaukee — 10
G. Koza Jr., Houston — 10
S. Luis Jr., Calif. Central Coast — 10
J. Cox, Northern Plains — 9
L. Davis, New Orleans — 8
A. Mattox, Lexington — 8
G. Putnam, Green & White Mts. — 8
D. Newman, Ozark — 7
C. Schiner, Wyoming — 7
W. Younkins, Mid-Ohio Valley — 7
D. Combs, Santa Clara Valley — 6
G. Gammill, Northeast Mississippi — 6
R. Grays, Kern — 6
R. Hutchison, Long Beach/Or. Cty. — 6
C. Kipp, Lehigh Valley — 6
D. Kowalski, Pittsburgh — 6
G. Saari, Inland Empire — 6
J. Angelo, El Paso — 5
J. Carney, Western Michigan — 5
C. Chancy, Long Beach/Or. Cty. — 4
A. Dropik, Northern Plains — 4
C. Neichol, Houston — 4
M. Rahn, Iowa — 4
C. Schiner, Wyoming — 4
D. Wright, Kansas City — 4
C. Yeager, Northeastern Carolina — 4
D. Zabel, Southeast Nebraska — 4
T. Zablocki, Pittsburgh — 4
J. Boyer, Lancaster — 3
C. Bridwell, Ozark — 3
T. García, New Orleans — 3
F. Gorglione, Connecticut — 3
L. Gross, Milwaukee — 3
L. Ibarra, San Francisco — 3
T. Moore, New Orleans — 3
R. Richwine, Indiana — 3
M. Vann, South Carolina — 3
R. Vann, South Carolina — 3

**Experts Needed:**

Cast Iron and Repair Welding

The Welding Handbook Committee seeks volunteers to help update the *Welding Handbook*, Vol. 4 — Materials and Applications. Volunteers are particularly needed for the chapters on cast iron and maintenance and repair welding. Volume 4 covers the ferrous metals, including cast iron, carbon and low-alloy steels, high-alloy steels, coated steels, tool and die steels, and stainless and heat-resistant steels. Other chapters will cover clad metals and dissimilar metals, surfacing materials, and underwater welding and cutting. If your expertise is in one of these areas, please contact Annette O’Brien, aoebrien@awc.org; (800) 443-9353, ext. 303; FAX (305) 443-7404.
Nominations Sought for Prof. Koichi Masubuchi Award

Nominations are sought for the 2007 Prof. Koichi Masubuchi Award, sponsored by the Dept. of Ocean Engineering at Massachusetts Institute of Technology. It is presented each year to one person who has made significant contributions to the advancement of materials joining through research and development.

The candidate must be 40 years old or younger, may live anywhere in the world, and need not be an 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 at least three 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.

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

December 1 is the deadline. All nominations should be submitted to Prof. John DuPont at jnd1@lehigh.edu.
DISTRICT 1
Director: Russ Norris
Phone: (603) 433-0855

BOSTON
DECEMBER 4
Activity: The Section hosted a Vendors’ Night program at Greater Lowell Technical High School (GLTHS) in Tyngsboro, Mass. Russ Norris, District 1 director, and Section Chair Tom Ferri presented the District Educator Award to Bob Sullivan, a GLTHS welding instructor.

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

PHILADELPHIA
NOVEMBER 8
Speaker: Ken Bird
Affiliation: OKI Bering Supply
Topic: Safety, safety equipment, and the new OSHA hexavalent chromium rules
Activity: Chairman Jim Korchowsky presented Frank Simone with the District Meritorious Award. The meeting was held at Ramada Inn in Essington, Pa.

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

READING and LANCASTER
OCTOBER 12
Activity: The Reading and Lancaster Sections toured PRL Industries in Cornwall, Pa. The facility is noted for its complete turnkey capabilities for high-specification castings manufactured for the military, nuclear power, and petrochemical industries. The plant features a metallurgical lab, radiographic testing, welding and fabrication, heat treating, and machining operations. Pat Herschkowitz conducted the tour. See photo on next page.

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

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

ESAB sales representative Mike Smith (seated) demonstrated his wares at the Boston Section program.

Boston Section Chair Tom Ferri (left) and District 1 Director Russ Norris (right) present Bob Sullivan the District Educator Award in December.

Frank Simone (left) accepts the District Meritorious Award from Jim Korchowsky, Philadelphia Section chairman.

Philadelphia Section Chair Jim Korchowsky (left) is shown with speaker Ken Bird at the November program.
Eric Frondorf discussed structural steel framing techniques for the Cincinnati Section members.

Shown are some of the industry representatives who participated in the Niagara Frontier Section’s Career Fair.

FLORIDA WEST COAST
DECEMBER 13
Speaker: Rich Lolli, southeast sales representative
Topic: Manufacturing processes for welding wires and electrodes
Activity: The program was held at Frontier Steak House in Tampa, Fla.

NIAGARA FRONTIER
NOVEMBER 16
Activity: The Section hosted a Welding Career Fair at Erie 1 BOCES Educational Campus in West Seneca, N.Y. Representatives from welding and fabrication shops throughout western New York state were on hand to discuss job opportunities with the 85 attendees.

NORTHERN NEW YORK
NOVEMBER 5
Activity: Eleven Section members visited Coxsackie Correctional Facility in Coxsackie, N.Y., to meet with 12 inmates enrolled in the AWS Donald D. Scarborough Student Chapter welder training program. Chapter Advisor and Section Chair Bruce LaVallee is the welding instructor at the facility. Jaime Rolfe and Alex Gonzales are the Chapter chair and vice chair, respectively. The students have worked in the program as long as four years learning math, communication and safety skills, shop machinery operation, oxyacetylene cutting, brazing, and all of the shop welding processes. The event featured small group discussions to share practical welding information and job experiences.

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

SYRACUSE
OCTOBER 11
Speaker: Russ Newell
Affiliation: Heli-Arc Field Service (ret.)
Topic: Welding safety
Activity: The program was held in Syracuse, N.Y.

NOVEMBER 8
Activity: The Syracuse Section members toured Haun Welding Supply in Syracuse, N.Y. The presenters included Dick Hauck and Bill Davis in addition to factory representatives from Lincoln Electric and Miller Electric. The attendees had the opportunity to try their hands working with 110-V welding and plasma machines to weld light-gauge stock.

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

CINCINNATI
NOVEMBER 21
Speaker: Eric Frondorf
Affiliation: SOFCO Erectors
Topic: Erection of the structural steel framing for the Bethesda North Hospital addition
Activity: The program was held at Corinthian Restaurant in Cincinnati, Ohio.

DECEMBER 14
Activity: The Cincinnati Section members and their guests enjoyed a behind-the-scenes tour of the Newport Aquarium in Covington, Ky.

DAYTON and CINCINNATI
DECEMBER 12
Speaker: Carl Thornton
Affiliation: 3M Corporation
Topic: Hexavalent chromium and its control in industrial operations
Cincinnati Section members and guests are shown during their tour of Newport Aquarium in December.

Activity: This joint meeting of the Dayton and Cincinnati Sections was held at Tom Katz Restaurant in Springboro, Ohio.

DAYTON

Activity: The Dayton Section hosted its traditional annual visit with the Southern Ohio Forge & Anvil Blacksmith Assn. The program included insights into metallurgy from a practical sense, plus historical information regarding the techniques used by blacksmiths today. The event was held at the Miami County Fairgrounds in Troy, Ohio.

DISTRICT 8

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

HOLSTON VALLEY

Activity: The Section members and students from Tennessee Technology Center and Northeast State Tech toured the Fluor Daniels Weld Shop, Tennessee Eastman site, to study its structural and pipe fabrication techniques.

WEST TENNESSEE

Activity: The Section hosted a Student Day featuring a welding contest at Tennessee Technology Center in Jackson, Tenn.

DISTRICT 9

Director: George D. Fairbanks
Phone: (225) 673-6600

Cleveland

Activity: The Section hosted its annual Christmas party and silent auction as a joint meeting with members of the local

DISTRICT 10

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

Lawson State C.C. Student Chapter

Activity: Birmingham Section Treasurer and Student Chapter Advisor Roy Ledford accompanied the officers of the Lawson State Community College Student Chapter on a full-day visit to the FABTECH International & AWS Welding Show in Atlanta, Ga.
At the Mahoning Valley Section program, District 10 Director Richard Harris (left in both photos) presents District Meritorious Award certificates to Kenny Jones (left photo) and Ron Siembieda, Mahoning Valley Section treasurer (right photo).

Cleveland Section Chair Dan Harrison (left) is shown with scholarship recipients Kathy Locascio, Scott Thomas, and Eric Tomas.

MAHONING VALLEY

NOVEMBER 16

Speaker: Bob Fisher, administrative representative
Affiliation: Hobart Institute of Welding Technology
Topic: Careers in welding
Activity: Kenny Jones and Ron Siembieda were presented the District Meritorious Awards by District 10 Director Richard Harris.

DISTRICT 11

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

District 11 Awardees Named

District Meritorious Award
David Beneteau, Detroit
Jim Koster, Western Michigan

District Educator Award
Bruce Faccio, Saginaw Valley
Ken Kuk, Western Michigan

District Director Award
Bill Neil, Northern Michigan

DETROIT

DECEMBER 14

Activity: The Section hosted its annual Christmas party at the Ukrainian Cultural Center in Detroit, Mich. John Bohr and Tim and Leigh Cesarz served as MCs. The silent auction event raised more than $700 for the Section scholarship fund.

NORTHWEST OHIO

NOVEMBER 14

Speaker: Eva Coch, owner
Affiliation: DSI Laser USA, Inc.
Topic: Use of laser micro welding on titanium, aluminum, stainless, tool steel, and beryllium copper parts
Activity: Eva Coch demonstrated the laser welding machine and each attendee experimented with the process. The Section donated $5000 to the Don Leonhardt Memorial Scholarship Fund at Owens Community College. The program was held at DSI Laser USA, Inc., in Perrysburg, Ohio.
DISTRICT 12
Director: Sean P. Moran
Phone: (920) 954-3828

MILWAUKEE
November 9
Speakers: Mike Kersey and Rob Stinson, sales managers
Affiliation: The Lincoln Electric Co.
Topic: Submerged arc welding using variable polarity inverter technology
Activity: The program and buffet dinner were held at a local VFW post.

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

CHICAGO
December 13
Speaker: Mike Pelegrino, instructor
Affiliation: Pipefitters Union
Topic: Overview of CWI renewal and certification highlights
Activity: The program was held at Moraine Valley Community College in Palos Hills, Ill.

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

INDIANA
November 16
Speaker: Elise Langenberg, consultant
Affiliation: North Safety
Topic: Hexavalent chromium standards
Activity: The program was held in Indianapolis, Ind.

LEXINGTON
November 16
Speaker: Alan Mattox
Affiliation: Bluegrass Community College
Topic: Welder certifications
Activity: Chairman Frank McKinley presented the District Meritorious Award to Craig Herald, and the Silver Membership Award for 25 years of service to the Society to Dwayne Conlen.

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

ARROWHEAD
November 28
Activity: Steve Purrington, general shift manager, discussed sales, service, repair, welding maintenance, and educational requirements for high-tech heavy-equipment jobs in the iron mining industry. Then he conducted a tour of the Caterpillar Ziegler, Inc., repair and service shops in Buhl, Minn.

SASKATOON
November 27
Speaker: Emenike Raymond Obi
Affiliation: University of Saskatchewan
Topic: Corrosion behavior of fly ash rein-

Shown at the Chicago Section program are (from left) Pete Host, AWS Past President Jim Greer, Craig Tichelar, and Bob Frustini.

Craig Herald (left) receives the District Meritorious Award from Frank McKinley, Lexington Section chair.

Dwayne Conlen (left) receives his Silver Membership Award from Lexington Section Chair Frank McKinley.

Arrowhead Section members and guests are shown during their November tour.
forced aluminum Alloy 535 metal matrix composites
Activity: The program, held at the University of Saskatchewan, attracted 51 attendees. Obi is a graduate student working under the direction of Ike Oguocha, Section membership chair.

OCTOBER 30
Activity: The Kansas Section held a Career Night program in Arkansas City, Kan. The presenters included Ron Jackson, Smith Equipment; Dwight Hayworth, Airgas; Ron Samuelson, Linweld; Beverly Shaw, JD Welding; Bob Moffatt, Cowley College; Adam Foster, Ark City High School; and Alan Groom, Alan Groom Welding.

NOVEMBER 2
Speaker: Mike Jones, plant manager
Affiliation: Caterpillar Toolworks
Topic: Advancements in welding and parts handling operations
Activity: Following the talk Jones demonstrated for the Kansas Section members how the company has implemented specialized equipment to ensure employee safety and improve production. The program was held at Caterpillar Toolworks in Wamego, Kan.

KANSAS CITY
NOVEMBER 9
Speaker: Shelly Pizzi, health manager
Affiliation: Black & Veatch
Topic: Hexavalent chromium in welding fume
Activity: The program was held at the Kansas City Masterpiece Barbeque.

DECEMBER 9
Activity: Kansas City Section members Chairman Scott Gronberg and Dennis Wright taught a class on gas metal arc welding for six students in the Engineering Dept. of University of Missouri — Kansas City. The students needed specialized training in order to participate in a welded bridge-building contest.

NEBRASKA and SOUTHEAST NEBRASKA
NOVEMBER 9
Activity: Members of the Nebraska and Southeast Nebraska Sections toured Lin-
Southeast Nebraska Section Chair Pat Wagner (right) presents a speaker appreciation plaque to Greg Reeder following the Nebraska and Southeast Nebraska Sections’ tour of Linweld.

Tom Kumke (left) and Brian Nehe made presentations for the Nebraska and Southeast Nebraska Sections’ tour of Linweld.

weld in Waverly, Neb., to study its techniques for processing gases, filling bottles, shipping, and recycling cylinders. Presenters included Tom Kumke, manager of gas products; Brian Nehe, production manager; and Greg Reeder, outside sales and Southeast Nebraska Section vice chair. They discussed the four major gas products for industrial, medical, food and beverage, and the specialty gases.

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

EAST TEXAS
November 16
Activity: The Section members toured Chicago Bridge and Iron in Tyler, Tex. Highlights included the pipe fabrication, electrical panel, and the module assembly shops. In process at the time was a 20- × 80- × 18-ft module weighing 150,000 lb.

The presenters included Victor Adkison and Shawn Forgy.

NORTH TEXAS
December 11
Activity: The Section held a silent auction to raise funds for scholarships. The event raised $1100. Dwight Grayson studying at ATI, Dallas, Tex., received a $500 scholarship. The award was presented by Chairman Howie Sifford and Donnie Williams, an ATI instructor and Section Vice Chair.

TULSA
November 11
Speaker: Paul Wittenbach, chief metallurgical and welding engineer
Affiliation: Conoco Phillips Co., Ponca

Southeast Nebraska Section Chair Pat Wagner (right) presents a speaker appreciation plaque to Greg Reeder following the Nebraska and Southeast Nebraska Sections’ tour of Linweld.

Shown during the East Texas tour of CB&I in Tyler, Tex., are (from left) Harvey Norris, Steve Pope, John Ellis, Victor Adkison, Bryan Baker, Shawn Forgy, Mike Bolt, and Joey Arnold.

Nebaska Section Chair Rick Hanny (left) is shown with Pat Wagner, chairman of the Southeast Nebraska Section, during the Linweld factory tour in November.

Shown at the North Texas Section program are (from left) Vice Chair Donnie Williams, scholarship recipient Dwight Grayson, and Chairman Howie Sifford.
Ron Theiss (left) accepts the District Educator Award from John Mendoza, District 18 director, at the Houston Section’s Fall Social event.

Shown during the El Paso Section tour of Automated Thermal Processing are (from left) Justin Aragon, Chairman David Twitty, Tom Evans, tour guide George DeVois, Lawrence Romero, John Wright, and Secretary Joseph Angelo.

Tulsa Section Chair Jerry Knapp (left) is shown with speaker Paul Wittenbach.

Ron Theiss (left) accepts the District Educator Award from John Mendoza, District 18 director, at the Houston Section’s Fall Social event.

Shown during the Spokane Section’s tour of Pearson Packaging Systems are (from left) Dave Fode, Mike Judd, Christie Harris, Matt Lewis, Phil Zammit, and Mike Allen.

City, Okla. Topic: Understanding weld failures in refining equipment. Activity: The program was held at S & Diner in Tulsa, Okla.

EL PASO
October 11
Activity: The Section members toured the Automated Thermal Processing heat-treatment plant in Las Cruces, N.Mex. George DeVois, president, conducted the tour.

HOUSTON
December 11
Activity: The Section hosted its Fall Social titled “Casino Night” at Brady’s Landing in Houston, Tex. District 18 Director John Mendoza presented the District Educator Award to Ron Theiss. Proceeds from the event supported welding scholarships.

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

DISTRICT 19
Director: Neil Shannon
Phone: (503) 201-5142

SPOKANE
November 15
Speaker: Dave Fode, assistant director of manufacturing operations
Topic: Welding processes and application in a lean manufacturing environment
Activity: Following the talk, Fode led the attendees on a tour of the facility.

DISTRICT 20
Director: William A. Komlos
Phone: (801) 560-2353

IDAHO/MONTANA
December 8
Activity: The Section joined with members of the Eastern Idaho Engineering Council for a Christmas social event. The program was held at Shilo Inn in Idaho Falls, Idaho.

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

SOUTHERN COLORADO
November 13
Activity: The Section members toured Springs Fabrication, Inc., in Colorado Springs, Colo. Tom Neppl, owner, and Belinda Popovich, director of marketing, conducted the program. The 50,000-sq-ft facility produces pressure vessels and is a custom-engineered metal fabricator utilizing rolling, punching, welding, and machining operations.
DISTRICT 22
Director: Dale Flood
Phone: (916) 933-5844

SACRAMENTO
December 9
Activity: The Section members and guests met for its holiday season dinner and white elephant gift exchange. Chairman Mike Rabo presented Vice Chair Lorne Grimes the Section Meritorious Award.

SAN FRANCISCO
December 6
Speakers: Chanin Cook, Jonathan Edie
Affiliation: Chajo Fine Furnishings
Topic: Blending art and fabrication
Activity: The meeting was held at Spenger’s Restaurant in Berkeley, Calif.

Middle East

EMIRATES WELDING
November 19
Speaker: Sebastian Z. Fernandes, quality manager
Affiliation: Emirates Welding member
Topic: QA, QC, and NDT in welding
Activity: The program was held at India Club in Dubai, UAE, for 60 attendees.

SACRAMENTO Section Chair Mike Rabo (left) presents the Section Meritorious Award plaque to Vice Chair Lorne Grimes.

Shown at the Sacramento Section’s holiday dinner program are (from left) Jason and Lisa Roberts, Angela Hood, Jane and Mike Rabo, Tammy and Lorne Grimes, Debi and Kerry Shatell, and Mark Feuerbach.

MARY HARKER and wife are shown at the Idaho/Montana Section program.

Shown at the San Francisco Section program are (from left) Chairman Rich Hashimoto, Jonathan Edie, Chanin Cook (holding Edie’s daughter Quinn), and Vice Chair Tom Smeltzer.

Shown at the Southern Colorado Section tour are (from left) Tom Neppl, Chairman Lee Corn, and Belinda Popovich.

San Diego Section Chair Bernard D’Silva (right) introduces speaker Sebastian Fernandes at the November program.

Southern Colorado Section members are shown during their tour of Springs Fabrication.
Guide to AWS Services

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(Phone extensions are shown in parentheses.)

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Provides liaison services with other national and international professional societies and standards organizations.

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Hugh K. Webster...jwebster@wc-bc.com
Webster, Chamberlain & Bean, Washington, DC
(202) 466-2976; FAX (202) 835-0243
Identifies funding sources for welding education, research, and development; monitors legislative and regulatory issues of importance to the industry.

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RWMA — Resistance Welding Manufacturing Alliance
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Susan Hopkins...susana@aws.org
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WEMCO — Welding Equipment Manufacturers Committee
Manager
Natalie Tapley...tapley@aws.org
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Corporate Director, Exhibition Sales
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National Sales Director
Bob Sallze...sally@aws.org
... (243)

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

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Christopher Pollock...copollock@aws.org
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Tracks effectiveness of programs and develops new products and services. Coordinates in-plant seminars and workshops. Administers the S.E.N.S.E. program. Assists Government Liaison Committee with advocacy efforts. Works with Education Committee to disseminate information on careers, national education and training trends, and schools that offer welding training, certificates, or degrees.

Also 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.

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

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(473) 703-9300
(466)
(470)
(475) Provides information on personnel certification and accreditation services.

TECHNICAL SERVICES
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Director, National Standards Activities
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AWS publishes about 200 documents widely used in the welding industry.
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Selvis Morales...smorales@aws.org
... (413)
Welding Qualification, Friction Welding, Railroad Welding, Definitions and Symbols

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.
Honorary Meritorious Awards

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

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

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

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

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

Nominees for National Office

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

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

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

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

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

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

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

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

E-mail the letter to Gricelda Manalich, gricelda@aws.org, c/o Damian J. Kotecki, chair, National Nominating Committee.

The next meeting of the National Nominating Committee is scheduled for November 2007. The terms of office for candidates nominated at this meeting will commence January 1, 2009.
New Automotive Welding Standard Issued

The American Welding Society recently released a new standard specifying welding criteria of particular value to the automotive industries.


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Catalog Updates Portable Magnetic Drill Tools

A 16-page catalog features the company's lineup of portable magnetic drills, accessories, and fabrication tools. The technical specifications are presented for 13 portable magnetic drills with hole-making capacities from ½ to 3½ in. diameters, and up to 3-in. depth of cut. Other products include the Copperhead™ carbide-tip annular cutting tools, tools for heavy-duty service and quick-change shanks, along with a variety of cutter kits packaged for easy storage and cutting tool protection. Accessories shown include stick lubricants and fluids, a sharpening machine, attachments for drilling holes in pipe and tap-
ping, a vacuum base for working with non-ferrous stock, pressurized coolant systems, twist drill adapters, countersink tools, etc. The RotaCut™ sheet metal cutting tool series is pictured with diameters from ¾ to 1⅛ in. for metals to ¾ in. thick, and the Holcutter™ series of cutting tools for metals up to ¼ in. thick.

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The full-color Environmental Product Selection Guide illustrates the company’s complete lines of mobile and heavy-duty, low-vacuum and high-vacuum industrial fume-extraction equipment. Shown are low-vacuum mobile units with nonfiltration, disposable filter, and self-cleaning filters. Stationary units with disposable filters and self-cleaning filters are pictured, as are telescopic arms, flexible arms, and extension cranes to 14 ft long. Five fan models are depicted with capacities from one extraction arm up to fifteen arms. The high-vacuum exhaust products include portable units and secondary units. Accessories shown include extraction nozzles, GMAW gun-mounted nozzles, and Xtractor fume guns with ratings from 250 to 500 A. Photos show typical low-vacuum and high-vacuum central systems and a robotic cell installation. The guide may be viewed or downloaded from the company’s Web site www.lincolnelectric.com.

The Lincoln Electric Co. 114
22801 St. Clair Ave. Cleveland, OH 44117-1199

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WELDING JOURNAL 79
ESAB Names VP Consumables

ESAB Welding & Cutting Products, Florence, S.C., has named Nick Culich vice president and general manager of consumables, based in Hanover, Pa. Previously, Culich was vice president of manufacturing, Automotive Div., for Burns Inc., based in Jamesville, Wis.

Wall Colmonoy Appoints Asian Business Manager

Wall Colmonoy Corp., Madison Heights, Mich., has appointed Lydia Lee Asian business manager for its Alloy Products Group, based in Madison Heights. Lee will concentrate on expanding the company’s customer base in the Asian industrial marketplace.

Alcoa Announces New Corporate Officers

Alcoa Inc., New York, N.Y., has named Joseph R. Lucot vice president, corporate controller, and an officer of the company. Lucot succeeds Charles D. McLane, who has been named CFO of Alcoa. Newly elected vice presidents of Alcoa include Kevin J. Anton, president, Alcoa materials management; Oliver Jarrau, leader of the Alcoa fastening systems business; Raymond B. Mitchell, president, Alcoa Investment cast and forged products; and Wayne G. Osborn, managing director, Alcoa world alumina Australia.

President Named at Milwaukee Electric Tool

Milwaukee Electric Tool Corp., Brookfield, Wis., has appointed Steven P. Richman president. With more than 25 years of experience in the business, Richman most recently served as president and CEO of Werner Co.

Jet Edge Names Sales Manager

Jet Edge, Inc., St. Michael, Minn., a supplier of ultrahigh-pressure waterjet and abrasivejet cutting systems, has appointed David Arthur regional sales manager for Southeast United States, based in Atlanta, Ga. Previously, Arthur held positions with Machinery Solutions, Inc., and Coldwater Seals/Coldwater Resins.

Robotics Engineer Joins Orbitform

Jason Schoonover has joined The Orbitform Group, Jackson, Mich., as robotics, weld, and automation engineer, in the company’s Marathon Welding Automation team. Schoonover brings to the job several years of experience as a production and process welding engineer.

President and CEO Named at Bosch Rexroth

Bosch Rexroth Corp., Hoffman Estates, Ill., has named Berend Bracht as its president and CEO. He replaces Wolfgang Dangel who has left to join the Schaeffler Group. Bracht previously served as the head of the company’s U.S. industrial hydraulics operation.

Two Managers Assigned at Genstar Technologies

Genstar Technologies, Co., Inc., Chino, Calif., has named Jim Littrell to the post of national accounts manager, and Scott Littrell to territory manager for south and west Texas. Jim has 40 years of experience in the field, most recently with Victor Equipment Co. and Thermadyne. Scott holds a computer science degree from Tarleton State University.

West Joins Ansell Marketing Team

Ansell, Red Bank, N.J., a supplier of hand-protection and safety apparel products, has appointed Don West as brand support manager for the company’s ergonomic line of products. West previously held product management positions at Standard Motor Products, Inc., and Truecraft Tools.

Western Enterprises Names VP

Mark J. Blakely has been promoted to vice president of marketing for Western Enterprises, Westlake, Ohio, a Scott Fetzer Co. The company specializes in high-performance transmission and control product solutions for the compressed gas markets. Since 2002, Blakely served as director of the industrial products group.
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Sep. 17–21
Baton Rouge, LA Apr. 16–20
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Houston, TX Apr. 30–May 4
Baton Rouge, LA Apr. 16–20

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A Methodology for Prediction of Fusion Zone Shape

This study proposes a methodology for prediction of fusion zone shape that is applicable not only for bead-on-plate welds, but also for T-joint fillet welds

BY N. OKUI, D. KETRON, F. BORDELON, Y. HIRATA, AND G. CLARK

ABSTRACT. This study presents a semi-empirical methodology for prediction of fusion depth and width in the gas metal arc welding process. The semiempirical methodology is based on the theoretical heat conduction solution of a moving point heat source with appropriate corrections obtained through experimentation. The corrections reduce the systematic errors observed when theoretical calculations and experimental fusion depth and width measurements are compared. The method uses an applied regression analysis by the least squares method for estimating these errors. The resulting prediction of fusion depth and width by the semiempirical model shows good agreement with experiments for bead-on-plate welds. The methodology is also applicable to T-joint fillet welding with appropriate heat distribution ratio to web and flange. Since this methodology does not require complicated or excessive computation, it is especially useful for actual welding process applications. It will also provide a robust approach to adaptive welding, as well as stabilizing weld quality. A similar welding process model for materials other than steel, such as aluminum alloys and stainless steel, can be developed through the same approach as proposed here with some ancillary experimentation.

Introduction

Prediction of fusion in welding is essential for obtaining adequate joining qualities and increasing productivity. Intelligent automated welding processes require adaptive control technologies that can predict weld fusion in a simple and easy manner. The purpose of this study is to present a practical methodology for the prediction of fusion in welding.

For the prediction of fusion in welding, there are a number of published numerical solutions based on heat conduction models (Refs. 1–5). Although the heat conduction solution provides a fairly accurate prediction of temperature in areas outside the fusion zone, it exhibits errors in fusion zone shape predictions. A major reason is that fluid flow dominates heat transfer in the weld pool, and consequently, determines the fusion zone shape. The various driving forces acting on the fluid flow in the weld pool include electromagnetic force, arc plasma flow, surface tension, and buoyancy. These were investigated in a number of simulation studies of fluid flow caused by interaction of various driving forces, as well as on the effect of individual driving forces (Refs. 6–18, 23).

Currently, simulation software development for welding processes is focused on obtaining supporting tools for production, such as development of a smart welding machine, an intelligent welding robot, and also on education and training for welding engineers and welders (Ref. 13).

Despite all these efforts, there still remains some difficulties in the practical application of numerical models. The numerical model simulations require many calculations for simultaneously solving the coupled fluid and energy equations taking into account all the phenomena occurring in the weld pool. Furthermore, essential data for high-temperature-dependent properties of material, such as the weld surface tension gradient and viscosity gradient, are inadequately defined at present (Ref. 18). The inclusion of many complex parameters has limited the utilization of simulation software in current production applications, especially for fluid flow in T-joint fillet welding. Our knowledge with regard to the T-joint is still limited.

In view of realizing a production-friendly predictive model, the present study adopts a method that obtains an approximation of the weld interface with the heat conduction solution by adopting semiempirical corrections obtained from systematic experiments. A reasonable estimate of the temperature distribution can be obtained via the heat conduction solutions when boundary conditions are given. For example, the following are important factors:

• welding parameters such as heat intensity and traveling speed,
• kinds of materials,
Mechanism of Fusion in Gas Metal Arc Welding

Fluid flow in the weld pool is the major factor to determine the fusion zone shape (Refs. 6, 17). The driving forces acting on the fluid flow vary with welding current, arc length, welding speed, and shield gas, resulting in large variations in the fusion zone shape. Nevertheless, three fusion zone cross-section shapes in Fig. 1 are frequently adopted (Refs. 16, 19, 20). They consist of 1) simple penetration type, 2) central penetration type, and 3) peripheral penetration type. In the simple penetration type, the cross-sectional weld interface has a semicircular or elliptical shape. It tends to appear in welding with a lower current and a shorter arc. The temperature distribution in this simple penetration type closely resembles the temperature distribution calculated through the moving point heat source assumption (Ref. 20).

The central penetration type frequently appears under heavy current. A strong plasma stream deeply depresses the molten pool at its center, resulting in deeper fusion at the center (Ref. 20). Surface-active elements such as sulfur and oxygen can also make the fusion deeper by altering surface tension gradients on the weld pool surface and thereby, changing the magnitude and/or direction of fluid flow in the weld pool (Refs. 11, 12).

Fig. 1 — Three typical cross-sectional penetration types in arc welding

The peripheral penetration type is observed when a long arc length is held for a long time. The formation of this type may be explained by internal convection in the molten pool. As the surface temperature at the center of the molten pool becomes higher than the peripheral zone, a surface flow from the center to the peripheral zone is enhanced by the surface tension gradient (Ref. 20).

Heat transfer along the welding direction also affects the determination of the horizontal fusion zone shape. Arc forces tend to push liquid metal toward the rear boundary of the weld pool. In addition, the surface tension gradient also enhances fluid flow in the same direction. This trend becomes significant at both a higher current and a higher speed of welding providing increase of fusion depth and decrease of width (Refs. 1, 21, 22).

A Moving Point Heat Source Solution

This study begins with the heat conduction solution. It provides an approximation of fusion zone shape through a simple calculation assuming a moving point heat source. It can be used to calculate fusion volume, fusion width and depth, weld ripple lag, and average temperature of the weld pool (Ref. 1). It has also been utilized to calculate the heat capacity and average temperature of the leading part and trailing part of the weld pool separately (Ref. 2). The general assumptions below are used in a moving point heat source solution (Ref. 2).

Only heat conduction by a moving point heat source is considered in heat transfer. The surface of the weld pool is assumed to be flat. Material properties such as heat conductivity, specific heat, and specific gravity are assumed to be constant. Latent heat is neglected. A semi-infinite plate geometry is assumed.

In addition, the present study includes heat dissipation by means of radiation and atmospheric convection from the plate surface in defining the arc efficiency.

Taking the position of a point heat source as the origin O, and the welding direction as x axis, and the distance of any point from the x axis as r, Z is defined as Z (x, r), the temperature at the point Z (x, r) in an infinite body is expressed as Equation 1 (Refs. 1, 2), where an arc is assumed as a moving point heat source.

\[ T = \frac{q}{2\pi^2\sigma} e^{-\frac{vr}{2\sigma}} \left(1 + \frac{2\pi\sqrt{\nu}}{\sqrt{x^2 + r^2}}\right) \]

where \( T \) = temperature rise at the point Z [K]; \( q \) = heat intensity [J/s]; \( v \) = welding speed [m/s]; \( \lambda \) = heat conductivity [W/(m·K)]; \( \kappa = \text{thermal diffusivity} [\text{m}^2/\text{s}] \) \((\kappa = \lambda / (\rho \cdot c)); c = \text{specific heat} [\text{J}/(\text{kg} \cdot \text{K})]; \rho = \text{density} [\text{kg}/\text{m}^3].

Let the welding conditions be defined by an operating parameter \( n \) — a quantity related to the product of heat intensity \( q \) and welding speed \( v \).

\[ n = \frac{q}{2\pi\lambda} \frac{\nu}{T_f} \]

1. The operating parameter \( n \) will prepare more accurate parameter for evaluating fusion of base material in welding. Many works use the parameter of the Heat Input \( [J/(\text{mm} \cdot \text{s})] \); however, the relation of fusion and heat intensity may express some more errors, because more heat will be dissipated to the adjacent base metal without fusing in a welding with slower speed.
Table 1 — Welding Parameters

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where $T_f$ = temperature rise to melting point; $T_f = T_m - T_0$; $T_m$: melting point ($T_m = 1808$ K, in the case of steel); $T_0$: room temperature.

Let the parameters $x$, $r$, and $z$ be represented by dimensionless parameters multiplying by $\nu/2k$.

$$X = x \frac{v}{2k}, R = r \frac{v}{2k}, Z = z \frac{v}{2k}$$

Substituting Equation 2 in Equation 1, one obtains

$$T = T_f \frac{1}{\nu} = \frac{Z^2}{1 + Z^2}$$

(4)

$$Z_m = \sqrt{x^2 + R^2 + Z^2}$$

(5)

$$Z_m \cdot e^{-n} = m$$

(6)

In addition, for $R = 0$, one obtains point $S (X_1)$ and $P (-X_2)$ in Equation 3.

$$X_1 \cdot e^{2X} = n$$

(7)

This results in a semicircle with radius $R$ for the cross-sectional isothermal contour for the weld pool.

Christensen et al. (Ref. 1) showed the experimental fusion width is greater than the calculated width, and the trend is reversed in fusion depth. The errors in the fusion depth and width calculations are attributed to the effects of heat source properties and weld pool convection. The increased arc forces at the high value of $n$ also introduce preferential currents flowing from the crater in directions downward and toward the rear boundary of the pool (Ref. 1).

In addition, the following are constants adopted in the theoretical calculations in this study:

- $\lambda$: Heat conductivity 33.47 [W/(m·K)]
- $c$: Specific heat 878.6 [J/(kg·K)]
- $\rho$: Density 7600 [kg/m³]
- $\kappa$: Thermal diffusivity $5 \times 10^{-6}$ [m²/s], $\kappa = \lambda/(c \cdot \rho)$
- $T_f$: Temperature rise to melting point 1500 [K]

Experimental Procedures

The experimental welding process employed in this study is bead-on-plate and T-joint fillet with gas metal arc welding (GMAW), with the following conditions: welding current for horizontal position, 193–242 A, welding speed, 0.0063–0.0118 m/s; for vertical position, 120–145 A, welding speed, 0.0033–0.0005 m/s; for overhead position, 169–198 A, welding speed 0.0077–0.0050 m/s; consumable welding wire, SF-1 seamless flux cored.
wire, 1.2 mm diameter; shielding gas 100% CO₂, flow rate 0.33 L/s. Table 1 lists welding parameters applied in this study. They were selected so that the combination represents the statistic sampling. The values of operating parameter n are in the range of 2.1 ~ 21.5. The base metal is carbon steel the size of 200 × 300 mm; plate thicknesses 12 mm and 5 mm, thermally insulated with ceramic block from the experimental slab. Figure 3 shows the assembly of the test specimen and welding orientation. About 25 mm of both ends of the welding bead are discarded, and two sections taken from the center section are used for the fusion area, depth, and width measurements.

**Estimation of Arc Efficiency**

Christensen et al. (Ref. 1) found the weld pool volumes derived from the moving point heat source solution are in good agreement with experiments. In the present study, the arc efficiency was estimated from comparing the theoretical fusion cross-section area 1/2πRm² with experiments. The experimental fusion area s was converted to a dimensionless basis

The sampled fusion area for the estimation of arc efficiency was obtained from bead-on-plate welds with a plate thickness of 12 mm. In the gas metal arc welding processes, heat dissipates into the atmosphere by means of heated shield gas dissipation, spatter, radiation, and atmospheric convection from the surface of weld pool and base material. Since welding current and speed, shape of weld pool, and volume of deposited metal have an effect on the heat dissipation, the welding orientation is one of the major factors that affect arc efficiency. The arc efficiency was estimated as 80% for horizontal position, 75% for vertical position, and 70% for overhead position. The theoretical fusion area calculated with these values agreed well with the experimental measurement in Fig. 4. The estimated arc efficiency values are consistent with those obtained by Christensen (Ref. 1) and are applicable to subsequent calculations of fusion depth and width.

**Predicting the Fusion Depth and Width in Bead-on-Plate Welds**

Figure 5 shows a typical cross-sectional macrostructure. It has a fusion zone shape representative of the other specimens of the simple penetration type (a).

The experimental measured fusion depth d and width w are converted to dimensionless basis

\[ D = \frac{V}{2k}, \quad W = \frac{V}{2k} \]

Figure 6 shows a comparison of the theoretical and experimental fusion depth and width in bead-on-plate welds. As postulated earlier, the theoretical fusion depth appears to be larger than the experiments; conversely, the width appears smaller. The errors between them seem systematic for both fusion depth and width for the wide range of operating parameter n; however, the fusion depth in plate thickness 5 mm appears wider than range scattering.

This study applies the least squares regression to welding a 12-mm plate without weaving to avoid any influences from weaving or a thinner plate using elasticity model. The data were fitted to a regression equation \( y = a + b \cdot x^n \). Taking the logarithm on both sides, one obtains:

\[ \ln y = \ln a + b \cdot \ln x \]  

Here, \( y \) is the dependent variable representing fusion depth or width and \( x \) is the independent variable representing operating parameter \( n \). The experimental
measured data were analyzed through a linear regression with Equation 8. The regression equations for fusion depth and width are expressed as follows:

\[ D^* = 0.4175 \cdot n^{0.6996} \text{ (D*Estimator for fusion depth)} \] (9)

\[ W^* = 1.9737 \cdot n^{0.5889} \text{ (W*Estimator for fusion width)} \] (10)

The correlations of determination \( R^2 \) are 0.945 and 0.984 for fusion depth and width, respectively. The other test statistics for the regression analysis are listed in Table 2.

Figure 7 shows the estimated fusion depth and width calculated by Equations 9 and 10 along with the experimental data. The regression equations show good agreement with the experiments. An experimental fusion depth in higher \( n \) value appears slightly larger than required by regression equation, and conversely, width is smaller. This tendency is consistent with the Christensen et al. results (Ref. 1). The estimation by the regression equations can predict well both fusion depth and width for the operating parameter less than 15.

It is well known that the temperature rise in the base material when welding a thinner plate is greater than in a thicker plate. This study also examined fusion area, depth, and width for a 5-mm plate thickness. As observed in Fig. 4, the experimental fusion area in the 5-mm plate also agrees with the theory, as well as in the 12-mm thickness. Figure 6 shows fusion depth and width in the 5-mm thickness. The fusion depth, however, seems to have larger fluctuations than in the 12-mm thickness. The reason for this fluctuation is discussed later. Figure 4 also shows the fusion area when welding with a 0.7 and 2 mm weave on a 12-mm plate. The fusion area by welding with weaving is slightly smaller than predicted by the calculation. In Fig. 6, experiments with weaving show good agreement with the regression equations. As known, weaving increases fusion width, and conversely, decreases fusion depth; however, the difference between with/without weaving is not significant when the weaving is less than 2 mm.

**Predicting the Fusion Depth and Width for T-Joint Fillet Welds**

A T-joint consists of two perpendicular plates, which can include different plate positions such as horizontal-vertical or vertical-overhead. The heat flow and fluid flow in T-joint fillet welding is significantly different from bead-on-plate welding. The volume and the shape of weld pool, the direction of plasma stream, and the discontinuity of heat conduction at the abutting surface on the other plate have an effect on the heat transfer and the fusion of each plate. Our knowledge of the T-joint fillet welding process with regard to the heat distribution, fluid flow, and mechanism of fusion is limited at present. Furthermore, there are many error factors in the welding process such as deviations of welding gun position and angle, and root opening. This study investigates fusion area, depth, and width in T-joint fillet welds applying the same regression equations obtained from the bead-on-plate welds.

Figure 8 presents a conceptual diagram of heat flow and fusion zone depth and width in T-joint fillet welding. The purpose of this figure is to illustrate the complexity of the T-joint geometry compared to the bead-on-plate geometry considered previously. For example, the fusion zone may not be symmetric about the point of maximum depth (D) because of asymmetric conditions. The present...
work estimates the total area of the fusion zone, not the detailed geometry. The following conditions are assumed:

1) Heat intensity is applied separately to web and flange with appropriate distribution ratio and the fusion is processed separately on each plate by the distributed heat.

2) The fusion area, depth, and width are calculated irrespective of the location of point heat source.

3) Fusion width on the web is designated as the distance from flange surface to outer weld interface on the plate surface.

Although two perpendicular plates have different welding positions, for simplicity, this study applies the same arc efficiency for bead-on-plate welding, i.e., 80% for horizontal, 75% for vertical, and 70% for overhead position.

Figure 9 shows theoretical total fusion area and experimental fusion area, i.e., the sum of the fusion area in web and flange. This figure shows the calculation results are slightly larger than experiments. Since the error is negligibly small, this figure shows the estimated arc efficiency is also applicable to the T-joint fillet welding.

The heat distribution into web/flange is complicated because the mass and shape of molten metal also affects heat transfer in three dimensions along the interface of the two perpendicular plates. In the present experiments, the web and flange are of equal thickness and the welding gun is maintained at a 45-deg angle. Further studies are appropriate to determine the sensitivity to web and flange thicknesses, gun angle, and material. The flange extends in two directions while the web extends in one direction. The temperature difference at the web-flange contact surface is small and more energy flows into the flange. This study found a distribution of 60% into the flange and 40% into the web yielded reasonable results.

Figure 10A and B show the fusion area in web and flange, along with a comparison of theoretical and experimental results. In lower n value, the fusion area of the web appears larger than the calculation, and conversely smaller in the flange. This study found a distribution of 60% into the flange and 40% into the web yielded reasonable results.
and width as well as fusion area. By taking this error into account, the calculated fusion area with the distribution ratio agrees well with experiments. The approximate distribution ratio is adopted in the subsequent calculations of fusion depth and width in T-joint fillet welding.

The web in the T-joint also has a finite material surface. In a finite body, the heat does not conduct beyond the surface; it raises the temperature higher than in an infinite body with some heat dissipating outside of the body from the surface. This end condition on temperature rise acts as if the heat reflects at the surface without further conduction. The temperature rise also enhances fusion at the near boundary of the web end surface. As this study adopts the heat conduction solution for an infinite body, the end effect of the surface on the temperature rise is not negligible. This study also includes the effect of heat reflection, so that the calculation meets well with experimental fusion depth. This results in making an assumption that there is an additional 60% of heat intensity.

Figure 11A shows estimated fusion depth using the heat intensity 0.4n × 1.6 and compares with experimental fusion depth. This assumption of heat intensity results in good agreement with the experiments over the entire range of n values used in this study.

The effect of reflected heat is neglected in the calculation of fusion width. This is due to the outer weld interface on the web having a significant distance from the web end surface. Figure 11B shows that the fusion width calculated with heat intensity 0.4n is in good agreement with the experiment for lower n values. For higher n values, the deviation between the calculations and experimental fusion width is considerably larger. In horizontal T-joint fillet welding, gravity force deforms the molten metal and it drops on the horizontal plate. This larger quantity of molten metal reduces the fusion width (Refs. 24, 25). Consequently, restrained fusion width in the horizontal plate is attributed to the inclined deposited metal on the horizontal plate. Further studies on the fluid flow in fillet welding are needed to clarify this process.

Figure 11A and B, and Fig. 12 also show fusion depth and width with weaving. Generally, weaving will decrease the fusion depth in the web, and conversely, will increase the width; however, the effect of weave with widths of 0.7 and 2.0 mm is not significant for either the web or the flange. (Note: In Fig. 11 WI° should be Ww°.)

Discussion

Effect of Plate Thickness

Figure 13A and B compares the cross-sectional macrostructure of welding 12- and 5-mm-thick plates, with the same welding parameters. In the 12-mm plate, the boundary of the heat-affected zone (HAZ) appears along the weld interface without the influence of reflected heat. In the 5-mm plate thickness, Fig. 13A shows the HAZ extends to the plate’s back surface. In addition, slight deformation is also observed on the plate’s back surface, implying the temperature exceeds At transition temperature (about 1023 K or 750°C in steel) at the plate’s back surface.

Figure 13A and B indicates weaving widths of 0.7 and 2.0 mm, including weaving positions of H, V, and O. This heat reflection also affects the fusion depth in the web of T-joint fillet welding. While the assumption of an additional 60% heat intensity provides
good agreement with the whole range of this experiment, for large values of \( n \) \((n = 21)\), adopting a value of 80% gives better agreement. This is understandable since the point of maximum fusion depth is located closer to the boundary of the material end surface with a higher value of operating parameter \( n \).

**Weaving**

Generally, weaving will have an effect on fluid motion in the weld pool, thereby decreasing fusion depth and increasing fusion width. The regression analysis indicate results there is little effect of the weaving for width under 2 mm. The effect of weaving seems to be concealed with the other driving forces in the weld pool when the weaving width is smaller than 2 mm. While a wider weaving width may increase the fusion width and decrease the fusion depth by changing the heat source properties, and the fluid flow in the weld pool, this requires further investigation.

**Applicable Range of the Semiempirical Methodology**

This study has presented the methodology and results for correcting the moving point heat source solution using bead-on-plate weld data. Because the errors are caused by the fluid flow in the weld pool that varies with different welding conditions, the estimates from the model will give an error because the fusion zone shape differs from the simple penetration type (a). The following is a summary of the applicable range:

- GMAW of the simple penetration type.
- Operating parameter \( n \leq 15 \).
- Weaving of 2 mm and less.
- Plate thickness of 5 mm and above.

**Summary**

This study uses the classical heat conduction solution with an assumption of a moving point heat source for the analysis of the fusion area, depth, and width in GMAW. The results of comparison with experimental fusion depth and width show systematic errors. These were corrected by corrections based on regression equations. The resulting semiempirical weld model shows good agreement with experimental data for both bead-on-plate welds and T-joint fillet welds. Moreover, the methodology using this semiempirical approach can be extended to practical prediction of weld fusion for materials other than steel.

The following conclusions have been obtained from this study:

While giving prediction errors in fusion depth and width, the theoretical heat conduction solution using a moving point heat source provides good qualitative agreement for the fusion area. This introduces the arc efficiency through fusion area for each welding position through theoretical and bead-on-plate weld comparisons.

The corrected solution also provides a good approximation of fusion depth and width by reducing the systematic errors between theory and experiments. The regression equations show good correlation with experimental data for bead-on-plate welds. This results in development of a reliable model for prediction of fusion.

This study also analyzes fusion depth and width in T-joint fillet welds using the same model. The model can predict fusion depth and width well for both web and flange by adopting an assumed heat distribution ratio and effect of reflected heat on the end surface of web.

The model provides prediction for fusion depth and width in GMAW in an easy and practical manner. It will be useful in the design of welding procedures and in adaptive control of welding parameters in automated welding systems. This semiempirical weld model can be ex-
tended using the developed methodology to a wider range of operating parameters with ancillary experimentation.

Acknowledgments

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References

A New Proposal of HAZ Toughness Evaluation Method: Part 2 — HAZ Toughness Formulation by Chemical Compositions

The HAZ toughness levels were measured and a relationship was established with the chemical compositions of structural steels

BY H. FURUYA, S. AIHARA, AND K. MORITA

ABSTRACT. This paper details an investigation into the measurement and the prediction of heat-affected zone (HAZ) toughness for construction structural steels. The HAZ toughness was examined using both single-layer and multilayer welded joints, and correlated to the chemical compositions of the steels used. From the series of the tests, the parameter, \( f_{HAZ} \), was derived to assess approximately whether a steel plate has adequate HAZ toughness. The condition is shown below.

\[
\begin{align*}
    f_{HAZ} & \leq 0.577 \text{ for } E_{273} \text{(single layer)} \\
    f_{HAZ} & \leq 0.632 \text{ for } E_{273} \text{(single layer)} \\
    \geq 70J & \text{ for } E_{273} \text{(multilayer)} \\
    \geq 12J & \text{ for } E_{273} \text{(multilayer)}
\end{align*}
\]

(Note: The content of Ti should be considered as 0 when it is equal to or less than 0.005 mass-%.)

Introduction

In Part 1 (Welding Journal 86(1): 1-8), the development of the available method to assess HAZ toughness was studied. In Part 2, the residual two issues, the measurement of the actual toughness level and the formulation of the relationship between HAZ toughness and chemical compositions, were examined.

As for the HAZ toughness measurement, both multilayer weld joints and single-layer weld joints were used. As was described in Part 1, the required toughness is more than 27 J or 70 J in \( E_{273} \) (absorbed energy at 273 K by the Charpy impact test). The aim of these tests was to determine if the HAZ toughness of SN steel accommodates the condition.

Regarding the HAZ toughness formulation, a procedure composed of three steps was adopted. First, the formulation of the relationship between the HAZ toughness in the single-layer weld joints and the chemical compositions was conducted. Since the HAZ toughness of the single-layer weld joints is not affected by the weld sequence, a high accuracy of formulation can be expected. Secondly, the relationship in HAZ toughness between the single-layer weld joints and the multilayer weld joints was clarified. Finally, the chemical composition equation to attain the required HAZ toughness level was produced based on the above two formulations.

A lot of study to clarify the effect of chemical compositions on HAZ toughness has been conducted (Refs. 1–13), and it is well known that the effect varies depending on the welding conditions or the chemical compositions of steel used. In this paper, the applicable scope was limited to the steels used in the Part 1 investigation, were used. The range of tensile strength was around 400 to 490 N/mm². The chemical compositions, JIS standard, type of products, whether industrial-made or laboratory-made, plate thickness, and \( E_{273} \) of the steels used are shown in Table 1.

Experimental Procedure

In this paper, a chemical composition condition that attains a certain HAZ toughness level is explained. The condition to attain 27 J or 70 J in HAZ toughness with the multilayer weld joint was examined. Forty-six steel plates and H-sections, including the steels used in the Part 1 investigation, were used. The range of tensile strength was around 400 to 490 N/mm². The chemical compositions, JIS standard, type of products, whether industrial-made or laboratory-made, plate thickness, and \( E_{273} \) of the steels used are shown in Table 1.

Similar to the method in Part 1, HAZ toughness was measured using multilayer and single-layer weld joints. Since it was clarified from the former investigation that the toughness in condition B (4 kJ/mm, 623 K) was a little lower than that in condition A (2 kJ/mm, 423 K), the welding condition was decided as 4 kJ/mm in heat input and 623 K in preheating and interheating temperature. The groove configurations, the welding direction, and the wires used were the same as in Part 1. The notch root position was set as HAZ1, because the toughness at this position was lower than those in the other positions, and it is thought important to avoid the effect of weld metal for the regression analysis. Regarding the thickness direction, 6 mm below the plate and bead surfaces were chosen for the multilayer and single-layer weld joints, respectively, because of the lower toughness compared to that in the quarter thickness (1/4t). The objective weld location was selected as the vertical edge so that the notch root samples contained as much coarsened microstructure as possible. For each condition, three specimens were tested at 273 K.

KEYWORDS

Chemical Composition
HAZ
H-Shapes
Structural Steel
Construction
Toughness
### Results

**Result of the HAZ Toughness Estimation**

Result of the HAZ toughness estimation for the steel plates and H-sections, whose chemical compositions are described in Table 1, is shown in Fig. 1. In the multilayer weld joints, the values for $E_{273}$ were more than 27 J, but partly less than 70 J. On the other hand, in the single-layer weld joints, the values for $E_{273}$ were usually less than those in the multilayer weld joints, and it was partly less than 27 J.

The relationship in HAZ toughness between the multilayer and the single-layer weld joints is shown in Fig. 2. Since most of the plots exist above the line whose gradient is one, it was confirmed that HAZ toughness of the multilayer weld joint is higher than that of the single-layer weld joint.

**HAZ Toughness Formulation by Chemical Compositions**

As was explained in Part 1, the degree of remaining coarsened microstructure is changeable in the multilayer weld joints depending on the difference in the welding deposition sequence. Therefore, it is possible to obtain quite different HAZ toughness even in the steel plates with the same chemical compositions, the same welding condition, and the same sampling position with multilayer weld joints. In fact, it is difficult to make clear the relationship between chemical compositions and HAZ toughness in the multilayer weld joints. On the other hand, it is easy to quantify the effect of chemical composition with single-layer weld joints.

So, the effect of chemical compositions on HAZ toughness is quantified using the data of the single-layer weld joints (Step...
Formulation of the Relationship between HAZ Toughness of Single-Layer Weld Joints and Chemical Compositions

Step 1

At first, a general expression, which relates toughness to chemical compositions, was assumed. Based on the result of the JWS-APD committee (Ref. 15), which used Nokota’s formulation (Ref. 16), the following expression is assumed:

\[
E_{f}^{273} \text{(single layer)} = \frac{300}{\exp(-f) + 1} \quad (1)
\]

\[
f = a_1 + a_2 \times C + a_3 \times Si + a_4 \times Mn + a_5 \times (P + S) + a_6 \times (Cu + Ni) + a_7 \times (Cr + Mo + V) + a_8 \times Nb + a_9 \times Ti + a_{10} \times N \quad (2)
\]

The term, \( E_{f}^{273} \text{(single layer)} \), means the absorbed energy of the single-layer weld joint in the Charpy impact test at 273 K on the Joule scale, and \( a_1 \) to \( a_{10} \) are coefficients, and the unit of each chemical composition is mass-%. The coefficient, 300, on the right side of Equation 1 corresponds to the upper shelf energy in the Charpy impact test. The range of the upper shelf energy in some steel plates was 250 to 350 J; therefore, the value 300 was employed here. It was confirmed that the change in this coefficient has less effect on the result of the regression analysis. Using formulations 1 and 2, the nonlinear regression analysis was conducted based on the aforementioned data, which are composed of 46 sets of chemical compositions and \( E_{f}^{273} \text{(single layer)} \).

The result of the nonlinear regression analysis is shown in Table 2. The term “coefficient of variation” is the standard error divided by the coefficient. Since a small coefficient of variation means that it has high reliability, the coefficients of C, Mn, (P+S), Ti, and N are expected to have a certain level of reliability. As for Si, (Cu+Ni), (Cr+Mo+V), and Nb, the reliability is thought to be relatively lower. As is shown in Table 2, the increase of the content such as C, Mn, P, S, and N deteriorates HAZ toughness. For C and Mn, the deterioration is attributed to the increase of hardness or the formation of the brittle phase such as martensite-austenite constituent (MA) (Refs. 2, 3). As for P, it is ascribed as the grain boundary segregation or the increase of the brittle phase (Refs. 4–6). According to S, it is on the ground of grain boundary embrittlement (Ref. 7) or the increase of inclusions. As for N, it is considered as the solute embrittlement (Refs. 4, 8, 9). On the other hand, Ti is expected to improve HAZ toughness through the refinement of austenite grain or the decrease of solute N (Refs. 10–12).

The relationship between the experimental value and the calculated value is shown in Fig. 3, and the relationship between \( E_{f}^{273} \text{(single layer)} \) and f is shown in Fig. 4. Since the favorable correlation was confirmed, it was considered to be appropriate to estimate \( E_{f}^{273} \) from the chemical compositions expression f.

### Table 1 — Continued

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<th>Factory or Laboratory</th>
<th>Thickness (mm)</th>
<th>( \Delta E_{f_{0}} ) (base metal)</th>
<th>( vE_{f_{273}} ) (single layer)</th>
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### Table 2 — Result of the Nonlinear Regression Analysis

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<td>(Cr+Mo+V)</td>
<td>( a_6 )</td>
<td>3.1</td>
<td>3.6</td>
<td>116</td>
</tr>
<tr>
<td>Nb</td>
<td>( a_7 )</td>
<td>-44.3</td>
<td>29.1</td>
<td>-66</td>
</tr>
<tr>
<td>Ti</td>
<td>( a_8 )</td>
<td>72.8</td>
<td>32.5</td>
<td>45</td>
</tr>
<tr>
<td>N</td>
<td>( a_9 )</td>
<td>-201.9</td>
<td>86.9</td>
<td>-43</td>
</tr>
</tbody>
</table>
It is not clear why the data scatter is limited only in the upper range of the average curve. A reason might be that the match between the notch root and the coarsened microstructure is better for the single-layer weld joint, and besides, it is interpreted as the size effect of the local brittle zone, presented in the Local Approach (Ref. 17).

Even if the coarsened microstructure exists on the notch root, as the fraction is low, the HAZ toughness of the multilayer weld joint is more than that of the single-layer weld joint, which appears to be the toughness of all coarsened microstructure.

Derivation of the Conditional Expression to Attain 70 J or 27 J in HAZ Toughness of the Multilayer Weld Joint

Step 3

From the results stated previously, the conditional expression is drawn on to attain 70 J or 27 J in $E_{273}$ (multilayer). As shown previously, $E_{273}$ (single layer) is needed to exceed 30 J or 12 J. Calculating from the Expression 1, the condition for $f$ is shown below.

\[ f \geq -2.197 \text{ for } E_{273} \text{(single layer)} \geq 30 \text{ J,} \]

\[ f \geq -3.178 \text{ for } E_{273} \text{(single layer)} \geq 12 \text{ J,} \]

Then the condition for chemical compositions can be calculated. As was mentioned previously, there is the difference in the reliability for each alloying element. As the coefficient for C, Mn, (P+S), Ti, and N have relatively higher reliability, the formulation is to be done using these six elements. As for the other elements, the average values were
calculated using all data of the factory-made steels, and it was substituted into the formulation. From this point, the applicable scope of this formulation is limited to SN steel or the equivalent steel. The value is 0.3 mass-% for Si, 0.1 mass-% for (Cu+Ni), 0.06 mass-% for (Cr+Mo+V), and 0.004 mass-% for Nb. Meanwhile, since Ca is often added in SN steel, the average value was also used for the calculation. Substituting the above values into the Expressions 3 and 4, the following expression was derived.

\[-18C - 2Mn - 112(P+S) - 202N + 73Ti \geq 30J, E_{273}^{\text{single layer}} \geq 70J \quad (5)\]

\[-18C - 2Mn - 112(P+S) - 202N + 73Ti \geq 12J, E_{273}^{\text{multilayer}} \geq 27J \quad (6)\]

Simplifying the above expression, the following expression was derived.

\[f_{HAZ} \leq 0.577 \text{ for } E_{273}^{\text{single layer}} \geq 30J, E_{273}^{\text{multilayer}} \geq 70J \quad (7)\]

\[f_{HAZ} \leq 0.632 \text{ for } E_{273}^{\text{single layer}} \geq 12J, E_{273}^{\text{multilayer}} \geq 27J \quad (8)\]

\[f_{HAZ} = C + Mn/8 + 6(P + S) + 12N - 4Ti\]

(The content of Ti is treated as 0 when it is lower than 0.005 mass-%.)

In addition, as for Ti, the effect on HAZ toughness is complicated, for example, the interaction with N (Ref. 18). Therefore, attention should be paid when treating it.

Discussion

Verification of the Reliability of the \( f_{HAZ} \) Formulation

In this section, the reliability of Formulation 7, the condition to attain 70 J in \( E_{273}^{\text{multilayer}} \), is verified. The relationship between \( E_{273}^{\text{single layer}} \) and \( f_{HAZ} \) is shown in Fig. 6. The figure is divided into four areas based on the two conditions. One (Condition A) is whether data accommodate to Expression 7, another (Condition B) is whether an experimental value of \( E_{273}^{\text{single layer}} \) is equal to or more than 30 J. More than 85% of data are in the area of Condition A-valid, Condition B-valid, or Condition A-invalid, Condition B-invalid. As for the data in the area of Condition A-invalid, Condition B-valid, it has no engineering problem because of the safety estimation. As for the problematic area, Condition A-valid, Condition B-invalid, \( E_{273}^{\text{single layer}} \) of two steels in three data are 27 J and 29 J, they are close to 30 J. As a whole,
Now, whether \( v_{E273}^{(\text{multilayer})} \) is equal to or more than 70 J was tested. In Table 3, \( v_{E273}^{(\text{multilayer})} \), \( v_{E273}^{(\text{single layer})} \), and \( f_{\text{HAZ}} \) and the results based on Expression 7, whether data are equal to or more than 30 J in \( v_{E273}^{(\text{single layer})} \), and whether data are equal to or more than 70 J in \( v_{E273}^{(\text{multilayer})} \) are shown. From this table, the number of samples that are invalid from Expression 7 is two, of which one has \( v_{E273}^{(\text{multilayer})} \) less than 70 J. As a whole, 28 of 32 samples adopted the condition 7, and reliability of more than 85% was clarified in this data set.

### Advertence on the Utilization of the \( f_{\text{HAZ}} \) Equation

The aim of this section is to present the necessity, the reliability, and the applicable scope of the \( f_{\text{HAZ}} \) equation. As was shown in Fig. 2, \( v_{E273}^{(\text{multilayer})} \) of the most specimens are more than 70 J, especially with all SN steels the toughness was beyond 70 J. From the experimental result, it may be considered that the \( f_{\text{HAZ}} \) equation is not necessary, but even when a sample adopts the SN standard, as is shown in steels No. 43 and 45, both of which were laboratory made. Therefore, it is considered that this equation to correlate HAZ toughness with the chemical compositions is needed.

The reliability of Equations 7 and 8 is now discussed. The result of verifying the chemical composition condition is shown in Table 3. The average correlations were adopted in formulating the relationships between \( v_{E273}^{(\text{single layer})} \) and the chemical compositions, and the correlation of \( v_{E273}^{(\text{multilayer})} \) and \( f_{\text{HAZ}} \). The condition is not sufficient to attain 70 J or 27 J. The only example is steel No. 43, whose chemical composition complies with Equation 7 but \( v_{E273}^{(\text{multilayer})} \) was less than 70 J. If we need the safest equation, the lower bound curve should be needed for both correlations. But the safest equation is excessively conservative, and it contradicts the fact that \( v_{E273}^{(\text{multilayer})} \) in most SN steels attain 70 J, and it is considered to lose the engineering availability. Then, as an indicator to attain 27 J or 70 J in \( v_{E273}^{(\text{multilayer})} \), the \( f_{\text{HAZ}} \) equation is proposed.

The applicable scope of \( f_{\text{HAZ}} \) is also important. Equations 7 and 8 are based on the data of the welding condition where heat input is 4 kJ/mm and preheating and interpass heating temperature are 623 K. They are not available if the welding condition is much different. Attention should be paid especially to low heat input and single-layer welding such as tack welding. For example, in the case of 2 kJ/mm in heat input and the single-layer weld, the microstructure is mainly composed of high-hardness martensite, and therefore, the toughness is generally low. Since the mechanism of the deterioration in HAZ toughness is different from the case with this study, the equation presented cannot be used.

Also, care should be taken as to the effect of the plate thickness. Even with the same welding conditions, as the cooling rate can change depending on the plate thickness, it can affect HAZ toughness. The thinner the plate thickness, the lower the cooling rate is. So, decreasing the plate thickness may deteriorate HAZ toughness in the same welding conditions. However, the range of plate thickness is 15 to 40 mm, and more than 60% of the samples are 22 to 28 mm in thickness. This subtle change in plate thickness can establish the accuracy of Equations 7 and 8.

Notice should be taken of the chemical conditions to attain \( v_{E273}^{(\text{single layer})} \) using chemical compositions of steel has adequate reliability for engineering use.
compositions. If the content of a composition exceeds the level of the steels used, there is a possibility for HAZ toughness to deteriorate more than expected. Especially, if other elements than C, Mn, P, S, and Ti used in the $f_{HAZ}$ equation, were used for the regression as the average value of steel used, the $f_{HAZ}$ formulation cannot be applied to steel containing a different content to a large degree.

Titanium is the one element that improves HAZ toughness with an increase in content. In contrast, if the content exceeds 0.013%, which is the maximum value of steels used, or the ratio of Ti content to the content of N changes remarkably, there is a possibility to deteriorate HAZ toughness. On the other hand, since the small amount of Ti may have less effect on toughness improvement, the lower limitation should be given. In this study, the detail is not examined, but for example, it is suggested the minimum value as 0.005 mass-% Ti.

**Effect of the Base Metal Toughness**

The relationships between the base metal toughness and HAZ toughness in multilayer weld joints and single-layer weld joints is shown in Fig. 7. Both figures have a positive correlation. In the region of HAZ1, where HAZ toughness was evaluated, the microstructure of the base metal does not remain because of the heating above $A_{	ext{C}3}$. The reason for the positive correlations may be attributed to the increase of elements such as C, P, S, and N leads to base metal toughness deterioration, as well as that of HAZ toughness. It means that the positive correlations of toughness between the base metal and HAZ are indirectly related to chemical compositions.

**Conclusions**

The HAZ toughness in beam-to-column connections of structural steel (SN steel) and its chemical compositions were investigated. The following results were derived:

1. In the multilayer weld joints, $E_{273}$ (absorbed energy at 273 K by the Charpy impact test) was more than 27 J but partly varies. (absorbed energy at 273 K by the Charpy impact test) was more than 27 J but partly varies.

2. In the single-layer weld joints, $E_{273}$ was usually less than those in the multilayer weld joints, and sometimes it was less than 27 J.

3. A chemical composition parameter to attain a certain level of HAZ toughness value was proposed. When JIS G 3136 SN steel or the equivalent steel is used, and a multilayer weld joint is made with a heat input of 4 kJ/mm and preheating or interpass heating temperature at 673 K, an approximate condition to attain 70 J or 27 J in the Charpy impact energy at 273 K is given below.

$$f_{HAZ} \leq 0.577 \times E_{273}^{(\text{single-layer})} \geq 30 \text{ J}, E_{273}^{(\text{multilayer})} \geq 70 \text{ J}$$

$$f_{HAZ} \leq 0.632 \times E_{273}^{(\text{single-layer})} \geq 12 \text{ J}, E_{273}^{(\text{multilayer})} \geq 27 \text{ J}$$

$$f_{HAZ} = C + 0.08 \times (P + S) + 12(N - 4T)$$

(Note: The content of Ti should be considered as 0 when it is equal or less than 0.005 mass-%.)

4. From the experimental data, it was clarified that the proposed expression has 85% reliability.

**Acknowledgments**

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**References**


Technical Note: Martensite Formation in Austenitic/Ferritic Dissimilar Alloy Welds

The reduced martensite layer thickness observed in welds prepared with Ni-based filler metals can be attributed to differences in concentration gradients in the partially mixed zone

BY J. N. DuPONT AND C. S. KUSKO

ABSTRACT. Electron microprobe analysis was utilized to examine the gradient of alloying elements across the weld interface of austenitic/ferritic dissimilar alloy welds. The concentration gradients were converted to martensite start (Ms) temperature gradients and used to explain the differences in martensite layer widths that have been observed in the partially mixed zone (PMZ) of dissimilar welds.

Introduction

Ferritic-to-austenitic dissimilar metal welds are used in a variety of industries including power generation, petrochemical, pulp, and paper. The presence of martensite adjacent to the weld interface of such welds has been well documented in literature (Refs. 1–3). The martensite layer is located within the partially mixed zone (PMZ) of the weld where the composition varies continuously from that of the ferritic steel to that of the weld metal. The PMZ forms due to incomplete liquid state mixing near the fusion line. The formation of martensite within the PMZ occurs due to the formation of intermediate compositions with high hardenability that form martensite upon rapid cooling from the weld thermal cycle. The formation of this martensitic region leads to steep microstructural and mechanical property gradients across the weld interface and is partially responsible for premature failure of dissimilar welds at elevated temperatures (Refs. 2, 3).

Nickel-based filler metals are often used to prolong the life of austenitic-to-ferritic dissimilar welds. The use of nickel-based filler metals produces a thinner martensite layer compared to stainless steel filler metals (Ref. 3), but the reason for this has not been investigated in detail. In this paper it is demonstrated that the reduced martensite layer thickness observed in welds prepared with Ni-based filler metals can be attributed to differences in concentration gradients in the PMZ.

Experimental Procedure

IN625 and 309L stainless steel were deposited onto A285 carbon steel using the electroslag welding process. The compositions of these materials are provided in Table 1. The dimensions of the carbon steel substrate were 61 × 15 × 4 cm. The electrode size was 30 × 0.5 mm. Sandvik commercial welding flux 59s was utilized during deposition. The strip electrode was deposited continuously along the top edge of the substrate to cover the entire length of the substrate at 565 A, 24 V, and 3.0 mm/s travel speed. (This unique sample configuration was used for convenient extraction of fatigue samples as part of a larger research program.) Sample cross sections were polished using standard metallographic techniques then etched electrolytically using a 90 mL methanol/5 g FeCl4 mL HCl solution. Electron probe microanalysis (EPMA) was performed using a JEOL 733 probe at an accelerating voltage of 15 kV and a beam current of 20 nA. Raw data were reduced to weight percentages using a ZAF algorithm (Ref. 5). The width of the martensite layer adjacent to the weld interface was measured using photomicrographs and an operator interactive digitizing pad.

Results and Discussion

Figure 1 shows light optical photomicrographs of the martensite layer observed in the welds deposited using 309L (Fig. 1A) and 625 (Fig. 1B) filler metals. The black vertical line in each photomicrograph represents the locations of EPMA traces. The variation in martensite layer widths is readily evident from these figures. Random measurements of the martensite layer thickness acquired along the weld interface of each weld in the region where the EPMA trace was acquired indicated that the martensite layer in the 309L weld was 30–37 μm in thickness, while that in the IN625 weld was 1–3 μm in thickness. The variation in major alloying elements (Fe, Ni, and Cr) across the weld interfaces of the welds is shown in Fig. 2. Due to the variation in nominal composition between the substrate and the cladding, a composition gradient exists within the PMZ. The gradient is steeper for the weld prepared with IN625 filler metal because of the increase in nominal Ni content and decrease in nominal Fe content compared to the weld prepared with 309L stainless steel.

As discussed in more detail below, the composition gradients produce a variation in the martensite start (Ms) temperature across the weld interface, and the differences in composition gradients and resultant Ms gradients between the two welds can be used to explain the observed variation in martensite widths. In view of this, it is useful to know the gradient of all elements across the weld interface that significantly affect the Ms temperature, which for the current alloy systems include C, Mn, Ni, Cr, and Mo (Ref. 6). Although Fe, Ni, Cr, and Mo were directly measured during the EPMA analysis, no attempt was made to measure C and Mn because of the low concentration (Mn) and light element character (C). However, the concentration gradient of these elements can be estimated by using the EPMA data of the major alloying elements to determine the variation in dilu.
tion within the PMZ. Once the variation in dilution within the PMZ is known, together with the nominal concentrations of alloying elements of the base metal and filler metal, the C and Mn concentrations can be estimated by back-calculation. The assumption with this approach is that C and Mn will be mixed in the liquid state to the same level within the PMZ as the major alloying elements.

Using the available microprobe data, the variation in dilution within the PMZ zone was determined by

$$ D = \frac{C_{pmz} - C_{fm}}{C_{fm} - C_{bm}} $$

where $D$ represents the dilution, $C_{pmz}$ represents the concentration of any element within the partially mixed zone, $C_{fm}$ is the nominal concentration of any element in the filler metal, and $C_{bm}$ is the concentration of any element in the base metal. The $C_{fm}$ and $C_{bm}$ values for Fe, Ni, Cr, and Mo were determined by wet chemical analysis (Table 1), while the $C_{pmz}$ values for the same elements were determined by EPMA — Fig. 2. Using each of these measurements, the dilution was determined for each position in the PMZ. Figure 3 shows an example of this for the weld prepared with 309L stainless steel filler metal, where the dilution values for Fe, Ni, and Cr were determined. Once the dilution is known, the corresponding C and Mn concentrations in the PMZ ($C_{pmz}$) can be estimated by

Table 1 — Nominal Compositions of Substrate and Strip Electrodes Measured by Wet Chemical Analysis. (All values listed in weight percent.)

<table>
<thead>
<tr>
<th>Material</th>
<th>Fe</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>Nb</th>
<th>Si</th>
<th>C</th>
<th>P</th>
<th>S</th>
<th>Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td>A285</td>
<td>Bal.</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>0.21</td>
<td>0.06</td>
<td>0.01</td>
<td>0.028</td>
<td>0.81</td>
</tr>
<tr>
<td>309L</td>
<td>Bal.</td>
<td>12.62</td>
<td>23.44</td>
<td>—</td>
<td>—</td>
<td>0.40</td>
<td>0.013</td>
<td>0.013</td>
<td>0.002</td>
<td>0.01</td>
</tr>
<tr>
<td>625</td>
<td>3.79</td>
<td>Bal.</td>
<td>21.01</td>
<td>8.72</td>
<td>3.51</td>
<td>0.13</td>
<td>0.01</td>
<td>0.009</td>
<td>0.002</td>
<td>0.01</td>
</tr>
</tbody>
</table>

Fig. 1 — Light optical photomicrographs of the martensite layer observed in the welds deposited using 309L (A), and 625 (B) filler metals.

Fig. 2 — The EPMA measurements acquired across the PMZ for A) 309L stainless steel/A285 carbon steel, and B) IN625/A285 carbon steel dissimilar alloy welds.
Gooch (Ref. 6) developed a Ms equation for martensitic stainless steels that have compositions similar to the martensite layer:

\[ Ms(°C) = 540 - (497°C + 6.3%Mn + 36.3%Ni + 10.8%Cr + 46.6%Mo) \] (3)

Using the measured values for Ni, Cr, and Mo along with the estimated values of C and Mn, the variation in Ms temperature across the PMZ was estimated with Equation 3. Figure 4 shows the results. The two curves on each plot represent the highest and lowest possible Ms temperature based on the range in dilution that was determined previously — Fig. 3.

The martensite layer within the PMZ should begin near the start of the composition gradient adjacent to the carbon steel base metal and end at a location where the Ms temperature intersects room temperature. The exact starting and end locations cannot be known with a high degree of certainty since this will depend on the local hardenability (as determined by local composition) and local cooling rate. However, comparison of the Ms gradient plots in Fig. 4 clearly shows that a thinner martensite layer is expected in welds prepared with Ni-based filler metals. This can be attributed to the higher concentration gradient within the PMZ (due to higher Ni concentration) that, in turn, stabilizes the austenite at a shorter location within the PMZ.

According to Fig. 4, the martensite layer thickness should be approximately 35–39 μm for the weld prepared with 309L filler metal and approximately 2–3 μm in the weld prepared with the IN625 filler metal. These values represent the distance between the start of concentration gradient near the ferritic steel side and the point where the Ms crosses room temperature. The start of the concentration gradient is chosen because it represents the beginning of the PMZ (i.e., on the ferritic steel side), while the point where the Ms crosses room temperature is chosen because it represents the location where martensite should no longer form with the PMZ (i.e., martensite will stop forming at the location where the Ms drops below room temperature). These values (~ 35–39 μm for the weld prepared with 309L and ~ 2–3 μm in the weld prepared with the IN625) compare reasonably well with those measured at the location of the microprobe trace for each weld in Fig. 1, ~34 μm for 309L and ~3 μm for IN625.

It should be noted that the exact width of the martensite layer can vary within a given weld due to local variations in the composition gradient (due to local variations in fluid flow behavior) and cooling rate. In addition, variations in fluid flow behavior are expected when changes are made to processing parameters. The objective here is not to predict the size of the martensite layer within a given weld or with variations in processing parameters, but to demonstrate why differences exist between the widths of martensite layers in welds prepared with Ni-based and Fe-based alloys. The results presented here demonstrate that the reduced width of the martensite layer in Ni-based alloys can be attributed to the steeper gradient in composition and concomitant Ms temperature within the PMZ.

**Conclusion**

Ferritic-to-austenitic dissimilar welds...
made with Ni-based filler metals will exhibit a steeper concentration gradient in the partially mixed zone (PMZ) compared to Fe-based austenitic alloys. The steeper concentration gradient causes the martensite start (Ms) temperature within the PMZ to intersect room temperature at a relatively short distance within the PMZ. This stabilizes the austenite at a relatively short distance within the PMZ and accounts for the relatively thin martensite layer observed in dissimilar welds prepared with Ni-based filler metals.

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References

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