WELDING Journal

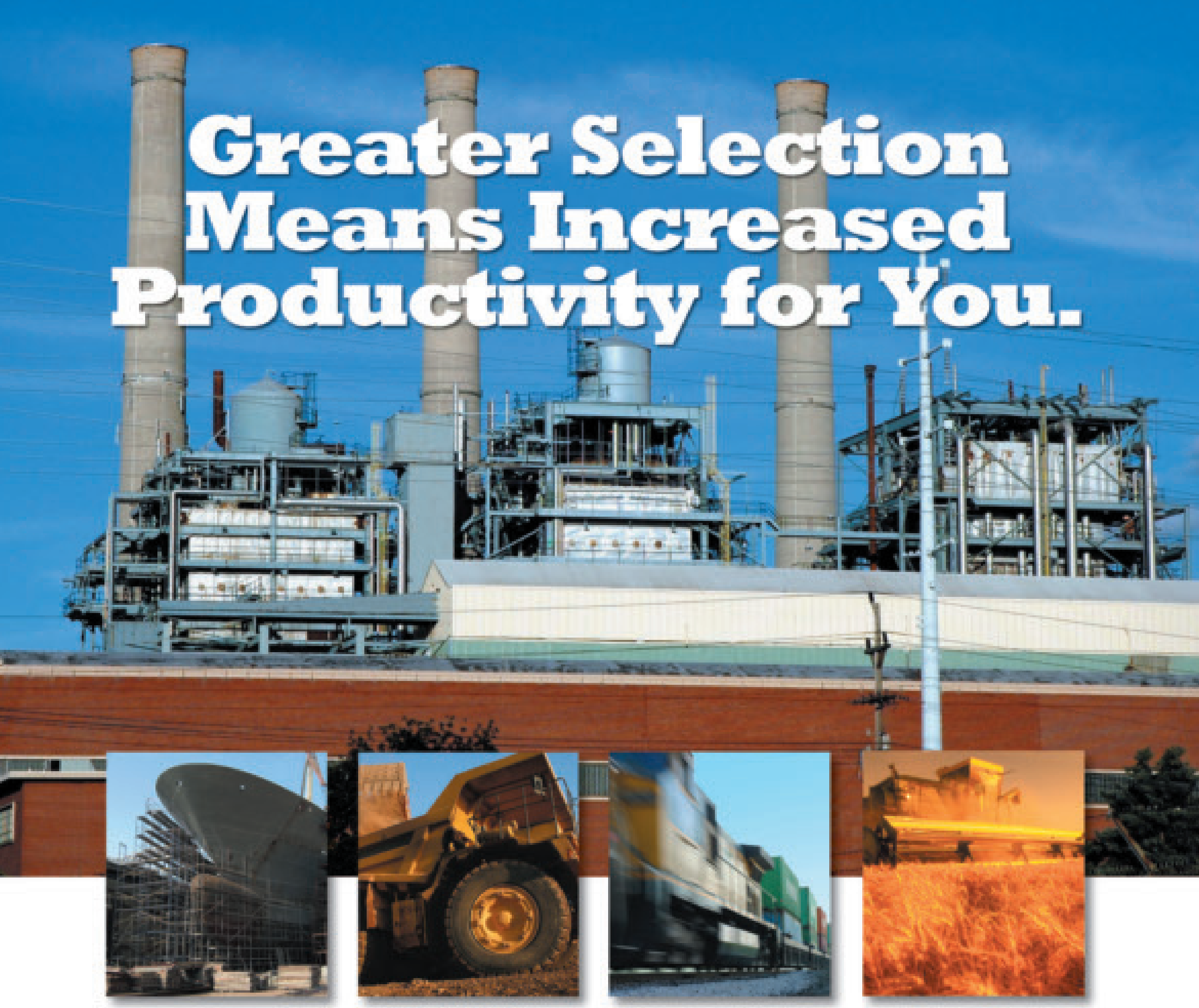
December 2007

•A Guide to Welding Titanium

•Nonvacuum EB Welding

•Cross Wire Welding of Everyday Products

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



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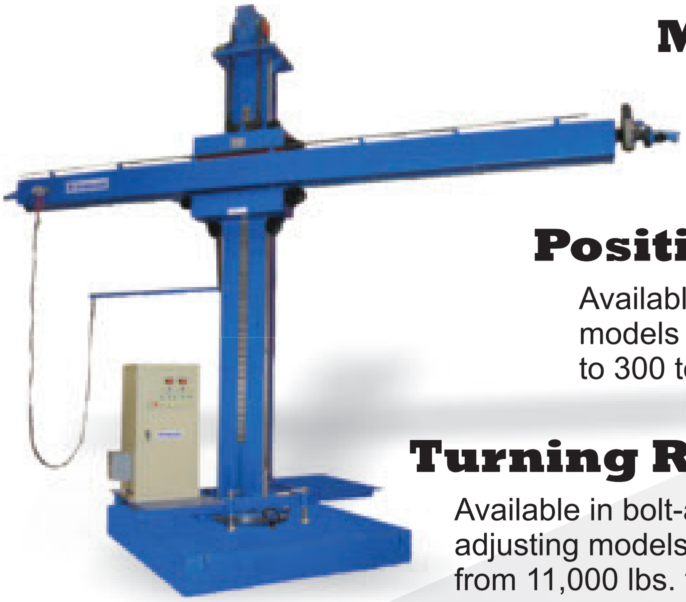

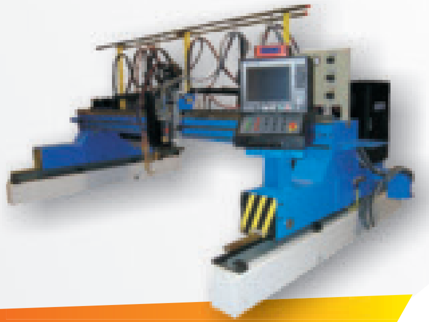

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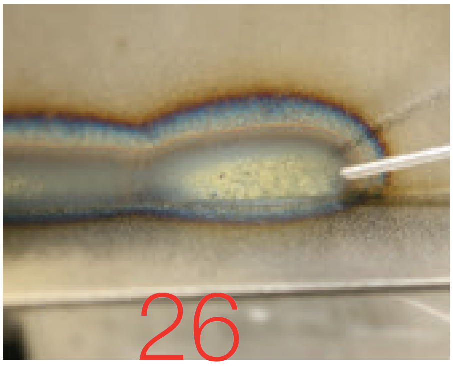
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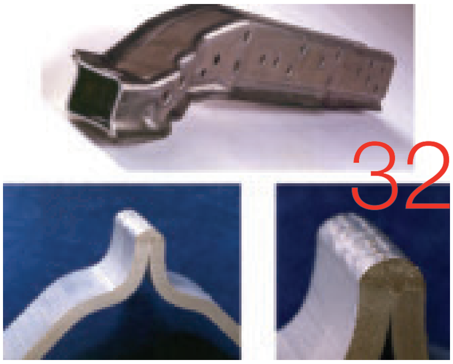
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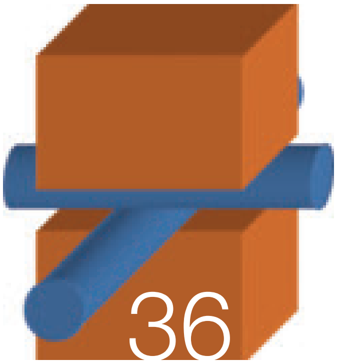
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WASHINGTON WATCHWORD

BY HUGH K. WEBSTER
AWS WASHINGTON GOVERNMENT AFFAIRS OFFICE

OSHA Issues Guidance on Combustible Dust

The U.S. Occupational Safety and Health Administration (OSHA) has issued a new safety and health instruction outlining OSHA policies and procedures for inspecting workplaces that handle combustible dusts.

OSHA's specific concern is fire and explosion hazards that may exist at facilities handling combustible dust. Almost 300 dust fires and explosions have occurred in U.S. industrial facilities over the past 25 years, resulting in 119 fatalities and more than 700 injuries.

Combustible dusts can be generated in various parts of the production process, and explosions can occur within any process where a combustible dust accumulates, is produced or stored, or is airborne. A variety of energy sources can trigger a dust explosion, including welding and cutting.

The instruction is available at *http://www.osha.gov/OshDoc/Directive_pdf/CPL_03-00-006.pdf*.

Bill Seeks to Expand Trade Adjustment Assistance

The Trade and Globalization Assistance Act of 2007 is moving quickly through Congress, and it is seen as a possible adjunct to several pending free trade bills, particularly the Peru Trade Promotion Agreement.

The Trade and Globalization Assistance Act of 2007 is designed to extend trade adjustment assistance coverage to more workers, including service workers, and improve the program's training opportunities and associated health care benefits. The bill also would create 24 manufacturing redevelopment zones, which would be eligible for various redevelopment tax incentives.

Bureau of Labor Statistics Industry Data Show Decrease in Workplace Injuries

The U.S. Department of Labor's Bureau of Labor Statistics announced that the rate of workplace injuries and illnesses in private industry declined in 2006 for the fourth consecutive year. Nonfatal workplace injuries and illnesses reported by private industry employers declined from 4.6 cases per 100 workers in 2005 to 4.4 cases in 2006. Manufacturing illness rates especially fell, from 66.1 in 2005 to 57.7 per 10,000 workers in 2006.

Companies with 10 or fewer workers had the lowest rate for injuries and illnesses combined (1.9 cases per 100 full-time workers), while midsize firms (50 to 249 workers) reported the highest rate (5.5 cases per 100 full-time workers).

> **The rate of workplace injuries and illnesses in private industry declined in 2006 for the fourth consecutive year, according to the Bureau of Labor Statistics. Compared to 2005, nonfatal workplace injuries and illnesses reported by private industry employers declined, and manufacturing illness rates especially fell.**

New Piracy Initiative Announced

The U.S. Trade Representative has announced that the United States and some of its key trading partners will seek to negotiate an Anti-Counterfeiting Trade Agreement (ACTA).

While there are already active ongoing international anticounterfeiting efforts, the concept here is that negotiation of a "plurilateral agreement" among a small group of like-minded trading partners will proceed more quickly and productively than a global agreement. The envisioned ACTA will include commitments in the following three areas:

1. strengthening international cooperation,
2. improving enforcement practices, and
3. providing a strong legal framework for intellectual property rights enforcement.

There has been increasing recognition that counterfeiting and piracy threaten U.S. jobs and economic growth, striking at the reputation of U.S. brands and stealing the products of U.S. creativity and innovation. Industry loss estimates run into hundreds of billions of dollars. Developing countries are among the biggest victims, as counterfeiters passing off shoddy and unsafe goods undermine emerging local economies.

Emissions Bill Introduced

The major global warming legislation in the U.S. Senate is America's Climate Security Act, recently introduced by Senators John Warner (R-Va.) and Joseph Lieberman (I-Conn.). This legislation would impose an emissions cap on electrical utilities, manufacturing sources, and transportation, and it would introduce a market-oriented "cap-and-trade" system, in which emission allowances could be bought and sold among firms.

Supporters are attempting to craft a balance between business and environmental concerns, both of which have expressed reservations about the bill, as has the White House.

College Cost-Reduction Act Signed into Law

The College Cost-Reduction and Access Act became law in September. This new law will raise the maximum annual Pell grant, the nation's main aid program for low-income students, from $4300 to $5400 a year by 2012.

Student loan forgiveness is provided for early childhood educators, school librarians, and public safety employees, and the act allows military personnel serving in Iraq and Afghanistan deferment on their student loan payments until they return home. ♦

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


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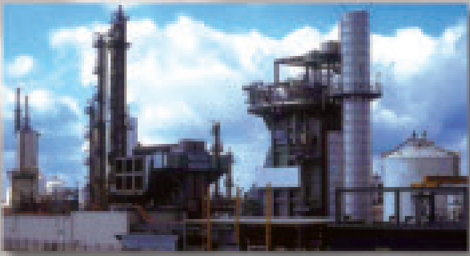

PRESS TIME NEWS

Canada's New Government Invests in Skills Training

Canada's new government is providing $366,906 in funding to the College of New Caledonia to purchase new mobile training equipment. This means residents in rural communities whose jobs have been affected by the Mountain Pine Beetle infestation will have access to new skills training through the college.

Dick Harris, member of Parliament for Cariboo-Prince George, recently made the announcement on behalf of Minister Rona Ambrose, president of the Queen's Privy Council for Canada, minister of Intergovernmental Affairs, and minister of Western Economic Diversification.

Provided through the Community Economic Diversification Initiative, funding will ensure the delivery of a full range of training programs, including welding. The first to have access to the program will be residents in Mackenzie, Burns Lake, Quesnel, and Fort St. James, with other communities identified through consultations by the college.

Chief Industries to Add 15 Welding Jobs

Chief Industries, Inc. Agri/Industrial Division, which markets steel buildings, grain bins, grain conditioning, bulk-handling, feedmill equipment, and accessories, recently announced its intention to add 15 new jobs to its Kearney, Neb., plant. The jobs will be for experienced and/or trained welders. Also, the company is planning to add the positions as soon as possible.

To establish a training program in Kearney, Chief has been working with Central Community College, the Buffalo County Economic Development Council, the Nebraska Workforce Development Kearney Career Center, the Nebraska Department of Economic Development, and other area metal fabrication employers. The six-week course will be offered at night so those currently employed, and wanting to improve themselves by becoming skilled in the field of welding, can attend in the evening.

H. B. Fuller Co. Donates $50,000 to SME Education Foundation

To commemorate its 120th anniversary, H. B. Fuller Co., St. Paul, Minn., a manufacturer and marketer of adhesives, sealants, paints, and other specialty chemical products, has donated $50,000 to the Society of Manufacturing Engineers (SME) Education Foundation to support science, technology, engineering, and math education. This foundation will use the donation to open the first Science, Technology & Engineering Preview Summer (STEPS) Academy programs in Minnesota next summer. In addition, the company's contribution will enable 120 Minnesota students to attend these STEPS Academies.

Helix Receives Letter of Intent for Installing Subsea Infrastructure

Helix Energy Solutions, Houston, Tex., has recently received a letter of intent for the installation of the subsea infrastructure for the VIC/P44 Stage 2 Development project in the Otway Basin offshore Australia.

The work consists of the preparation and welding of a 22-km, 12-in. gas pipeline at a designated spoolbase; the installation of the pipeline together with the electrohydraulic control umbilical, flowline jumpers, and control flying leads; and the precommissioning and commissioning of the system.

The expected duration of the work is four and a half months, including mobilization and demobilization to the Otway Basin from and to India.

Welding Employment and Education Site to Help Address Skilled Welder Shortage

A new Web site, *HireWelders.com*, has been officially launched. Worldwide information about welding jobs and welding education is offered here in an effort to develop a stronger link between the two. It aims to offer those seeking welders, welding jobs, welding education, or welding students a single place to find what they need.

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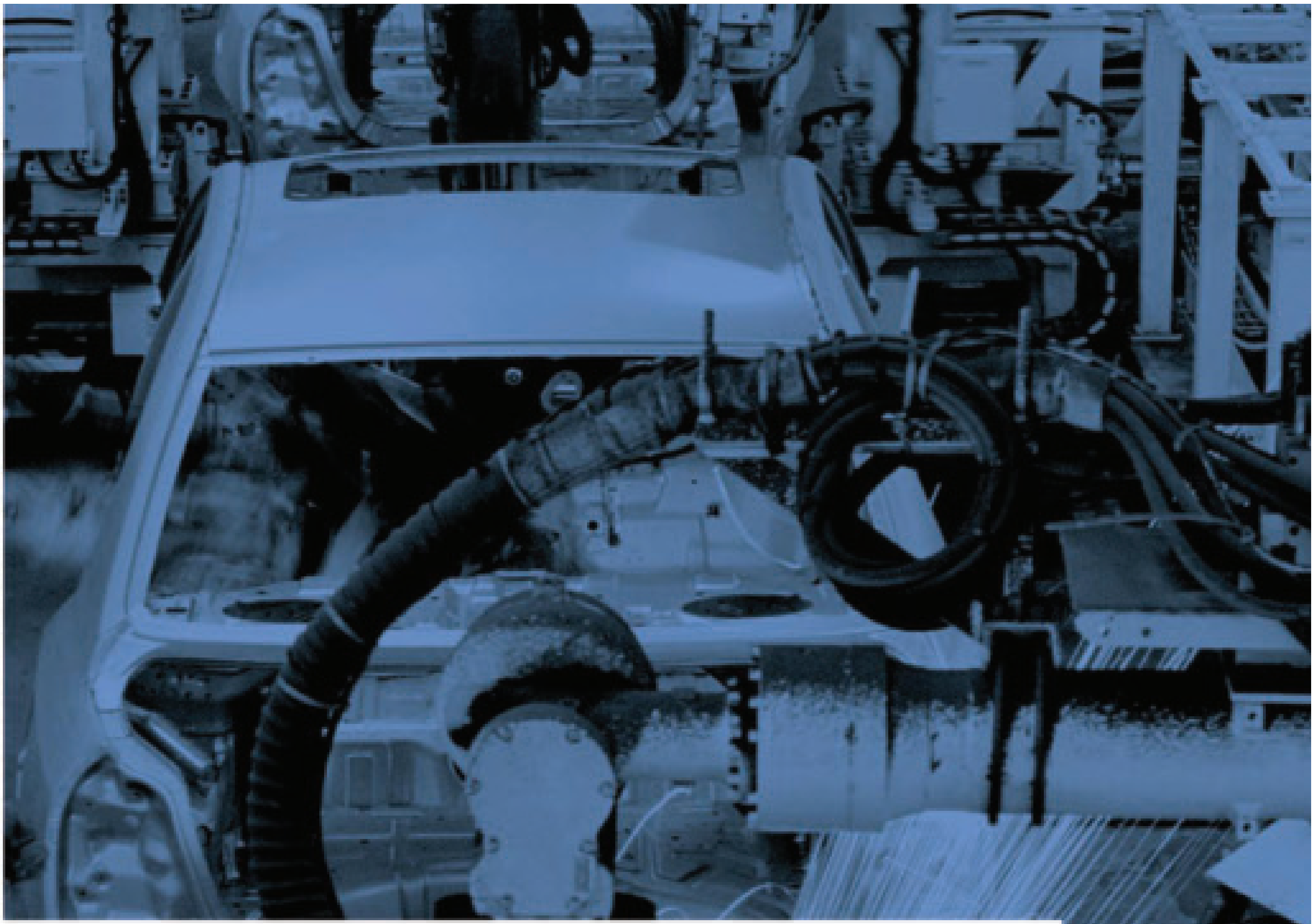


Welder Shortages: A Worldwide Problem

The high average age of today's welders and the large numbers of Baby Boomers starting to retire are causing a significant welder shortage in the United States. Unfortunately, there are far fewer welding students coming in to replace them. A skilled welder shortage is projected to get significantly worse.

While representing AWS as this year's president, I presented keynote speeches on welder shortage issues at conferences in Peru, Denmark, and South Korea, and discussed the subject while in China, Croatia, and the UK. The folks in those countries indicated they have similar problems. At one of the conferences, a person from Germany mentioned the welder shortage there was severe and requested copies of my slides that discuss approaches to improve the situation.

According to a survey conducted by a manpower research group this year, skilled manual trades workers are at the top of employers' wish lists in Germany, United Kingdom, Canada, Australia, Spain, Italy, Belgium, Austria, Sweden, France, and Switzerland.

Even during the discussions I had in China, it was stated that young people there are coming from the country to the larger cities to work in office jobs, not in skilled trades. Most countries had similar stories, the exception being South Korea where an entrepreneurial statement was made independently by several folks. When it was mentioned there is no problem obtaining skilled welders at Hyundai Shipyard, one of the largest in the world, I asked why. Officials there simply said, "We pay a lot." Representatives from the Korean steelmaker, Posco, said the same thing.

The entrepreneurial attitude found throughout South Korea was reinforced at Posco. The steel mill was started as a greenfield plant in 1968 and is now one of the largest, most prosperous steel mills in the world despite requiring all iron ore and coal to be imported. The excellent environment and clean operation at the mill were most impressive. We also visited a large Hyundai automotive assembly plant where they solve their welder needs with extensive automation. There was almost no manual welding. Robots made gas metal arc, laser, and resistance welds, and performed most of the assembly tasks as well. Skilled welding technicians are on staff.

Areas of the United States also showed some promise for solving the shortage problem. I visited a number of welding schools and was pleasantly surprised with the large numbers of enthusiastic students. The principal of York County School of Technology said when he first came to the school, he would not have sent his child to the welding program at the facility. With the help of local industry and volunteers, they upgraded the quality of their facility, which resulted in significantly increased enrollment. Currently, the program includes approximately 100 very enthusiastic welding students.

A scholarship donation to the AWS Foundation by ESAB earmarked for the Southeastern Institute of Manufacturing Technology in South Carolina is helping to get quality high school students interested in welding. Scholarship funds are for students who attend the welding degree program at the Institute. Ross Gandy, the school's welding business manager, convinced state regulators and the college to give one semester's worth of credit to high school students graduating from qualified welding programs. The ESAB scholarship funds will help motivate high-potential incoming high school freshmen to consider welding as a career.

In summary, the shortage of skilled welders is a worldwide problem. We can learn from the entrepreneurial approach in Korea where "high pay" provides one solution. In addition, the fabricating industry needs to support scholarships for quality high school students to consider acquiring a technology degree in welding.

Gerald D. Uttrachi
AWS President

IIW Celebrates 60 Years of Service

The International Institute of Welding (IIW) commenced a year of activities to celebrate the 60th anniversary of its operation as a worldwide innovation and technology platform for welding and joining at its 2007 Annual Assembly in Croatia in July.

A nonprofit organization, the IIW was originally proposed by a group of scientists and researchers to promote innovation and best joining practices. Their idea was to provide a global platform for the exchange and diffusion of evolving welding technologies and applications.

Founded in 1948 by the welding institutes or societies in 13 countries, this organization has 52 member countries today. It is driven by the combined synergy of thousands of experts who conduct and participate in technical IIW Commission meetings, international congresses, assemblies, and themed conferences.

The mission of IIW is to "act as the worldwide facilitating network for knowledge exchange of joining technology to improve the global quality of life."

The General Assembly decides the organization's policies, at which all the national member societies are represented, and also elects its president and the members of the board of directors.

The president of IIW from 2005 to 2008 is Chris Smallbone, executive director of the Welding Technology Institute of Australia. The day-to-day work is ensured by a permanent secretariat currently under the responsibility of Daniel Beaufils, the chief executive. On Beaufils's retirement in January 2008, this role will be taken up by André Charbonnier. The secretariat role is currently provided by the French Institut de Soudure.

The technical document database of the organization currently references more than 12,700 IIW documents. The motivators of this output are the IIW Commissions. Additionally, the voluntary chairs of the Commissions manage the activities of the commission and subgroups.

In 1986, it was selected as one of the world's three official International Standardizing Bodies in the areas of welding and joining. Taken up in 2005 was the IIW Project "To Improve the Global Quality of Life Through the Optimum Use of Welding Technology."

The organization has established a system of requirements for the proper education, training, qualification, and certification of welding professionals. The IIW Manufacturer Certification Scheme for the Management of Quality, Environment, and Health and Safety in Welded Fabrication has been established as well.

IIW, its member societies, and individuals, are currently collaborating to prepare a White Paper or common vision document that can be used to promote a positive image of welding.

Miller to Give Away a Weld Shop

Miller Electric Mfg. Co., Appleton, Wis., is giving away a weld shop valued at more than $17,000. The giveaway includes a welding machine/generator, welding and plasma cutting power sources, autodarkening helmet, safety gear, welding accessories, and personalized expert training. It runs October 1 through December 31, 2007, and offers participants the opportunity to win more than 1300 Instant Win prizes. Go to www.MillerWelds.com/ultimate/ *for official rules and registration.*

Lincoln Electric Breaks Ground for Consumables Plant Expansion

Lincoln Electric recently held groundbreaking ceremonies for a 120,000-sq-ft expansion of its Mentor, Ohio, consumables plant. Shown from left is John Stropki, Lincoln Electric chairman and CEO; the Honorable Ray Kirchner, mayor of Mentor, Ohio; George Blankenship, Lincoln Electric SVP of global engineering and U.S. operations; and Tony Panzica, president of Panzica Construction Co. The plant, built in 1977, is being expanded to handle increased wire-drawing capacity at the company's consumables manufacturing operations. The project is expected to be completed during the first quarter of 2008.

Instructor Earns Workforce Development Award for South Dakota State University

At the South Dakota Workforce Development Council's awards banquet in September, Harvey Svec (center) served as South Dakota State University's representative for the "Outstanding Adult Program for 2007." The impetus for the award was an introductory welding training course he taught. Also pictured (at left) are Jeff Kjenstad of Brookings Career Center and (at right) Viola Richards, Brookings Area Learning Center.

South Dakota State University (SDSU), Brookings, S.Dak., has received the "Outstanding Adult Program for 2007" from the South Dakota Workforce Development Council through the South Dakota Department of Labor Workforce Investment Act.

An introductory welding training course taught by Harvey Svec, instructor in the College of Engineering's Engineering Technology and Management Department, and hosted by SDSU during this past summer, was the impetus for the award. Svec served as the college's representative at the South Dakota Workforce Development Council's awards banquet as well.

The Brookings Area Career Learning Center and the South Dakota Career Center in Brookings coordinated the 80-h welding class for Twin City Fan and Blower Co., who needed experienced production welders to fill open positions. As a result, seven new $30,000-a-year jobs were created.

Svec covered wire feed welding methods, shop safety, and related industrial topics during the two-week class.

Report Finds Industry Is Concerned about Overall Confidence

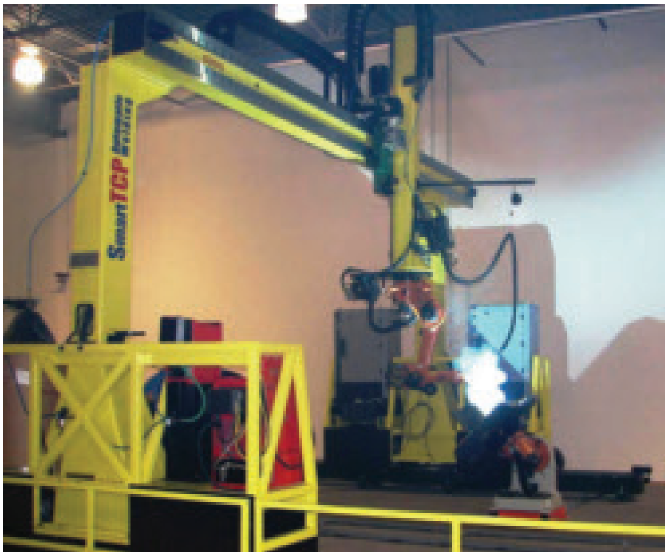
The Small Business Research Board recently reported fewer owners and managers of small manufacturing companies during the third quarter expressed confidence in their business prospects for the next 12 months.

According to the poll cosponsored by International Profit Associates, Northfield, Ill., the Manufacturing Industry Small Business Confidence Index (SBCI) declined to 38.33 from the 40.3 that was reported during the second quarter of 2007.

In addition, the current index is lower than the SBCI of 43 reported for all U.S. small businesses.

The lower index resulted largely from the change in revenue predictions. During the next 12 months, the poll tabulations showed that 45% are expecting revenues to increase.

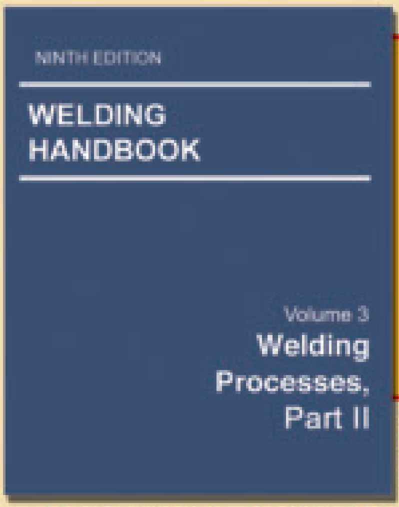
SmartTCP Chosen by NPK Manufacturing to Automate Welding Operations



SmartTCP, Farmington Hills, Mich., recently announced its SmartTCP automatic welding equipment has been installed and is running in NPK Construction Equipment, Inc.'s, new manufacturing facility to increase the company's production volumes of large weldments. Designed for complex fabrications in small batch production, the robotic welding equipment combines hardware and software into a welding cell that automates the robot programming and weld production of NPK's high-mix, low-volume parts.

Wenzel Dedicates New North American Manufacturing Facility

Wenzel GmbH of Germany, a manufacturer of coordinate measuring machines (CMMs), officially opened a new 24,000-sq-ft North American headquarters and manufacturing facility in Wixom, Mich., at dedication ceremonies held in October. Frank Wenzel (seen above), managing director of Wenzel GmbH, cuts the grand opening ribbon. The two-story building houses all of the company's North American administrative and engineering offices, the production operation for the X-Orbit and Xtreme LH series of bridge-style CMMs, and a dedicated customer training and demonstration facility.



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Welding Handbook, 9th Ed., Vol 3, Part II

Save $167 when you purchase the *Welding Handbook, 9th. Ed., Vol. 3, Part II* for only $25*. Only AWS Individual Members (Class 'B') are eligible for this special offer. Don't miss out on this exclusive offer for AWS Individual Members.

Volume 3 of the Welding Handbook, 9th Edition, Welding Processes, Part 2, presents over 600 pages of comprehensive information on solid-state and other welding and cutting processes. The book includes chapters on resistance spot and seam welding, projection welding, flash and upset welding, and high-frequency welding. In addition to a chapter on friction welding, a new chapter introduces friction stir welding, the process that has users excited about the significant advantages it offers. The most recent developments in beam technology are discussed in the greatly expanded chapters on laser beam welding and cutting and electron beam welding. A diverse array of processes are presented in chapters on the ultrasonic welding of metals, explosion welding, diffusion welding and diffusion brazing, adhesive bonding and thermal and cold spraying. The last chapter covers various other welding and cutting processes, including modernized water jet cutting, and two emerging processes, magnetic pulse welding and electro-spark depositing. Written, updated, and peer reviewed by a group of highly respected technical and scientific experts, **the book has 15 chapters and more than 239 line drawings, 264 photographs, 57 tables, 3 appendixes and a comprehensive index.**

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ALUMINUM Q&A

BY TONY ANDERSON

Q: I am a welder who has worked with gas metal arc welding (GMAW) of steel and GMAW of aluminum. I have seen resistance spot welding (RSW) of steel but do not fully understand the process. How does this process work, and can it be used for welding aluminum?

A: Resistance spot welding is one of a group of welding processes that rely on the resistance of metals to the flow of electrical current to produce the heat required for coalescence. The RSW process produces a localized weld spot between the metals being welded. This is achieved by clamping two, or sometimes more, pieces of material together between two copper electrodes, and then passing a current between the electrodes for a short period of time while the material is subjected to localized pressure — Fig. 1. The heat that is generated during this welding process is a result of the electrical resistance of the metals through which the electricity is passed. It is a fusion welding process because melting must occur at the interface between the joint members to cause coalescence, form a cast nugget, and join the members together.

Sectioned and polished resistance spot welds are shown in Figs. 2 and 3. Figure 2 shows an aerospace industry weld of very high quality made in a high-strength 2xxx series alloy, and Fig. 3 shows a commercial-quality spot weld in aluminum sheet that has some characteristic discontinuities.

We can now examine some of the advantages and disadvantages of the RSW process.

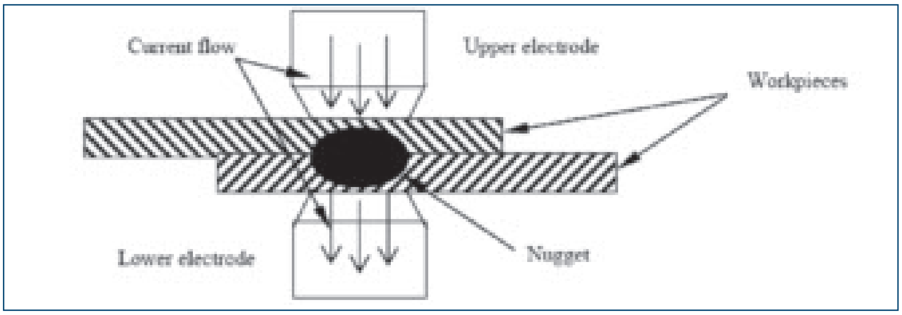

Fig. 1 — An illustration of the resistance spot welding process.

Advantages of RSW

- It is an automatic process that requires little operator training.
- It is commonly used for robotic applications.
- The potential for distortion is minimal.
- Welds are typically completed in a very short cycle time (less than 1 s).
- Welds can be conducted through lubricants, sealers, and structural adhesives.
- Weld location and spacing can be easily adjusted to provide the required joint strength.
- Almost all aluminum alloys are weldable.
- Weld appearance is generally consistent.
- No filler metal is required.

Disadvantages of RSW

- It is limited to lap joints.
- It requires access to both sides of the joint.
- The maximum size of a welded assembly is not unlimited.
- The process is not easily made portable.

Differences between RSW Aluminum and Steel

Aluminum can be welded very successfully with the RSW process; however, because of the differences in some of the physical properties of aluminum and steel, the procedures used to weld aluminum are somewhat different than those used for steel. The primary differences are discussed below.

Surface Oxide

When exposed to the atmosphere, aluminum oxidizes rapidly to form its characteristic oxide covering. With prolonged exposure to the atmosphere, the aluminum oxide increases in thickness progressively until the oxidation rate slowsdown substantially after about ten days.

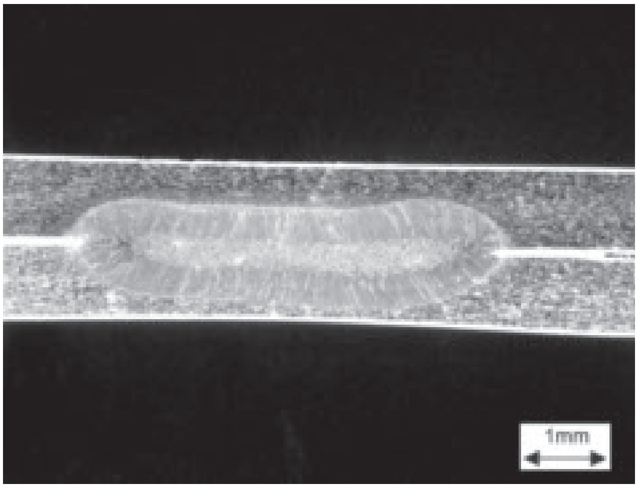

Fig. 2 — An aerospace-quality weld in 0.9 to 1.0 mm Alclad 2024 alloy. (Reproduced by permission, TWI Ltd.)

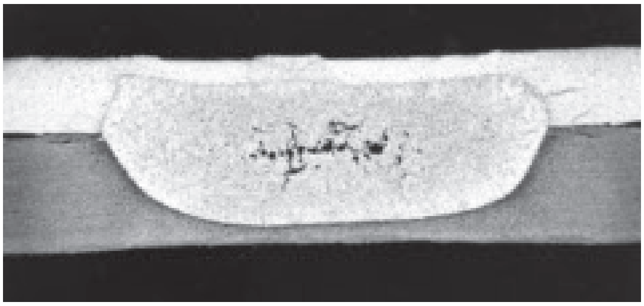

Fig. 3 — Commercial-quality spot weld in 2 mm 6082 to 1.2 mm 6016. (Reproduced by permission, TWI Ltd.) The shrinkage cracking within the center of this weld is not uncommon in commercial-quality aluminum spot welds, particularly in the more crack sensitive 6xxx series materials. These types of discontinuities in the center of the weld nugget do not dramatically reduce the weld's strength as the majority of the applied load to this type of joint is at the edges of the nugget. On testing, such a weld would normally fail by tearing out from the thin sheet, leaving a button the same diameter as the weld nugget on the other sheet.

Controlling the oxide surface on the aluminum is probably the most important single factor in producing consistently good resistance spot welds in aluminum. If the aluminum oxide is relatively thin, has a uniform electrical resistance at all points, and is consistent from part to part, then welding procedures can be developed to make consistently high-quality welds.

The condition of the aluminum oxide on the material to be welded may vary greatly due to the length and method of storage and/or the effects of prior fabrication procedures. For best results, the aluminum oxide should be removed from all surfaces prior to welding and the weld performed as soon as possible after oxide removal. This is particularly important for aircraft-quality welds. About one day is a practical limit for lapsed time between cleaning and welding to obtain high-quality welds.

Coefficient of Thermal Expansion

The coefficient of thermal expansion of aluminum is approximately twice that of steel. Consequently, aluminum alloys undergo greater expansion and contraction when going from a solid to a liquid and back to a solid state. These increased dimensional changes are greatest in the weld zone and can result in cracking of the nugget if the time interval is very short, or if the welding machine being used is not equipped to accommodate all of the physical characteristics of aluminum. Weld cracking and the stresses built up by metal shrinkage are eliminated or substantially reduced by features found in resistance welding machines designed for joining aluminum.

One of these is a welding head of low inertia and low friction, which permits the head to be moved quickly and with a high degree of control. It has been found that a quick, closely controlled increase in forging pressure, applied when the aluminum in the weld zone is cooling across its plastic range, helps to avert cracks or voids in the weld. Another pertinent feature is the use of current decay, which retards the cooling rate and thus lengthens the time over which the nugget freezes. Current decay makes the controlled application of forging pressure more effective and also relieves the rapid buildup of shrinkage stresses in the weld.

Thermal Conductivity

The thermal conductivity of aluminum and its alloys is approximately three times that of steel. Therefore, the rate of heat loss from the weld area is much greater in aluminum than steel. Since the amount of heat loss is also a function of time, it is especially advantageous that welding time be kept short in aluminum welding. Higher welding current and shorter welding time must be used to resistance weld aluminum when compared to steel.

Electrical Conductivity

Aluminum and its alloys have a much higher electrical conductivity than steel. Consequently, welding current is typically required to be three times that used for an equivalent gauge in steel. High electrical conductivity can also increase the potential for shunting, which is welding current by-passing or shunting through a previous weld instead of going through the surface contacts where the weld is being made. Care should be taken to compensate for shunting with increased current where necessary.

Electrode Wear

The copper that is used for the electrodes in spot welding can become alloyed with the aluminum surface leading to rapid electrode wear and deterioration of weld quality. Consequently, electrode life is generally shorter than when welding steel. Careful control of electrode condition and good water cooling are essential. The best results are obtained with very frequent light cleaning of the electrode tips to prevent significant build-up of an alloy layer.

Conclusion

The unique properties of aluminum typically require welding procedures and equipment that may have some special features. The equipment will deliver higher currents at lower weld times than for steel. However, once the physical differences of the material and the need for specific equipment are understood, excellent welds can be made by this process.◆

References

1. *Welding Aluminum Theory and Practice*. The Aluminum Association, Arlington, Va.

2. *Welding Kaiser Aluminum*. Oakland, Calif.

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.

LETTERS TO THE EDITOR

Reader Corrects Error in Aluminum Q&A Column

This letter is in reference to the Aluminum Q&A column that appeared in the October 2007 issue. Tony Anderson's response follows.

I was reading your article regarding laser beam welding of aluminum in the *Welding Journal* when I discovered a couple of inaccuracies. You incorrectly stated the wavelengths of the carbon dioxide laser as 10.6 mm and the YAG laser as 1.06 mm. The actual wavelengths are carbon dioxide 10,600 nm (0.0106 mm) and YAG 1064 nm (0.001064 mm).

Steven A. Kocheny
Applications Engineer
LEISTER Technologies, LLC
Itasca, Ill.

Thank you for identifying this technical error. The wavelengths should have been shown as 10.6 µm (microns) and not 10.6 mm (millimeters) for CO_2 *laser and 1.06 µm and not 1.06 mm for YAG laser. This, of course, is the same as 10,600 nm (nanometers) and 1064 nm for* CO_2 *and YAG laser, respectively.*

Tony Anderson

Reader Examines History of Filler Metals Article

This letter relates to The American Welder article, A Brief History of Filler Metals, in the October 2007 Welding Journal*. The author's response follows.*

I couldn't wait to read the article. I love the "history of welding" stuff you publish now and then.

But what a disappointment — I found some errors.

For example, Sir Humphry Davy did not discover arcs in 1800. That was the year batteries were discovered. It wasn't until 1809–1810 that the "Great Battery" of the Royal Institution was in full use. Davy's "electric arch" (hence the term "arc") between horizontal carbon electrodes was discovered when he broke a circuit while doing chemical experiments. At the time, the arc was referred to as a "voltaic flame." Only later was it called an arc.

Also, the inventor's name is "Benardos" not "Bernardo." I checked the original patent for the spelling.

Gas metal arc welding was not "perfected until 1948 at the Battelle Memorial Institute" as stated in the article. It was perfected at the laboratories of Airco, in Murray Hill, N.J., where the inventors were located. Some work was contracted to Battelle by Airco. (For more information see The Dawn of Gas Metal Arc Welding, *Welding Journal*, January 1990, all about Glenn Gibson, one of the inventors of GMAW.)

Airco also was the first developer of short circuit metal transfer with GMAW, now known as GMAW-S. They called it "dip transfer." Linde, a division of Union Carbide Corp., whose labs were close by in Newark, N.J., also worked with the process. Linde called it "short arc." When Hobart developed its equipment much later, they introduced the name "microwire."

Most of the early work of Airco and Linde was with argon-based mixtures with oxygen and carbon dioxide. The carbon dioxide version was developed in Europe because at the time, there wasn't much argon (remember, this was shortly after WW II). Now, everybody uses all the gases.

August F. Manz
AWS Fellow
Honorary Historian

Thank you for providing these additional details. As mentioned in the article's opening, history as a whole can indeed be vague and some records inexact. The history of welding and filler metals seems even more so.

Through the dedication of historians like yourself and accurate record keeping on everyone's part, we hope this century's welding advancements will be carefully preserved for future generations.

Many thanks for your comments.

Tim Hensley
Hobart Brothers Co.

CAN WE TALK?

The *Welding Journal* staff encourages an exchange of ideas with you, our readers. If you'd like to ask a question, share an idea or voice an opinion, you can call, write, e-mail or fax. Staff e-mail addresses are listed below, along with a guide to help you interact with the right person.

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AWS FELLOWSHIPS

To: Professors Engaged in Joining Research

Subject: **Request for Proposals for AWS Fellowships for the 2008-09 Academic Year**

The American Welding Society (AWS) seeks to foster university research in joining and to recognize outstanding faculty and student talent. We are again requesting your proposals for consideration by AWS.

It is expected that the winning researchers will take advantage of the opportunity to work with industry committees interested in the research topics and report work in progress.

Please note, there are important changes in the schedule which you must follow in order to enable the awards to be made in a timely fashion. Proposals must be received at American Welding Society by **February 15, 2008**. New AWS Fellowships will be announced at the AWS Annual Meeting, October 6-8, 2008.

THE AWARDS

The Fellowships or Grants are to be in amounts of up to $25,000 per year. A maximum of six students are funded for a period of up to three years of research at any one time. However, progress reports and requests for renewal must be submitted for the second and third years. Renewal by AWS will be contingent on demonstration of reasonable progress in the research or in graduate studies.

The AWS Fellowship is awarded to the student for graduate research toward a Masters or Ph.D. Degree under a sponsoring professor at a North American University. The qualifications of the Graduate Student are key elements to be considered in the award. The academic credentials, plans and research history (if any) of the student should be provided. **The student must prepare the proposal for the AWS Fellowship**. However, the proposal must be under the auspices of a professor and accompanied by one or more letters of recommendation from the sponsoring professor or others acquainted with the student's technical capabilities. Topics for the AWS Fellowship may span the full range of the joining industry. Should the student selected by AWS be unable to accept the Fellowship or continue with the research at any time during the period of the award, the award will be forfeited and no (further) funding provided by AWS. The bulk of AWS funding should be for student support. AWS reserves the right not to make awards in the event that its Committee finds all candidates unsatisfactory.

DETAILS

The Proposal should include:

1. Executive Summary
2. Annualized Breakdown of Funding Required and Purpose of Funds (Student Salary, Tuition, etc.)
3. Matching Funding or Other Support for Intended Research
4. Duration of Project
5. Statement of Problem and Objectives
6. Current Status of Relevant Research
7. Technical Plan of Action
8. Qualifications of Researchers
9. Pertinent Literature References and Related Publications
10. Special Equipment Required and Availability
11. Statement of Critical Issues Which Will Influence Success or Failure of Research

In addition, the proposal must include:

1. Student's Academic History, Resume and Transcript
2. Recommendation(s) Indicating Qualifications for Research
3. Brief Section or Commentary on Importance of Research to the Welding Community and to AWS, Including Technical Merit, National Need, Long Term Benefits, etc.
4. Statement Regarding Probability of Success

The technical portion of the Proposal should be about ten typewritten pages; maximum pages for the Proposal should be twenty-five typewritten pages. Maximum file size should be 2 megabytes. It is recommended that the Proposal be typed in a minimum of 12-point font in Times, Times New Roman, or equivalent. Proposal should be sent electronically by **February 15, 2008** to:

Vicki Pinsky (vpinsky@aws.org)
Manager, AWS Foundation
American Welding Society
550 N.W. LeJeune Rd., Miami, FL 33126

Yours sincerely,

Ray W. Shook
Executive Director
American Welding Society

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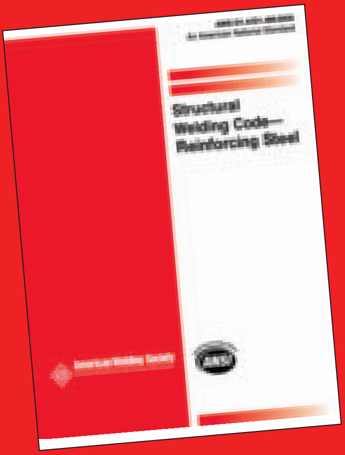
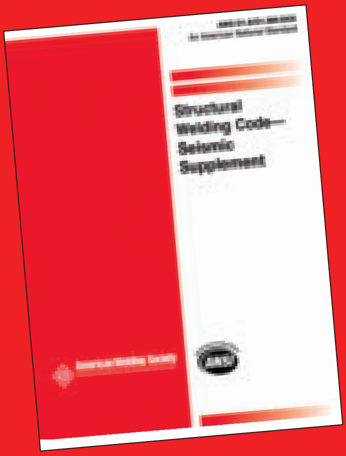
2008 EDITION AVAILABLE SOON! *AWS D1.3/ D1.3M:2008 Structural Welding Code—Sheet Steel*, among other things, defines the allowable capacities used in sheet steel applications in which the transfer of calculated load occurs.



AWS D1.4/D1.4M:2005 Structural Welding Code—Reinforcing Steel covers the requirements for welding reinforcing steel in most reinforced concrete applications.

2008 EDITION AVAILABLE SOON! *AWS D1.5/D1.5M:2008 Bridge Welding Code* covers welding requirements of the American Association of State Highway and Transportation Officials (AASHTO) for welded highway bridges.

2007 EDITION! *AWS D1.6/ D1.6M:2007 Structural Welding Code—Stainless Steel* covers requirements for welding stainless steel assemblies and components (excluding pressure vessels and piping).



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

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BY R. L. PEASLEE

Q: We are brazing 304L, in vacuum, with BNi-9 brazing filler metal. How do we determine the proper clearance (gap) for a brazed joint?

A: The first place to look is the *Brazing Handbook,* chapter 2, Brazement Design. It includes most of the brazed joint design requirements, including a table of recommended joint clearances (gaps) (Table 2.1). There are many variables to consider when designing a brazed joint.

I normally recommend a minimum of a 0.001 to 0.002 in. (0.025 to 0.051 mm) clearance. When getting smaller, the length of the joint enters the picture, as well as the brazing atmosphere quality, mutual solubility between filler metal and base metal, and many other variables. Some of these critical variables are as follows:

Brazing Clearance vs. Joint Length. When brazing a base metal that is mutually soluble with the brazing filler metal, some of the base metal will be dissolved by the filler metal as it travels through the joint, and this will change the filler metal chemistry and melting temperature. When the joint is too long, the filler metal picks up enough base metal to solidify the filler metal and stop its progression in the joint. From my experience with a zero joint clearance, some test specimens braze fully, but many fall apart during machining, or only have a partial joint — not good uniformity.

Table 2.1 — Recommended Joint Clearance at Brazing Temperature

Filler Metal AWS Classification	Joint Clearance*, in.
BAlSi group	0.000–0.002 for furnace brazing in a vacuum atmosphere and clad brazing sheet in salt bath 0.002–0.008 for length of lap less than 0.25 in. 0.008–0.010 for length of lap greater than 0.25 in.
BCuP group	0.001–0.005 no flux and for flux brazing for joint length under 1 in. 0.007–0.015 no flux and for flux brazing for joint length greater than 1 in.
BAg group	0.002–0.005 flux brazing 0.000–0.002 **atmosphere brazing
BAu group	0.002–0.005 flux brazing 0.000–0.002 **atmosphere brazing
BCu group	0.000–0.002 **atmosphere brazing
BCuZn group	0.002–0.005 flux brazing
BMg	0.004–0.010 flux brazing
BNi group	0.002–0.005 general applications (flux/atmosphere) 0.000–0.002 free-flowing types, atmosphere brazing

*Clearance is measured on the radius when rings, plugs, or tubular members are involved. On some applications it may be necessary to use the recommended clearance on the diameter to assure not having excessive clearance when all the clearance is on one side. An excessive clearance will produce voids. This is particularly true when brazing is accomplished in a high quality atmosphere.
**For maximum strength a press fit of 0.001 in. per in. of diameter should be used.

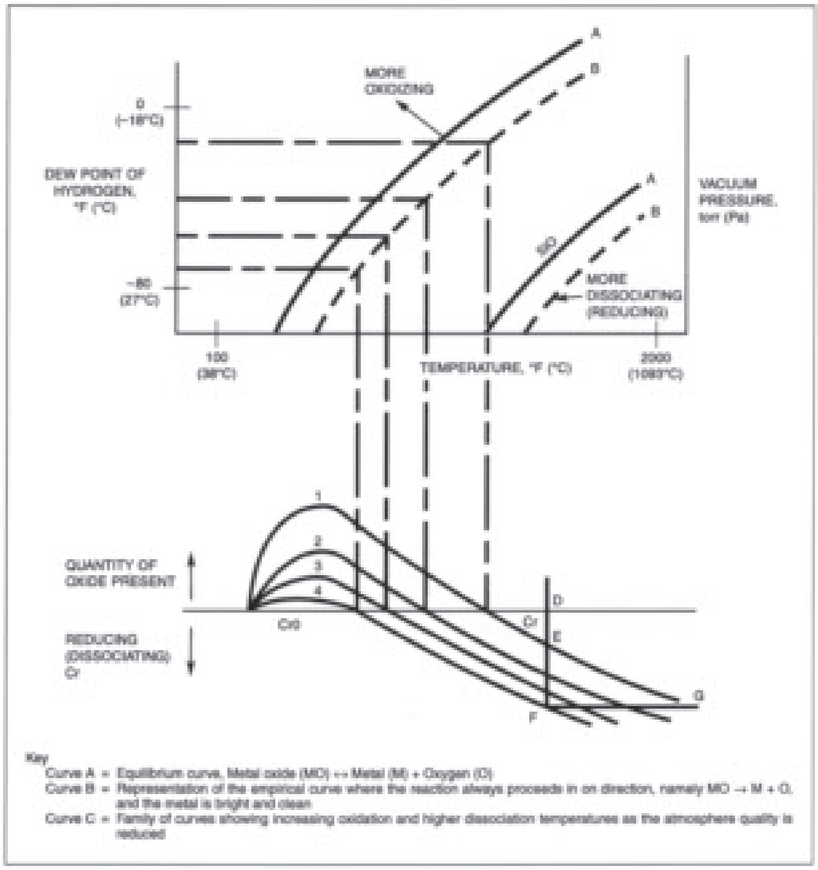
Brazing Clearance vs. Brazing Atmosphere. In all vacuum furnaces, the temperature range of 1000° to 1700°F (550° to 925°C) is oxidizing to the chromium, boron, silicon, and phosphorus that are found in most of the nickel brazing filler metals. While the vacuum gauge is a good starting point, it does not tell the entire story. To obtain more information, use the "T" Specimen. There is an Engineering Data Sheet on the "T" Specimen, which can be downloaded from the Wall Colmonoy Web site, *www.wallcolmonoy.com.* This sheet has a listing of some of the nickel-based brazing filler metals and their varying degrees of sensitivity to the brazing atmosphere.

I have seen vacuum atmospheres of 10^{-6} torr that were not suitable for some nickel-based brazing filler metals, while a vacuum of 10^{-3} torr was very good for the same atmosphere-sensitive filler metal. As the vacuum atmosphere degrades, it takes longer for the oxides of chromium to dissociate, and the base metal and filler metal to clean up and be receptive to the flow of the brazing filler metal — Fig. 4.3 from the soon to be released *Brazing Handbook,* 5th edition.

When boron oxidizes in the vacuum furnace, it vaporizes and is removed from the brazing filler metal, and this changes the melting and flow temperatures. Therefore, the condition of the vacuum brazing furnace atmosphere has a profound effect on the brazing quality. This is particularly true when brazing close to, or in, the solidus-liquidus range that occurs in brazing diamonds to dressing wheels.

Brazing Clearance vs. Metallic-Grit Blasting. When clearances are small, the above two items have a profound effect on the brazing. One way we have found to ensure good flow below 0.001 in. (0.025 mm) clearance and down to 0.000 clearance, when larger clearances are recommended, is to blast with a special Ni-Cr-B-Fe grit that puts a compressive stress in the surface of the metal. This compressive stress pulls the brazing filler metal through a 0.000 clearance and ensures a completely brazed joint. Caution must be used when blasting thin base metal as the base metal will distort from the induced surface stress.

Not too long ago, a very thorough program was used to test many of the blasting materials, and it was found that the special Ni-Cr-B-Fe grit was the best at improving the wetting and flow of the brazing filler metal. Primarily, this test program looked at using the Ni-Cr-B-Fe to eliminate the nickel plating required to



Source O'Brien, R. L., ed., 1991, *Welding Processes*, Vol. 2 of Welding Handbook, 8th ed., Miami: American Welding Society, Figure 12.17.

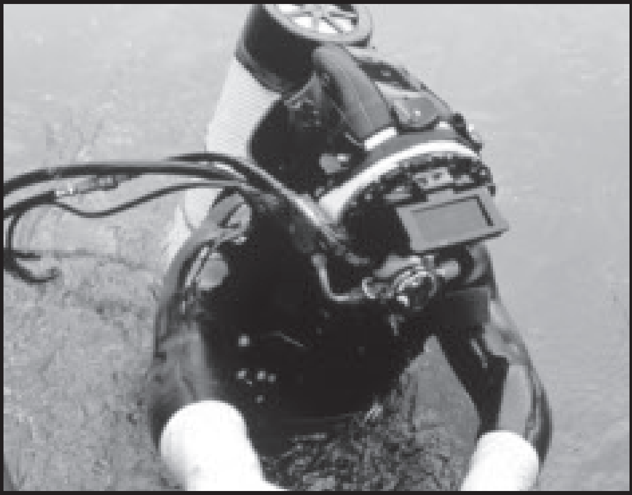
Figure 4.3—Effect of Varying Atmosphere Quality on the Degree of Oxidation and Dissociation of Chromium-Chromium Oxide in a Chromium-Containing Base Metal

braze Alloy 718 that contains low levels of aluminum and titanium. The paper, The High-Temperature Wetting Balance and the Influence of Grit Blasting on Brazing of IN718, was published in the October 2003 *Welding Journal*, pp. 278-s to 287-s.

The flow with zero clearance has many variables to control. As mentioned above, Ni-Cr-B-Fe grit blasting will improve the odds of having good flow through the joint. This assumes that there are no drawing compounds or other surface contaminants, and that the base metal was not processed in a nitrogen-rich atmosphere, which would nitride the boron in the filler metal during brazing, thus stopping all flow. Many of these things have happened over the years that have caused variations in the brazing process.

I suggest using the 0.001 to 0.002 in. (0.025 to 0.051 mm) clearance, as it hides a multitude of problems that may show up at smaller clearances with BNi-9 and others. With the smaller clearances, many more variables will have to be identified and controlled.♦

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



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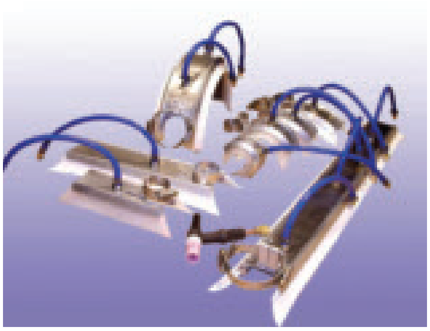

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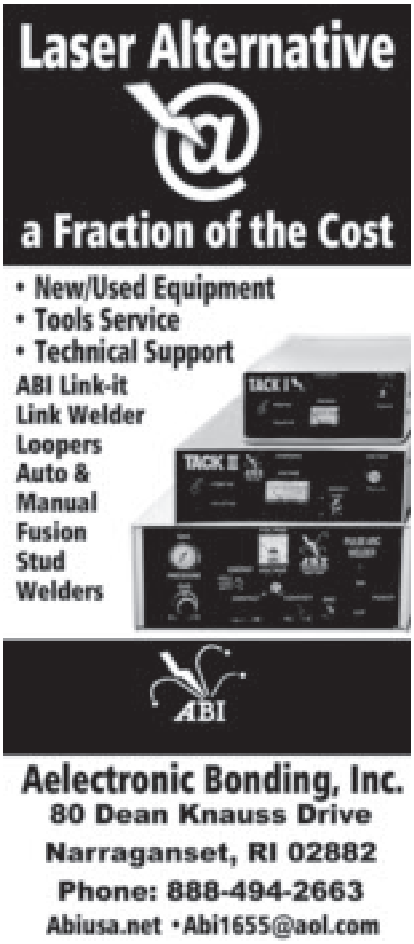

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— continued on page 73

Titanium Welding 101: Best GTA Practices

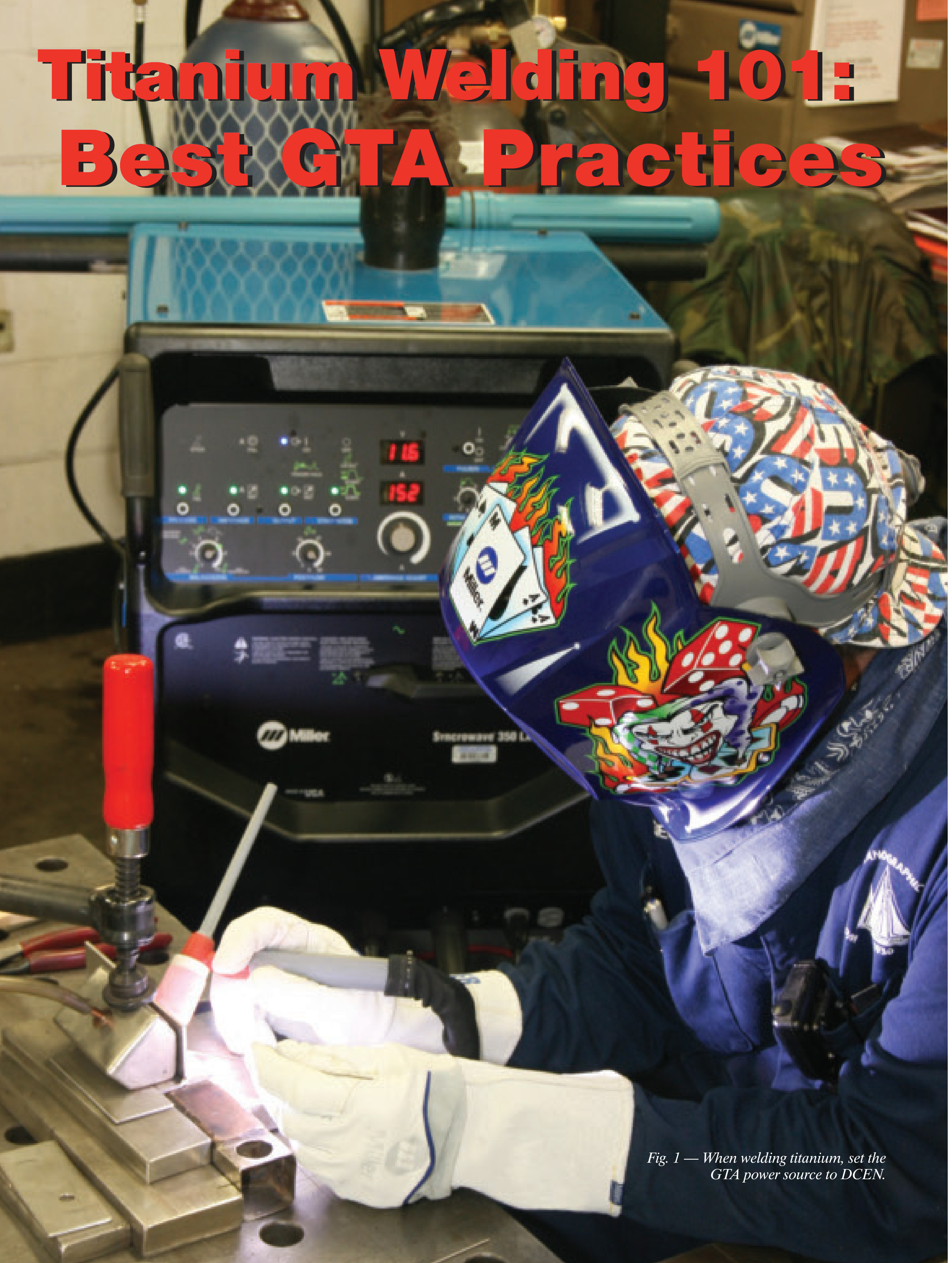

Fig. 1 — When welding titanium, set the GTA power source to DCEN.

Use the following tips to help you produce the highest quality gas tungsten arc welds on titanium

BY JOHN LUCK AND JACK FULCER

Pretty colors are fine for titanium jewelry. However, the colors blue, violet, green, gray, and white indicate atmospheric contamination in a gas tungsten arc (GTA) welded titanium component. In critical applications, welds exhibiting such colors may suffer reduced strength and loss of ductility and could (or must) be rejected.

Responsible fabricators owe it to their customers and themselves to produce welds that meet standards such as those outlined in AWS D1.9, *Structural Welding Code — Titanium*, as well as their own high standards. This article provides an introduction to titanium and the GTAW process, focuses on best practices, and outlines common pitfalls. It is especially written with smaller companies in mind, as they perform the bulk of GTA welding.

About Titanium

Titanium and its alloys offer excellent corrosion resistance to acids, chlorides, and salt; a wide continuous service temperature range, from –322°F (liquid nitrogen) to 1100°F; and the highest strength-to-weight ratio of any metal.

For example, the most widely used grade of titanium alloy, ASTM Grade 5 (Ti-6Al-4V), has a yield strength of 120,000 lb/in.^{2} and a density of 282 lb/ft^3. In comparison, ASTM A36 steel has a yield strength of 36,000 lb/in.^{2} and a density of 487 lb/ft^3, while 6061-T6 aluminum has a yield strength of 39,900 lb/in.^{2} and density of 169 lb/ft^3.

In short, titanium is about 45% lighter than steel, 60% heavier than aluminum, and more than three times stronger than either of them. While expensive initially, titanium lowers life cycle costs because of its long service life and reduced (or nonexistent) maintenance and repair costs. For example, the Navy replaced copper-nickel with titanium for seawater piping systems on its LDP-17 San Antonio Class of ships because it expects titanium to last the entire 40 to 50 year life of the ship.

In addition to military applications, other common uses for this light, strong, and corrosion-resistant metal include those for aerospace, marine, chemical plants, process plants, power generation, oil and gas extraction, medical, and sports.

Shielding Gas Is Critical

Titanium falls into a family of metals called reactive metals, which means that they have a strong affinity for oxygen. At room temperature, titanium reacts with oxygen to form titanium dioxide. This passive, impervious coating resists further interaction with the surrounding atmosphere, and gives titanium its famous corrosion resistance. The oxide layer must be removed prior to welding because it melts at a much higher temperature than the base metal and because the oxide could enter the molten weld pool, create discontinuities, and reduce weld integrity.

When heated, titanium becomes highly reactive and readily combines with oxygen, nitrogen, hydrogen, and carbon to form oxides (titanium's famous colors actually come from varying thicknesses of the oxide layer). Interstitial absorption of these oxides embrittles the weldment and may render the part useless. For these reasons, all parts of the heat-affected zone (HAZ) must be shielded from the atmosphere until the temperature drops below 800°F (note: experts disagree on the exact temperature, with recommendations ranging from 500° to 1000°F. Use 800°F as a reasonable median unless procedures, standards, or codes indicate otherwise).

One of the most common mistakes when welding titanium is not verifying the many variables that contribute to good shielding gas coverage prior to striking the first arc. Make it a practice to always weld on a test piece before beginning each "real" welding session. To ensure that gas purity meets your requirements, AWS recommends using analytical equipment to measure shielding gas purity prior to welding. Gas purity varies by application. Typical specifications require that the shielding gas (typically argon) be not less than 99.995% pure with not more than 5 to 20 ppm free oxygen and have a dew point better than –50° to –76°F.

Clean, Clean, Clean

Contamination from oil on your fingers, lubricants, cutting fluid, paint, dirt, and many other substances also causes embrittlement, and is a leading cause of weld failure. When working with titanium, follow the three Cs of welding: clean, clean, clean. Keep a clean work area, one free from dust, debris, and excess air movement that could interfere with the shielding gas. Clean the base metal and bag parts not immediately welded, clean the filler rod, and wear nitrile gloves when handling the filler rod and parts.

Welding Advice

ASTM International recognizes 31 grades of titanium. Different grades address the need for various combinations of mechanical properties, corrosion resistance, formability, ease of fabrication, and weldability. While the various properties of these grades can be somewhat overwhelming (see the boxed item for a brief explanation), the welding of titanium is relatively similar to other alloy metals.

The following images and advice demonstrate the basic best practices for welding titanium, expanding on the information given previously.

A standard GTA power source with high-frequency arc starting, remote am-

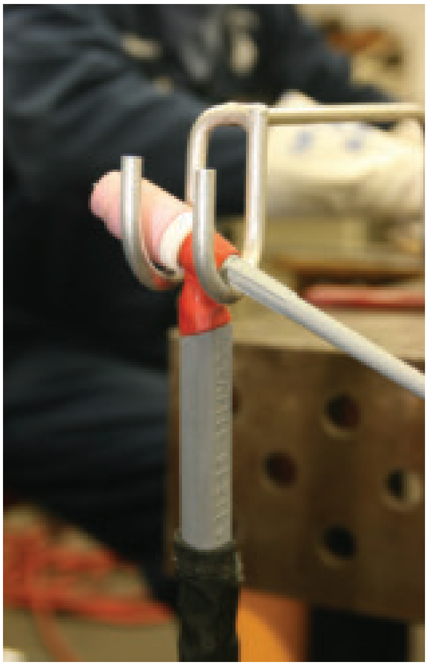

Fig. 2 — GTA torch and home-fabricated holder.

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perage control capabilities, a postflow shielding gas timer, and an output of at least 250 A will work well for welding titanium — Fig. 1. Set polarity to DCEN (straight polarity).

Gas tungsten arc torches can be air or water cooled, depending on equipment preference, as most welds will be short and at lower output levels. Water-cooled torches are smaller, more maneuverable, and permit welding at higher amperages for extended periods, while air-cooled torches cost less. Notice the home-fabricated torch holder, which keeps the torch from falling on the floor — Fig. 2.

For welding titanium, use a 2%-ceriated tungsten electrode sized to carry the required welding current: 1⁄16 in. or smaller for welding at <125 A; 1⁄16 to 3⁄32 in. for 125 to 200 A; and 3⁄32 or 1⁄8 in. for welding >200 A. Use a gas lens (Fig. 3) to evenly distribute the gas and create a smooth gas flow, and use a cup with a diameter of at least ¾ to 1 in. A larger cup will enable you to make a longer weld.

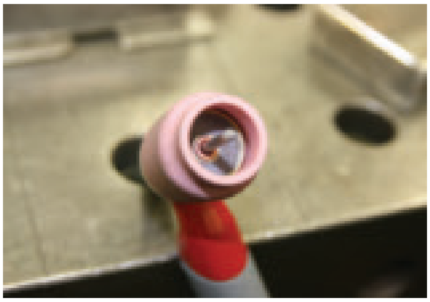

Fig. 3 — GTA torch consumables.

A trailing shield such as the one shown in Fig. 4 extends the length of the weldment compared to a lesser length when welding with a cup alone. It is constructed similarly to the purge blocks (commercial shields are also available). Notice that the electrode is extended longer than the norm, which is only advisable when using trailing shields or oversized cups, as they provide extended gas coverage. Normally, the electrode should extend just far enough to permit visibility and access to the joint, or about 1½ times the diameter of the electrode.

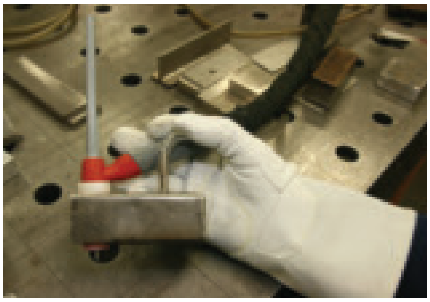

Fig. 4 — Trailing shield.

To provide shielding gas coverage on the back and bottom sides of a joint, most facilities custom fabricate their own purge blocks from porous copper sheet and stainless steel — Fig. 5. The porous copper acts like a gas lens, evenly distributing the gas. To further smooth gas flow, the blocks are filled with stainless steel wool. Set the gas flow at 10 ft^3/h for the purge blocks and trailing shield. Use 20 ft^3/h for the torch.

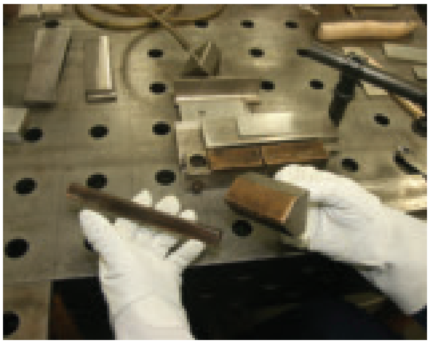

Fig. 5 — Purge blocks.

When awkward joints preclude the use of standard purge blocks, welders fabricate shielding gas dams or chambers using stainless steel foil and fiberglass tape — Fig. 6. To ensure purity, a rule of thumb is that the gas must flow long enough to exchange the gas inside the chamber ten times prior to welding.

Fig. 6 — Home-built dams.

For demanding applications and where complex parts need to be welded, consider a vacuum-assisted welding chamber. The model shown in Fig. 7 utilizes a steel riser with glove ports and features a hemispherical, Plexiglas® dome for viewing. After loading parts, a vacuum pump quickly removes the air, and the chamber is then filled with inert gas for welding.

Fig. 7 — Welding chamber.

This gas manifold system (Fig. 8) distributes shielding gas to the torch and all purge blocks using separate gas lines; notice the use of surgical grade tubing for quality purposes. Because moisture content rises as cylinder pressure drops, consider switching cylinders when the pressure reaches about 25 bar.

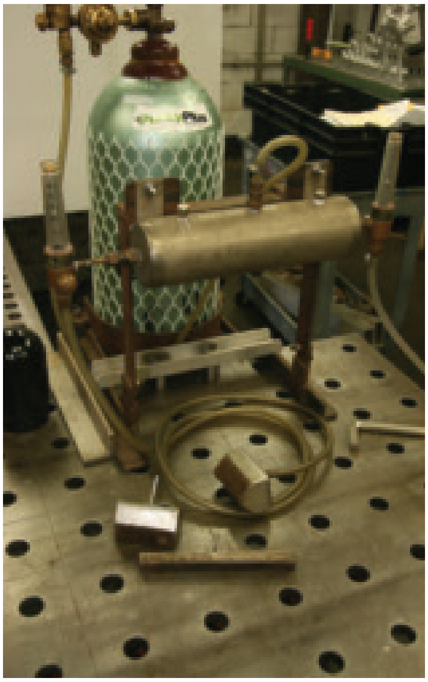

Fig. 8 — Gas manifold.

First, select the appropriate filler rod to match the material grade (Table 1). Then, use a lint-free cloth and acetone or methyl ethyl ketone (MEK) to clean the filler rod just prior to welding — Fig. 9. (After cleaning, store the acetone in a safe place prior to welding. Also, read the manufacturer's safety precautions.) To prevent the body's natural oils from contaminating the filler rod or base metal, always wear nitrile gloves when handling titanium.

Table 1 — Recommended Titanium Filler Metal Alloys

Base Filler	AWS A5.16 ERTi-2	AWS A5.16 ERTi-2	AWS A5.16 ERTi-3	AWS A5.16 ERTi-5	AWS A5.16 ERTi-9 and ERTi-9ELI	AWS A5.16 ERTi-23
Grade 1 (CP-1, or commercially pure)	X					
Grade 2 (CP-2)	X	X				
Grade 3 (CP-3)			X		X	
Grade 9 (Ti-3Al-2.5V)						
Grade 5 (Ti-6Al-4V)				X		X
Grade 23 (Ti-6Al-4V) ELI (extra low interstitial)						X

Fig. 9 — Clean the filler rod.

To prevent contaminants from entering the weld pool via the filler rod (notice the discoloration on the end of the rod), clip off the end of the filler rod before every use — Fig. 10. Store the filler rods in an airtight container when not in use.

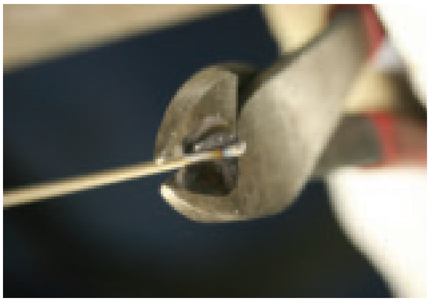

Fig. 10 — Clip rod end.

To break down the oxide layer prior to welding, use a die grinder with a carbide deburring tool to prep the edges of the joint — Fig. 11. Do not use the tool for anything else except titanium. Follow mechanical cleaning by cleaning with a lint-free cloth and acetone or MEK.

Fig. 11 — Deburring tool.

A carbide file — dedicated to titanium — may also be used to prepare the joint — Fig. 12. Note the nitrile gloves, which are worn to prevent contamination. Simply wear welding gloves over the nitrile gloves to prevent accidentally handling clean titanium with bare hands.

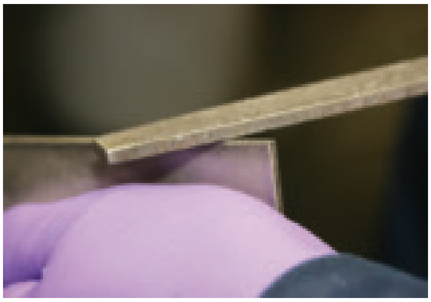

Fig. 12 — Carbide file.

To hold the purge blocks in place while welding, consider a fixture/clamp arrangement like the one shown in Fig. 13. The holes in the welding table allow weldments and purge blocks to be clamped in a wide variety of positions.

Fig. 13 — Fixtures.

Notice the variety of stainless steel blocks and shims used to position and balance the purge blocks. The holes in the welding table make it much easier to position the purge blocks, as it permits access for the gas lines from the bottom side — Fig. 14.

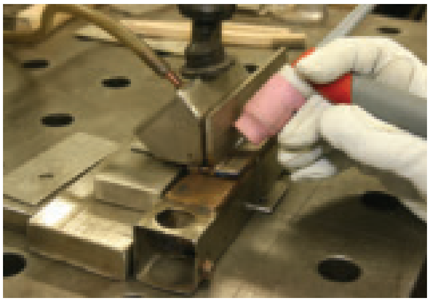

Fig. 14 — Weldment positioning.

Common Grades of Titanium

Titanium is divided into four classes: commercially pure (CP or unalloyed), alpha, alpha-beta, and beta. Note that many companies and experts treat CP and alpha alloys as one group. The “alpha” and “beta” refer to phases of the metal’s crystalline structure at various temperatures. Adding oxygen, iron, aluminum, vanadium, and other elements to the alloy can precisely control the crystal structure, and hence the alloy’s properties.

The most common CP grades are ASTM Grades 1, 2, 3, and 4. They differ by the varying degrees of oxygen and iron content; greater amounts of these elements increase tensile strength and lower ductility. Grade 2 is the most widely used, notably in corrosion-resistant applications. CP grades have good ductility, good elevated-temperature strengths to 572°F, and excellent weldability. They cost less than alloyed grades, but have a relatively low tensile strength, such as 70,000 to 90,000 lb/in.^{2} for Grade 2.

Grade 5 (Ti-6Al-4V), an alpha-beta, is the most widely used of any grade of titanium (50 to 70% of all uses, according to various sources). The addition of aluminum and vanadium increases tensile strength to 120,000 lb/in.^{2} and service temperature up to 752°F, but it also makes Grade 5 less formable and slightly harder to weld than Grade 2. It is used for a range of applications in the aerospace, marine, power generation, and offshore industries.

Grade 23 is similar to Grade 5, but features reduced oxygen content that improves ductility and fracture toughness with just a slight loss of strength. Grade 9 strengths fall between Grades 4 and 5, so it is sometimes referred to as a “half 6-4.” Grade 9 can be used at higher temperatures than Grade 4, offers 20 to 50% higher strength than commercially pure grades, and is more formable and weldable than Grade 5.

Use a stainless steel brush — dedicated for this one purpose — to remove any impurities (e.g., light oxide coating) that may develop before continuing to weld — Fig. 15. If welds require visual inspection for QA/QC purposes, omit this step. Note that the bead length is just about 1 in. Short beads minimize heat input and ensure that the bead won’t “outrun” its shielding gas coverage.

Fig. 15 — Cleaning.

After turning off the arc, hold the torch in position so that the postflow shielding gas continues to cool the weldment until its temperature drops below 800°F — Fig. 16. Postflow duration will vary by the mass of the weldment, size of the weld, and total heat input (postflow was set at 20 s for the weld shown here).

Fig. 16 — Postflow.

To keep interpass temperatures below the critical 800°F threshold, use an infrared temperature gauge — Fig. 17. Also, weld at the lowest amperage level that still produces complete fusion. Finally, do not travel too quickly, as that is a leading cause of porosity and weld failure.

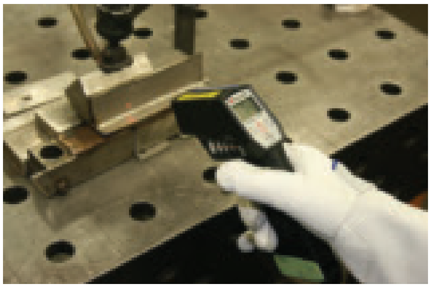

Fig. 17 — Temperature gauge.

The front and bottom of the weld, which were properly shielded, show no evidence of contamination — Fig. 18. To demonstrate the importance of shielding all sides of a weldment, the purge block was intentionally removed from the backside of this fillet weld and two welds approximately ¾ to 1 in. long were made.

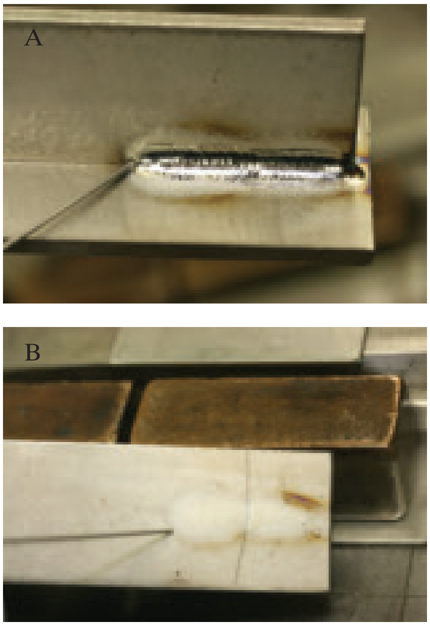

Fig. 18 — No contamination is visible in this weld because it was properly shielded. A — The front of the weld; B — bottom of the weld.

The back of the weld shown in Fig. 19 indicates a completely unacceptable weld. Note the progressive degree of contamination, with the “chalky dust” showing extreme contamination. The weld cracked internally with an audible “tink” after cooling for about 90 s. Welds with such contamination may not be repaired: scrap the entire part or cut out and completely remove the contaminated section.

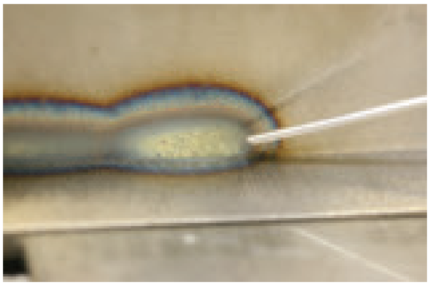

Fig. 19 — A weld showing contamination.

When adding filler rod, be sure the rod end stays within the shielding gas envelope — Fig. 20. Use a dab technique to lower overall heat input (as opposed to leaving the rod end in the weld pool, which increases the mass of metal and total heat necessary to melt it).

Fig. 20 — Adding filler.

The color of a titanium weld indicates varying degrees of oxide thickness, or the degree to which the shielding gas failed to protect the weld from contaminants during the welding process — Fig. 21. Note that color is just one means of judging weld quality; dye penetrant inspection, hardness testing, X-ray, ultrasonic testing, and destructive tests may also be necessary to confirm acceptable quality. Table 5.3 in AWS D1.9 (which appears here in modified form as Table 2) provides direction for judging weld quality. ◆

Fig. 21 — The color of a titanium weld indicates quality.

Table 2 — Color Acceptance Criteria

Weld Color	Quality Indication
Bright Silver	Acceptable$^{(a)}$
Silver	Acceptable$^{(a)}$
Light Straw	Acceptable$^{(a)}$
Dark Straw	Acceptable$^{(a)}$
Bronze	Acceptable$^{(a)}$
Brown	Acceptable$^{(a)}$
Violet	Unacceptable$^{(b, c)}$
Dark Blue	Unacceptable$^{(b, c)}$
Light Blue	Unacceptable$^{(b, c)}$
Green	Unacceptable$^{(b, c)}$
Gray	Unacceptable
White	Unacceptable

(a) Discoloration must be removed prior to additional welding.
(b) On the weld and in the HAZ up to 0.03 in. beyond the weld.
(c) Violet, blue, and green discolorations are rejectable if additional welding is to be performed. Blue and green discolorations are acceptable on finished welds but must be removed prior to subsequent processing.

Note: Discoloration comes in various shades, hues, and tones.

Acknowledgments

The authors would like to acknowledge the significant contributions to this article made by two people. Geoff Ekblaw has more than 40 years of experience (and the patience to pose for the photos in this article). He is the senior welder at Woods Hole Oceanographic Institution, a private, independent organization in Falmouth, Mass., dedicated to marine research, engineering, and higher education. Jody Collier is an AWS Senior Certified Welding Inspector and instructor/developer, Welding Training/Certification with Delta Air Lines Technical Operations Center in Atlanta, Ga.

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Fifty Years of Nonvacuum Electron Beam Welding

The nonvacuum EB process is capable of satisfying a variety of applications, including complex-shaped parts

BY DONALD E. POWERS

The nonvacuum electron beam welding process has been used to do commercial joining applications for upward of five decades now, and over this more than 50-year time span has repeatedly shown itself to be a rugged and reliable production tool. The present primary concept of utilizing a differentially pumped, multistage vacuum scheme as the method for both generating the beam under high-vacuum conditions and transmitting it out into the atmosphere was initially proposed in 1953 (Ref. 1), and subsequently demonstrated in 1954 in Germany. Since that time, the experience gained from an ever-increasing use of the process has allowed today's manufacturers of nonvacuum EBW units to supply equipment with both functional capability and operating flexibility.

In nonvacuum electron beam welding (NVEBW), which was initially called both "atmospheric electron beam" (AEB) welding and "workpiece out of vacuum" (WPOV) electron beam welding, a high-energy stream of electrons produced under vacuum is employed to bombard a target located under atmospheric conditions. This ability to apply an electron beam directly in atmosphere, rather than placing its target component in a vacuum environment as required with vacuum EB processing (Fig. 1), not only enhances the EB process's capacity for satisfying applications demanding high-volume production rates, but also its capability to address the welding of both large and 3-D-shaped parts.

Early Uses of the Process

Initial efforts at utilizing the NVEBW process for high-volume applications were directed at continuously welded tubing at very high speeds. Thus, by the mid-1960s, a number of NVEBW units were being supplied to tube mills. These units produced the closure weld on tubing that was being continuously formed out of flat strip at speeds approaching 100 ft/min when doing comparatively thin-wall type tubing. These speeds were much faster than those achievable with more conventional joining methods being employed at that time. Toward the late 1960s, the process was adopted for welding discrete tube sections for the automotive industry, specifically the outer tube portion of Saginaw Steering Gear's collapsible steering column assembly. For this application, a carousel or a "merry-go-round" type of part transfer device was used to pass the tubular segments under the beam. This setup provided the capacity to produce 600 to 800 welded tubes per hour off each unit. Thus the three NVEBW systems initially supplied for doing this particular joining task were able to provide a total hourly part-production capability of 1800 to 2400 parts/h. In the late 1960s, the process began to be widely accepted by the automotive industry for welding a broad range of sizes, shapes, and material composition components for use in both passenger and heavy-duty (trucks and buses) style vehicles (Refs. 2–4).

Process Description

A differentially pumped nonvacuum EBW gun/column assembly consists of a high-vacuum beam generation section (where a triode-style gun is used to generate the electron beam), and a series of separately pumped vacuum stages that provide the beam a graded vacuum-to-atmospheric pressure path to travel in. Thus, when the beam is generated, it travels down through a series of increasing pressure stages, connected in tandem by a set of concentrically aligned orifices, and out into the surrounding atmosphere. Electromagnetic focusing and deflection coils, positioned along the beam's travel path, help ensure the beam passes cleanly through this series of orifices it encounters while making its journey from high vacuum to atmospheric pressure.

Although some random collisions will occur between electrons in the beam and the residual gas molecules in the column as the beam travels down through the col-

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umn, they don't result in the beam electrons suffering much, if any, energy loss or deviation in travel path direction during their passage down through the column structure. Greater than 90% of the beam power being generated by the electron gun is delivered out into the atmosphere; consequently, the overall (total "wallplug-to-workpiece") energy conversion efficiency capability of a nonvacuum EBW system generally exceeds 60% — a value equal to or greater than most conventional welding, and much greater than various other power beam joining methods.

Once the beam exits the last column orifice, however, and enters the ambient atmosphere region, the frequency of collisions between beam electrons and ambient gas molecules increases appreciably. Although these collisions don't greatly impact the energy of the beam electrons themselves, they do cause the beam's core diameter to increase, and thus its power density to decrease, with distance traveled out into the ambient atmosphere. Additionally, it produces a much greater overall "beam glow" envelope, as illustrated in Fig. 2. In order to help reduce the impact of this type of normal beam scattering occurrence, a helium-blowdown style exit orifice may be utilized. This style of exit orifice provides a helium effluent, which exits the orifice coaxial with the beam. As such, it provides a lower (than ambient) density gas channel for the beam to temporarily travel in, thereby allowing a greater than normal "standoff distance" (the distance measured from the bottom of exit orifice to the top of workpiece) to be achieved.

The differentially pumped NVEBW gun/column assembly is approximately 18 in. in cross section, roughly 40 in. in length and weighs on the order of 1000 lb (when complete with any radiation shielding that might be required). This present-day assembly is designed to be able to operate mounted in any attitude ranging from fully vertical to fully horizontal and to be capable of travel motion during operation. It is additionally designed to perform reliably under adverse operating conditions. It should be noted that over the years, a variety of methods have been investigated for transferring an electron beam from vacuum into atmosphere; however, in most all cases, these schemes have generally proven to be far too sophisticated for commercial application usage under the standard operating conditions normally encountered in the majority of high-volume part throughput operations.

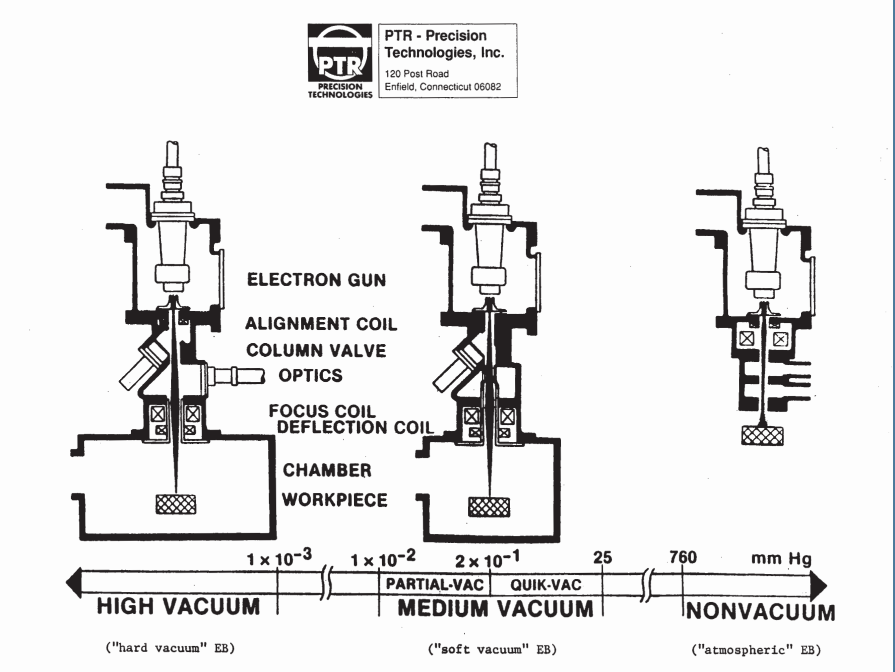

Fig. 1 — Various modes of operation in electron beam welding.

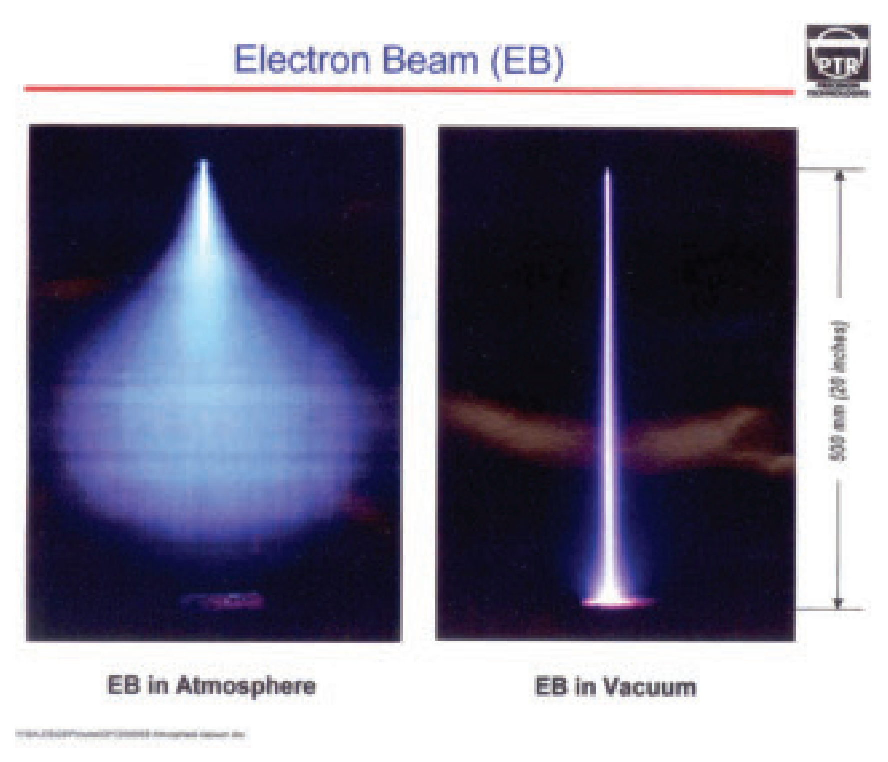

Fig. 2 — Beam glow profiles produced by an in-vacuum and out-of-vacuum electron beam.

Applications for NVEBW

The steering column jacket units previously described were followed by two high-volume production automotive applications: the A. O. Smith "blank" welding units and the GM Powertrain Div. torque converter; the latter application resulted in 20 NVEBW systems being put into production from 1970 to 1995. A number of these units are still being utilized in production today (Ref. 5).

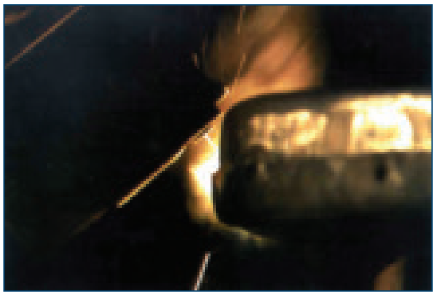

Fig. 3 — View of a NVEBW beam producing a 45-deg angled fillet weld.

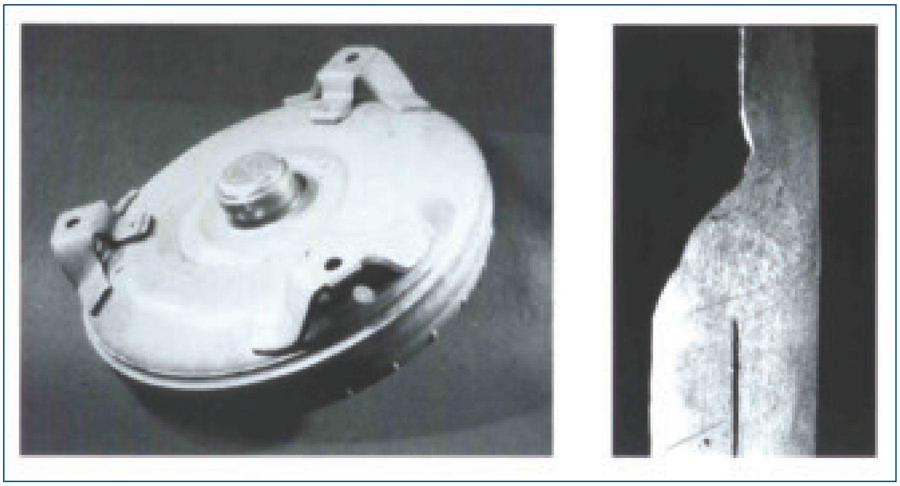

Fig. 4 — Nonvacuum EB welded torque converter.

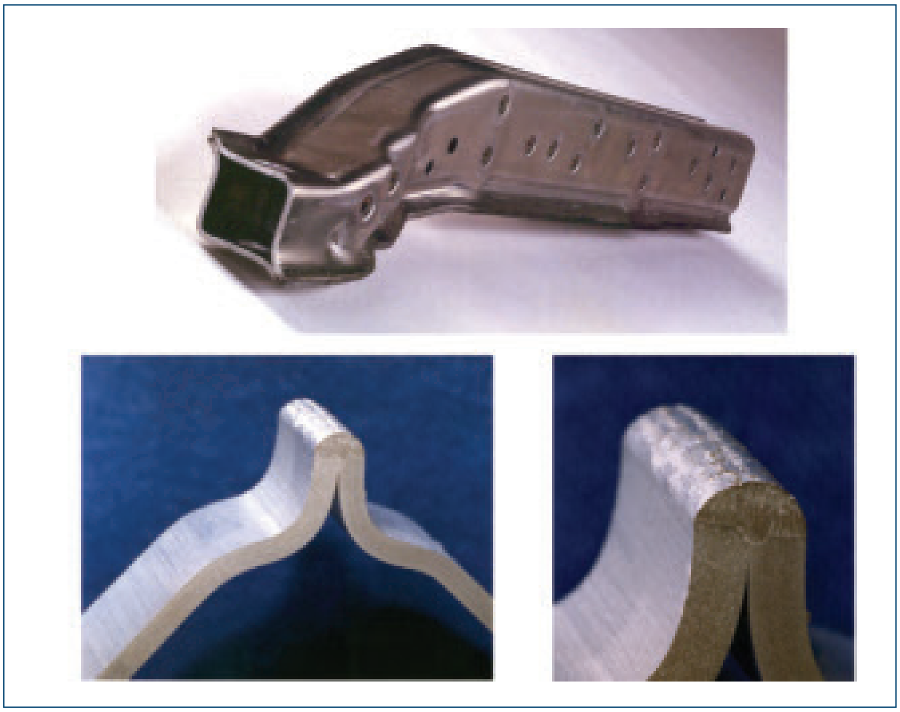

Fig. 5 — Nonvacuum EB-welded aluminum dashboard beam component.

Tailored Blanks

During the mid 1960s, A. O. Smith used EBW for one of the earliest tailored blank applications noted. Tailor blank welding joins contoured segments of low-carbon steel into a single finished blank, which can then be deep-drawn into a complex, three-dimensional-shaped configuration used in sections of car frames (Ref. 2). A more cost-effective utilization of raw material was gained from stamping out shorter contoured segments, and then joining these together to form the full-length blank section, thereby reducing the cost associated with producing the finished blanks. Welded components ranged from roughly ⅛ to 3⁄16 in. in thickness, and could be joined using weld speeds on the order of 200 in./min. Parts were passed under the NVEBW column (located inside of a safety enclosure) utilizing a conveyor-style of tooling arrangement that continuously transported parts through the weld zone. Up to 800 parts/h were achieved off each of the two NVEBW systems being employed. Because of the slight broadening effect the beam incurs when traversing the distance between exit orifice and workpiece, the process proved to be able to weld the "as-sheared" butting edges on the part segments, thus saving on the cost of a post-shear preparation of these edges prior to welding.

Torque Converter Assembly

Not too long after the A. O. Smith application, GM Powertrain's Hydra-Matic Div. employed the NVEBW process (Refs. 3, 4) for doing the final fillet weld required on torque converter assemblies, utilizing a beam angled at 45 deg (Fig. 3) to produce the hermetic weld desired (Fig. 4). The initial system designed for this application involved using an inline, manually fed part transfer scheme for getting parts in/out of area where welding was performed. Later systems employed a multistation dial index form of part transport with auto load/unload features for transferring parts through the weld area. This allowed total floor-to-floor cycle times of 13 to 15 s (depending on whether a 9.75 in. or 11.5 in. converter was being welded) to be achieved. Production rates in the range of 235 to 275 parts/h were attained. When the NVEBW process was initially employed for doing this task, the converter assembly's cover and body segments were quality stamping-type parts produced out of aluminum killed steel, and thus were very conducive to being directly hermetically welded. With time, however, material and part tolerance quality decreased due to cost-reduction efforts. Consequently, it became necessary to equip each system with wire feeder capability in order to provide a combined filler metal and deoxidizer capacity to help ensure a hermetic weld could be accomplished on every part welded, regardless of part material and/or fit-up conditions.

With the advent of CNC motion control capability in the 1970s, the process began to be adapted for joining components having relatively complex, 3-D-shaped weld paths such as die cast aluminum intake manifold assemblies (Refs. 3, 4). This application was a prime example of using the process not only to accomplish welding of a part having a complex weld joint geometry and joint path, but also one that contained components made out of a material that was difficult to weld. The NVEBW process successfully welded these manifold assemblies at speeds of 200 to 400 in./min.

Catalytic Converters

Another example of a difficult-to-weld component is the catalytic converter assemblies produced with nonvacuum EBW. Four layers of 0.050-in.-thick steel were hermetically welded at speeds around 300 in./min. This involved utilizing a tooling configuration that employed a press frame capable of providing the 1000-lb force needed for maintaining the edges on all four layers of material tightly together until the roughly 50 in. of edge weld needed on each part could be fully completed. The 17 nonvacuum EBW systems put into operation to do this joining task in the late 1970s and early 1980s supplied the capacity needed for producing the 7,000,000 catalytic converters required annually at that time.

Conclusion

Since its introduction to industry some 50 years ago, the nonvacuum EBW process has been employed for welding a variety of high-volume production components for the automotive industry. Initially the process was used for fairly simple linear welds, but the process evolved to the point where it could be used for complex two- and three-dimensional welds. Figure 5 shows a 40-in.-long automobile dashboard component presently being produced with the NVEBW process in both Europe and Japan. A CNC controlled simultaneous motion of both part (X/Y-axes) and gun/column assembly (Z-axis) is used to accomplish joining of these two aluminum segments at welding speeds in the range of 300 to 500 in./min (Ref. 6). Thus the process has over the past five decades demonstrated its inherent capacity for adapting to a broad range of workpiece conditions and operating environments generally associated with automotive applications. In recent years, the process has also shown itself to be capable of successfully accomplishing applications requiring tight afterweld dimensional tolerances (Ref. 7).♦

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The Other Resistance Process: Cross Wire Welding

Cross wire welding — perhaps the most common nonautomotive application for resistance welding — can be used for many everyday products ranging from toaster guides to fences

BY NIGEL SCOTCHMER

Cross wire welding is used in many everyday applications. It is perhaps the most common nonautomotive application for resistance welding. There are many everyday uses for products made with cross wire welding, including shopping carts, toaster guides, wire meshes for reinforcing concrete, fences, and jail bars. In fact, our world would be unrecognizable without the reinforcing mesh used in buildings, roads, tunnels, and prefabricated components. It is used around the world in all types of products, even in the nanoscale cross wire welding of micro joints in electronic applications.

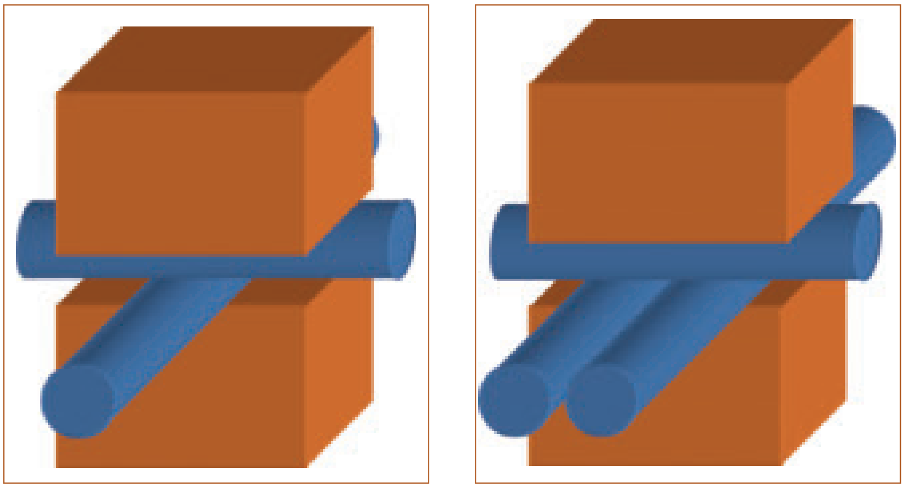

Fig. 1 — 'Single' and 'double knot' cross wire welds.

Features of Cross Wire Welding

Most people are familiar with spot welding, which is heavily used in joining automotive sheet body parts together, but fewer people are familiar with the ubiquitous presence and properties of cross wire welding. Cross wire welding is actually a type of projection welding. Projection welding is a unique form of resistance welding that uses the resistance heating of a small cubic area prior to, and during, its collapse under pressure to weld frequently different thicknesses of metal together. In this process, the size and shape of the projection is very important, as is the speed of the movement of the cylinder applying the pressure. If the metal of the projection collapses too quickly, before the resistance melting occurs, then there may be no fusion weld, or nugget, formed as the heat generated may be diffused over too large an area. If there is too much heat generated on the projection before its collapse, or if the cylinder is moving too slowly to follow the collapse, then there may only be expulsion and also no weld. Thus, it is imperative that the electrode force is maintained at the appropriate level during the collapse of the projection. It is also worth noting that it is an inexpensive and quick process, taking only a fraction of a second, and does not require shielding gases or filler metals.

These similar characteristics occur in cross wire welding. Generally, there are two wires or rods welded together, and their combined radii present a challenge and act like the projections in projection welding. The heating is rapid, and deformation occurs almost instantaneously.

One of the ways to improve quality has been the increasing use of automation. The last thirty years have seen an increase in the quantity of mesh welding machines, which attempt to mass produce and keep consistent the quality of production cross wire welding. At the same time, there has been an increase in the number of the types of reinforcing steels used, and it has become a challenge to effectively fabricate these new reinforcing meshes by resistance welding. Mesh welding machines are available in various sizes for the production of reinforcing mesh. These machines are computer controlled and can be automated with an assortment of loading, feeding, straightening, cutting-to-length, and pay-off features in order to form an automatic production line. Rods and wires can be welded one on top of the another in practically any arrangement. Exact, reproducible control of the current, time, and welding force is assured by the welding process control system. Figure 1 shows a typical setup for a single and double knot cross wire weld.

Cross wire welding is performed by direct welding (Fig. 4) or indirect welding (Fig. 2). The definition of direct welding is that only one weld per current flow is produced. Indirect welding uses the current flow through the actual workpiece to facilitate other welds or for heat management, weld appearance, or material property reasons.

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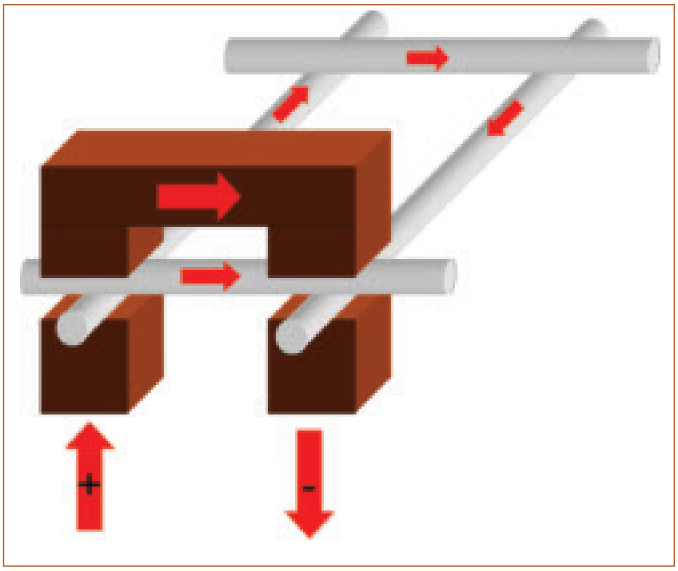


Fig. 2 — Series welding.

Fig. 3 — A series welding machine.

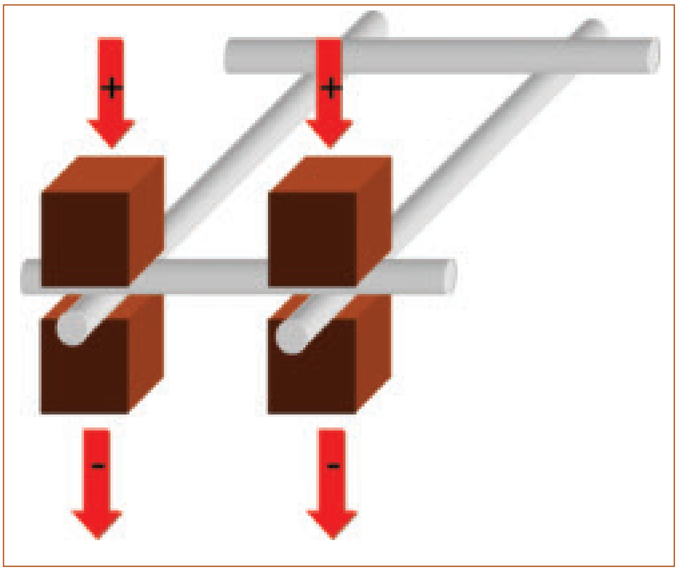


Fig. 4 — Direct welding.

Fig. 5 — A direct welding machine.

Looking at Series Welding (One-Sided Welding)

A common type of indirect cross wire mesh machine employs series welding or one-sided welding. They are often used for making storage meshes as they are limited in how longitudinal bars are divided. In this case, both electric poles are on the same side of the mesh. Usually, two welds per current flow are made. This method tends to melt material at the electrode contact area of the longitudinal rod. This effect is generally agreed to be caused by the systematic bypass of the welding current along the transverse bar of the last weld — see the arrows in Fig. 2. Naturally, the amount and rate of the bypass current depends on the rod diameter and the position of the next transverse rod. This bypass current has to be compensated for by a higher total current (Table 1).

Thus, the power supply for the welding machine, and of the power of the transformer, becomes very important and a limiting variable. A series welding machine has a simple construction with an open mesh plane that allows the feeding of the cross rod or wire in or toward the production direction. Figure 3 shows a high-speed series welding machine with the transfer rods inserted over the longitudinal rods just prior to welding.

Table 1 — Bypass Factors for Series Welding

Diameter of Wire (mm)	Division (mm)	Bypass Factors I_{tot}/I_x
4 + 4	25/25	1, 25
5 + 5	25/25	1, 4
5 + 5	40/40	1, 33
5 + 5	50/50	1, 3
6 + 6	50/50	1, 42
8 + 8	50/50	1, 65
10 + 10	100/100	1, 34

Details of Direct Welding

The most impressive direct welding machines are made up of any number of floating, independent welding assemblies — Fig. 5. Each welding assembly is a self-sufficient system consisting of transformer, welding press, and power supply. A floating system allows for different diameters of longitudinal rods to be welded quickly and accu-

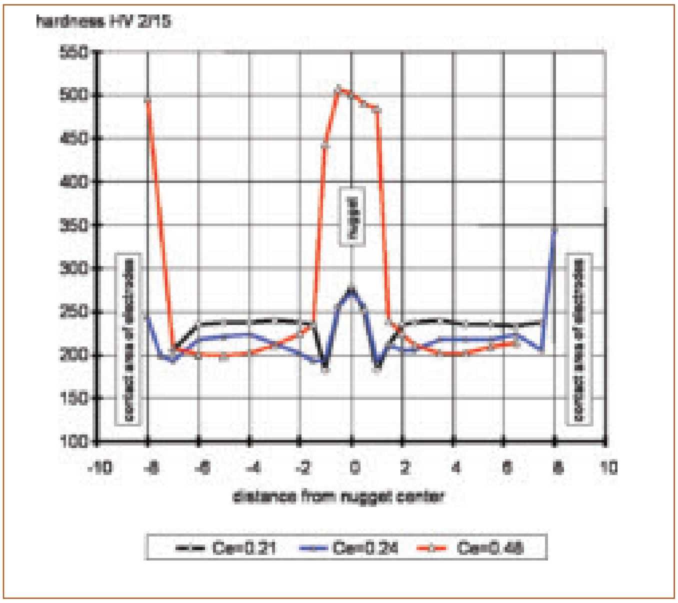


Fig. 6 — Cross-section hardness of a weld of different carbon equivalent (CE) steels.

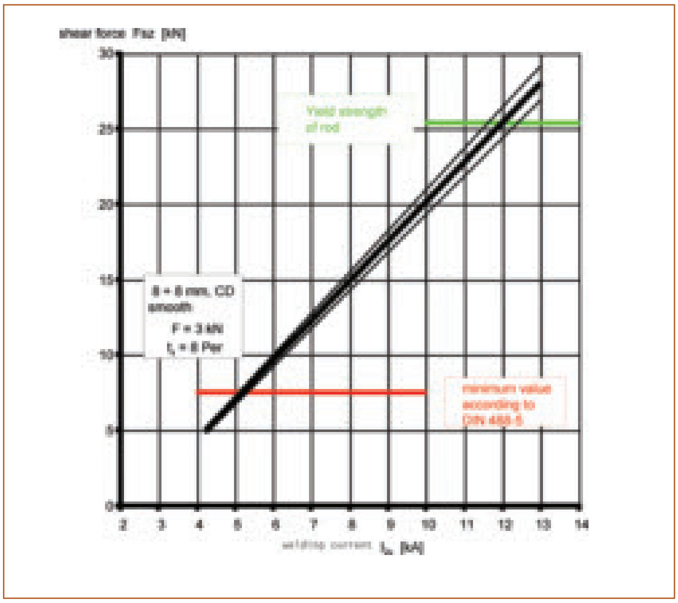


Fig. 7 — Reinforcing steel, cold drawn, carbon equivalent CE = 0.21.

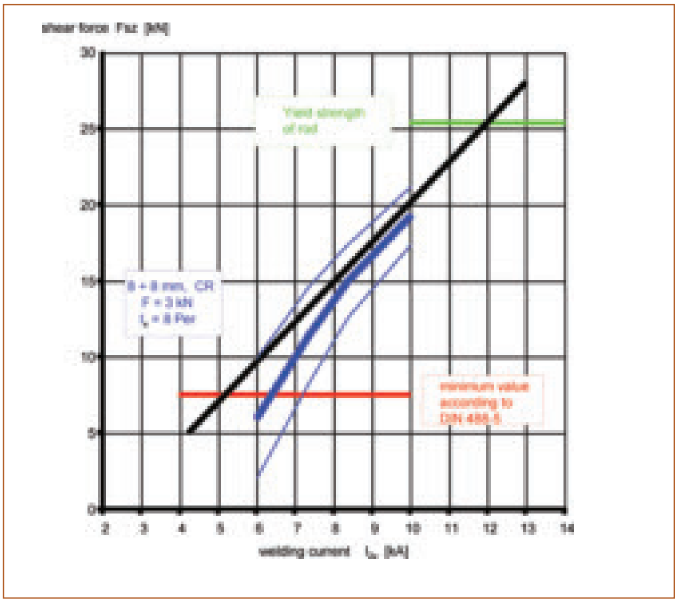


Fig. 8 — Reinforcing steel, cold rolled, carbon equivalent CE = 0.24.

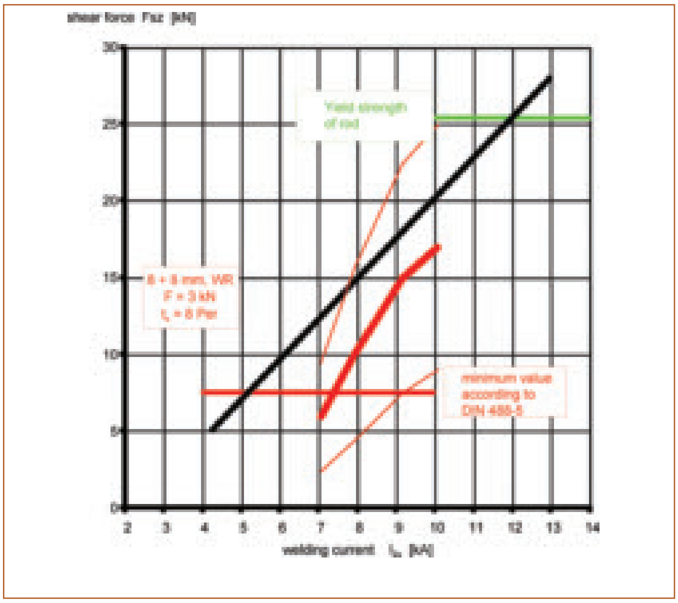


Fig. 9 — Reinforcing steel, hot rolled, carbon equivalent CE = 0.48.

rately, even with very small and varying distances between cross wires or rods.

Generally, such machines are more expensive and are capable of producing a wider range of manufactured parts. They are designed to allow for variable adjustment in longitudinal bar division. This would mean that the mesh could be adjusted during production to create a mesh with different material properties with more frequent, or less frequent, cross welds. Except where 'double knots' (two longitudinal wires are welded between an electrode pair, as in Fig. 1) are used, only direct welding is used.

The Need for Standards to Improve Quality

The aim is always to improve quality. The easier a material is to weld, the better is its 'weldability.' The better its weldability, the less effort is expended to get consistently good welds. In spot welding, a sheet steel's weldability is usually measured by its welding current range (lobe), electrode life in use, and the tendency of the material to harden. The weldability of reinforcement bars in cross wire welding is given by its chemical components, surface condition, and rib formation. In current national and international standards, the focus is limited to the chemical components of the material, and there is no differentiation of the weldability between the welding processes of arc welding and resistance welding.

With the recent wave of new steels coming on the market, many believe that there is an increasing need to create a standardized procedure to determine the weldability of reinforcing steel for resistance wire welding (as is already the case for spot welding). Such a tool for evaluating the weldability of materials for pro-

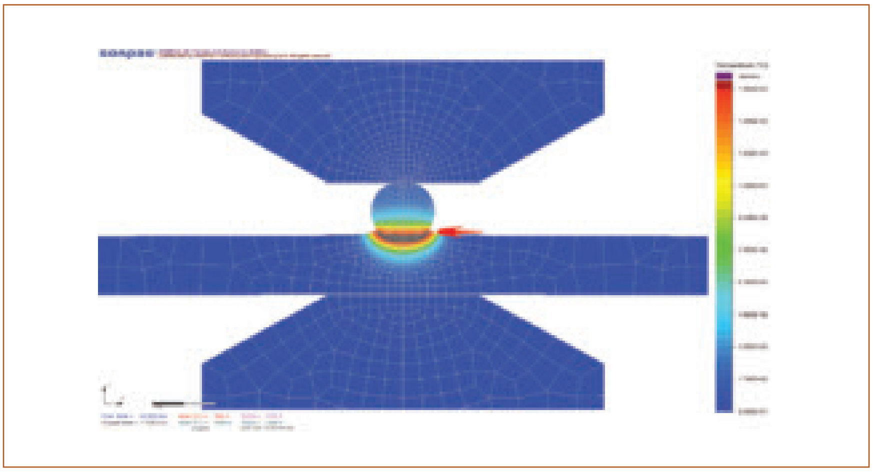


Fig. 10 — A simulation output of a cross wire weld, showing expulsion as a red flame.

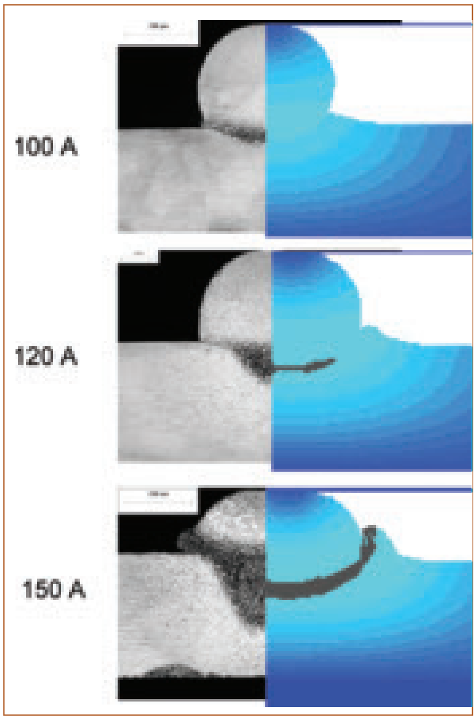


Fig. 11 — Metallographic results of microweld with superimposed simulation.

Table 2 — Welding Parameters for Reinforcing Steel (60 Hz AC)

d (mm)	F_E (kN)	tx_up (cycle)	tx (cycle)	Cold Drawn I_{2x} (kA)	Cold Ripped I_{2x} (kA)	Hot Rolled I_{2x} (kA)
5	1.5	1	4	4.5	5.0	6.3
6	2	2	6	5.4	6.0	7.4
7	2.5	2	7	6.6	7.3	9.1
8	3	2	9	7.6	8.4	10.5
9	3.5	3	11	8.6	9.6	11.9
10	4	3	13	9.7	10.8	13.4
12	5	5	18	11.2	13.1	16.3
14	6	6	25	13.7	15.2	18.9
16	7	8	32	15.8	17.5	21.7

jection welding would improve the overall quality of cross wire welding. Figure 6 further illustrates this by showing differences in the typical weld nugget hardness between three common steels.

Marc Mueller of H. A. Schlatter AG, a maker of a wide range of cross wire welding machines from Switzerland, has provided some interesting graphs that illustrate some critically important values for projection welding that illustrate the need of a standardized procedure for determining the weldability for reinforcing steels. Today's standards define reinforcing steel with CE up to 0.50 as 'weldable' (Fig. 6) without any restrictions, even if there is a high tendency to harden. Figures 7–9 illustrate the challenge of achieving the shear test requirements of DIN 488-5 using the parameters of Table 2. These figures illustrate that a high current level is required to achieve the deep penetration required, especially in hot-rolled reinforcement mesh, and are the result of years of experience from Mueller and his customers.

The thinner lines in the diagrams show the 95% area (using duplex standard deviation) of shear test force results. For a comparison, the mean of cold- and hot-drawn material is also given in Figs. 8 and 9. These graphs show the necessity of controlling the welding parameters to achieve the required strength. Established international standards would improve quality by mandating acceptable strength. To decrease the amount of expulsion during welding, an upslope is necessary to reduce the current concentration at the start of the current flow when welding hot rolled reinforcing steel of types shown in Fig. 9.

Another way of improving the quality of resistance cross wire welding is the emerging use of simulation software, which attempts to predict the performance of cross wire welding based upon the finite element modeling of input parameters of the material, time, current, and force. An example of the output of this process is given in Fig. 10. Peak temperature achieved in the simulation is cross referenced to the bar at the right.

Michael Kuntz of the University of Waterloo has taken this a step further with the small-scale microwelding simulation of cross wire welding of fine stainless steel wires for biocompatible material applications such as medical implants. Figure 11 shows how he has used a simulation software program to predict the outcome of DC welding under differing scenarios to see the peak temperature distribution, which would assist him in evaluating the size of the heat-affected zone, and understanding how the mechanical properties might be affected. Three weld currents of 100, 120, and 150 A are illustrated, respectively. The simulations are paired with a microphotograph of the actual resultant weld for comparison.

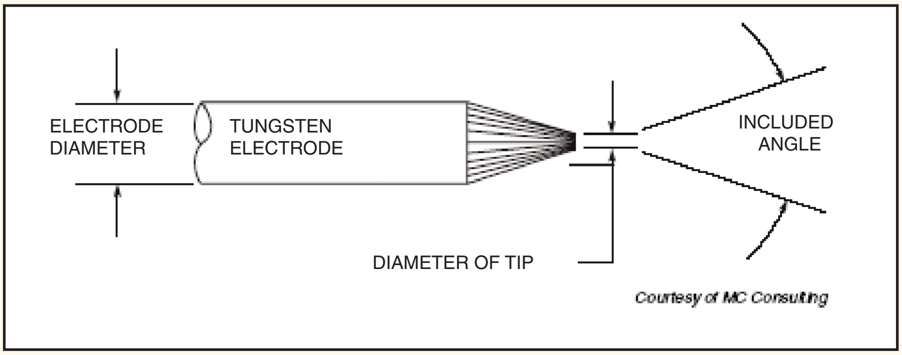
Final Thoughts

This article has looked at some applications of cross wire welding, has highlighted the need for the industry to create tensile shear strength standards for projection welding with the increasing use of advanced high-strength steels and ultrahigh-strength steels, and the emerging trend toward the adoption of simulation resistance welding to reduce weld verification testing and preproduction scrap and labor. In projection welding, it is not possible to weld without expulsion. The problem is controlling the amount of expulsion and obtaining the required strength. Standardized procedures are needed for determining the weldability of materials for cross wire welding.♦

The Welding of Titanium and Its Alloys

Be aware of proper procedures and the result will be quality welds in titanium

BY RICHARD SUTHERLIN



Courtesy of MC Consulting

Fig. 1 — Tungsten electrode tip shape.

Titanium and its alloys are used primarily in two areas of applications where the unique characteristics of these metals justify their selection. Corrosion-resistant applications typically utilize the lower strength, commercially pure grades. However, as technical requirements in corrosive applications have become more severe, the use of higher-strength alloys with enhanced corrosion resistance is increasing. Most titanium alloys can be fusion welded and all alloys can be welded by solid-state processes. Properly made welds in the as-welded condition are ductile, and, in most environments, nearly as corrosion resistant as the base metal. However, improperly made welds can be severely embrittled or exhibit reduced corrosion resistance.

The equipment and techniques used in welding titanium are similar to those required for other high-performance materials, such as stainless steels and nickel-based alloys. However, titanium demands greater attention to cleanliness and to the use of auxiliary inert gas shielding. To prevent contamination from air, complete inert gas shielding of the face and root of the weld is required. Hence, the parts to be welded must be meticulously cleaned of mill scale, oil, and grease from machining operations, dust, dirt, moisture, and other potential contaminants.

Arc Welding Processes

Titanium can be joined using common processes such as gas tungsten arc, gas metal arc, plasma arc welding, electron beam, and other methods. This article describes the practices used with the gas tungsten arc welding process (GTAW), since this is the most widely used process for titanium. This inert gas-shielded process is well suited for joining titanium and titanium alloys, provided that the gas shielding arrangement adequately protects the weld area from the atmosphere. The GTAW process can be performed using manual, semiautomatic, or automatic equipment in a chamber or an open-air environment with auxiliary inert gas shielding.

Gas Tungsten Arc Welding (GTAW)

In the GTAW process, an arc between the tungsten electrode and base metal generates the heat for welding. Inert gas from the torch maintains the arc and protects the tungsten electrode and weld pool from atmospheric contamination. Welds can be made autogenously (i.e., without filler metal) or with the addition of wire. GTAW can be performed in all positions and is the only process routinely used for orbital pipe welding of titanium.

Equipment

Power Source

Titanium and its alloys can be welded with most conventional power sources. For GTAW and PAW, best results are achieved with direct current, electrode negative (DCEN) polarity. Superimposed, high-frequency power or other noncontact method is used to initiate the arc to prevent tungsten contamination at the weld start that occurs with a touch or scratch starting technique.

The power source must also be capable of breaking the arc on completion of the weld without stopping the inert gas flow, or weld contamination will occur at the weld stop position. This is best achieved with a remote-controlled contactor or foot pedal that controls both the welding current and the contactor. Preflow and postflow timers for torch, trailing, and backup shielding are necessary to ensure adequate protection from atmospheric contamination.

Welding Torch

Welding torches are of two types, manual and automatic, and are rated in accordance with the maximum current that can be used at 100% duty cycle without overheating. Torches with oversized gas cups and a gas

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RICHARD SUTHERLIN, PE, is with ATI Wah Chang, an Allegheny Technologies Company, and chairman, AWS G2D Subcommittee on Reactive Alloys. This article is a summary of AWS G2.4/G2.4M:2007, Guide for the Fusion Welding of Titanium and Titanium Alloys, *developed by the G2D Subcommittee.*

lens are mandatory for welding titanium compared to those used for welding other materials. The large cup and lens are necessary to provide sufficient gas coverage around the weld pool and are among the most important aspects of quality welding of titanium. This type of cup and associated gas lens also allows the tungsten electrode to be extended beyond the cup for visibility or welding in areas of limited accessibility.

Tungsten Electrodes

For titanium welding, the 2% thoriated tungsten (AWS EWTh-2) electrode, color-coded red, is generally preferred. Tungsten tip shape varies with welder preference, but a simple cone with a 30–40-deg included angle and blunted tip (equal to ⅓ D max) will give satisfactory results for most applications — Fig. 1. Grinding parallel to the axis of the tungsten is recommended for optimum performance.

Materials

Base Metals

Titanium base metals for common industrial applications are covered by the ASTM International product specifications. These specifications cover the grade, chemistry, dimensions and tolerance, manufacturing method, finish, identification, marking, and packaging requirements for all commonly used product forms. The grade designations developed by ASTM provide a convenient and widely used system for specific identification of the various grades of unalloyed or commercially pure titanium and titanium alloys.

Filler Metals

American Welding Society (AWS) specification A5.16/A5.16M-2004 covers the grades of filler metals suitable for welding most of the titanium base metals covered by the ASTM specifications. Each wire composition is specifically matched to the corresponding base metal and identified by a numbering system. For example, in the case of ERTi-XX, the XX is the base metal grade designation used in the ASTM specification.

The recommended filler metals are shown in Table 1 (from A5.16/5.16M-2004). Generally, matching filler metals should be used for each base metal grade.

Procedure Qualification

The American Society of Mechanical Engineers (ASME) provides a widely accepted international standard for procedure qualification suitable for titanium. For pressure vessel construction, the ASME *Boiler and Pressure Vessel Code*, Section IX, details procedure and performance tests for ASTM Grades 1, 2, 3, 7, 9, 11, 12, 16, 17, 26, 27, and 38 (under a code case). The acceptance criteria are based on the result of tensile and bend tests from welds made under the same conditions as intended for production. Once good procedures, including cleaning and shielding practices, are established for a welding process/joint design, they must be strictly followed in subsequent production welding.

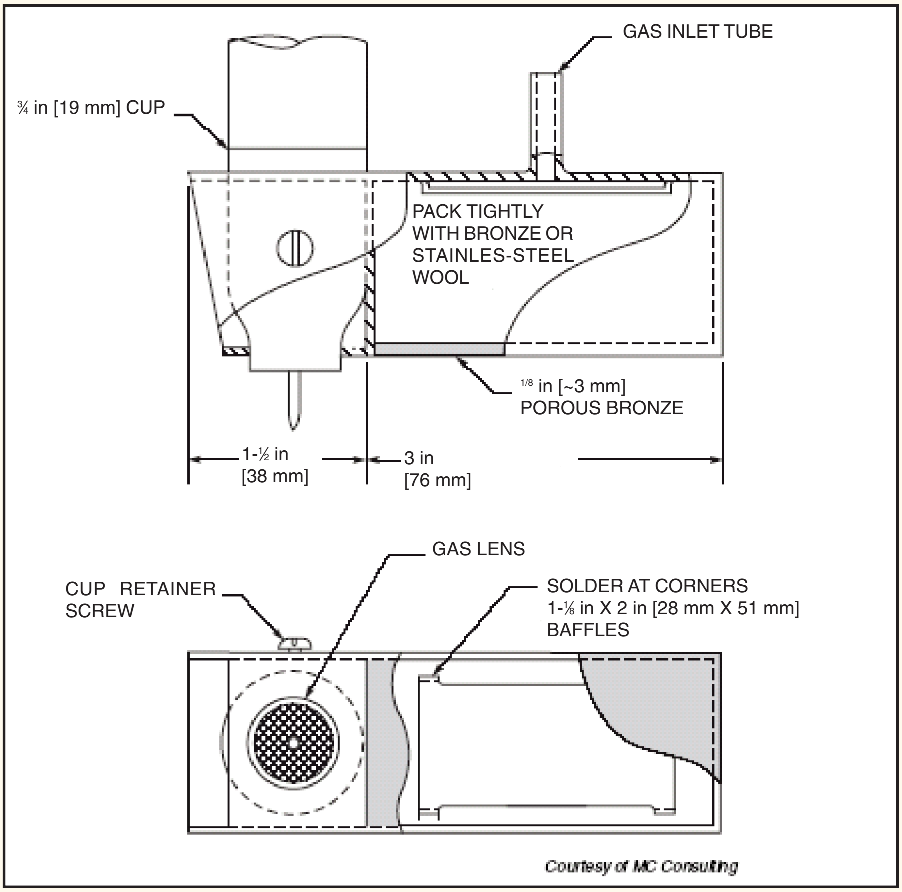


Fig. 2 — Typical trailing shield design. (Courtesy of MC Consulting.)

Workshop Practice

Workshop Layout

Although in-chamber welding is still practiced by some fabricators for smaller components, most titanium welding is performed in an open fabrication shop and, less commonly, in the field. Regardless of where the welding is performed, a clean and protected environment is necessary to produce a high-quality weld. A separate welding area should be set aside for titanium fabrication. This area should be kept clean and protected from dirt, dust, smoke, and other airborne contaminants from welding, cutting, and grinding operations. Likewise, the working area should be protected from winds and drafts that can interfere with inert gas shielding. An enclosed area, protected by floor-to-ceiling partitions and equipped with a positive-pressure air system, is preferred. For organizations engaged in titanium welding on an infrequent basis, temporary enclosures, such as curtains or plastic tents around the weld site, are also acceptable.

Material Identification and Storage

All titanium materials should be stored in a clean, dry area and protected from contact with non-titanium materials, particularly steel that can lead to surface iron contamination. For example, storage racks can be lined with wood or plastic, and wood blocks should always be placed under titanium before it is set on a concrete surface. It is also recommended that fork protectors be used or wood can be placed between forks and titanium.

It is good practice to segregate all titanium materials. Retain marking of the grade and heat number (at a minimum),

Table 1 — Chemical Composition Requirements of Titanium Filler Metals (wt-%)[(a)]

ASTM Grade	AWS Grade	UNS Numbers	C	O	H	N	Al	V	Fe	Other
1	ERTi-1	R50100	0.03	0.03–0.10	0.005	0.012			0.08	—
2	ERTi-2	R50120	0.03	0.08–0.16	0.008	0.015			0.12	
3	ERTi-3	R50125	0.03	0.13–0.20	0.008	0.02			0.16	
4	ERTi-4	R50130	0.03	0.18–0.32	0.008	0.025			0.25	
5	ERTi-5	R56402	0.05	0.12–0.20	0.015	0.03	5.5–6.7	3.5–4.5	0.22	
7	ERTi-7	R52401	0.03	0.08–0.16	0.008	0.015			0.12	0.12–0.25 Pd
9	ERTi-9	R56328	0.03	0.08–0.16	0.008	0.02	2.5–3.5	2.0–3.0	0.25	
11	ERTi-11	R52251	0.03	0.03–0.10	0.005	0.012			0.08	0.12–0.25 Pd
12	ERTi-12	R53401	0.03	0.08–0.16	0.008	0.015			0.15	0.6–0.9 Ni 0.2–0.4 Mo
13	ERTi-13	R53423	0.03	0.03–0.10	0.005	0.012			0.08	0.04–0.06 Ru 0.4–0.6 Ni
14	ERTi-14	R53424	0.03	0.08–0.16	0.008	0.015			0.12	0.04–0.06 Ru 0.4–0.6 Ni
15	ERTi-15A	R53416 (15A)	0.03	0.13–0.20	0.008	0.02			0.16	0.04–0.06 Ru 0.4–0.6 Ni
16	ERTi-16	R52403	0.03	0.08–0.16	0.008	0.015			0.12	0.04–0.08 Pd
17	ERTi-17	R52253	0.03	0.03–0.10	0.005	0.012			0.08	0.04–0.08 Pd
18	ERTi-18	R56326	0.03	0.06–0.12	0.005	0.012	2.5–3.5	2.0–3.0	0.2	0.04–0.08 Pd
23	ERTi-23	R56408	0.03	0.06–0.11	0.005	0.012	5.5–6.5	3.5–4.5	0.2	
24	ERTi-24	R56415	0.05	0.12–0.20	0.015	0.03	5.5–6.7	3.5–4.5	0.22	0.04–0.08 Pd
25	ERTi-25	R56413	0.05	0.12–0.20	0.015	0.03	5.5–6.7	3.5–4.5	0.22	0.04–0.08 Pd 0.3–0.8 Ni
26	ERTi-26	R52405	0.03	0.08–0.16	0.008	0.015			0.12	0.08–0.14 Ru
27	ERTi-27	R52255	0.03	0.03–0.10	0.005	0.012			0.08	0.08–0.14 Ru
28	ERTi-28	R56324	0.03	0.06–0.12	0.005	0.012	2.5–3.5	2.0–3.0	0.2	0.08–0.14 Ru
29	ERTi-29	R56414	0.03	0.06–0.11	0.008	0.02	5.5–6.5	3.5–4.5	0.2	0.08–0.14 Ru
30	ERTi-30	R53531	0.03	0.08–0.16	0.008	0.015			0.12	0.04–0.08 Pd 0.20–0.80 Co
31	ERTi-31	R53533	0.03	0.13–0.20	0.008	0.02			0.16	0.04–0.08 Pd 0.20–0.80 Co
32	ERTi-32	R55112	0.03	0.05–0.10	0.008	0.012	4.5–5.5	0.6–1.4	0.2	0.6–1.2 Mo 0.6–1.4 Zr 0.6–1.4 Sn 0.06–0.14 Si
33	ERTi-33	R53443	0.03	0.08–0.16	0.008	0.015			0.12	0.01–0.02 Pd 0.02–0.04 Ru 0.35–0.55 Ni 0.1–0.2 Cr
34	ERTi-34	R53444	0.03	0.13–0.20	0.008	0.02			0.16	0.01–0.02 Pd 0.02–0.04 Ru 0.35–0.55 Ni 0.1–0.2 Cr

(a) Single values are maximum.

as it is essentially impossible to distinguish between titanium grades by appearance. Extra caution is appropriate on jobs involving several grades of titanium.

Each filler metal wire container or sheath should carry an identification label. Where identification tags are not provided on each wire length, fabricators often color code the material on each end. All filler metals should be stored in closed and sealed containers until issued for use and then kept in a clean container or sheath until they are selected for welding.

Inert Gas Protection

The weld pool, solidified weld, and heat-affected zones on the face and root sides of the weld must be protected until the metal cools to below 800°F (427°C). Only argon or helium (or mixtures) are used as shielding gases. Other gases, including argon-oxygen mixtures, nitrogen or CO_2, should never be used. The low tolerance of titanium to atmospheric contamination also extends to gas impurities and moisture in the shielding gas. The purity of the shielding gases should be at least 99.995%, but it is recommended that higher-purity gas be used. The dewpoint of the gases should be –60°F (–50°C) or lower.

Inert Gas Distribution

Shielding gases are supplied in pressurized cylinders or as a liquid in both portable dewers and large stationary insulated tanks. For central liquid systems, the liquid is vaporized and the gas is piped to points within the fabrication facility through a distribution system. Gas distribution lines should be stainless steel with welded or silver soldered joints or brazed copper tubing, except where flexibility or electrical insulation is required. All manifolds, valves, regulators, flowmeters, fittings, tubing, hoses, torches, and other associated equipment should be clean, leak-free, and free of moisture.

Inert gas for the torch, trailing, and backup shielding should be supplied through separate flowmeters. Interlocked solenoid valves or manual on-off valves are used to control preflow and postflow of gas. A suggested arrangement is a timer-controlled preflow and postflow for torch shielding and solenoid valves with manual switches interlocked with the welding current for trailing and backup shielding.

Table 2 — Surface Color in Titanium Welds

Color	Interpretation	Action
Silver	Correct shielding	None
Light straw to dark straw	Excessive surface oxide, acceptable	Remove surface oxide by brushing, correct shielding
Purple to light blue	Moderate surface contamination, unacceptable	Remove ~1⁄32 in. of the surface by rotary filing, correct shielding
Dark blue	Heavy contamination, unacceptable	Remove weld bead
Yellow to gray to white	Very heavy contamination, unacceptable	Remove weld bead and 1⁄32–1⁄16 in. of the material beneath

Table 3 — Bend Test Requirements for Titanium Alloys

Titanium Grades	Bend Radius (from AWS D1.9)
1, 11, 17, 27	4T
2, 7, 16, 26	4T
3	5T
12	6T
9, 18, 28	8T
5, 24	8T
23, 29	8T

Gas hoses should be nonporous, flexible, and made only of polytetrafluoroethylene (PTFE), polypropylene (PP), or high-density polyethylene (HDPE). FEP-lined Tygon® has superior resistance to moisture absorption and is recommended. Rubber hoses absorb moisture and should never be used in any titanium welding operation.

In-Chamber Welding

Welding chambers are typically restricted to the fabrication of smaller components. Although the use of a chamber can be quite cumbersome and requires significant operator skill, complete inert gas protection of the weld can be provided regardless of the joint geometry or component complexity.

Open Air Welding

The requirement for additional gas shielding to protect the face and root of the weld and the cooling base metal during open air welding is the most significant factor that differentiates titanium from most stainless steel fabrications.

Trailing Shields

The function of the trailing shield is to blanket the solidified weld and adjacent heat-affected zone with inert gas until the surface temperature has dropped to below 800°F (427°C) or such that no visible oxide color forms on the surfaces. The trailing shield can be attached directly to the gas nozzle on either manual or automatic torches. See Fig. 2 for a typical trailing shield configuration.

The width and length of the trailing shield is a function of the welding heat input and must be determined for each particular joint design during welding procedure development. If the trailing shield is too short, excessive oxidation on the surface of the solidified weld will occur (indicated by visible surface color). A shield about 4 in. in length and 1½–2 in. in width is suitable for most manual work.

Backup Shields

Inert gas shielding of the root side of welds is required unless the backside remains below 800°F (427°C) or until sufficient weld thickness (typically ¼ in. or 6 mm) is deposited so that no color forms on the root during welding. Backup shields can be made following the same design principles used for trailing shields and then manually held, clamped, or taped in place.

For smaller pipe sizes or in structures where root access is limited, pure argon purging is satisfactory for backup shielding. The ends of the pipe or open areas of a structure can be sealed with clear plastic, metal sheet, or thin plastic film and sealed with masking tape (cardboard or paper would allow air to diffuse and should not be used). In general, gas is fed continuously from one end of the pipe or low point in the structure and is vented at a higher point with secondary escape through the weld preparation (partially sealed with masking tape while the root pass is completed).

Argon is usually the best choice for purging because of its lower cost compared to helium.

Shielding Gases

Gas selection is driven by the physical properties of the shielding gases, which have a major effect on arc characteristics, heat input, and overall process performance. Welding-grade argon is generally employed for torch shielding because its arc stability is better than with helium. Argon is also heavier than helium, and after leaving the torch, forms a blanket over the weld pool, whereas helium tends to rise in a somewhat turbulent fashion. Excessive flows can entrain air into the torch shielding gas resulting in contamination of the weld deposit. While the manufacturer's recommended gas flow rates to the torch should be used, argon flow rates in the vicinity of 15–40 ft^3/h (7.1–19 L/min) have proven satisfactory in practice. Individual flowmeters should always be used for each device.

Joint Preparation

The need for care and planning at the materials preparation stage cannot be overemphasized. Selection of the preparation method and provision for protection of the weld surfaces are both important. A smoothly machined surface is generally best, where practical. Thermally cut surfaces must have contaminated materials completely removed. Ground or abrasive cut surfaces require rotary or draw filing to remove local burned areas and abrasive particles.

Joint Design

Weld joint designs for titanium have the same function as those for other metals, which is to provide access to the root for the welding arc. However, the joint design for titanium must provide accessibility for inert gas shielding devices as well as postweld inspection of both sides of the weld as much as possible. This enables visual inspection to determine if shielding has been effective. For GTA welds, a square groove can be used for all butt joint and corner welds in thin-gauge sheet and other product forms where the thickness does not exceed ⅛ in. (3.2 mm). Thicker material up to about ¾ in. (19 mm) is usually prepared with a single- or double-V groove with an included angle in the range of 45 to 75 deg and a root opening of 1⁄32 (0.8 mm) to ⅛ in. (3.2 mm). For greater plate thicknesses, a U groove (with an included angle as small as possible, consistent with achieving good sidewall fusion) may be used to reduce total weld metal required. As a guide, the total included angle should not be >30 deg or <15 deg. A double-V or U groove is a better alternative when there is access to both sides of the weld for economy and minimum distortion.

Cutting

Titanium can be cut with conventional oxyfuel, plasma arc, waterjet, or laser cutting equipment. A significant amount of titanium dioxide smoke is produced by oxyfuel and plasma arc cutting operations, and local exhaust ventilation should be used. An allowance for removal of contaminated metal that includes allowance for cutting tolerances, cut width, and any surface roughness plus ⅛ in. (3.14 mm) for oxyfuel or 1⁄16 in. (1.58 mm) per surface for plasma arc is usually considered sufficient.

Waterjet cutting is an excellent process for cutting titanium, but can trap abrasive particles in the cut surface. It is recommended that the waterjet joint cut edges (as a minimum) be followed by draw filing to remove the embedded abrasive particles.

Preliminary Preparation

Techniques for preparation include machining, sawing, abrasive cutting, grinding, and filing are suitable for the preliminary preparation of titanium joints. It is important to note that the final joint surfaces should be smooth and contain no crevices, roughness, or overlaps that can trap dirt or cleaning fluids.

Machined joints provide a uniform smooth surface and the most accurate fit-up and are recommended for titanium. Water-soluble lubricants are recommended. Chlorinated cutting fluids should never be used on titanium.

Abrasive cut or ground edges should be rotary or draw filed to remove burrs and abrasive particles. Friction (abrasive) sawing produces similar shallow surface contamination that must be removed in subsequent grinding, filing, or machining operations. Any visible metal oxide (burns) should be removed.

Tungsten carbide burrs (rotary files) and/or metal draw files are recommended for all final surface preparation and conditions.

Final Cleaning

Best results are obtained if the entire component is thoroughly cleaned prior to final surface preparation of the weld joint and cleanliness is maintained throughout welding operations.

The cleanliness of the actual weld joint surfaces and adjacent metal is critical to the quality of the weld and requires careful local cleaning prior to final fit-up and welding.

A common method to clean the joint and adjacent base material on both the face and root for a minimum of 1 in. (25.4 mm) on either side of the joint is by brushing with a stainless steel wire wheel followed by a thorough cleaning with lint-free cloths or tissues dampened in a suitable solvent. Acetone (100% purity and not reconstituted) is recommended. Other solvents in order of decreasing effectiveness include isopropyl alcohol and denatured alcohol (100% purity not reconstituted).

All tools that come in contact with the final joint surface, including burrs, files, and stainless steel brushes, should be clean and used only on titanium.

After final cleaning, the prepared surfaces should not be touched or, if necessary, only with clean, dry cotton gloves.

Fit-up and Tack Welding

Accurate fit-up is more critical for titanium than other materials. Uniform fit-up minimizes irregular root fusion, helps control underbead contour, and reduces distortion. Poor fit-up increases the possibility of contamination from air trapped at the joint interface. When possible, joints should be clamped rather than tack welded. All clamps and fixtures should be clean and grease free. When tack welds are used, the same cleaning and shielding requirements as used for all titanium welds should be employed, including the use of trailing and backup shielding.

Welding Technique

Welding Parameters

Gas tungsten arc, plasma arc, and gas metal arc welds can be made using a variety of current/speed combinations.

Preheating

Preheat may be required if the presence of moisture is suspected due to cold material, low temperature, high humidity, or a wet work area (in repair situations). In such cases, preheating of titanium using lamps, resistance heaters, or induction heating equipment is preferred. Where gas torches are used, the torch should be set to a slightly oxidizing flame and the flame moved continuously during heating. No visible color should form during heating.

Filler Metal Practice

Wire and rod are typically supplied from the manufacturer in a clean condition. However, filler materials have a large surface-to-volume ratio, and if the material is slightly contaminated from die lubricants, the resulting weld will be severely contaminated. Manually fed wire or rod should be handled with clean, lint-free cotton gloves.

Starting and Stopping the Arc

Before starting an arc, the torch, trailing shield, and backup shielding must be prepurged for several seconds to ensure clean argon flow.

The torch and shield should be positioned over the part and held for 5 to 10 seconds before the arc is initiated to establish an initial inert gas blanket over the part. The arc should then be initiated with high frequency and the welding current increased to the required range.

Wire Feeding

For manual welding, cut lengths of welding wire should be kept in a clean sheath until selected for use by the welder. Welding wire should be fed into the weld pool at the junction of the arc and joint surface in a smooth and continuous manner. At the completion of each weld stop, approximately ½ in. of the wire or rod should be removed before reuse, unless the wire is kept under the gas protection during cooling.

Interpass Cleaning

In addition to inspections for surface imperfections, each weld pass should be visually inspected for surface color in the as-deposited condition. Interpass cleaning is not required if the weld deposit is bright and silvery. For other colors, welding should be stopped, the shielding problem corrected, and the unacceptable area repaired (Table 2) and inspected in accordance with the recommendations provided in the section on "Visual Inspection."

Interpass Temperatures

A maximum interpass temperature of 250°F (120°C) is recommended to avoid heat buildup that may require additional shielding for subsequent weld passes.

Weld Quality Tests

Visual Inspection

Most elements of visual inspection of titanium welds are the same as for other metals, including weld contour, undercut, penetration, and reinforcement. Visual inspection for surface color can also be used to assess the effectiveness of inert gas shielding, and indirectly, weld quality. A properly shielded weld will exhibit a bright and lustrous silver color. Atmospheric contamination will change the surface color of the welds from silver to straw, yellow, purple, light blue, dark blue, dull grey, and powder white as the degree of contamination increases.

Visual inspection must be performed in the as-deposited condition, prior to any type of cleaning, brushing, or grinding operations. Welding over a contaminated weld to remove color will only make the weld worse even though it looks bright and shiny. The contamination from the surface is now absorbed in the weld and must be fully removed. Qualified personnel should inspect each weld pass and adjacent material, including the root side of two-sided welds. A bright silver color indicates correct shielding, and no corrective action is necessary. A straw to light blue color on the final weld surface indicates heavier oxide that should be removed by wire brushing, but generally does not require removal of the weld metal. Colors beyond straw to light blue generally indicate sufficient contamination to warrant complete removal of the weld and adjacent material.

It should be noted that surface color is an indication of the effectiveness of the trailing shield only and does not guarantee that the torch shielding was adequate. This is due to the fact that entrainment of air into the torch shield gas can contaminate the weld but still result in a silver color if the trailing shield provides adequate protection.

Bend Testing

Bend testing is a very effective method for assessing contamination in welding qualification tests. Standard face, root bends, or side bends are typically used. Welds with satisfactory ductility will bend over the radii shown in Table 3 without cracking.

Hardness Testing

Hardness tests provide direct evidence of atmospheric contamination, since contaminated welds exhibit greater hardness. More importantly, hardness testing will detect contamination that occurs from inadequate torch gas shielding for welds exhibiting acceptable surface color. It should be noted that the hardness delta is so small with the high-strength alloys that it may or may not be a reliable measure of contamination.

Nondestructive Examination

Radiography

Radiography is a very useful inspection technique for titanium, and its application does not differ substantially from the radiography of other metals.

Liquid Penetrant Testing

Surface cracks and other discontinuities open to the surface can be detected by liquid dye penetrant inspection. Visible dyes are commonly used in industrial applications, but fluorescent penetrant may provide greater sensitivity in some instances.

Repair of Defects

Repairs Following Service Failures

Field repairs represent the most difficult situation under which to produce welds of satisfactory quality. The titanium equipment is usually dirty and may have corrosion products on the surface. Repairs must often be done under less than ideal conditions, including high winds, high humidity, or extremes in temperature. Significantly more time will be required in preparation than actual welding. The equipment must be cleaned to eliminate any source of water or dirt.

After removal of the defective material by cutting or grinding, the entire work area should be cleaned and then enclosed to eliminate drafts, dirt, water, etc. This can be accomplished by plastic sheets draped over the work area or attached to temporary supports. Preweld cleaning follows the procedures outlined earlier.

Repairs that must be made to partial penetration welds or in areas where there are crevices present a special problem. This is due to the difficulty of removing the contaminants in crevices or the faying surfaces of partial penetration welds. Preheating to dry the restricted area and possibly volatize potential contaminants may minimize this problem during a repair. Welding over poorly cleaned areas will result in contamination, a poor weld, and possibly premature failure, and a repeat of the costly repair.

Conclusion

Titanium and titanium alloys can be welded successfully using equipment and procedures used for other materials, but with additional considerations. The most important considerations are joint preparations/cleanliness and completely shielding the weld using inert gas. If proper procedures are followed, a high-quality titanium weld can be achieved.◆

Technology Delivers Laser Cutting Productivity Gains

BY LAURENT RIMANO

The laser beam cutting process is used mainly in the transportation equipment manufacturing industry, the construction industry, and other sectors of the metal fabricating industry. During the process, a laser beam is focused on the base metal, while an assist gas is used to eject the molten metal along the kerf. The laser beam is physically produced by an electrical discharge that is induced in a cavity filled with a gaseous medium composed mainly of nitrogen, carbon dioxide, and helium, which produces a consistent monochromatic light. This process is used primarily for cutting metal sheets when extreme precision is required and where a large number of pieces must be cut at high speed.

While laser cutting technology requires maintaining control over many parameters and major investments in machinery, the cutting speed and quality that are its hallmarks make laser beam cutting a preferred process. A new laser technology has increased laser cutting speeds even more.

According to observations made since it was first marketed, this technology, which is sold under the name Bifocal, increases cutting speed for metals that use nitrogen as an assist gas (e.g., stainless steel and aluminium alloys) by 20 to 40%. The Bifocal effect is created using a mirror or a replaceable lens.

The technology focuses the laser beam at the base of the workpiece, which prevents the formation of burrs. The second focus point for the new optics is located on the same axis as the first, but is directly on the surface of the workpiece. It is this second focus point that speeds up cutting. It concentrates sufficient energy at the surface to initiate penetration of the beam.

The new technology from Air Liquide utilizes a second focus point that concentrates sufficient energy at the surface to initiate penetration of the beam to speed up laser beam cutting.

Productivity Statistics. In general, increases in cutting speed of 20 to 40% have been observed, depending on the type of laser source, the type of alloy, and the thickness of the metal sheet. In addition, by focusing the energy and the beam on two points, the technology can cut metal sheets that are 10 to 20% thicker.

In the case of carbon steel, the fact that the laser beam used with this technology is narrower at the base of the material (first focus point) than that used by traditional technologies also reduces surface oxidation.

With traditional cutting technologies, slag is a by-product that results from a more diffuse beam. Because it is applied uniformly to a larger surface of the material, the beam used with a standard focus acts more slowly, which causes impurities that are contained in the molten metal, or dross, to rise to the surface. The absence of slag and burrs results in a much cleaner cut, which facilitates the subsequent processing of cut workpieces. For example, paint adheres better to a workpiece that is free of slag and burrs. As a result, the new technology contributes to increased productivity during subsequent steps of the fabrication process. The faster cutting speed also generates savings in terms of energy and the volume of assist gas, such as nitrogen or oxygen.

How to Adopt the Technology. Implementing the technology in a plant is easy. In fact, the optics (lens or mirror) can replace the standard optics that are installed on most CO_2 laser cutting machines that use nitrogen or oxygen as an assist gas. However, the geometry of each optics (lens or mirror) must be optimized for the specific anticipated use of the machine.

Tests and adjustments must be carried out by a laser specialist, who starts by determining which type of optics for the new technology is best suited to the anticipated type of production. The optics are then installed on the cutting machine for testing purposes. Finally, the parameters of the laser cutting machine that is equipped with the new technology are optimized. This step is carried out on site, with the collaboration of the cutting machine operators.

Significant Impact. Anyone who works in the field of manufacturing production can appreciate the importance of new technological progress. Steel cutting is one of the more common operations in the manufacturing industry. Any productivity increases at this stage have a significant impact on manufacturing productivity as a whole.

Over the past decade, the productivity gains the Canadian economy has recorded are mainly the result of technological advances, as revealed by a recent Statistics Canada study. This new laser beam cutting technology fits into this category. In addition to increasing cutting speed and the capacity of cutting machines, it also significantly improves the quality of cuts, which results in a substantial increase in productivity in a number of areas. ♦

LAURENT RIMANO is product manager, Welding Equipment and Advanced Fabrication Technologies, Air Liquide Canada, Montreal, Canada.

Serious networking opportunities (and fun in the sun)

Join Welding Equipment Manufacturers Committee (WEMCO) as we focus on the "Present and Future Trends in Supply Chain Management." WEMCO will have its highly anticipated 12th Annual Meeting on January 24-26, at the popular Resort at Longboat Key located on Florida's Gulf Coast. The 2008 Annual Meeting will be even more rewarding than the previous meeting in Palm Springs. And as an added bonus, it is guaranteed that Florida's weather will be warmer than last year's.

First-Time Guests Are Welcome!

The Annual Meeting is an excellent opportunity to network with some of the strongest leaders in the welding manufacturing industry from around the country. In addition, you will not want to miss presentations from WEMCO's dynamic list of speakers, including:

- Mike Weller of Miller Electric
- George Ristevski of Praxair Distribution
- Joe Stachowicz of Grainger Global Sourcing

Participate in Our Industry Leader Panel Discussion

Be a part of the solution for tough business issues regarding the challenges faced by the manufacturer and distributor in today's national and global arenas. Leading our panel discussion will be:

- Bob Ames of Commonwealth Supply and GAWDA 2007 President
- Dan Taylor, Norco
- Dave Nangle, Harris Products Group
- Jeff Deckrow, Hypertherm

Alan Beaulieu...Back by Popular Demand

The highly respected Alan Beaulieu of Institute for Trends Research will present his vibrant economic forecasting report. Alan is a vital part of the WEMCO Annual Meetings, and we are glad to have him back with us.

Take Time to Recharge

Also, what better way for you to unwind than an afternoon game of golf at the resort's Islandside golf course, or a relaxing spa treatment at the resort's Island House Spa? You will appreciate the personal service, suite accommodations, and the four restaurants and lounges. Maybe you would prefer a candlelit dinner at the enchanted St. Armand's Circle, or a sunset stroll on the white sand beach. Any choice you make will only leave you feeling refreshed and rejuvenated!

12th Annual WEMCO Meeting
January 24 – 26, 2008
Longboat Key Club and Resort
Longboat Key, Florida

Meeting Fee	$720
Spouse Fee	$225
Spouse Tour	$75

WEMCO has established special group rates for various room types.

Register for the Annual Meeting and today by contacting Natalie James-Tapley, WEMCO Program Manager, at 1-800-443-9353, ext. 444, or e-mail to wemco@aws.org

So don't delay, and register for the meeting today! We'll be waiting...

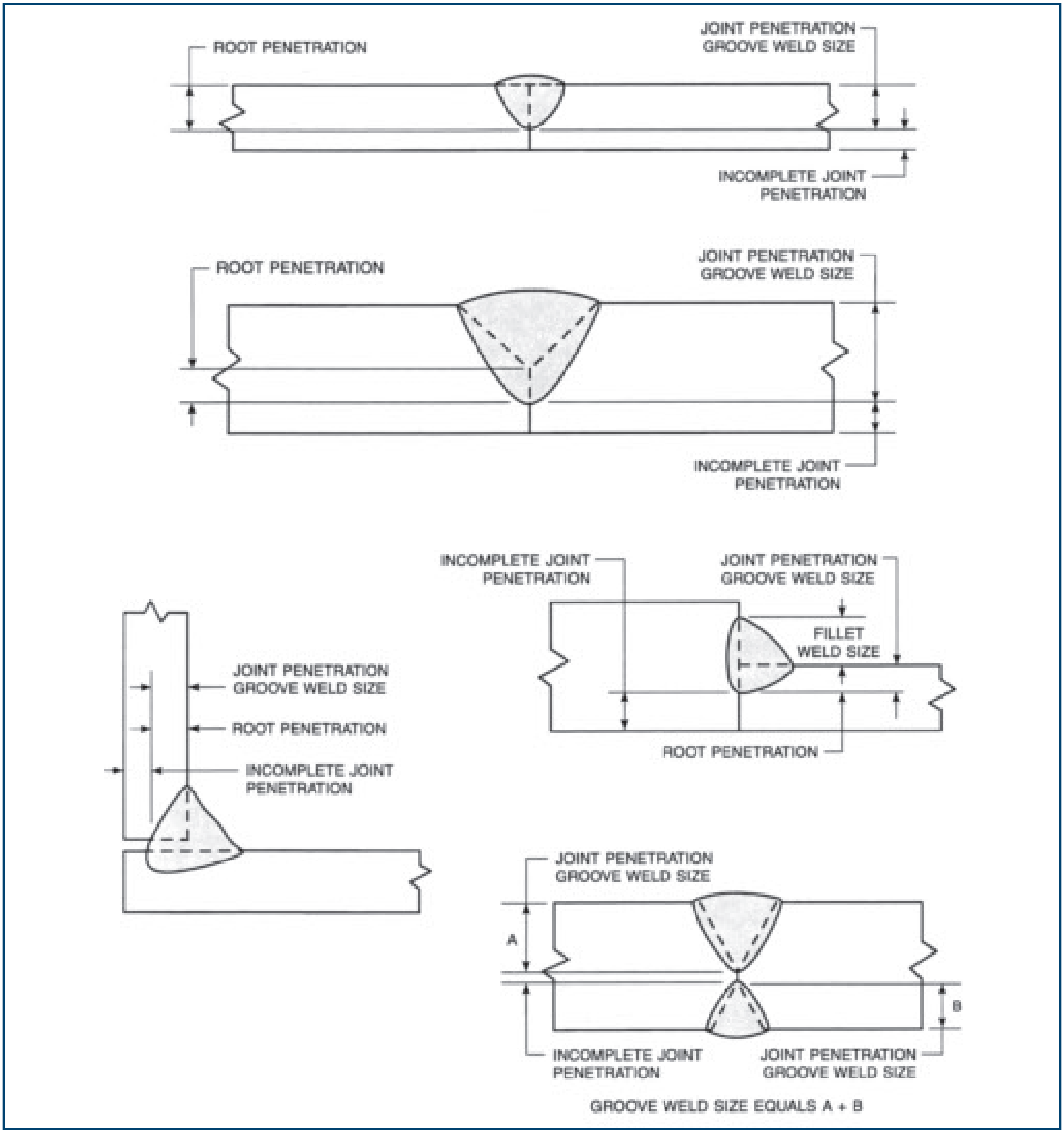
AWS WEMCO
WELDING EQUIPMENT MANUFACTURERS COMMITTEE

Weld Joint Terminology

joint penetration — The distance the weld metal extends from the weld face into a joint, exclusive of weld reinforcement.

root penetration — The distance the weld metal extends into the joint root.

incomplete joint penetration (IJP) — A joint root condition in a groove weld in which weld metal does not extend through the joint thickness.



Excerpted from AWS, A3.0:2001, *Standard Welding Terms and Definitions*.

NJC Initiates New Joining Development Projects to Support Navy Platforms

The Navy Joining Center (NJC), operated by Edison Welding Institute, has been awarded four new projects from the U.S. Navy's ManTech Office to address materials-joining issues for new weapons platform systems. The projects, in support of the next-generation destroyer (DDX) and Virginia Class Submarines (VCS) (Fig. 1) are Weld Development of Large Structures for Hull Integration, Improved Hull Fabrication and Assembly Welding, Structure Fabrication Weld Improvement, and Improved Affordability of Sheet Metal Products.

Weld Development of Large Structures for Hull Integration. The current design concept for the multirole surface combatant includes a number of large structures fabricated from thick-section, high-strength steel for each ship. The heavy structures are to be manufactured in modular form then brought shipside for erection with the hull. Without significant improvements in welding and manufacturing technology, the cost to integrate the large modules into the ship hull will be excessively high and production cycle times will be lengthy. The goal of this project is to develop mobile, high-productivity welding technology for integration of the heavy, thick-section modules to the DDG 1000 hull. The development will investigate several processes to facilitate out-of-position erection welding. Robust welding procedures will be developed with the preferred processes, and the integration of weld mechanization to reduce welding labor hours and maximize first-time quality.

Improved Hull Fabrication and Assembly. The objective of this project is to reduce construction costs for VCS by developing and applying technology to reduce welding costs for hull fabrication and assembly. The shipyards are focusing on reducing construction costs from $2.4 to $2 billion per hull. The specific goal is to achieve a 20% reduction in welding costs by focusing on operations that have been identified to have the greatest potential for savings. One objective is to reduce construction time from 84 to 60 months by 2009. Another part of the program addresses reduction of ship construction labor costs, including welding operations. Development opportunities have been identified by the U.S. Navy and its subcontractors to apply new manufacturing processes and technologies to reduce the costs of welding hull cylinders and subassemblies. Initial reviews of hull welding operations have identified a number of opportunities to improve welding processes and equipment to reduce ship construction labor costs. As a result of these reviews, this project will address horizontal butt joint welds, i.e., ships-position C-seams, high-heat-input welding, welding hull inserts and penetrations, and adaptive mechanized welding of butt joints.

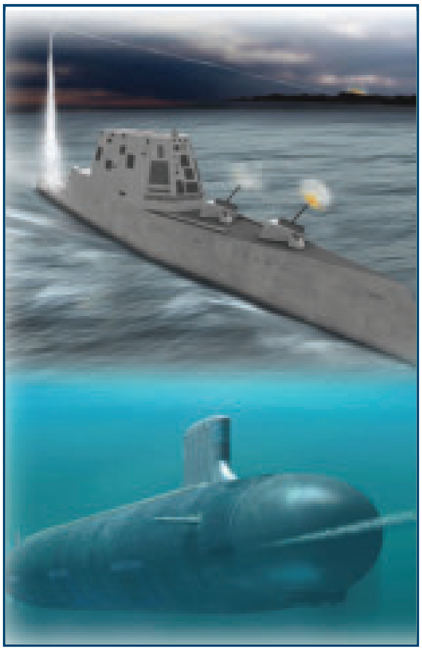


Fig. 1 — Shown are (top) the next-generation destroyer DDX, and (bottom) the Virginia Class Submarine (VCS).

Structure Fabrication Weld Improvement. In follow-on activity to support the need for continuous improvement for VCS, operations involved with the production of structural fabrications have been identified as major contributors to construction costs. Specific fabricated structural elements include tank internals, midspan bulkhead structures, main propulsion foundations, manhole liners, and penetrations. Preliminary assessments have identified areas to improve the accuracy of weld preparations, component assembly and fit-up, preheating, welding processes and equipment, as well as increased use of fixtures, positioning, automation, and mechanization. This project will be performed in two phases addressing mechanized welding of structures, reducing the cost of preheating weldments, and developing an improved welding method for fill and vent holes. Phase 1 activity will determine the requirements and supporting business cases for implementation of new technology. Phase 2 will develop mechanized equipment and procedures to increase weld productivity. The developed systems will be demonstrated at the NJC then moved to the shipyards for performance evaluations.

Improved Affordability of Sheet Metal Products. Significant fabrication of sheet metal products, such as electrical enclosures, racks, lockers, HVAC ducting, etc., is utilized in submarine construction. Because of the distinctive design of submarines and the necessity to maximize space, these products represent many common features, but comprise a wide variety of sizes and shapes. In many instances, they are custom built for a particular boat. The variations in design and size of these components have necessitated significant hand fitting and fabrication, which is costly. Of particular interest is the manual joining techniques that are used for this construction, manual gas tungsten arc welding and upsetting rivets. Both processes involve significant labor and, applied to the current product forms, are not easily adapted to more efficient manufacturing techniques. The primary objective of the project will be to identify alternate joining techniques to enable greater efficiency and affordability in sheet metal construction. The Navy Joining Center will investigate adhesive bonding, gas metal arc welding, ultrasonic spot welding, laser welding, and resistance spot welding.

For more information, contact Larry Brown, *larry_brown@ewi.org;* (614) 688-5080.

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COMING EVENTS

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

PACE 2008, The Power of Paint + Coatings. Jan. 27–30, Los Angeles Convention Center, Los Angeles, Calif. Visit *www.PACE2008.com.*

Advanced Mfg. Expo. March 26, 27, Int'l Centre, Mississauga, Canada. Society of Mfg. Engineers. Call (313) 425-3187, or visit *www.smecanada.ca/assembly.*

WESTEC 2008 Expo and Conf. March 31–April 3, Los Angeles Convention Center, Los Angeles, Calif. Call (313) 425-3187, or visit *www.sme.org/westec.*

METALFORM. April 1–3, Birmingham-Jefferson Convention Complex, Birmingham, Ala. Contact: Precision Metalforming Assn., (216) 901-8800; *www.pma.org; www.metalform.com.*

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

TechEd 2008: 13th Annual Technology in Education Int'l Conf. & Tech Expo. April 13–16, Ontario Convention Center, Ontario, Calif. Visit *www.TechEdEvents.org.*

Composites Manufacturing 2008. April 14–16, Hilton Salt Lake City Center, Salt Lake City, Utah. Society of Mfg. Engineers. Call (313) 425-3187, or visit *www.sme.org/composites.*

PICALO 2008. April 16–18, Capital Hotel, Beijing, China. Third Pacific Int'l Conf. on Applications of Lasers and Optics. Visit *www.laserinstitute.org/conferences.*

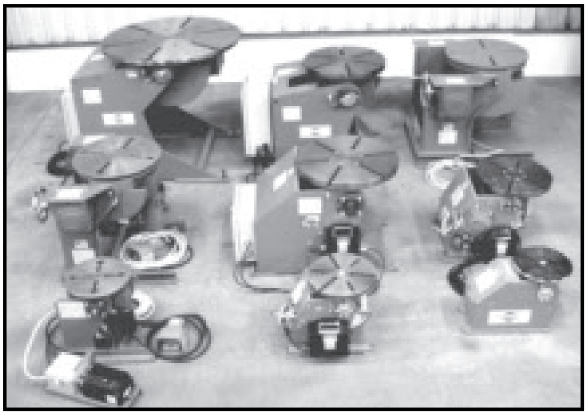
IWOTE '08. April 22, 23, Hotel Munte, Bremen, Germany. Conference language is English. Second Int'l Workshop on Thermal Forming and Welding Distortion. Visit *www.bias.de/Events/IWOTE08/index_html.*

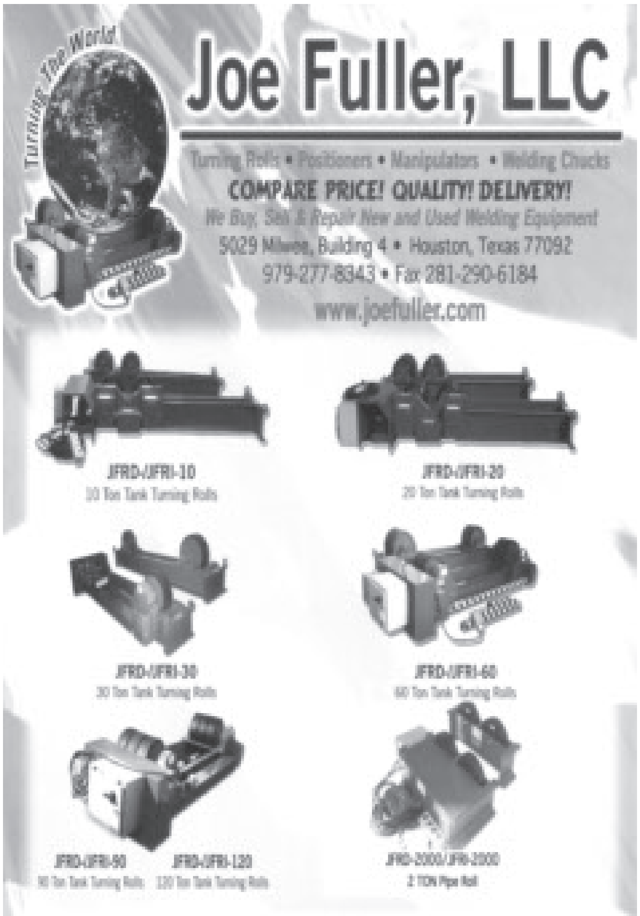
MicroManufacturing and **NanoManufacturing Confs. & Exhibits.** April 22, 23, Sheraton Framingham Hotel, Framingham, Mass. Society of Mfg. Engineers. Call (313) 425-3187, or visit *www.sme.org/micro; www.sme.org/nano.*

INTERTECH 2008. May 5–7, Contemporary Resort, Walt Disney World, Orlando, Fla. Abstracts of papers accepted until Jan. 1. It will explore practical applications for superabrasives for machining, grinding, drilling, polishing, wear parts, wire dies, etc. Visit *www.intertechconference.com.*

Montreal Mfg. Technology Show. May 12–14, Place Bonaventure, Montreal, Canada. Society of Mfg. Engineers. Call (313) 425-3187, or visit *www.smecanada.ca/montreal.*

XXXIX Steelmaking Seminar — Int'l. May 12–16, Estação Embratel Convention Center, Curitiba, Paraná, Brazil. Visit: *www.abmbrasil.com.br/seminarios/aciaria/2008/default-i.asp.*





Automotive Laser Application Workshop, ALAW 2008. May 13–15, Plymouth, Mich. Contact: The Laser Institute of America, *www.alawlaser.org;* (407) 380-1553.

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

EASTEC 2008 Expo. May 20–22. Eastern States Exposition Grounds, West Springfield, Mass. Society of Mfg. Engineers. Call (313) 425-3187, or visit *www.sme.org/eastec.*

Rapid 2008 Conf. and Expo. May 20–22. Disney's Coronado Springs Resort & Convention Center, Lake Buena Vista, Fla. Society of Mfg. Engineers. Call (313) 425-3187, or visit *www.sme.org/rapid.*

15th Int'l Conf. on Textures of Materials. June 1–5. Carnegie Mellon University Center, Pittsburgh, Pa. Contact: American Ceramic Society, *www.ereleases.com.*

◆Trends in Welding Research™, 8th Int'l Conf. June 2–6. Callaway Gardens Resort, Pine Mountain, Ga. Sponsored by ASM International, *www.asminternational.org/trends;* cosponsored by the American Welding Society, *www.aws.org.*

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

◆FABTECH International & AWS Welding Show. Oct. 6–8. Las Vegas Convention Center, Las Vegas, Nev. This show is the largest event in North America dedicated to showcasing the full spectrum of metal forming, fabricating, tube and pipe, and welding equipment and technology. Contact: American Welding Society, (800/305) 443-9353, ext. 462; *www.aws.org.*

Educational Opportunities

ASME Section IX Seminars. Dec. 3–5, Atlanta, Ga.; April 8–10, 2008, Las Vegas, Nev. Contact: ASME Continuing Education Institute. Call (800) 843-2763, or visit *www.asme.org/education.*

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

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

Continuing Education for Welding Inspectors and CWIs. Dec. 11–14. Chicago, Ill. Atema, Inc. Call (312) 861-3000, or visit *atemasolutions.com.*

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

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

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

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

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

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

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

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

Flux Cored Arc Welding/Semiautomatic. A one-week course offered Dec. 17–21, Cleveland, Ohio. Contact: Lincoln Electric Co. Welding School. Call (216) 383-8325, or visit *www.lincolnelectric.com* to request Bulletin ED.122.

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)

Location	Seminar Date	Exam Date
Reno, NV	Dec. 16-21	Dec. 22
Houston, TX	Dec. 16-21	Dec. 22
Beaumont, TX	Jan. 6-11, 2008	Jan. 12, 2008
Fresno, CA	Jan. 6-11	Jan. 12
Miami, FL	Jan. 13-18	Jan. 19
Albuquerque, NM	Jan. 13-18	Jan. 19
Knoxville, TN	EXAM ONLY	Jan. 19
Pittsburgh, PA	Jan. 27-Feb. 1	Feb. 2
Denver, CO	Jan. 27-Feb. 1	Feb. 2
Seattle, WA	Feb. 3-8	Feb. 9
Milwaukee, WI	Feb. 3-8	Feb. 9
Indianapolis, IN	Feb. 10-15	Feb. 16
Atlanta, GA	Feb. 10-15	Feb. 16
Miami, FL	EXAM ONLY	Feb. 21
Houston, TX	Feb. 24-29	Mar. 1
San Diego, CA	Feb. 24-29	Mar. 1
Norfolk, VA	Feb. 24-29	Mar. 1
Corpus Christi, TX	EXAM ONLY	Mar. 1
Boston, MA	Mar. 2-7	Mar. 8
Phoenix, AZ	Mar. 2-7	Mar. 8
Portland, OR	Mar. 2-7	Mar. 8
Perrysburg, OH	EXAM ONLY	Mar. 8
Anchorage, AK	Mar. 9-14	Mar. 15
Miami, FL	Mar. 9-14	Mar. 15
Mobile, AL	EXAM ONLY	Mar. 15
Rochester, NY	EXAM ONLY	Mar. 29
York, PA	EXAM ONLY	Mar. 29
Dallas, TX	Mar. 30-Apr. 4	Apr. 5
Chicago, IL	Mar. 30-Apr. 4	Apr. 5
Springfield, MO	Apr. 6-11	Apr. 12
Baton Rouge, LA	Apr. 6-11	Apr. 12
San Francisco, CA	Apr. 6-11	Apr. 12
Miami, FL	EXAM ONLY	Apr. 17
Portland, ME	Apr. 13-18	Apr. 19
St. Louis, MO	EXAM ONLY	Apr. 26
Nashville, TN	Apr. 20-25	Apr. 26
Jacksonville, FL	Apr. 20-25	Apr. 26
Baltimore, MD	Apr. 27-May 2	May 3
Detroit, MI	Apr. 27-May 2	May 3
Waco, TX	EXAM ONLY	May 3
Miami, FL	May 4-9	May 10
Albuquerque, NM	May 4-9	May 10
Spokane, WA	May 4-9	May 10
Corpus Christi, TX	EXAM ONLY	May 10
Oklahoma City, OK	May 18-23	May 24
Birmingham, AL	May 18-23	May 24
Long Beach, CA	EXAM ONLY	May 31
Hartford, CT	Jun. 1-6	Jun. 7
Pittsburgh, PA	Jun. 1-6	Jun. 7
Fargo, ND	Jun. 1-6	Jun. 7
New Orleans, LA	Jun. 1-6	Jun. 7
Sacramento, CA	Jun. 8-13	Jun. 14
Kansas City, MO	Jun. 8-13	Jun. 14
Miami, FL	EXAM ONLY	Jun. 19
Phoenix, AZ	Jun. 22-27	Jun. 28
Orlando, FL	Jun. 22-27	Jun. 28

For information on any of our seminars and certification programs, visit our website at **www.aws.org/certification** or contact AWS at (800/305) 443-9353, Ext. 273 for Certification and Ext. 455 for Seminars. Please **apply early** to save Fast Track fees. **This schedule is subject to change without notice.** Please verify the dates with the Certification Dept. and confirm your course status before making final travel plans.

9-Year Recertification Seminar for CWI/SCWI

Location	Seminar Dates	Exam Date
New Orleans, LA	Jan. 14-19, 2008	NO EXAM
Denver, CO	Feb. 11-16	NO EXAM
Dallas, TX	Mar. 10-15	NO EXAM
Sacramento, CA	Apr. 14-19	NO EXAM
Pittsburgh, PA	May 19-24	NO EXAM
San Diego, CA	Jun. 9-14	NO EXAM
Orlando, FL	Sept. 8-13	NO EXAM
Dallas, TX	Oct. 20-25	NO EXAM
Miami, FL	Dec. 1-6	NO EXAM

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

Certified Welding Supervisor (CWS)

Location	Seminar Dates	Exam Date
Atlanta, GA	Jan. 21-25	Jan. 26
Houston, TX	Jan. 28-Feb. 1	Feb. 2
Baton Rouge, LA	Mar. 31-Apr. 4	Apr. 5
Atlanta, GA	Apr. 28-May 2	May 3
Columbus, OH	May 19-23	May 24
Minneapolis, MN	Jun. 23-27	Jun. 28
Atlanta, GA	Jul. 14-18	Jul. 19
Philadelphia, PA	Aug. 18-22	Aug. 23
Atlanta, GA	Sept. 15-19	Sept. 20

CWS exams are also given at all CWI exam sites.

Certified Radiographic Interpreter (CRI)

Location	Seminar Dates	Exam Date
Long Beach, CA	Jan. 14-18	Jan. 19
Indianapolis, IN	Feb. 11-15	Feb. 16
Houston, TX	Mar. 10-14	Mar. 15
Philadelphia, PA	Apr. 14-18	Apr. 19
Nashville, TN	May 19-23	May 24
Manchester, NH	Jun. 9-13	Jun. 14
Manchester, MA	Jul. 14-18	Jul. 19
St. Louis, MO	Aug. 18-22	Aug. 23

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 prep course for CWI Exam-Part A); Visual Inspection Workshop (prep course for CWI Exam-Part B); and D1.1 and API-1104 Code Clinics (prep courses for CWI Exam-Part C).

On-site Training and Examination

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

American Welding Society®

SOCIETY NEWS

BY HOWARD M. WOODWARD

Image of Welding Winners Announced at FABTECH Int'l & AWS Welding Show

The American Welding Society and the Welding Equipment Manufacturers Committee (WEMCO) honored the seven winners of 2007 Image of Welding Awards Nov. 12 during the FABTECH Int'l & AWS Welding Show in Chicago, Ill. The following persons and organizations were cited:

Individual Category: **Carl Occhialini,** Detroit, Mich.

AWS Section Category: **Houston**

Large Business Category: **Bucyrus International, Inc.,** South Milwaukee, Wis.

Small Business Category: **Greiner Industries, Inc.,** Mount Joy, Pa.

Welding Distributor Category: **Sutton-Garten Co.,** Indianapolis, Ind.

Welding Educator Category: **Robert Sandelier,** Camden County Technical School, Pennsauken, N.J., and Cumberland Vocational School, Vineland, N.J.

Educational Faculty Category: **Sheet Metal Workers Local #33 Cleveland District, Joint Apprenticeship & Training Program** in Ohio.

The stories of these winners speak of their dedication to the future of the welding industry as well as their resourcefulness when faced with tough decisions.

One example is the AWS **Houston Section** coming to the aid of the devastated **Sabine Section** (Beaumont, Tex.) in the aftermath of Hurricane Rita.

Reacting positively to the worsening welder recruiting environment resulting from the growing shortage of skilled welders, **Bucyrus International, Inc.,** partnered with local educational institutions to find solutions, recruit students, and build careers.

Robert Sandelier did not let reaching retirement age interfere with his passion for teaching welding; he redirected his talents to teaching nighttime welding classes and continued working with students to raise their awareness about the diverse and lucrative careers welding has to offer.

Greiner Industries owner **Frank Greiner** personally leads about ten plant tours annually for local students. He stresses the value of careers in welding and manufacturing. CWI **Joseph Kane,** who nominated Greiner for the award, said, "Students see the emphasis on quality and safety when touring Greiner. It's one of the best quality-minded shops I have ever been in."

The qualities that these individuals and companies have demonstrated through their continued efforts have been instrumental in enhancing the image of welding and strengthening the industry. ♦

Railroad Welding Committees Meet in St. Louis

The D15 Committee and the D15A Subcommittee recently met in St. Louis, Mo., to put the finishing touches on their document D15.1, *Railroad Welding Specification — Cars and Locomotives,* soon to be published. **Michael Untermeyer,** D15 Committee chair, works for Union Tank Car Co. in Houston, Tex., and **Chris Boulden,** D15A subcommittee chair, represents Trinity Rail Group in Dallas.

If you are interested in helping to develop railroad welding standards, contact **Reino Starks,** AWS staff committee secretary, (800/305) 443-9353, ext. 304, to learn more about committee work.

In the photo, Starks is shown in front of the committee members. Others shown are (from left) **Norman Brown, Dennis Allbritten, Steve Coughlin, Chris Boulden, Jared Haacke, Michael Untermeyer** (rear), **Marcel Desjardins, Alan Willaredt, Michael Oddie,** and **John Pearson.** ♦

Changes to ASME Section IX, 2007 Edition

BY WALTER J. SPERKO

The following is a summary of the changes that appear in the 2007 edition of ASME Section IX. Readers are advised that the opinions expressed in this article are those of the author and not the official opinion of Subcommittee IX. The changes become mandatory Jan. 1, 2008.

Section IX Gets a New Name

Section IX has a new name: *Qualification Standard for Welding and Brazing Procedures, Welders, Brazers, and Welding and Brazing Operators.* The old title, *Welding and Brazing Qualifications,* was just as descriptive, but the new one conforms with the ISO style where the nature of the standard, in this case, "Qualification," is the first word, similar to ISO 9606-1, *Qualification test of welders — Fusion welding — Steels.* In its effort to reinforce recognition as an international standard, ASME seems to be headed in the direction of reformatting its standards after ISO standards. While not a bad idea, ISO standards tend to be highly specialized individual standards rather than complete stand-alone documents (e.g., in order to determine the visual acceptance standards for a welder test coupon, one must refer to another standard, ISO 17637). In the writer's opinion, standards that are mostly stand-alone, such as Section IX and other ASME Code Sections, are more user-friendly.

Welding Procedure (QW-200) Changes

Table QW-451.1 has been revised to incorporate the provisions previously found in QW-403.7. That paragraph dealt with how to qualify for welding of materials that were more than 8 in. (200 mm) in thickness, and it has been deleted. There is a new line in QW-451.1 that says that, for test pieces that are 6 in. (150 mm) thick, the minimum thickness qualified is 3/16 in. and the maximum thickness qualified is 1.33 times the test coupon base metal and weld deposit thickness.

During this revision, there was considerable discussion attempting to identify the purpose of this variable. This variable has been around for decades, and some of the old-timers on the committee were consulted to illuminate its origins. It seems that 50 years ago, the art of steel making was such that a plate more than 8 in. thick did not have very uniform properties throughout its thickness, and to ensure that fabricators could weld such thick plates successfully, Subcommittee IX members imposed a requirement to qualify on material that was more than 8 in. thick if one was going to weld on materials more than 8 in. in thickness. While significant variations in properties may not be a technical concern when welding heavy sections today, no data were available to show that it was not, so the technical requirement to qualify heavy sections was sustained, although in a more user-friendly format.

Those doing resistance welding of titanium and zirconium can rest easy. The requirements of qualification of the welding machine (essentially an endurance test of the power supply and related equipment) did not address how to show that the equipment was adequate when welding titanium and zirconium and now QW-284 specifically addresses those materials. This was simply an oversight when QW-284 was revised in 2005.

Welder Qualification (QW-300) Changes

The only change in the rules for welder qualification were in QW-322. A user asked if it was necessary, when extending a welder's qualifications for a process, for that welder to be doing welding under the supervision and control of the organization that qualified him or her, or could that organization accept the word of another manufacturer or contractor that the welder had used the process. The reply was that the former was required, and QW-322.1(a)(1) and (2) were revised to specify that, in order for a welder's or welding operator's qualifications to be extended for an additional six months, the welder or welding operator must weld under the supervision and control of the manufacturer or contractor who qualified him or her. The exception is when testing was done under QW-300.3, which allows for mass simultaneous qualification such as is done under the "Common Arc" program.

Section IX requires that the manufacturer or contractor observe and document that the welders have welded with each process for which they are qualified in order for those welders to continue to be qualified. The purpose of this requirement is not only to document that those welders have "struck an arc" with the process, but that the manufacturer or contractor is satisfied with the quality of work that that welder has produced with that process. This does not happen if someone other than the manufacturer or contractor that qualified the welder observes the worker welding.

This revision should present no problem where welders and operators work in a shop, but in the construction environment, ASME B31 piping code sections permit welders and welding operators to be interchanged among contractors without requalification. This means that, under the new QW-322.1 rules, once a welder is no longer working for the contractor who qualified him, his qualifications will quickly expire, even though he may be working and producing satisfactory welds for a new employer. However, the B31 Subcommittees has reviewed the matter and philosophically agreed that, since the B31 Sections allow interchange of welders among contractors (taking exception to Section IX in this matter), it would be inconsistent not to allow a contractor other than the qualifying contractor to extend a welder or welding operator's qualification.

Most of the B31 Code Sections will have made appropriate changes to allow the contractor for whom the welder is working to extend his continuity by the time the revision to QW-322.1 is mandatory, or they have determined that no changes are necessary due to the way a specific B31 Code Section is written.

Base Metals and Filler Metals

Various grades of materials were added and others deleted from QW/QB-422. Those changes are most easily identified

WALTER J. SPERKO is president, Sperko Engineering Services, Inc., Greensboro, N.C. (sperko@asme.org; www.sperkoengineering.com); *(336) 674-0600.*

in the Summary of Changes that begins on page xxv of Section IX.

SFA 5.4 and 5.9 have been updated to add several new duplex and austenitic filler metals and to eliminate several ferritic filler metals E/ER502, E/ER-505, and E7Cr. The ferritic alloys have already been moved to SFA 5.5 except for the E7Cr, which is no longer manufactured.

Brazing (QB) Changes

There were no significant changes to the rules on Brazing, but all of the forms have been revised and are an improvement over the previous forms.

Inquiries

One inquiry is of particular interest to those who use SI (metric) units in their welding documents. The first question was, when working in U.S. Customary Units, was it acceptable to leave welder qualification records in metric units provided the welder did not exceed the weld deposit thickness for which he or she was qualified. The reply was "yes," provided there were convenient tools, such as a conversion table, so that the limits were not exceeded.

The second question asked whether the same practice was permitted for WPSs, and the reply was positive.

Coming Attractions

Pending exciting changes in Section IX include revision of the welding forms, addressing qualification of "G" classification electrode and filler metal, provisions to use a macro-etch specimen for materials with less than 3% ductility in lieu of a bend test, and possibly the elimination of S-numbers by turning them all into P-numbers. Finally, due to significant concerns over abuse of Grade 91 and similar creep strength enhanced ferritic steels such as Grades 92, 911, 23, etc., during postweld heat treatment and other local heating operations, all these new materials will be assigned P-15A through P-15G to distinguish them from the older P-5A through P-5C materials.

Special rules will be prepared for dealing with these materials similar to those that I reported on in my 2006 Addenda update, published in the April 2007 *Welding Journal,* for Grade 91.

Readers are advised that ASME Code Committee meetings are open to the public. The schedule is available on the writer's Web site and at *www.asme.org.* ♦

Standards for Public Review

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

A5.10/A5.10M:1999 (R200X), *Specification for Bare Aluminum and Aluminum-Alloy Welding Electrodes and Rods.* Reaffirmed — $25. Review expired.

B2.1/B2.1M:200X, *Specification for Welding Procedure and Performance Qualification.* Revised — $156. 12/17/07.

B2.3:200X, *Specification for Soldering Procedure and Performance Qualification.* New — $31. 12/3/07.

Standards Approved by ANSI

C3.6M/C3.6:2008, *Specification for Furnace Brazing.* Approved: 9/12/07.

C4.4/C4.4M:2007, *Recommended Practices for Heat Shaping and Straightening with Oxyfuel Gas Heating Torches.* Approved: 9/11/07.

B5.15:2003-AMD1, *Specification for the Qualification of Radiographic Interpreters.* Approved: 10/12/07.

ISO Drafts for Public Review

Copies of the following Draft International Standards are available for review and comment through your national standards body, which in the United States is ANSI, 25 W. 43rd St., 4th Floor, New York, NY, 10036; (212) 642-4900.

In the United States, if you wish to participate in the development of International Standards for welding, contact Andrew Davis, (305) 443-9353, ext. 466; *adavis@aws.org.* Otherwise contact your national standards body.

ISO/DIS 15609-4, 2560, *Welding consumables — Covered electrodes for manual metal arc welding of non-alloy and fine grain steels – Classification.*

Technical Committee Meetings

All AWS technical committee meetings are open to the public. Persons wishing to attend a meeting should call (800/305) 443-9353 and extension of the staff engineer listed with the meeting.

Dec. 5, 6, SHC Safety and Health Committee. Miami, Fla. Contact Steve Hedrick, ext. 305.

Dec. 5, SH1 Subcommittee on Fumes and Gases, Miami, Fla. Contact Steve Hedrick, ext. 305. ♦

Amendment B5.15

AWS B5.15:2003-AMD1
Specification for the Qualification of Radiographic Interpreters

The following Amendment has been made to this document and has been incorporated into the current reprints.

Page 3, 8.1 Near Vision Acuity, amend text to read:

8.1 Near Vision Acuity. Radiographic interpreters shall have the ability to read a minimum of Jaeger Number 2 letters at a minimum of 12 in. (305 mm) or better in at least one eye. ~~in each eye~~.

Technical Interpretation

D1.1
Structural Welding Code — Steel:2004

Subject: Qualification Responsibility
Code Edition: D1.1:2004
Code Provision: Sections 1.4.1, 4.1.1.1, and 4.1.2.1
AWS Log: D1.1-04-I05

Inquiry:

(1) Can a subcontractor use the manufacturer's qualified WPS to perform welder qualification testing?

(2) Can the manufacturer's Engineer, documenting a specific qualified WPS, accept subcontractor's welder qualification test based on the same manufacturer's specific qualified WPS including performance qualification to other standards?

Response:

(1) Yes, for the purposes of welder qualification.

(2) Yes, per Section 4.21, and only if 1.3.1 is satisfied.

Member-Get-A-Member Campaign

Shown are members participating in the Member-Get-A-Member Campaign for the period 6/01/07–5/31/08. See page 65 of this *Welding Journal* for campaign rules and prizes. Call the Membership Dept., (800) 443-9353, ext. 480, for more information.

Winner's Circle

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

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

President's Guild

Members sponsoring 20 or more new Individual Members.

L. Taylor, Pascagoula — 67

President's Club

AWS Members sponsoring 3–8 new Individual Members.

S. Christensen, Nebraska — 7
R. Ellenbecker, Fox Valley — 7
E. Ezell, Mobile — 7
A. Castro, South Florida — 6
K. Kotter, Utah — 4
L. Garner, Mobile — 3
C. Gilbert, East Texas — 3
P. Hanley, Peoria — 3
T. Nielsen, Pittsburgh — 3

President's Honor Roll

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

J. Compton, San Fernando Valley
R. Gaffney, Tulsa
W. Galvery Jr., Long Beach/Or. Cty.
H. Jackson, L.A./Inland Empire
C. Johnson, Northeast Plains
J. Johnson, Northern Plains
D. Landon, Iowa
F. Schmidt, Niagara Frontier
D. Wright, Kansas City
R. Wright, San Antonio
P. Zammit, Spokane

Student Member Sponsors

Members sponsoring 3 or more new AWS Student Members.

G. Euliano, Northwestern Pa. — 34
R. Evans, Siouxland — 34
G. Seese, Johnstown-Altoona — 19
C. Kipp, Lehigh Valley — 18
T. Zablocki, Pittsburgh — 15
C. Overfelt, SW Virginia — 14
A. Stute, Madison-Beloit — 14
R. Munns, Utah — 12
R. Tully, San Francisco — 10
P. Bedel, Indiana — 9
D. Williams, N. Texas — 9
R. Hutchinson, Long Bch./Or. Cty. — 8
W. Komlos, Utah — 8
C. Schiner, Wyoming Section — 8
A. Badeaux, Washington, D.C. — 7
J. Boyer, Lancaster — 7
R. Hutchison, Long Bch./Or. Cty. — 7
W. Troutman, Cleveland — 7
J. Boyer, Lancaster — 6
E. Norman, Ozark — 6
B. Wenzel, San Francisco — 6
B. Hardin, San Francisco — 5
D. Vranich, N. Florida — 5
J. Angelo, El Paso — 4
N. Carlson, Idaho/Montana — 3
W. Galvery Jr., Long Bch./Or. Cty. — 3
R. Olesky, Pittsburgh — 3
S. Robeson, Cumberland Valley — 3
C. Rossi, Washington, D.C. — 3
L. Taylor, Pascagoula — 3
D. Zabel, SE Nebraska — 3 ♦

Be a Tech Volunteer

Reinforcing Steel Code

Volunteers are sought to serve on the D1I Subcommittee on Reinforcing Bars to help revise D1.4, *Structural Welding Code — Reinforcing Steel,* specifically in areas of carbon or low-alloy structural steel, their application, inspection, qualification, and regulations. This is an active subcommittee that meets during spring and fall of each year. Members are expected to attend meetings, participate in discussions, and respond to correspondence. Qualified parties are encouraged to submit an online application at *www.aws.org/w/s/technical/.* For more about this committee's work, contact S. Morales, (800) 443-9353, ext. 313; *smorales@aws.org.*

Resistance Welding

Pros interested in the design, construction, calibration, safe operation, and maintenance of resistance welding equipment are sought by the J1 Committee on Resistance Welding Equipment to help prepare standards related to RW consumables, components, and machinery. Contact A. Alonso, (800) 443-9353, ext. 299; *aalonso@aws.org*. To apply for membership online, visit *www.aws.org/171T.*

On-Premise Sign Structures

Volunteers are sought to help draft a new AWS standard for welding of on-premise sign structures. Experts involved in the manufacture and installation of signs and related structures as well as users of on-premise sign structures are urged to join. Int'l Sign Assn. members initiated the project and will participate. Contact J. Gayler, (800/305) 443-9353, ext. 472; *gayler@aws.org*.

Cast Iron Welding

Volunteers are sought to help update *Welding Handbook,* Vol. 4 — Materials and Applications. Assistance is particularly needed for the chapters on cast irons and maintenance and repair welding. Other chapters concern carbon and low-alloy, high-alloy, coated, tool and die, and heat-resistant steels. Contact A. O'Brien, (800) 443-9353, ext. 303; *aobrien@aws.org*.

SECTION NEWS

DISTRICT 1

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

BOSTON

OCTOBER 1

Activity: The Section members toured the Airgas Fill Plant in Salem, N.H., to observe its testing, blending, and filling operations for the welding, general industrial, medical, and beverage industries. The presenters included **James Harris,** production supervisor, and **Doug Wood,** testing supervisor. Long-time executive board member **Richard Jones** received the District Meritorious Award for his many decades of service. **John Puffer** received the District Dalton E. Hamilton CWI of the Year Award. District 1 Director **Russ Norris** attended the program.

Boston Section Chair Tom Ferri (left) presents an appreciation award to James Harris (center) and Doug Wood during the Section's tour of Airgas in October.

Richard Jones (center) receives the District Meritorious Award from Boston Section Chair Tom Ferri (left) and Russ Norris, District 1 director.

John Puffer (center) accepts the CWI of the Year Award from Tom Ferri (left), Boston Section chairman, and Russ Norris, District 1 director.

MAINE

SEPTEMBER 20

Activity: The Section held an executive committee meeting at Village Cafe in Portland, Maine. **Jeff Fields** presented a report on the upcoming SkillsUSA welding competition. Secretary **Mike Gendron** brought up additional topics. CWI **Mark Legal** discussed the upcoming vendors' night program he will host at the local community college. District 1 Director **Russ Norris** presented the District and national news.

Shown at the Maine Section executive meeting are (from left) Scott Lee, Jeff Fields, District 1 Director Russ Norris, Mark Legal, and Mike Gendron.

Seacoast School of Technology Student Chapter

SEPTEMBER 24

Activity: Chapter Advisor **Jonathan Theberge,** a welding instructor at the school, conducted a craft committee meeting with members of the welding community to discuss class curriculum, welding equipment needs, and changes to the classroom and welding stations. In attendance were **Greg Bushey** of Merriam-Graves, **Dan Chabot** from Pinkerton Academy, **Adam Fallon** with The Lincoln Electric Co., **Tony Hanna** with New Hampshire Community Technical College, **Tom March** with Thompson School, and **Russ Norris,** District 1 director.

DISTRICT 2

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


New Jersey Section Treasurer Al Fleury (left) presents a speaker gift to Seann Bradley, Section secretary.


Shown at the Philadelphia Section program are (from left) Past Chair Jim Korchowsky, speaker Pramathesh Desai, and Chairman John DiSantis.

Eric Shaffer receives the Supporting Company in Industry certificate from Reading Secretary Merilyn McLaughlin.


Reading Section members posed during their program held at Aquajet Services.


Ruben Nolt (left) is shown with Reading Section Chair Joe Young.


Ted Wills Jr. accepts the Supporting Company in Industry award from Reading Section Secretary Merilyn McLaughlin.

NEW JERSEY

SEPTEMBER 18
Speaker: **Seann T. Bradley,** sales engineer
Affiliation: The Lincoln Electric Co.
Topic: What to think about when considering welding automation
Activity: The meeting was held at L'Affaire Restaurant in Mountainside, N.J.

PHILADELPHIA

OCTOBER 10
Speaker: **Pramathesh Desai,** global sales manager
Affiliation: Tempil, Inc.
Topic: The methods and applications for preheating, and importance of temperature-indicating markers
Activity: Following the talk, Desai offered samples of the company's new Tempilstick Pro to the attendees. The meeting was held at Ramada Inn in Essington, Pa.

DISTRICT 3

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

READING

SEPTEMBER 20
Speaker: **Matt Doyle**
Affiliation: Fox Machinery Assn., Inc.
Topic: Waterjet cutting and programming
Activity: The Section members watched demonstrations of waterjet cutting performed by **Ruben Nolt,** owner, and employees of Aquajet Services, LLC. Section Secretary **Merilyn McLaughlin** presented the Supporting Company in Industry award to **Eric Shaffer** of G.T.S., a supplier of welding and gas supplies in the Reading area, and to **Ted Wills Jr.,** representing Anchor Fire Protection. The program was held at the Aquajet Services facilities in Kutztown, Pa.

DISTRICT 4

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

DISTRICT 5

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

Shown at the Florida West Coast Section program are speaker Steve Womble (left) and Al Sedory, Section chairman.

The Atlanta Section members are shown during their tour of the Praxair facilities in Norcross, Ga.

ATLANTA

SEPTEMBER 20

Activity: The Section members toured the Praxair facility in Norcross, Ga., to see its distribution and retail sales center and to study its high-pressure cylinder filling operations. **Scott Neal,** regional director, conducted the program.

FLORIDA WEST COAST

OCTOBER 10

Speaker: **Steve Womble**

Affiliation: State of Florida DOT

Topic: The design, construction, maintenance, and inspection of the Sunshine Skyway Bridge in St. Petersburg, Fla.

Activity: The program was held at Frontier Steak House in Tampa, Fla.

SOUTH CAROLINA

SEPTEMBER 20

Activity: The Section members visited Soil Consultants Inc. in Charleston, S.C. The company offers many services, including nondestructive testing and inspection using a variety of testing methods. Presenters included **Chris Eure,** senior inspector; **Kenny Johnson,** vice president; and **Richard Grumbine,** an inspector for Metal Trades, Inc. The topics discussed were nondestructive inspection, development of WPSs, and the importance of grinding skills to inspection and repair.

SOUTH FLORIDA

OCTOBER 18

Speaker: **Nola Garcia,** CEO

Affiliation: BattleBotsIQ, Miami, Fla.

Topic: How students benefit from participating on robot-building teams

Activity: Garcia emphasized how robot-building projects help students gain a broad interest in practical math, science,

Shown during the South Carolina Section meeting held at Soil Consultants Inc. are (from left) Gale Mole, Section chairman; Chris Eure, Richard Grumbine, and Kenny Johnson.

Shown are the South Florida Section members and guests at AWS headquarters in Miami.

Columbus Section members met with the Buckeye Iron Mongers for a hands-on metalworking demonstration in October.

The Pittsburgh Section members toured the Holtec International facility in September.

Shown (from left) are robotics educators Bill Garcia and speaker Nola Garcia with Mary Ruth Johnsen, South Florida Section secretary and senior editor of the Welding Journal.

electronics, welding, engineering materials, and manufacturing processes. Following a seven-minute-long video of the 2007 National BattleBots competition showing combat robots in action, the attendees watched a demonstration of a 15-lb "attack" robot controlled by **Bill Garcia.** Also present were five 16-year-old girls, members of a robot-building team from Carrollton School of the Sacred Heart, an all-girls school in Miami. This South Florida Section meeting was held at AWS headquarters in Miami for 37 attendees.

DISTRICT 6

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

DISTRICT 7

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

COLUMBUS

October 11

Activity: **Larry Heckendorn** and the Buckeye Iron Mongers presented a hands-on demonstration of forging and metalworking for the Section members. Each attendee fabricated ornamental gate hooks from square steel bar stock. The program was held at The Ohio State University Agricultural Engineering building in Columbus, Ohio.

PITTSBURGH

September 11

Activity: The members toured Holtec International to study its manufacture of containers for spent nuclear fuel rods for wet and dry storage and transportation.

DISTRICT 8

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

Pittsburgh Section Vice Chair Dave Daugherty (right) presents a speaker gift to John Menhart.

CHATTANOOGA

September 11

Speaker: **Samuel D. Kiser,** director of technology

Affiliation: Special Metals, Newton, N.C.

Topic: Dissimilar metal welds — a practical approach

Activity: **Paul Huffman** received the AWS Silver Membership Award for 25 years of service to the Society. The discussion concerned the importance of dilution, metals compatibility, and how to select the proper welding consumable when working with dissimilar metal welds. The meeting was held at Komatsu America Corp. in Chattanooga, Tenn. The Section officers for the new season are **William C. Brooks,** chair; **Eric Zumbrun** and **Dusti L. Jones,** vice chairs; **Gerald Hargis,** secretary and *Buzz Box* editor; **Don Russell,** treasurer; **Eric Zumbrun,** program chair; **Greg Wilmoth,** membership committee chair; **Delbert Butler,** technical representative; **David Hamilton,** student affairs, scholarships, education, and certification chair; **Dusti L. Jones,** publicity chair; and **Ronnie Smith,** awards chair.

WESTERN CAROLINA

October 2

Activity: Chairman **Jamie Whims**, Vice Chair **Duke Moses,** and Treasurer **Bob Fellers** presented $1500 Section scholarships to **Kyle Morris** from Spartanburg T. C. and **Phillip Warda,** a student in the welding program at Greenville T. C. Warda intends to pursue a career in nuclear pipe welding. In addition to funds received from AWS, the Section finances its scholarship program through an annual golf tournament, a calendar fundraising event, and a career night for local vocational center students.

DISTRICT 9

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

Speaker Sam Kiser (left) is shown with William Brooks, Chattanooga Section chairman.

Paul Huffman (right) accepts the AWS Silver Membership Certificate Award from William Brooks, Chattanooga Section chairman.

Shown at the Western Carolina Section program are (from left) Treasurer Bob Fellers, scholarship recipient Phillip Warda, and Bob Humphrey, his welding instructor.

Southeastern Louisiana University Student Chapter members participated in the Baton Rouge program.

Baton Rouge Section Chair Barry Carpenter (right) presents a speaker appreciation plaque to Andy Afflick.

The top three prize-winning students at the New Orleans Section program are (from left) Johnny Tapp, Donny McMahon, and Brandon Kennedy.

New Orleans Section Chair Travis Moore (center) presents a sponsor plaque to Craig Collins (left) and Robbie LaChute.

Shown at the Baton Rouge Section program are (from left) District 9 Director George Fairbanks, Chairman Barry Carpenter, and speaker Roy Bonnette.

BATON ROUGE

SEPTEMBER 20

Activity: **Andy Afflick,** welding manager, Trinity Marine, discussed welding of barges, bridges, and large industrial structures. **Roy Bonnette,** Southeastern Louisiana University (SLU) Industrial Technology staff member, assisted by District 9 Director **George Fairbanks,** presented an overview of a joint project between the SLU staff and Student Chapter members and local industry to build a replica of the submarine *Pioneer*.

NEW ORLEANS

SEPTEMBER 18

Activity: The Section joined with Dynamic Inc., at Boomtown Casino to host a student welding education program. A highlight of the meeting was the students' answers to questions related to their experiences working in the welding industry and what they could do to attract other students into the welding profession. Dynamic Inc., donated the prize money. The winners included **Johnny Tapp, Donny McMahon,** and **Brandon Kennedy.**

DISTRICT 10

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

DISTRICT 11

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

Dynamic Inc. employees attended the New Orleans Section program in September.

Speaker Rick Kreczmer (right) is shown with Mark Rotary, Detroit Section technical program chairman.

Shown during the Lakeshore Section's tour of Robinson Metal are (from left) Neil VanLanen, Section Chair James Hoffman, and Tom Verboncouer.

Shown at the September Milwaukee Section program are (from left) Chairman Jerry Blaski, speaker Scott Raether, Tom Dega, and Jennifer Koeller.

Shown at the October Milwaukee Section program are (from left) Dan Graves, Dave Christofferson, and Chair Gerald Blaski.

DETROIT

OCTOBER 11
Speaker: **Rick Kreczmer,** Mid-West manager
Affiliation: Farr APC, Granger, Ind.
Topic: Determining the type, size, use, and maintenance of welding fume-collection systems
Activity: The meeting was held at the Ukrainian Cultural Center in Warren, Mich.

DISTRICT 12

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

LAKESHORE

OCTOBER 11
Activity: The Section members toured Robinson Metal, Inc., in De Pere, Wis., to study its numerous processes using laser and waterjet cutting, forming, welding, machining, and assembly. The products viewed included cabinets, consoles, conveyors, and enclosures. **Tom Verboncouer,** sales and marketing manager, and **Neil VanLanen,** floor supervisor, conducted the program. Following the tour, the members had dinner at Legends in De Pere where they discussed plans for their bus trip to attend the FABTECH Int'l & AWS Welding Show.

MILWAUKEE

SEPTEMBER 20
Speaker: **Scott Raether,** director of operations
Affiliation: Novum Structures, LLC
Topic: Architectural wonders
Activity: Raether discussed the architectural features of the Overture Performance Center in Madison, Wis., Wrigley Building in Chicago, Ill., and Dolphin Stadium in Miami, Fla. Assisting Raether were **Tom Dega,** contract administrator, and **Jennifer Koeller,** purchasing agent. The program was held at Charcoal Grill & Rotisserie in Milwaukee, Wis.

OCTOBER 18
Activity: The Milwaukee Section members toured the Quad/Graphics, Inc., 1.7 million sq-ft printing plant in Sussex, Wis. The presenters included pressman **Kurt Miller, Dan Graves,** and **Dave Christofferson.** Following the tour, the group dined at Thunder Bay Grille.

DISTRICT 13

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

CHICAGO

OCTOBER 10
Speaker: **Steve Berg**
Affiliation: Berg Engineering and Sales

Speaker Steve Berg (left) is shown with Craig Tichelar, Chicago Section chairman.

Topic: Phased array ultrasonic inspection of welds

Activity: This Chicago Section program was a joint meeting with members of the local chapter of ASNT. The program, held at Bohemian Crystal Restaurant, was attended by 58 members and guests.

Shown at the joint Chicago Section and ASNT Chapter meeting are (from left) Pete Host, Eric Krauss, Chair Craig Tichelar, and Treasurer Marty Vondra.

ILLINOIS VALLEY

September 19

Activity: The Section members toured Nicor Gas gas storage areas in Mendota, Ill. The presenters included **Michael W. Fugate,** region manager, supply operations; and **George Wilson,** supervisor supply operations, supply/storage at Troy Grove.

DISTRICT 14

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

INDIANA

September 19

Activity: The Section members toured the Lift-A-Loft Corp. facilities in Cowan, Ind. **William P. Fulton,** company president and CEO, conducted the tour. **Charles "Butch" Weidner,** district manager, Hobart Brothers Performance Welding, presented a talk on weld size in relation to cost and cost-effectiveness, and metal core vs. solid wire. Twenty members attended the program.

Nathan Lamirande (left) is shown receiving underwater welding and cutting instruction from his father, Jim Lamirande, Lexington Section chairman.

Indiana Section members are dwarfed by a Lift-A-Loft machine custom made for FedEx Corp.

LEXINGTON

June 9

Activity: The Section members met at Ocean Corporation, Inc., in Houston, Tex., to participate in a wet welding workshop for welding instructors. Section Chair **Jim Lamirande,** an instructor at Southside Tech Center in Lexington, Ky., had the opportunity to teach underwater welding and cutting techniques to his son, **Nathan Lamirande,** who is employed at Oceaneering International of Morgan City, La. About 40 participated in the activity.

St. Louis Section members and guests are shown during their tour of Cooper B-Line. Front row (from left) are presenters Keith Simon and Walter Ford Jr., Chairman Rick Suria, District 14 Director Tully Parker, and Pat Cody, a past Section chairman.

Nebraska Section members are shown during their tour of Valmont Industries. Presenter Scott Christensen is at far left.

East Texas Section Chair Bryan Baker (left) is shown with speaker Scott Melton (center), and Andy Divin, Section program chair.

Shown at the joint Iowa and Eastern Iowa Sections meeting are (from left) Brad Wells, District 16 Director David Landon, and Gerald Uttrachi, AWS president.

Shown at the joint North Texas Section and ASM Int'l meeting are (from left) ASM speaker Ricky Baron, Section Chair Robert Tessier, and speaker Michael Beaton.

Scott Christensen (left) receives a speaker appreciation plaque from Jason Hill, Nebraska Section vice chairman.

Shown at the Saskatoon Section executive meeting are (from left) Kevin Jones, Jay Janzen, Vice Chair Ike Oguocha, and Chairman Gus Marisca.

ST. LOUIS

September 20
Activity: The Section members toured Cooper B-Line in Troy, Ill., to study its manufacturing and welding of aluminum and steel cable tray products. **Walter Ford Jr.,** welding supervisor, and **Keith Simon,** manufacturing engineer, conducted the program. District 14 Director **Tully Parker** attended the event.

DISTRICT 15

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

ARROWHEAD

September 29
Activity: The executive committee met to discuss upcoming Section events. The meeting was held at Goodfella's Restaurant in Eveleth, Minn.

October 9
Speaker: Chair **Tom Baldwin,** CWI, CWE
Affiliation: Mesabi Range Community & Technical College
Topic: Brazing and braze welding
Activity: The seminar was held at Mesabi Range Community & Technical College in Eveleth, Minn.

SASKATOON

September 26
Activity: The Section's executive committee met at Boston Pizza in Saskatoon, Saskatchewan, Canada, to discuss seminars and conferences for the upcoming year. **Jay Janzen** was elected treasurer, succeeding Membership Chair **Kevin Jones**; and Vice Chair **Ike Oguocha** was named technical representative, succeeding Chairman **Augustin (Gus) Marisca**.

DISTRICT 16

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

IOWA and EASTERN IOWA

September 11
Speaker: **Gerald Uttrachi,** AWS president
Affiliation: WA Technology, LLC
Topic: Welding race cars and street rods
Activity: This was a joint meeting of the Iowa and Eastern Iowa Sections. The program included a tour of Vermeer Mfg. Co. in Pella, Iowa. **Bob Kephart** received the District 16 and the Iowa Section Meritorious Awards. **Brad Wells** received the District 16 and the Iowa Section Dalton E. Hamilton CWI of the Year Awards. **Joe Steenhoek** received the District 16 and the Iowa Section Howard E. Adkins Instructor Awards. **Brett Baer** received the District 16 and Eastern Iowa Meritorious Awards, and District 16 and Eastern Iowa Section Private Sector Awards. District 16 Director **David Landon** attended the program.

KANSAS CITY

September 20
Activity: The Section members toured the Kansas Speedway to see the pit areas, repair garages, and operations in the Lincoln Electric repair booth.

NEBRASKA

September 20
Activity: The Section members toured Valmont Industries in Valley, Neb., to study the welding operations used to manufacture light poles, utility poles, and irrigation equipment. Also studied were the company's galvanizing and anodizing powder coatings facilities. **Scott Christensen,** production manager, made a presentation and conducted the tour.

DISTRICT 17

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

EAST TEXAS

September 20
Speaker: **Scott Melton,** regional manager
Affiliation: Fanuc Robotics America
Topic: Recent innovations in robotic arc welding


Shown at the Houston Section's program are (from left) speaker Jon Lee, Vice Chair Ron Theiss, Julie Theiss, Dan Gates, and Wayne Knupple.


Shown at the British Columbia Section program are welding instructors Merv Kube (left) and Barry Donaldson (far right) with scholarship-winning students (from left) Dan Smythe, Taylor Squires, and Barbara Santinelli.

NORTH TEXAS

October 16
Speakers: **Ricky Baron,** with Material Analysis and chairman of the North Texas Chapter of ASM Int'l; and **Michael Beaton,** with Trinity Metals Lab
Topic: Failure analysis of welds
Activity: This was a joint meeting with members of the North Texas ASM Int'l Chapter attended by 62 members and guests. Discussed were updates on the Section's drive to assist the Dallas food bank, and progress on the silent auction event. Past AWS President **Ernest Levert** attended the program. The meeting was held at Spring Creek Barbeque in Irving, Tex.

TULSA

September 25
Speaker: **Ron Weisz,** account executive
Affiliation: 3M Occupational Health and Environmental Safety Div.
Topic: Respirators and protecting workers from hexavalent chromium
Activity: The program was held at Furr's Buffet in Tulsa, Okla.


Shown at the Tulsa Section program are speaker Ron Weisz (left) with Chairman Jamie Pearson.

DISTRICT 18

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

HOUSTON

September 19
Speaker: **Jon Lee**
Topic: Hydrogen-induced cracking in welds
Activity: The Section hosted its annual awards presentation night at Brady's Landing. **Jon Lee** earned the District Pri-

Shown at the Olympic Section program are (from left) Publicity Chair John Powers, Secretary Chris Hobson, speaker Sjon Delmore, and Chairman Bob Plummer.

Sjon Delmore demonstrates digital GMA welding for the Olympic Section members.

Shown at the Colorado Section program are (from left) Bob Page and Sam Sequra with General Air, Section Chair James Corbin, and presenter Steve Duran.

Don Schwemmer conducted the tour of the AMET facilities for the Idaho-Montana Section and ISA and IEEE chapters.

Mariana Ludmer, Section secretary, is shown at the Los Angeles/Inland Empire Section program.

Dave Baron discussed nondestructive testing methods with the British Columbia Section members in September.

vate Sector Instructor Award, Houston Section Vice Chair **Ron Theiss** was presented the District 18 Meritorious Award, **Julie Theiss** won the District 18 Director's Award, **Dan Gates** accepted the Section CWI of the Year Award, and **Wayne Knupple** received the District 18 Educator Award.

DISTRICT 19

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

BRITISH COLUMBIA

September 20
Speaker: **David Baron,** supervisor of visual inspection
Affiliation: Acuren Group, Inc.
Topic: Nondestructive testing methods
Activity: Scholarships were presented to **Dan Smythe, Taylor Squires,** and **Barbara Santinelli,** students enrolled in the UA Local 170 Piping Trades School welding program. In attendance were their welding instructors **Merv Kube** and **Barry Donaldson.** The event was held in New Westminster, B.C., Canada.

October 16
Activity: The British Columbia Section members toured Vancouver Shipyard Co., Ltd., Washington Marine Group, in North Vancouver, B.C., Canada. **Norman Whyte,** project manager, intermediate class ferry, addressed the group prior to the tour presenting the history of the project, design specifications, project time lines, and other details. Forty-three members and guests participated in the program.

OLYMPIC

October 18
Speaker: **Sjon Delmore**
Affiliation: Digital Welding Solutions, Fronius U.S.A. (West)
Topic: European aluminum welding technology for U.S. boat and shipbuilding
Activity: Following the PowerPoint presentation featuring Fronius welding equipment, the 25 attendees participated in demonstrations of 100% digital push-pull aluminum gas metal arc welding. The program was held in Bremerton, Wash.

DISTRICT 20

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

COLORADO

September 13
Speaker: **Steve Duran**
Affiliation: General Air
Topic: Getting the most out of your welding work cell
Activity: Following a PowerPoint presentation, Duran offered a hands-on demonstration that compared metal core arc welding with flux core arc welding for shielding gas usage and metal deposition rates.

IDAHO-MONTANA

October 12
Activity: The Section members joined members of the local IEEE and Instrumentation, Systems, and Automation Society of America (ISA) chapters for a project briefing and tour of the Advanced Manufacturing Engineering Technologies, Inc. (AMET), facilities in Rexburg, Idaho. **Don Schwemmer,** cofounder of the company, presented a talk then led the tour of the automated welding systems, circuit board, machining, and assembly fabrication operations.

DISTRICT 21

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

L.A./INLAND EMPIRE

September 22
Speaker: **Ricky Morgan,** CWI, deputy inspector, ASNT board member
Affiliation: Smith-Emery Co.
Topic: The Northridge earthquake revisited
Activity: **Ted Peet** assisted Morgan with his presentation. **George Rolla** was introduced as the incoming chairman. Rolla presented a talk about his plans for improving member involvement and interactivity in the Section. Recognized for their services to the Los Angeles/Inland Empire Section over the years were AWS President-Elect **Gene Lawson**, **Henry Jackson**, and **Bob Gibson**.

DISTRICT 22

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

SAN FRANCISCO

September 18
Speakers: **Dan Finnigan** and **Jack Minser,** district business manager, and technical sales manager, respectively
Affiliation: Thermal Dynamics Corp.
Topic: Plasma cutting in the 21st century
Activity: The program was held at Spenger's Restaurant in Berkeley, Calif. Following the presentations, the 35 members reassembled outside at a Thermal Dynamics demo truck to participate in demonstrations of plasma arc cutting. Five Section past chairmen were present and recognized at the program.

Idaho-Montana Section members joined members of the local chapters of IEEE and ISA for a tour of the AMET facilities.

San Francisco Section Chair Tom Smeltzer (center) thanks presenters Dan Finnigan (left) and Jack Minser at the September meeting.

Shown at the Los Angeles/Inland Empire Section program are (from left) speaker Ricky Morgan, Chairman George Rolla, and Ted Peet.

Lia Gombo-Shoel (right) receives her Certified Welding Inspector certificate from Shimon Address, Israel Section certification committee chairman, in September.

International

ISRAEL

September 5
Activity: **Lia Gombo-Shoel** was presented her Certified Welding Inspector certificate from **Shimon Address,** Section certification committee chairman. The presentation took place in Tel-Aviv, Israel.

New AWS Supporters

Sustaining Companies

Intermountain Electronics
1503 S. Hwy. 6, PO Box 914
Price, UT 84501
Representative: **Darek Martinez**
www.intermountainelectronics.com

Intermountain Electronics is a Utah-based corporation servicing the electrical and electronics needs of customers worldwide. It specializes in the manufacture of electrical distribution and control equipment for use in various manufacturing facilities including surface and underground mining, power-generation, oil, and gas-generation plants, and refineries. Its engineering, sales, and manufacturing staff members have many years of experience in the design, fabrication, installation, and maintenance of these types of equipment. The company earned the MEP Utah Manufacturer of the Year Award for 2006.

SAS Global Corp.
21601 Mullin Ave.
Warren, MI 48089
Representative: **John R. Nolan**
www.sasglobalcorp.com

For more than 50 years, SAS Global Corp. has been one of the nation's leading suppliers of the highest-quality abrasion-resistant steels, ceramics, and hardfacing materials, custom fabrications, engineering services, and solutions. The company supplies a number of industries, including power, cement, and mining throughout North and South America, Europe, and Asia.

Affiliate Companies

AMT Metal Fabricator, Inc.
211 Parr Blvd.
Richmond, CA 94801

Cushing Mfg. Co.
2901 Commerce Rd.
Richmond, VA 23234

DaveCo Industries
4201 Mead Dr.
Plano, TX 75024

HKA Enterprises
337 Spartangreen Blvd.
Duncan, SC 29334

Hanco, Ltd.
102 Freedom Dr., PO Box 510
Lawrence, PA 15055

InSpec Resources, LLC
16815 Royal Crest Dr., Ste. 120
Houston, TX 77058

OFI Custom Metal Fabrication
10412 Design Rd.
Ashland, VA 23005

S S Stainless, Inc.
PO Box 88637, Newton Town Centre
Surrey, BC V3W 0X1, Canada

Silverado Steel Solutions, LLC
1450 N. First St.
Garland, TX 75040

Steel Effects
12300 Zavalla St.
Houston, TX 77085

V & F Fabrication Co., Inc.
13902 Seaboard Cir.
Garden Grove, CA 92843

Suppporting Companies

Advance Welding
47 Allston Ave.
West Springfield, MA 04108

A. Zahner Co.
1400 E. 9th St.
Kansas City, MO 64106

Poynter Sheet Metal
8768 N. State Rd. 37
Bloomington, IN 47402

Educational Institutions

Colegio Mayor de Tecnologia, Inc.
Morse St., 151 N.
Arroyo, PR 00714

Davenport W. Voc. Welding Program
3505 W. Locust
Davenport, IA 52804

Lebanon Technology & Career Center
757 Brice
Lebanon, MO 65536

Photon School of Welding, Inc.
5528 W. 84th St.
Indianapolis, IN 46268 ◆

Membership Counts

Member Grades	As of 11/1/07
Sustaining	467
Supporting	289
Educational	443
Affiliate	408
Welding distributor	49
Total corporate members	**1,656**
Individual members	46,921
Student + transitional members	5,413
Total members	**52,334**

December 31 Deadline for Robotic and Automatic Arc Welding Award

Nominations are solicited for the 2008 Robotic and Automatic Arc Welding Award. December 31 is the deadline for submitting nominations.

The nomination packet should include a summary statement of the candidate's accomplishments, interests, educational background, professional experience, publications, honors, and awards.

Send your nomination package to Wendy Sue Reeve, awards coordinator, 550 NW LeJeune Rd., Miami, FL 33126.

For more information, contact Reeve at *wreeve@aws.org,* or call (800/305) 443-9353, ext. 293.

In 2004, the AWS D16 Robotic and Automatic Arc Welding Committee, with the approval of the AWS Board of Directors, established the Robotic and Automatic Arc Welding Award. The award was created to recognize individuals for their significant achievements in the area of robotic arc welding. This work can include the introduction of new technologies, establishment of the proper infrastructure (training, service, etc.) to enable success, and any other activity having significantly improved the state of a company and/or industry. The Robotic Arc Welding Award is funded by private contributions. It will be presented next year at the AWS Awards and AWS Foundation Recognition Ceremony and Luncheon to be held in conjunction with the FABTECH International & AWS Welding Show, Oct. 6–8, 2008, in Las Vegas, Nev.

Guide to AWS Services

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

AWS PRESIDENT

Gerald D. Uttrachi
guttrachi@aol.com
WA Technology, LLC
4313 Byrnes Blvd., Florence, SC 29506

ADMINISTRATION

Executive Director
Ray W. Shook.. *rshook@aws.org* . . . .(210)

CFO/Deputy Executive Director
Frank R. Tarafa.. *tarafa@aws.org* . . . .(252)

Deputy Executive Director
Cassie R. Burrell.. *cburrell@aws.org* . . . . .(253)

Associate Executive Director
Jeff Weber.. *jweber@aws.org* . . . .(246)

Executive Assistant for Board Services
Gricelda Manalich.. *gricelda@aws.org* . . . .(294)

Administrative Services

Managing Director
Jim Lankford.. *jiml@aws.org* . . . .(214)

IT Network Director
Armando Campana..*acampana@aws.org* (296)

Director
Hidail Nuñez..*hidail@aws.org* . . . .(287)

Database Administrator
Natalia Swain..*nswain@aws.org* . . . .(245)

Human Resources

Director, Compensation and Benefits
Luisa Hernandez.. *luisa@aws.org* . . . .(266)

Manager, Human Resources
Dora Shade.. *dshade@aws.org* . . . .(235)

INT'L INSTITUTE of WELDING

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

GOVERNMENT LIAISON SERVICES

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

Brazing and Soldering Manufacturers' Committee

Jeff Weber.. *jweber@aws.org* . . . .(246)

RWMA — Resistance Welding Manufacturing Alliance

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

WEMCO — Welding Equipment Manufacturers Committee

Manager
Natalie Tapley.. *tapley@aws.org* . . . .(444)

CONVENTION and EXPOSITIONS

Associate Executive Director
Jeff Weber.. *jweber@aws.org* . . . .(246)

Corporate Director, Exhibition Sales
Joe Krall.. *krall@aws.org* . . . .(297)
Organizes the annual AWS Welding Show and Convention, regulates space assignments, registration items, and other Expo activities.

PUBLICATION SERVICES

Department Information . . . .(275)
Managing Director
Andrew Cullison.. *cullison@aws.org* . . . . .(249)

Welding Journal

Publisher/Editor
Andrew Cullison.. *cullison@aws.org* . . . . .(249)

National Sales Director
Rob Saltzstein.. *salty@aws.org* . . . .(243)

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

Welding Handbook

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

MARKETING COMMUNICATIONS

Director
Ross Hancock.. *rhancock@aws.org* . . . . .(226)

Assistant Director
Adrienne Zalkind.. *azalkind@aws.org* . . . .(416)

MEMBER SERVICES

Department Information . . . .(480)

Deputy Executive Director
Cassie R. Burrell.. *cburrell@aws.org* . . . . .(253)

Director
Rhenda A. Mayo... *rhenda@aws.org* . . . . .(260)
Serves as a liaison between Section members and AWS headquarters. Informs members about AWS benefits and activities.

CERTIFICATION SERVICES

Department Information . . . .(273)
Managing Director
Peter Howe.. *phowe@aws.org* . . . .(309)

Director, Operations
Terry Perez.. *tperez@aws.org* . . . .(470)
Directs the department operations.

Director, Int'l Business & Certification Programs
Priti Jain.. *pjain@aws.org* . . . .(258)
Directs all int'l business and certification programs. Is responsible for oversight of all agencies handling AWS certification programs.

Senior Manager, Certification Programs
Frank Lopez Del Rincon. *flopez@aws.org* (258)
Manages all national certification programs, including Accredited Test Facilities.

EDUCATION SERVICES

Managing Director
Dennis Marks.. *dmarks@aws.org* . . . .(237)

Director, Education Services Administration and Convention Operations
John Ospina.. *jospina@aws.org* . . . .(462)

Director, Education Product Development
Christopher Pollock.. *cpollock@aws.org* .(219)
Coordinates in-plant seminars and workshops. Administers the SENSE program. Assists Government Liaison Committee and Education Committees. Also responsible for conferences, exhibitions, and seminars. Organizes CWI, SCWI, and 9-year renewal certification-driven seminars.

AWS AWARDS, FELLOWS, COUNSELORS

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

TECHNICAL SERVICES

Department Information . . . .(340)
Managing Director
Andrew R. Davis.. *adavis@aws.org* . . . . . .(466)
Int'l Standards Activities, American Council of the Int'l Institute of Welding (IIW)

Director, National Standards Activities
John L. Gayler.. *gayler@aws.org* . . . .(472)
Personnel and Facilities Qualification, Computerization of Welding Information, Arc Welding and Cutting

Manager, Safety and Health
Stephen P. Hedrick.. *steveh@aws.org* (305)
Metric Practice, Safety and Health, Joining of Plastics and Composites

Technical Publications
AWS publishes about 200 documents widely used throughout the welding industry.
Senior Manager
Rosalinda O'Neill.. *roneill@aws.org* . . . . .(451)

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

Stephen Borrero.. *sborrero@aws.org* . . . . .(334)
Welding Iron Castings, Joining of Metals and Alloys, Brazing and Soldering, Brazing Filler Metals and Fluxes, Brazing Handbook, Soldering Handbook

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

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

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

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

Reino Starks...*rstarks@aws.org* . . . .(304)
Welding in Sanitary Applications, High-Energy Beam Welding, Aircraft and Aerospace, Friction Welding, Railroad Welding.

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

Nominees for National Office

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

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

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

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

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

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

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

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

E-mail the letter to Gricelda Manalich, *gricelda@aws.org,* c/o 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.

Honorary Meritorious Awards

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

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

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

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

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.

AWS Publications Sales

Purchase AWS standards, books,
and other publications from
World Engineering Xchange (WEX), Ltd.
orders@awspubs.com; www.awspubs.com
Toll-free (888) 935-3464 (U.S., Canada)
(305) 824-1177; FAX (305) 826-6195

Welding Journal Reprints

Copies of *Welding Journal* articles may be
purchased from Ruben Lara.
(800/305) 443-9353, ext. 288; *rlara@aws.org*

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

AWS Foundation, Inc.

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

Chairman, Board of Trustees
Ronald C. Pierce

Executive Director, AWS
Ray Shook

Executive Director, Foundation
Sam Gentry

550 NW LeJeune Rd., Miami, FL 33126
(305) 445-6628; (800) 443-9353, ext. 293
general information:
(800) 443-9353, ext. 689; *vpinsky@aws.org*

AWS Mission Statement

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

It is the intent of the American Welding Society to build AWS to the highest quality standards possible. The Society welcomes your suggestions. Please contact any staff member or AWS President Gerald D. Uttrachi, as listed on the previous page.

NEW PRODUCTS

— continued from page 25

Metal Cutting Saw Features Dry Cutting Technology

The saw, equipped with a 14-in., 72-tooth steel cutting carbide-tipped Metal Devil® blade, is powered by a 15-A motor optimized for metal cutting at 1300 rev/min. Clean cuts with minimal sparks are produced. The heavy-duty steel base provides stability with predrilled holes for bolt down to any workbench. Six preset markings in the base allow the vise to be set for 45- or 90-deg cuts.

The M. K. Morse Co.
www.mkmorse.com
(800) 733-3377

Drum Lowers Quality Defects

The eXacto-Pak™ precision payout drum increases precision and improves quality on automatic and robotic welding applications using metal cored wire. The product, available in 400- and 600-lb drums, is designed for high-volume production using 0.045- to 1⁄16-in.-diameter wire. It essentially eliminates quality defects attributed to wire wander, while improving wire feedability as well. To provide better weld joint tracking by ensuring that the arc is consistently focused in the center of the weld joint, the drum pays out wire in a straight and reliable pattern.

Hobart Brothers Co.
Hobartbrothers.com
(800) 424-1543

Welding Helmets Include Three Arc Sensors

The Motorsports™ and Fire Storm™ designs have been added to the company's Performance Series™ line of autodarkening welding helmets. New features include three arc sensors instead of two, a quick-release front cover lens holder with a rubber spatter gasket, and lens controls located at the bottom of the lens. A competition yellow background accented with red and green tear-aways and checkered flag graphics on all four sides is featured in the Motorsports helmet. The Fire Storm helmet sports a black background with yellow and red flames along the front, sides, and top.

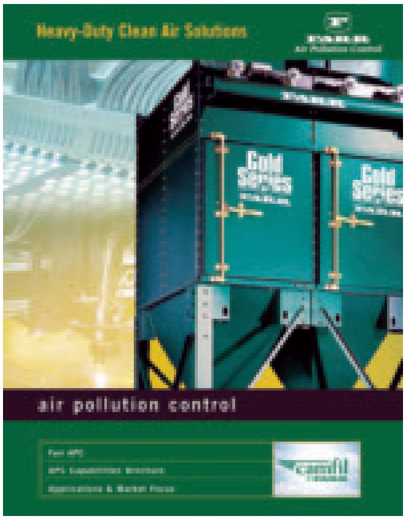
Miller Electric Mfg. Co.
www.MillerWelds.com/products/weldinghelmets
(800) 426-4553

Hybrid Laser Welding Systems Pictured

A brochure introduces the company's HLx Series mechanized laser welding systems utilizing hybrid laser arc, laser-only, or laser with cold wire fill welding. Detailed are 2D gantry, 3D robotic, and options for custom-mechanized configurations. Described is the company's patented closed-loop welding process control that allows the system to monitor the weld joint in real time and modify the process to accommodate joint mismatches. The hybrid laser arc welding (HLAW) process combines deep weld penetration and low heat input with the superior root opening tolerance offered by gas metal arc welding. Call the phone number listed to obtain a copy of the brochure.

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

Heavy-Duty Clean Air Systems Illustrated



A profusely illustrated, 13-page, full-color brochure displays the company's Gold Series® customized heavy-duty, clean-air installations for a wide range of industrial applications using either outside exhaust or recirculating. Pictured are typical installations for controlling dust and fume for welding and grinding, laser and plasma arc cutting, blasting, mining, paper scrap handling, fiberglass, and pharmaceutical compounds. Described is the company's HemiPleat® dust collector media with Poly-Tech™ high-filtration and Dura-Pleat® media for sticky dusts. Detailed is the company's extensive testing services designed to determine each customer's types of contaminants, particle sizes, solubilities, etc., in order to recommend and install the air-filtration system best suited for the application.

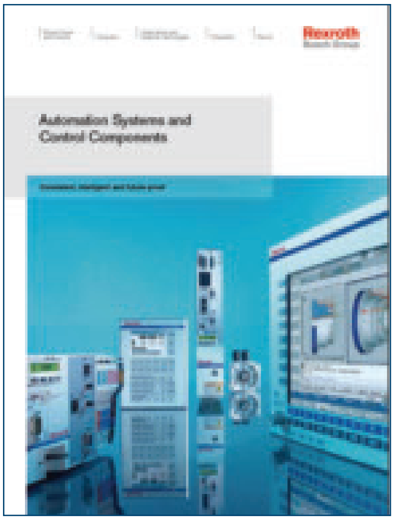
Farr Air Pollution Control
www.farrapc.com
(800) 479-6801

ASM Literature Online

ASM International has more than 20,000 authoritative technical articles posted online via its new "Everything Material" global community. Many of the individual titles can be downloaded for free, while others have a nominal fee. Some single articles, previously only available bundled in complete volumes such as books in the *ASM Handbook* series, are now offered separately. Content from DoE InformationBridge, the *Handbook of Thermal Spray Technology,* and International Thermal Spray Conference proceedings, as well as selected articles from the NASA Technical Reports Server and the Defense Technical Information Center, are also available through the site. A list of content that is available free or on a per-article basis can be found at the Web site.

ASM International
http://asmcommunity.asminternational.org/portal/site/asm/everythingmaterialcelebration
(440) 338-5151

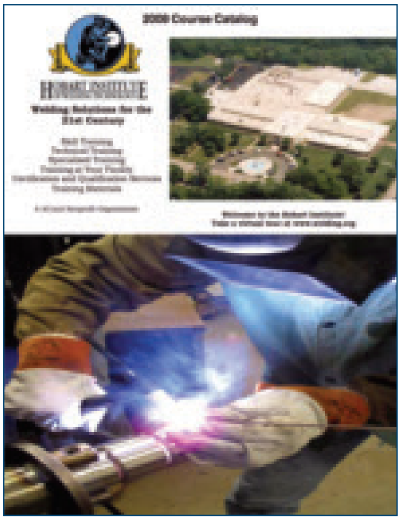
Catalog Details Automation Systems



Automation Systems and Control Components is a 165-page, full-color catalog featuring complete information on the company's automation products, including its IndraLogic open PLC system, IndraMotion systems family, IndraControl L rack-based controls, and IndraWorks engineering framework software. Details are provided on how each modular automation system and control component can increase the capacity, flexibility, and overall efficiency of a production facility using the interplay of motion, logic, and automation. Visit the Web site to view or download the document.

Bosch Rexroth Corp.
www.boschrexroth-us.com/brccatalog
(847) 645-3600

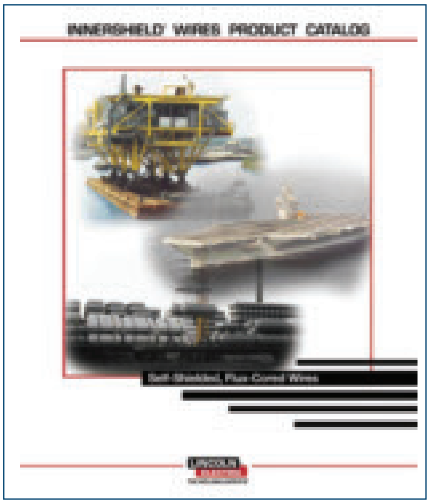
Hobart Institute Releases 2008 Course Catalog



The 48-page *2008 Course Catalog* provides complete details about all of the Institute's programs and courses, class schedules, and services to be offered during the coming year. Included are details on entrance requirements, workbooks, the training facility, on-site equipment, training methods, class sizes, code certifications offered, students' equipment list for each course, course dates and tuition, placement and graduation rates, enrollment forms, local accommodations, loan programs, and scholarships. Information is also provided for in-plant training, and welder certification and qualification. View or download the catalog from the Web site or call to receive a copy by mail.

Hobart Institute of Welding Technology
www.welding.org/downloads.html
(800) 332-9448

Innershield® Wires Detailed in New Brochure



The company has released a new version of its Innershield® wire product catalog highlighting the complete line of self-shielded flux cored wires for both automatic and semiautomatic welding for a wide range of mild steel and low-alloy applications. Displayed are wires for sheet and thick base metals, galvanized, specialty zinc-coated carbon steels, and low-alloy and mild steel. The line of gasless wires are ideal for welding outdoors and welding metals with surface contaminants, scale, or light rust. Included is a selection guide, and a detailed description of each product, including key advantages, applications, recommended welding procedures, and positions, along with deposited chemistry and mechanical properties. Call for Bulletin C3.10, or download from the Web site.

The Lincoln Electric Co.
www.lincolnelectric.com
(216) 481-8100

— continued on page 77

Auburn Names Mfg. VP

Ernest Mattox III

Auburn Mfg. Inc., Mechanic Falls, Maine, a supplier of heat-resistant fabrics and products for welding and industrial applications, has appointed **Ernest C. (Skip) Mattox III** vice president of manufacturing. Prior to joining the company, Mattox was vice president for sales and manufacturing at Newtex Industries, Inc.

Airgas Appoints Senior VP

Robert Young

Airgas, Inc., Radnor, Pa., has appointed **Robert H. Young Jr.** senior vice president and general counsel, replacing **Dean Bertolino,** who has left the company. Young previously served as president of the Radnor-based law firm, McCausland, Keen & Buckman, where he served as outside counsel to Airgas for many years.

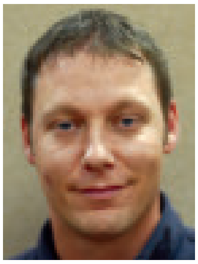
Laser Mechanisms Makes Management Changes

Laser Mechanisms, Inc., Farmington Hills, Mich., has named **Mark Taggart** managing director North American operations, and **Glenn Golightly** managing director Pacific Rim operations. Taggart, with the company since 1989, previously served as general manager medical operations. Golightly, also with the company since 1989, most recently served as general manager industrial operations.

RobotWorx Promotes Two

RobotWorx, Marion, Ohio, has appointed **Josh Holtsberry** to acquisitions and sales manager, and named **Michael Hall** customer service manager. With the company for five years, Holtsberry previously served as applications engineer, shop manager, and sales manager. Hall, with the company for three years, will oversee parts inventories and manage all service requests.

Josh Holtsberry



Michael Hall

Magnatech Appoints Sales Director

Scott Anthony

Magnatech, East Granby, Conn., has named **Scott Anthony** director sales and marketing — western hemisphere. Previously, Anthony worked for Naiad Marine, Inc., with responsibilities in domestic and international sales and marketing.

Tregaskiss Designates India Business Manager

S. P. Vaidya

Tregaskiss, Windsor, Ont., Canada, has appointed Major **S. P. Vaidya** to its international sales team as regional business manager for India. Vaidya, based in Mumbai, has developed his own welding torches and worked as a welding consultant and company representative for several welding brands in India during the past 20 years.

Five Laser Scientists Honored at ICALEO®

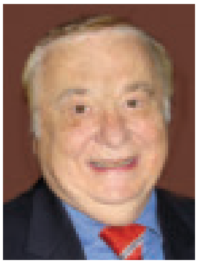
Laser Institute of America (LIA), Orlando, Fla., named **Marshall G. Jones** to receive its 2007 Arthur L. Schawlow Award and named four new LIA Fellows during the 26th Int'l Congress on Applications of Lasers & Electro-Optics (ICALEO®) held in October. The Schawlow Award is conferred each year to honor an outstanding, career-long contributor to basic and applied research in laser science and engineering whose achievements have led to increased application of lasers in industry, medicine, and daily life. **William Shiner,** LIA president, introduced the incoming Fellows: **Lin Li,** professor of laser engineering at the University of Manchester, England; **William Patrick Roach,** senior science advisor, and **Robert Thomas,** a senior research physicist, both at the U.S. Air Force Research Laboratory in Texas; and **John Tyrer,** a LIA Senior Member and a professor in the department of mechanical engineering at Loughborough University, England.

Bosch Rexroth Names VP

Jeff Blackman

Bosch Rexroth Corp., Hoffman Estates, Ill., has appointed **Jeff Blackman** vice president — automation sales. Blackman joined the company in 1980 as a sales engineer in Leicester, UK, and held several managerial positions until 2001 when he was named executive vice president and managing director of sales and marketing for Bosch Rexroth China Ltd.

Genstar Hires National Sales Manager



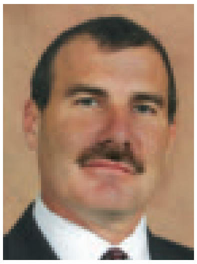
Fred Herauf

Genstar Technologies, Chino, Calif., has named **Fred M. Herauf** national sales manager for its welding and cutting automation products. Herauf has more than 25 years' experience in the thermal cutting business, most recently as sales manager for Controlled Automation.

New Chairs Elected to PMA's Local Districts

The Precision Metalforming Association (PMA), Cleveland, Ohio, has announced new chairs for its 20 local districts. Elected were **Chris Nantau** (Canada), **Keith Herbs** (Carolinas), **Dennis Spitz** (Chicago), **Liz Comstock** (Cleveland), **Pat Westergaard** (E. Mich.), **Jim Eichelberger** (E. Pa.), **Peter Fischer Sr.** (Greater Mo.), **Pat Bosler** (Ind.), **Michael Tofte** (Lone Star), **David Vaz** (New England), **Mark Weissenrieder** and **Elisabeth Bennis** (N.Y./N.J.), **Fermin Rodriguez** (N. Calif.), **Dave Kubacki** (NW Ohio), **Jim McGregor** (Ohio Valley), **Dale Congelliere** (S. Calif.), **Peter Doolittle** (S. New England), **Al Hentsch** (Tenn.), **Stuart Peterson** (Twin Cities), **Don Dawson** (W. Mich.), and **Michael Steger** (Wis.).

Alberici Constructors Names Project Director



J. Klingensmith

Alberici Constructors, St. Louis, Mo., has appointed **James G. Klingensmith,** P.E., a project director in its General Building Division. Previously, Klingensmith was a multiproject executive with Gilbane Building Co.

Obituaries

George Kampschaefer

G. Kampschaefer

George Edward Kampschaefer Jr., 78, died October 3 in Houston, Tex. An AWS Life Member, he served as District 18 director from 1988 through 1996. Born in Chicago, Ill., he went to school in Middletown, Ohio, and received his degree in metallurgical engineering in 1951 from Purdue University. He served as an officer in the U.S. Navy, and later worked as manager of technical services for Armco Steel Corp. He served as a leading metallurgical and welding engineer in the Houston area. A Life Member of ASM International, he served AWS and ASM in numerous committee positions, as well as serving as Section chairman for both organizations.

Mr. Kampschaefer is survived by his wife, Peggy; sons, Mike and Scott; grandchildren, Ian, Annelise, and Aric; and a sister, Georgia Croake. The family requests donations be made to the George Kampschaefer Scholarship Fund of the American Welding Society, Houston Section, or a charity of your choice.

Kelvin D. Spain

Kelvin D. Spain

Kelvin D. Spain, 59, former president of Radyne Corp., Milwaukee, Wis., died Sept. 21. An AWS member since 2000, Mr. Spain was born in London, UK. He was a marathon biker in school where he also played the hooker position on the rugby team. When he was 17 years old, he took an apprenticeship at Radyne Ltd., in Wokingham, UK, to become a test engineer in dielectric and induction heating systems, then worked his way up to senior project engineer. He moved his family to the United States in 1978 where he worked for Radyne Corp. in Canton, Ohio. While there, he was instrumental in the purchase of AKO, an induction manufacturing plant in Butler, Wis. In 2001, he was appointed president of Radyne.

Just prior to his death, he had been promoted to president of Inductoheat, Inc., one of Radyne's sister companies, which had always been his goal.

Mr. Spain presented many papers on induction heating for brazing, heat treating, forging, quality assurance, and water-cooling for AWS, ASM International, SME, and many other organizations.

He was a past master of Masonic Lincoln Lodge in Menomonee Falls, Wis., and served as secretary/treasurer. He was a member of the church choir, played guitar weekly at the services, served as a vestry member, Sunday school teacher, lay director of happening for the Episcopal Diocese of Milwaukee for high-school-age youths, and was a member of the Diocesan Youth Commission for many years. Mr. Spain is survived by his wife, Barb, and daughters, Joanna, Vickie, and Jess.

H. Clay Birkhead Jr.

H. Clay Birkhead Jr., 75, died Oct. 7, 2006. An AWS Life Member, he had been active in the Society since 1957, affiliated with the Milwaukee Section. During the Korean War he served overseas in the Army Counterintelligence Corps. Mr. Birkhead was a commander of the American Legion in Birmingham, Ala., where he coached the Little League *Cardinals*. Mr. Birkhead retired in 1996 after many years in the welding supply business. He is survived by his wife, Marianne, two daughters, a brother, and five grandchildren.

Joseph M. Moll III

Joseph M. Moll III, 55, a member of the AWS New Orleans Section, died Feb. 26. Mr. Moll was a sales manager with Gulf States Airgas for more than 30 years. A graduate of Nicholls State University, he was a member of Tau Kappa Epsilon fraternity, and a former member of the Caesar and Endemiyon Carnival Organizations. He is survived by his wife, Pemela; a daughter, Michelle; and a son, Joe.

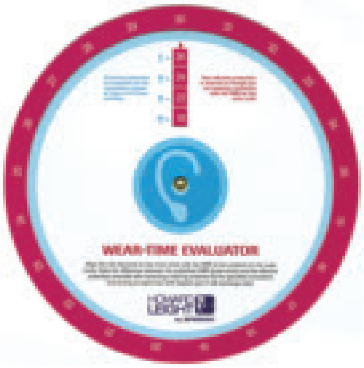
Frank C. Hemelt

Frank C. Hemelt, 63, a member of the AWS New Orleans Section and vice president of Industrial Welding Supply (IWS), died March 14. A graduate of Tulane University, he spent more than 30 years in the welding supply business, starting at Woodward Wight then Mon-Arc Welding before joining IWS. He is survived by his wife, Cynthia; daughter, Kai; a sister, June H. Walker; and four grandchildren.

NEW LITERATURE

— *continued from page 75*

Free Hearing Protector Wear-Time Tool Offered



The Howard Leight Wear-Time Evaluator alerts noise-exposed workers to how damaging it can be to remove their hearing protection even for a few minutes during an 8-h shift. Intended primarily as a training device, the outer ring of the larger disc shows a range of decibel (dB) levels of attenuation (noise-reduction rating or NRR) provided by various hearing protectors, while the smaller disc shows time increments of 5, 10, 15, and 30 min. By aligning the two discs, it can be determined how much protection is lost by removing the hearing protector. The tool is available free to safety officers and educators by calling the number shown.

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ASTM Releases Steel Standards Handbook

ASTM International offers its extensively revised DS67C, *The Handbook of Comparative World Steel Standards,* 4th Edition. It presents detailed explanations of how to identify comparable steels that are found in standards from around the world, and evaluate each standard to ensure that the selected steel is suited for the intended application. With the *Handbook*, users can compare standards from ASTM, AFNOR, API, ASME, BSI, EN, CSA, DIN, GB, ISO, JIS, and SAE. It features more than 6100 steels, 450 worldwide standards, 275 new or updated standards, and more than 30,000 pieces of Chinese steel data. The 840-page, softcover, 8½-× 11-in. volume is priced at $425. The Table of Contents may be viewed online. Order online or by phone.

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2007	Chance Pollo
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2001	Dien Tran
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1995	Branden Muehlbrandt
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1991	Robert Pope*

*1991 and 1993 recipients received alternate scholarship funds, which were prior to the start of the Miller Electric Mfg. Co. Scholarship.

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WELDING JOURNAL INDEX

Part 1 — WELDING JOURNAL SUBJECT INDEX

AUTHORS FOR FEATURE ARTICLES

Part 2 – RESEARCH SUPPLEMENT SUBJECT INDEX

AUTHORS FOR RESEARCH SUPPLEMENTS

TECHNICAL PROGRAM ABSTRACT SUBMITTAL
Annual FABTECH International & AWS Welding Show
Las Vegas, October 6-8, 2008

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

Primary Author (Full Name):

Affiliation:

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City: **State/Province** **Zip/Mail Code** **Country:**

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Co-Author(s):

Name (Full Name): Affiliation Address: City: State/Province Zip/Mail Code Country: E-Mail: Name (Full Name):	Name (Full Name): Affiliation: Address: City: State/Province: Zip/Mail Code: Country: E-Mail:
Affiliation: Address: City: State/Province: Zip/Mail Code: Country: E-Mail:	Name (Full Name): Affiliation: Address: City: State/Province: Zip/Mail Code: Country: E-Mail:

Answer the following about this paper

Original submittal? Yes ☐ No☐ Progress report? Yes ☐ No☐ Review paper? Yes ☐ No☐ Tutorial? Yes ☐ No☐

What welding processes are used?

What materials are used?

What is the main emphasis of this paper? Process Oriented ☐ Materials Oriented ☐ Modeling ☐

To what industry segments is this paper most applicable?

Has material in this paper ever been published or presented previously? Yes ☐ No☐

If "Yes", when and where?

Is this a graduate study related research? Yes ☐ No☐

If accepted, will the author(s) present this paper in person? Yes ☐ Maybe ☐ No☐

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

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- New science or research.
- Selection based on technical merit.
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<u>Applied Technology</u>

- New or unique applications.
- Selection based on technical merit.
- Emphasis is on previously unpublished work that applies known principles of joining science or engineering in unique ways.
- Preference will be given to submittals with clearly communicated benefit to the welding industry.

<u>Education</u>

- Welding education at all levels.
- Emphasis is on education/training methods and their successes.
- Papers should address overall relevance to the welding industry.

☑ Check the category that best applies:

☐ Technical/Research Oriented ☐ Applied Technology ☐ Education

Proposed Title (max. 50 characters):
Proposed Subtitle (max. 50 characters):

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Introduction (100 words max.) – Describe the subject of the presentation, problem/issue being addressed and it's practical implications for the welding industry. Describe the basic value to the welding community with reference to specific communities or industry sectors.

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

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

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

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

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(Complete a separate submittal for each poster.)

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Name (Full Name):	Name (Full Name):
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- Maximum size – 44 inches tall x 30 inches wide. (Vertical format, please).
- Must be legible from a distance of 6 feet. A minimum font size of 14 pt. is suggested.
- Posters must be submitted to AWS as a single flat printed medium (e.g. laminated print or foam core board mount).
- Any technical topic relevant to the welding industry is acceptable (e.g. welding processes & controls, welding procedures, welding design, structural integrity related to welding, weld inspection, welding metallurgy, etc.).
- Submittals that are incomplete and that do not satisfy these basic guidelines will not be considered for competition.

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

Criteria by category as follows:

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- Students enrolled in 2 yr. college and/or certificate programs at time of submittal.
- Presentation need not represent actual experimental work. Rather, emphasis is placed on demonstrating a clear understanding of technical concepts and subject matter.
- Practical application is important and should be demonstrated.

(B) Student

- For students enrolled in baccalaureate engineering or engineering technology programs at the time of submittal.
- Poster should represent the student's own experimental work. Emphasis is place on demonstrating a clear understanding of technical concepts and subject matter.
- Practical application and/or potential relevance to the welding industry is important and should be demonstrated.

(C) Student

- For students enrolled in graduate degree programs in engineering or engineering technology at time of submittal.
- Poster should represent the student's own experimental work. Poster must demonstrate technical or scientific concepts. Emphasis is placed on originality and novelty of ideas presented.
- Potential relevance to the welding industry is important and should be demonstrated.

(D) Professional

- For anyone working in the welding industry or related field.
- Poster must demonstrate technical or scientific concepts. Emphasis is placed on original contributions and the novelty of the presentation.
- Potential relevance to the welding industry is important and should be demonstrated.

(E) High School

- Junior or Senior high school students enrolled in a welding concentration at the time of submittal.
- Presentation should represent technical concepts and application to the welding industry.
- Practical application and creativity are important and should be demonstrated.

Check the category that applies:

☐ (A) Student 2-yr. or Certificate Program ☐ (B) Student 4-yr. Undergraduate ☐ (C) Graduate Student ☐ (D) Professional ☐ (E) High School

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Poster Subtitle (max. 50 characters):

Abstract:

Introduction (100 words) – Describe the subject of the poster, problem/issue being addressed and it's practical implications for the welding industry.

Technical Approach & Results (200 words) – Explain the technical approach. Summarize the work that was done as it relates to the subject of the poster.

.

Conclusions (100 words) – Summarize the conclusions and how they could be used in a welding application.

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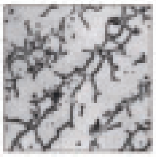

WELDING RESEARCH

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A PVD Joining Hybrid Process for Manufacturing Complex Metal Composites

A unique brazing method offers the possibilities of joining very small and geometrically diverse components

BY FR.-W. BACH, T. A. DEISSER, U. HOLLAENDER, K. MOEHWALD, AND M. NICOLAUS

ABSTRACT. In the present work, a new hybrid process is introduced: the gas/solid-transient liquid phase (TLP) bonding. With this process, the filler metal is transported by a gaseous phase to the joining area. The filler metal reacts with the base metal by a metallurgical gas-solid reaction and forms a liquid transition phase, which solidifies isothermally during further heat treatment. In this work, a fundamental investigation was made of the process, and simple model systems such as antimony (gas.)/iron (sol.), antimony (gas.)/steel (sol.), and zinc (gas.)/nickel (sol.) were developed. The entire process was modeled, taking into account the physical sequences (filler metal evaporating, filler metal transport to the joining areas, filler metal adsorption to the base metal, alloying of the filler metal and the base metal, isothermal solidification). The gas/solid-TLP-bonding process allows the joining of very small and complex components, where up to now no suitable joining process existed.

Introduction

For manufacturing complex metal components, soldering or brazing is often the sole way of realizing tight and strong joints between the manufacturing materials. The choice of the filler metal depends on the base material, the brazed joint requirements, and the brazing technique (Refs. 1, 2). The application of the filler metal is usually effected in the form of wires, foils, pastes, and increasingly by coatings like PVD, CVD, electroless and electrodeposited layers, as well as thermal spraying (Refs. 3–9).

Especially with the application of PVD technology, further development of the brazing with isothermal solidification occurred using transient-liquid-phase (TLP) bonding (Refs. 10–12). This technology is characterized by the use of heterogeneous solder systems, which show a low melting eutectic on their own or in combination with the base material. During the brazing process, a eutectic liquid transient phase is constituted at the surfaces of the base material, which again solidifies with further heat treatment and develops a strong and tight joint.

For joining very small and geometrical ambitious components, the filler metal dosage has to be very accurate. With further miniaturization of the joining components, coating technologies reach their limits with brazing, considering the complex handling required (i.e., positioning of the components in a PVD-recipient or in an electrolyte solution for electro- or electroless deposition). Due to these facts, it is desirable to develop a new joining technology that applies the filler metal in a different way than the standard brazing process; for example, tranporting the filler metal to the base materials through a gaseous phase during brazing. Subsequently, a metallurgical gas/solid reaction occurs and a liquid transition phase is constituted, which solidifies during further heat treatment. This is the so-called gas/solid-TLP-bonding process.

The principle of the gas/solid-TLP bonding can be divided into five sequences. In the first stage, the filler metal evaporates in an evacuated container. During the second stage, the gaseous filler metal is transported to the surface of the specimens by means of convective gas flow. The third stage describes the adsorption of the filler metal onto the specimen's surface. Accordingly, in stage 4, the alloying of the filler metal with components from the base material proceeds until the formation of a liquid transition phase takes place. Finally, in stage five, there is an isothermal solidification of the alloy by means of further enrichment of the components from the base material caused by diffusion processes.

KEYWORDS

Brazing
Filler Metal
Gas/Solid Reaction
Liquid Transition
Soldering
Vapor

For a successful joining process, some conditions have to be met. There must be suitable kinetics. That means that the transport of the filler metal onto the specimen's surface has to be faster than the alloying of the filler metal with the base material to the solid composition, because otherwise no transient liquid phase is formed. Hence, the vapor pressure of the solder metal has to be sufficiently high to be transported to the specimens. Lastly, suitable mixing thermodynamics must be taken into account, since a liquid solder-poor alloy has to exist within the filler metal/base material system at the dedicated temperature.

This leads to an appropriate model system: the iron-antimony system — Fig. 1. This system was chosen because it is of practical relevance; the filler metal, as mentioned above, has to be transported by means of a convective gas flow onto the specimen's surface. The properties for antimony (vapor pressure of 35 mbar at 1100°C [Ref. 13]) are given. Finally, at this temperature, antimony can be alloyed to iron with a substance of 0.7 before reaching the solidus of α-iron.

The gray line and the right axis of the phase diagram represent the thermodynamic activity of antimony in an idealized form, according to Raoult's law.

Alloying on the iron surface takes place with antimony, and the Sb-activity

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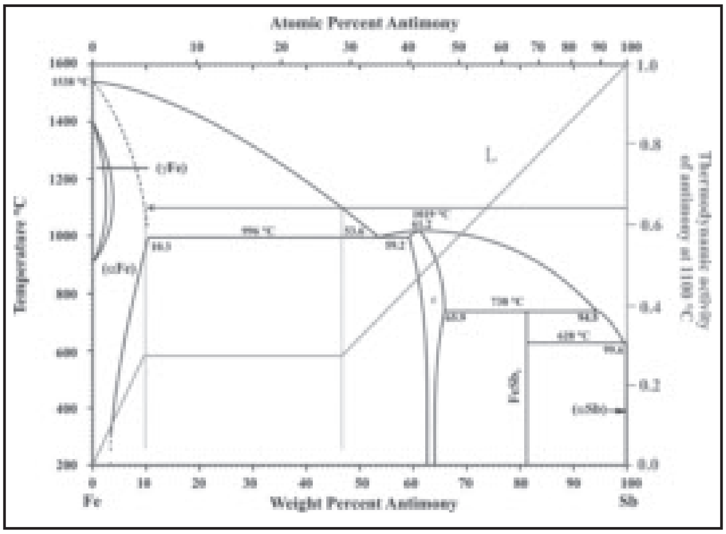

Fig. 1 — Phase diagram of Fe–Sb.

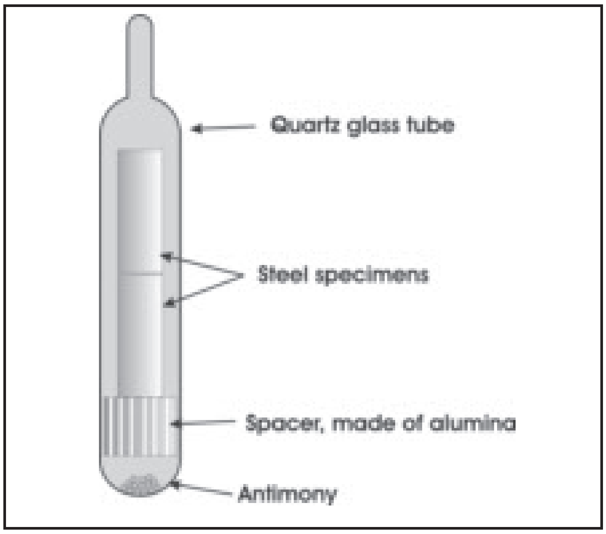

Fig. 2 — Process cell.

decreases by reason of vapor pressure degradation over the mixture. Concerning the activity varieties of antimony, a Sb-transport is initiated (thermodynamic power). By a further diffusion process (Sb diffuses into Fe and/or vice versa), an alloying up to α-Fe proceeds and an isothermal solidification occurs that is characteristic for the TLP bonding (Refs. 14, 15).

$$a_{Sb}(T,\,x_{Sb}) = \frac{p_{Sb}(T,\,x_{Sb})}{p^{0}_{Sb}(T)},$$

$$\text{with} \lim_{x_{Sb}\to 1} a_{Sb} = 1 \left(\begin{array}{c}\text{Raoult's}\\ \text{standardization}\end{array}\right) \qquad (1)$$

Where $a_{Sb}(T, x_{Sb}) =$ Sb activity

$p_{Sb}(T,\,x_{Sb}) =$ Sb-vapor pressure over the mixture

$p^{0}_{Sb}(T) =$ vapor pressure of pure Sb at temperature T

Experimental

Brazing experiments were carried out in a process cell made of quartz-glass — Fig. 2. At the bottom of the cell, antimony granules were deposed in an amount of about 100 mg. A spacer made of alumina or quartz glass was located slightly above to separate the iron specimens from the antimony. The iron rods were 20 mm long and 8 mm in diameter, and were placed onto the spacer. The front surfaces of the rods were face ground in such a way that a maximum joint clearance of 20 microns was in between. The prepared process cell was connected to a rotary vane pump, evacuated (approximately 10^{-3} mbar), melted off, and placed in a furnace for further heat treatment. The process times varied from 2.5 h up to 10 h, and all experiments were carried out at a temperature of 1100°C. For microstructure investigations, the brazed specimens were cut through, ground, polished, and micrographs were made.

Results

Figure 3 shows the cross sections of the samples brazed for 2.5–10 h at 1100°C. For the sample processed for 2.5 h at 1100°C, a partial closed brazing joint clearance (approximately 70 μm) was observed. The bright phase within the brazing clearance was identified as ε phase (FeSb). With the sample for the 5-h process, the joint clearance was just 20 μm wide, and it was nearly closed after 7.5 h, showing the ε phase just in some isolated areas. Complete filling was reached after 10 h. This behavior is reasonable with the diffusion process. The longer the heat treatment, the more antimony was able to diffuse into the iron (and contrary) until the solidus of α-Fe was reached. Figure 4 depicts a cross section of a brazed steel sample. Except for a few pores within the contact area, the joint clearance was entirely filled. Despite etching, no differing phases from the base material were found. The specimen was a homogenous compact body. However, SEM-studies revealed a Fe-Sb-mixed phase at the border area (ε phase of the Fe-Sb-phase diagram).

On the other hand, inside the body, the brazed joint, by reason of the long heat treatment, was alloyed such that no more ε phase was detected. The braze joint was a compact single-phased area of α iron, containing less than 2 at.-% of Sb. This sample was “welded” far below its melting temperature.

Butt joint round specimens, brazed with gaseous antimony and provided with external screw threads for fixing, were tensile tested. The metallographic results were reflected by the tensile strength data outlined in Fig. 6. As the heat treatment period increased and an accordingly decrease in Fe-Sb phases within the braze joint occurred, the tensile strength grew to a final value of 177 MPa after 10 h — Figs. 5, 6.

Discussion

The sequences of this new joining technique are structured as follows:

1) Filler metal evaporation inside a vacuum chamber

2) Filler metal transport to the brazing joint by convective gas flow

3) Filler metal adsorption onto the base material surface

4) Alloying with constituents from the base material to form a liquid alloy film within the braze joint

5) Isothermal alloy solidification within the braze joint by further enrichment with constituents from the base material.

Antimony Transport over Gaseous Phase by Convective Gas Flow

Steps 1 and 2 — Proceeding on the assumption of freely exposed surfaces, the material transport in the gaseous phase of sequences 1 and 2 proceeds so fast that these steps do not affect the total kinetics, e.g., between solid iron and gaseous antimony. The vapor pressure is the equilibrium vapor pressure of the pure filler metal, as a function of temperature. However, thin gaps indicate a reduced vapor pressure, because the alloying occurring reduces the thermodynamic activity of antimony. At first approximation, the vapor pressure within small cavities can be attributed to Raoult's law. The resulting pressure deviation between the inner gap and the free ambient gas affects the convective gas transport in the cavity. Furthermore, this depends on the inlet geometry. So, additionally, the inlet geometry must be taken into account, the dimensions of which constitute the free path of the gaseous particles, and the gas transport must be regarded as a Knudsen-effusion. Reaction conditions existing with the antimony experiments (750°C up to 1100°C) resulted in vapor pressures of approximately 3000 Pa maximum — Fig. 4. Consequently, transport within the gaseous phase can be described in good approximation, according to ideal gases.

Adsorption of Sb onto the Fe-Surface

Step 3 — For describing the adsorption occurrences at the border of the solid/gaseous phase, a set of rules for the characterization of such adsorption isotherms exist. On one hand experimental data is required. On the other hand, known appendages about diffusion processes into the solid, as well as chemical reactions between gaseous and solid phase, must be considered. In the case of gaseous antimony, which adsorbs on solid iron, an immediate alloying up to the liquidus curve will occur, causing a reduction of the thermodynamic activity of the adsorbing gaseous Sb in comparison with the ambient gaseous Sb. On this basis — beyond the knowledge of precise adsorption isotherms — the maximum possible adsorption rate can be formulated as the number of collisions per time unit of antimony atoms on the interface (less the desorbed Sb atoms at reduced vapor pressure). This leads to a simplified dependency of the mass-oriented Sb-adsorbtion rate on the temperature and composition of the formed alloy layer at the liquidus curve

$$\frac{\overset{\circ}{m}_{Sb-adsorbed}}{A} = \left(p_{Sb} - X_{Sb-Liquidus}\, p_{Sb}^{0}\right)\sqrt{\frac{2\pi M_{Sb}}{RT}} \tag{2}$$

where $\frac{\overset{\circ}{m}_{Sb-adsorbed}}{A}$ = mass-oriented adsorption rate per Area A

$X_{Sb-Liquidus}$ = amount of substance Sb at liquidus (dependent on T, cp. Fig. 1)

M_{Sb} = molar mass Sb

p_{Sb} = vapor pressure Sb above surface

p_{Sb}^{0} = vapor pressure equilibrium of pure Sb

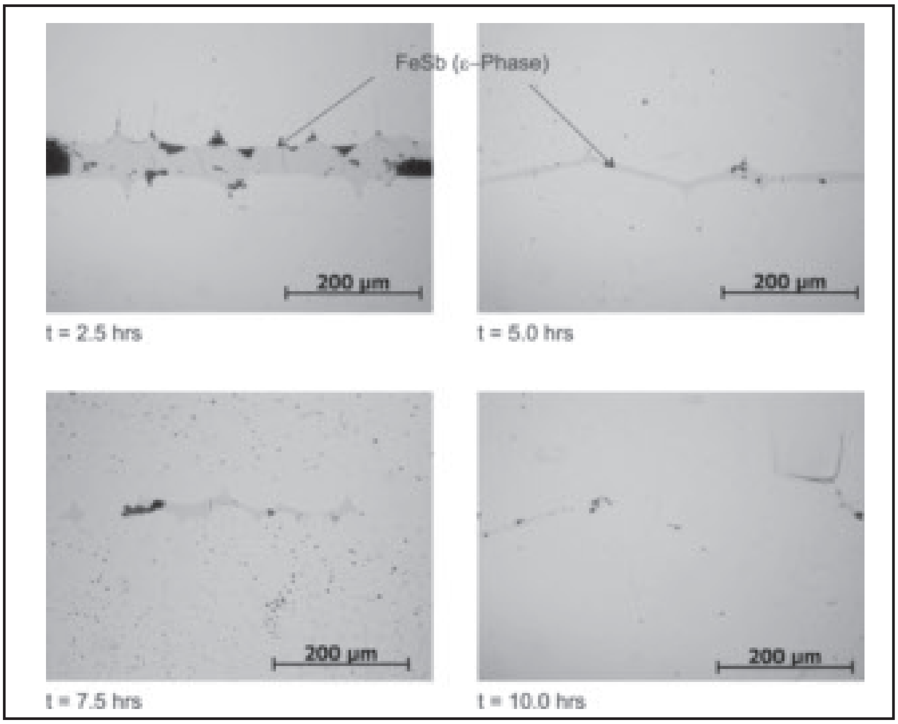

Fig. 3 — Cross sections of brazed specimens.

Diffusion Processes at the Fe-Sb System

Steps 4 and 5 — Basic principle for describing the diffusion process is the following equation (Fick's 2nd law):

$$\frac{\partial c}{\partial t} = D \bullet \frac{\partial^2 c}{\partial x^2} \tag{3}$$

where c = concentration (particle density), t = time, x = location coordinate, and D = diffusion coefficient.

If the diffusion coefficient D is not a function of the particle density N and the location x, then Equation 3 is valid. From the presented experiments and the test conditions, the results indicate the following method of resolution:

Figure 8 shows the braze experiment sequence. First, the joint clearance d_0 between the iron samples is closed by means of gaseous phase transported antimony. Iron is alloyed. Until the liquidus equilibrium is reached, iron is alloyed by antimony because of occurring diffusion processes (Sb diffuses into Fe and vice versa). At 1100°C, c_{Sb}(liq.) = 47 wt-% — Fig. 1. Due to the formed liquid phase, d_0 expands to the area d_{liq}, where an iron-antimony mixture is located. Having the formation of a liquid transient phase, antimony diffuses further into the iron substrate. The Fe-Sb phase is impoverished of antimony until the isothermal solidification is initiated. The solidus equilibrium concentration is reached. At 1100°C c_{Sb}(sol.) amounts to 10 wt-%.

The change in joint clearance width is given from

$$\begin{aligned} d_{liq.} &= \frac{1}{A}\cdot n_{Sb}\cdot \bar{V}_{Sb} \\ &+ \frac{1}{A}\cdot n_{Fe}\cdot \bar{V}_{Fe} \\ &= d_0 + \frac{1}{A}\cdot n_{Fe}\cdot \bar{V}_{Fe} \end{aligned} \tag{4}$$

where n_i = amount of i,

$\bar{V}_i$ = molar volume of i,

A = cross section of specimen.

Considering

$$n_i = \frac{m_i}{M_i},\ \rho_i = \frac{M_i}{\bar{V}_i},\ c_i = \frac{m_i}{V}$$

where m_i = mass of i,

M_i = molar mass of i,

ρ_i = density of i,

c_i = concentration of i,

V = total volume,

is received

$$d_{liq.} = d_0 \bullet \left(1 + \frac{c_{Fe}(liq.)\cdot \rho_{Sb}}{c_{Sb}(liq.)\cdot \rho_{Fe}}\right) \tag{5}$$

The concentration distribution of antimony out of the liquid mixed phase into iron is characterized by dissolving the diffusion equation (Equation 3). Solutions therefore are given standard work, like

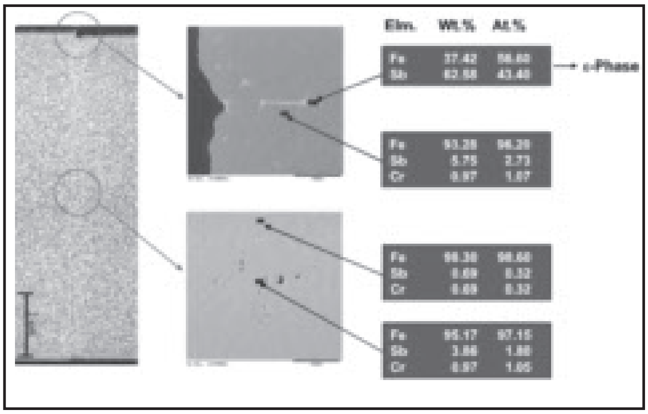

Fig. 4 — Micrographs, SEM pictures, and EDX-analysis of brazed steel specimens.

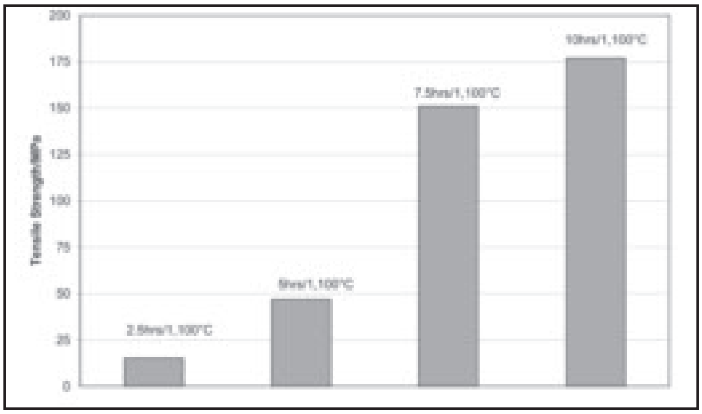

Fig. 6 — Tensile strength of brazed Fe samples as a function of exposure time to Sb gas.

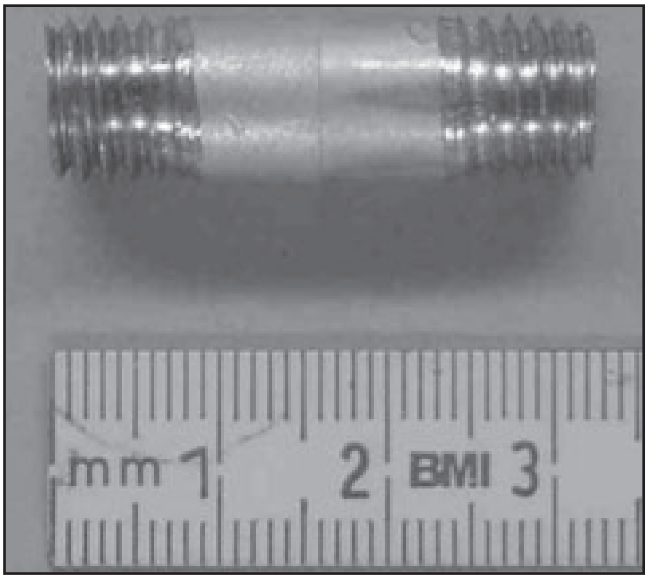

Fig. 5 — Sb-gaseous brazed Fe tensile test specimen.

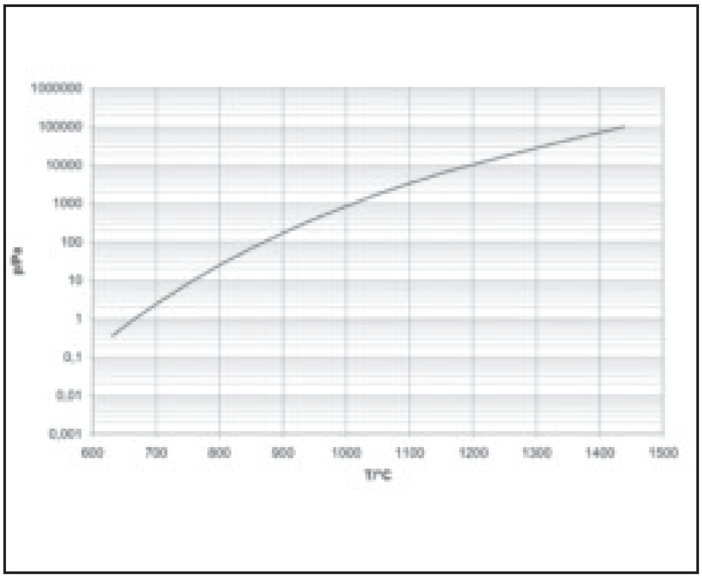

Fig. 7 — Antimony vapor pressure curve.

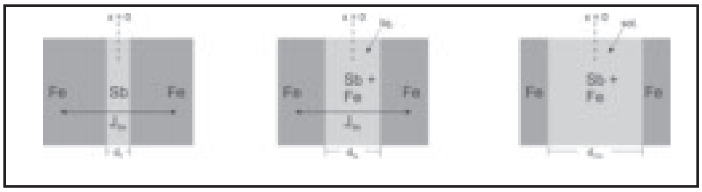

Fig. 8 — Braze experiment sequences.

Ref. 16. The following terms are applied

$$\left.\frac{\partial c_{Sb}}{\partial x}\right|_{x=0} = 0;\ c_{Sb} = c_{Sb}^{0} \text{ for } |x| > \left|\frac{d_{liq.}}{2}\right| \text{ and } t = 0$$

As a result the antimony concentration distribution is given by

$$c_{Sb}(x,t) = \frac{1}{2} \cdot c_{Sb}(liq.) \cdot \times \left[\operatorname{erf}\left(\frac{\frac{d_{liq.}}{2} - x}{2 \cdot \sqrt{D_{Sb} \cdot t}} \right) + \operatorname{erf}\left(\frac{\frac{d_{liq.}}{2} + x}{2 \cdot \sqrt{D_{Sb} \cdot t}} \right) \right] \quad (6)$$

Equation 7 defines the Gaussian error function

$$erf(x) = \frac{2}{\sqrt{\pi}} \cdot \int_{0}^{z} e^{-x^2}\, dx \quad (7)$$

The experiments mentioned in the previous section are supported by Equation 6. With $D_{Sb} = 3 \cdot 10^{-9}$ cm²/s (according to Ref. 17) and $d_0 = 30\ \mu$m as well as c_{Sb}(liq.) = 47 wt-% (Fig. 1), the concentration distribution depicted in Fig. 6 was the result. These calculations indicated that the equilibrium concentration was not yet reached after 2.5 h and 5 h. Consequently, the formation of ε phase is impossible. With a duration of 7.5 h, the equilibrium concentration of α-Fe (c_{Sb}(sol.) = 89.7 wt-%) was achieved and the joint clearance was all but closed, which is in line with the experiments.

Conclusions

The presented method provides the opportunity of joining components with a gaseous phase by applying PVD-technol-

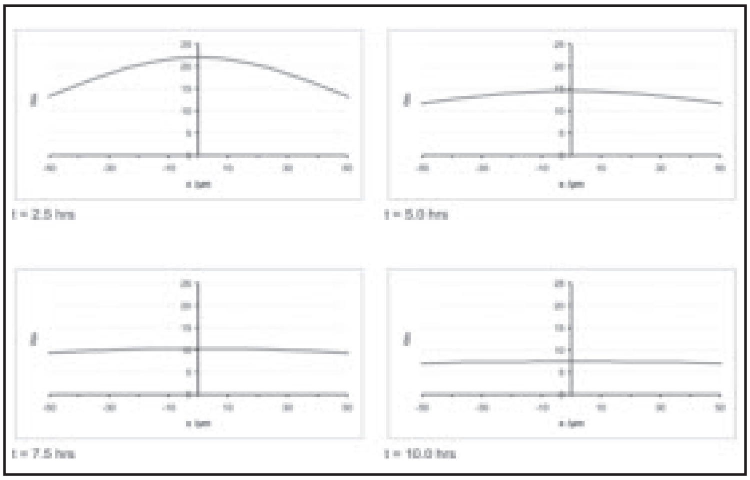

Fig .9 — Concentration distribution of Sb calculated with Equation 6.

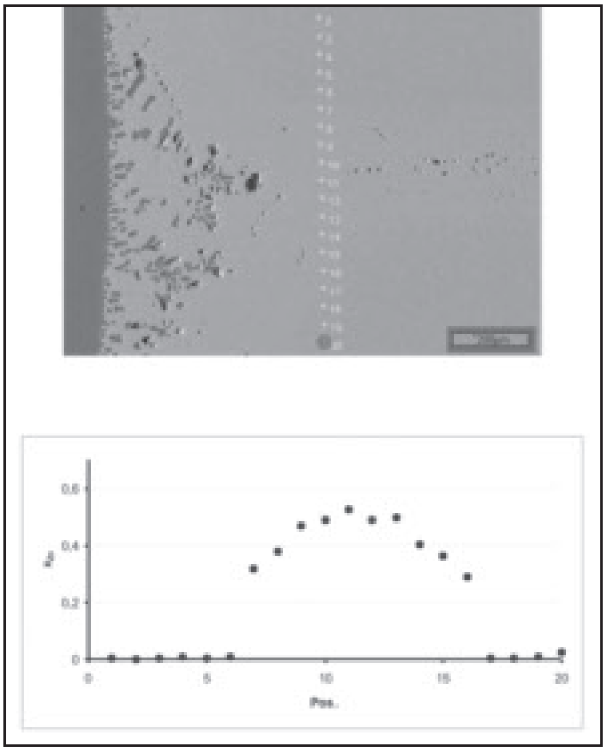

Fig. 10 — Nickel brazed with gaseous Zn (REM-photograph, concentration distribution).

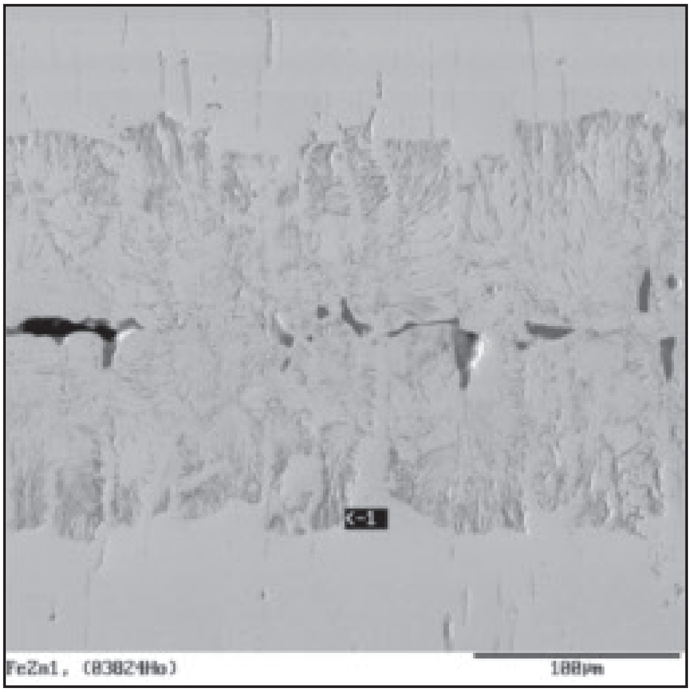

Fig. 11 — Iron brazed with gaseous Zn.

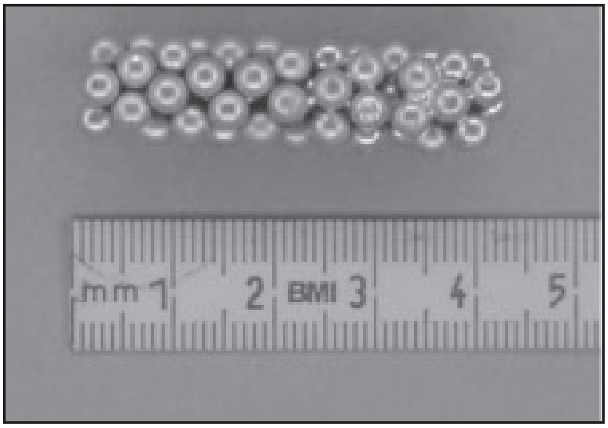

Fig. 12 — Rod of brazed steel balls using antimony gas.

ogy. Besides using antimony as a gaseous filler metal, other metals were considered. Brazing of nickel using zinc is also possible as seen in Fig. 7. Here within the brazing joint a β-phase (NiZn) can be found. In this system, the concentration distribution can be described qualitatively according to Equation 6 as well. The brazing of iron with gaseous zinc is also possible — Fig. 11.

This new joining technology is suitable for a series of applications. The gaseous braze transport allows small and complex components to be brazed where previously no joining technology was available. Potential applications can be found in microsystems or light construction. Goods in bulk, such as small steel balls, can be joined (Fig. 12), which offers the possibility of manufacturing low-weight rigid parts of any geometry.

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Weld-Bottom Macrosegregation Caused by Dissimilar Filler Metals

Filler metals with a large difference in liquidus temperature from the base metal can cause severe macrosegregation, and mechanisms are proposed to explain this

BY Y. K. YANG AND S. KOU

ABSTRACT. Filler metals different (dissimilar) from the base metal in composition are common in arc welding, but macrosegregation can exist in the resultant welds and degrade the weld quality. Two macrosegregation mechanisms (Mechanisms 1 and 2) have been proposed recently for the case of complete mixing between the filler metal and the bulk weld pool. Here the case of incomplete mixing was investigated. The liquidus temperatures of the bulk weld metal T_{LW}, base metal T_{LB}, filler metal T_{LF}, and partially mixed filler metal near the pool bottom $T_{LF'}$ were considered in addition to the stagnant or laminar-flow layer of liquid base metal along the weld pool boundary suggested by Savage. Mechanism 3 is for filler metals making $T_{LW} < T_{LB}$ and thus $T_{LF} < T_{LF'} < T_{LW} < T_{LB}$. The partially mixed filler metal solidifies into a filler-rich zone near the pool bottom with a solidification front at $T_{LF'}$. Since $T_{LF'}$ is well below T_{LB}, there exists ahead of the front a wide region cooler than T_{LB}. Thus, convection can easily carry the liquid base metal from the layer into the cooler region to freeze quickly before complete mixing occurs. This results in a partially mixed base metal in a filler-rich zone near the weld bottom. The binary Ni-Cu alloy system was chosen because large differences in liquidus temperatures can be selected to clearly verify the mechanisms. Ni was welded by gas metal arc welding (GMAW) with filler metal Cu. A filler-rich zone existed as proposed, with islands of partially mixed base metal scattered near the weld bottom. Evidence of quick freezing was found. Mechanism 4 is for filler metals making $T_{LW} > T_{LB}$ and thus $T_{LF} > T_{LF'} > T_{LW} > T_{LB}$. The partially mixed filler metal freezes quickly in the region cooler than $T_{LF'}$ near the pool bottom. This results in a filler-rich zone near the weld bottom that intrudes into a filler-deficient beach along the fusion boundary. Cu was welded with filler metal Ni. A filler-rich zone and a filler-deficient beach existed as proposed. Evidence of quick freezing was again found. With filler metal Cu-30Ni, macrosegregation was similar but less.

Introduction

Dissimilar filler metals, that is, filler metals different from the workpiece in composition, are routinely used in arc welding. It has been recognized for more than 40 years that macrosegregation can exist near the fusion boundary of arc welds made with dissimilar filler metals and degrade the weld quality (Refs. 1–17). The present study deals with welding one workpiece material with a dissimilar filler metal, that is, dissimilar-filler welding, and the resultant weld is called a dissimilar-filler weld. Welding two metals of different compositions together with or without a filler metal, that is, dissimilar-metal welding, is beyond the scope of the present study.

Kou and Yang (Refs. 18, 19) have recently studied macrosegregation near the fusion boundary of dissimilar-filler welds. The filler metal mixed completely with the homogeneous bulk weld pool and macrosegregation was caused by poor mixing of the liquid base metal with the bulk weld pool alone. The liquidus temperature of the bulk weld metal T_{LW} and the liquidus temperature of the base metal T_{LB} were considered in addition to the stagnant or laminar-flow layer of liquid base metal along the weld pool boundary suggested by Savage (Ref. 3).

KEYWORDS

Dissimilar Filler Metals
Macrosegregation
Solidification
Weld Pool
Liquidus Temperature
Ni-Cu
Filler-Rich Zone

Kou and Yang (Ref. 18) presented the following fundamental solidification concepts for dissimilar-filler welding, which can also be applied to the present study. First, the melting front is at T_{LB} instead of T_{LW}, because solid-state diffusion is far too slow to change the composition of the solid to that in equilibrium with the bulk weld metal to make it melt completely at T_{LW}. Second, the solidification front is no longer isothermal everywhere at T_{LW} as in welding without a dissimilar filler metal (undercooling is assumed negligible in most arc welding). It is at T_{LW} only along the bulk solidification front where the homogeneous bulk weld pool begins to solidify at its liquidus temperature T_{LW}. Third, the liquid base metal can freeze quickly in a liquid cooler than T_{LB} before complete mixing occurs, so can the liquid weld metal freeze quickly in a liquid cooler than T_{LW}. Either way, macrosegregation is promoted. Fourth, if the filler metal makes $T_{LW} < T_{LB}$, complete mixing throughout the weld pool may be possible under ideal conditions, but if the filler metal makes $T_{LW} > T_{LB}$, complete mixing is impossible because the base metal along the outside of the boundary of complete mixing is still above T_{LB} and thus must form a liquid layer of the base metal.

Macrosegregation can occur near the fusion boundary even when the filler metal mixes completely with the bulk weld pool. In light of the solidification concepts described above, Kou and Yang (Ref. 18) proposed two mechanisms for such macrosegregation. In Mechanism 1, for filler metals making $T_{LW} < T_{LB}$, the region of liquid weld metal immediately ahead of the bulk solidification front (T_{LW}) is below T_{LB} simply because of $T_{LW} < T_{LB}$ and not any undercooling. The liquid base metal swept in here from the liquid base-metal layer by convection can freeze quickly into filler-deficient penin-

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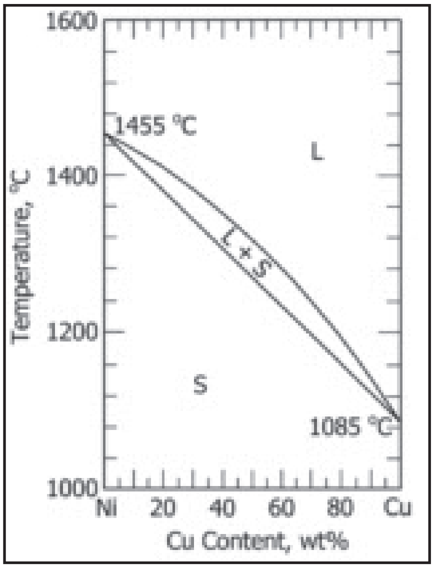

Fig. 1 — Ni-Cu phase diagram (Ref. 21).

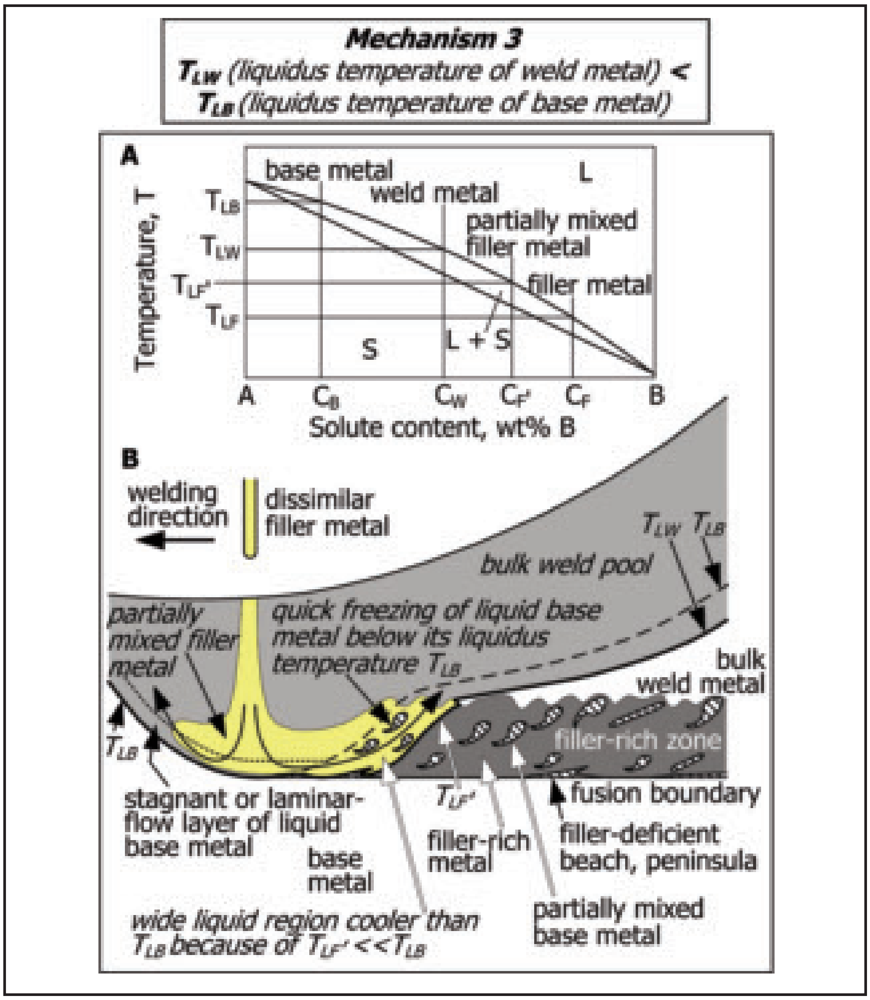

Fig. 2 — Mechanism for macrosegregation formation caused by a partially mixed dissimilar filler metal that makes $T_{LW} < T_{LB}$ (Mechanism 3). A — Phase diagram; B — longitudinal cross section of weld pool.

sulas or islands. These peninsulas or islands often appear roughly parallel to the fusion boundary in a weld transverse or longitudinal micrograph. The liquid base metal remaining in the layer solidifies as a filler-deficient beach. This mechanism was confirmed by macrosegregation in gas metal arc welds of 1100 Al (essentially pure Al) made with filler metal 4145 Al (essentially Al-4Cu-10Si), which made $T_{LW} < T_{LB}$.

In Mechanism 2, for filler metals making $T_{LW} > T_{LB}$, the stagnant or laminar-flow layer of liquid base metal is below T_{LW} simply because $T_{LW} > T_{LB}$. The liquid weld metal pushed in here from the bulk weld pool by convection can freeze quickly as weld-metal intrusions into an often continuous filler-deficient beach. Meanwhile, the liquid base metal left in the space between the intrusions can solidify into filler-deficient peninsulas or islands of random orientations. These filler-deficient features are distinctly different from those formed by Mechanism 1. This was a new kind of macrosegregation not reported previously. This mechanism was confirmed by macrosegregation in gas metal arc welds of Cu made with filler metal Cu-30Ni, which made $T_{LW} > T_{LB}$.

The present study focuses on the macrosegregation that forms in the weld when the dissimilar filler metal reaches the weld pool bottom before it is completely mixed with the bulk weld pool. Two mechanisms, Mechanisms 3 and 4, are proposed to explain such macrosegregation. These two mechanisms are more complicated than Mechanisms 1 and 2 described previously for the macrosegregation that forms near the fusion boundary when the dissimilar filler metal is completely mixed with the bulk weld pool. The binary Ni-Cu alloy system is selected as a test material. Macrosegregation in these welds differs significantly both in morphology and severity from that observed previously near the fusion boundary (Ref. 18).

The binary Ni-Cu alloy system is selected for welding because of the following reasons. First, as will be shown later (in Fig. 1), it has a simple phase diagram easy for understanding the weld microstructure. Second, it has a wide temperature range over which T_{LW} and T_{LB} can be varied relative to each other. A large difference between T_{LW} and T_{LB} will make its effect on macrosegregation more signifi-

Table 1 — Welds, Dilutions, Compositions, and Liquidus Temperatures

		Composition (wt-%)			Liquidus Temperature (°C)			
Welds	Dilution	Base Metal (b)	Filler Metal (f)	Weld Metal	Base Metal (T_{LB})	Filler Metal (T_{LF})	Weld Metal (T_{LW})	$\Delta T = T_{LB} - T_{LW}$ (°C)
Ni(b)/Cu(f)	51.4%	Ni > 99.0	Cu > 99.99	Cu-51.3Ni	1455	1085	1321	+134
Ni(b)/Cu-30Ni(f)	38.9%	Ni	Cu-30.4Ni	Cu-57.4Ni	1455	1239	1342	+113
Cu(b)/Ni(f)-1	35.3%	Cu > 99.99	Ni > 99.67	Cu-64.7Ni	1085	1455	1366	–281
Cu(b)/Ni(f)-2	44.1%	Cu	Ni	Cu-55.9Ni	1085	1455	1338	–253
Cu(b)/Cu-30Ni(f)	49.1%	Cu	Cu-30.4Ni	Cu-15.3Ni	1085	1239	1168	–83

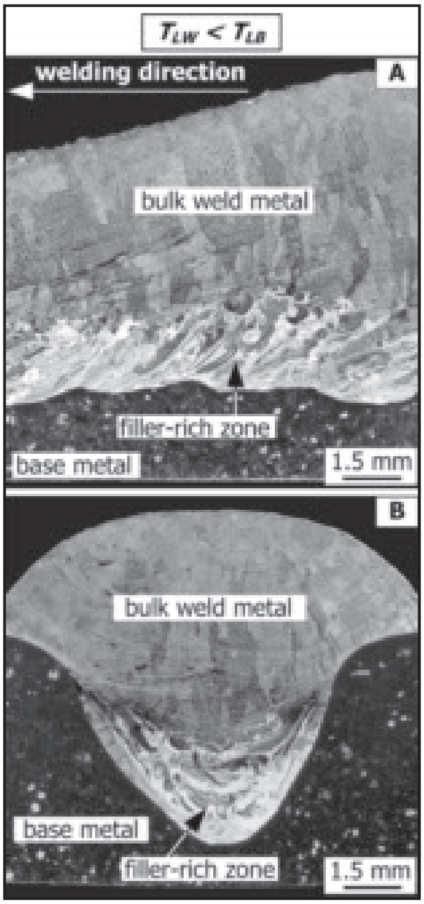

Fig. 3 — Macrographs of filler-rich zone when $T_{LW} < T_{LB}$. A — Longitudinal; B — transverse. Base metal: Ni; filler metal: Cu.

Fig. 4 — Longitudinal micrograph showing filler-rich zone with islands of partially mixed base metal in filler-rich metal when $T_{LW} < T_{LB}$. Base metal: Ni; filler metal: Cu.

Fig. 5 — Longitudinal micrograph showing filler-rich zone with islands of partially mixed base metal in filler-rich metal and filler-deficient peninsulas along fusion boundary when $T_{LW} < T_{LB}$. Base metal: Ni; filler metal: Cu.

cant and thus easier to verify. Third, Ni and Cu are soluble in each other completely, and there are no intermetallic compounds either to complicate the weld microstructure or cause weld cracking. Fourth, welding wires or Ni, Cu, and Cu-Ni alloys (such as Cu-30Ni) are commercially available.

Experimental Procedure

Ni 200 (commercially pure Ni, 99.6% purity) and Cu 101 (also known as oxygen-free, electronic-grade Cu, 99.99% purity) were used for welding. They were all 6.4 mm (¼ in.) thick, 51 mm (2 in.) wide, and 102 mm (4 in.) long. The copper plates were heat-treated at 800°C for 24 h under argon atmosphere and cleaned before welding. This was found to improve penetration. Pure Ni, pure Cu, and Cu-30.40Ni welding wires were used. The wire diameters were 1.1, 1.3, and 1.1 mm, respectively.

Bead-on-plate gas metal arc welding (GMAW) was carried out under the following welding conditions: 6.4–8.5 mm/s (15–20 in./min) travel speed, 169 and 212 mm/s (400, 500 in./min) wire feeding rate, 30–37 V arc voltage, 300–350 A average current, and Ar shielding. The contact tube to workpiece distance was about 19 mm (¾ in.), and the torch was held perpendicular to the workpiece. The weld length on the Ni plate was about 97 mm long. As for the weld on a Cu plate, a Cu run-on plate about 75 mm long was used, allowing an extra weld length of about 25 mm on the run-on plate.

The resultant welds were cut in the middle and polished to prepare longitudinal and transverse cross sections. In some cases, in order to help reveal the development of macrosegregation, an additional longitudinal cross section was taken to include the weld crater. The samples were etched with two different etching solutions. The first etching solution was an iron chloride solution consisting of 3 g of $FeCl_3$, 2 mL of 37% HCl, and 100 mL of methanol. The second was an ammonium persulfate solution consisting of 10 g of $(NH_4)_2S_2O_8$ and 100 mL of distilled water. Welds made on pure copper were etched with the first solution to highlight the filler-rich intrusions, and then etched again with the second solution to reveal the fusion boundary in copper more clearly. All other welds were etched with the first solution only.

The concentration of any element, E, in a homogeneous weld metal can be calculated as follows (Ref. 20):

% E in weld metal = (% E in base metal)

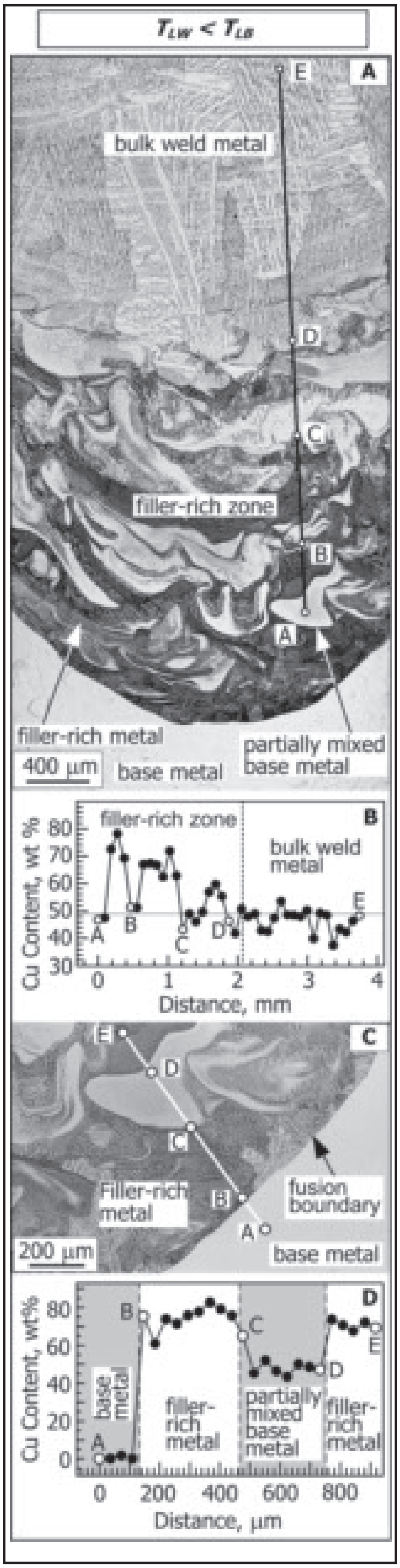

Fig. 6 — Macrosegregation in weld with $T_{LW} < T_{LB}$. A — Transverse micrograph; B — composition profile; C — transverse micrograph near fusion boundary; D — composition profile across fusion boundary. Base metal: Ni; filler metal: Cu.

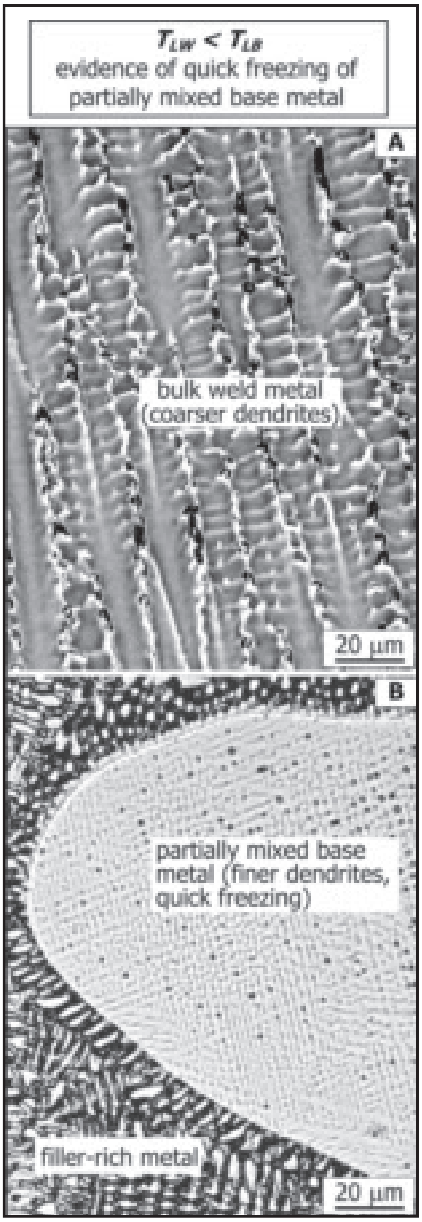

Fig. 7 — Evidence of quick freezing of partially mixed liquid base metal suggested by Mechanism 3. A — Bulk weld metal showing coarser dendrites near point E in Fig. 6A; B — left side of island at point A in Fig. 6A showing much finer dendrites than bulk weld metal. Both have about the same composition of Ni-48Cu. Base metal: Ni; filler metal: Cu.

$$\times [A_b / (A_b + A_f)] + (\%\ E \text{ in filler metal}) \times [A_f / (A_b + A_f)] \qquad (1)$$

where A_b and A_f are the areas in the weld transverse cross section that are below and above the workpiece surface, respectively. Equation 1 is based on the assumption of uniform composition in the weld metal, that is, no macrosegregation (Ref. 20). Although macrosegregation was severe in the present study, it was essentially limited to near the weld bottom. Arc welds are typically much narrower at the bottom than at the top, and those in the present study were no exceptions. Thus, the volume within which macrosegregation occurred was still much smaller than the overall volume of the weld, and Equation 1 was still used as an approximation for calculating the average composition of the weld metal. Since the density of Ni (8.90 g/cm^3) is almost identical to that of Cu (8.96 g/cm^3), the accuracy of Equation 1 will not be affected by the concentrations of Ni and Cu relative to each other in the weld metal.

In Equation 1, areas A_b and A_f represent contributions from the base metal and filler metal, respectively. The ratio $A_b / (A_b + A_f)$ is the so-called dilution ratio. Areas A_b and A_f were determined by enlarging the transverse macrograph on a computer monitor and by using commercial computer software.

The welds were also examined under a scanning electron microscope, and the composition profiles across the fusion boundary were determined by energy dispersive spectroscopy (EDS).

Results and Discussion

Table 1 summarizes the results of welding experiments. For convenience, each weld is identified with the base metal (b) followed by the filler metal (f). For instance, weld Ni(b)/Cu(f) refers to a weld with pure Ni as the base metal and pure Cu as the filler metal. Similarly, weld Cu(b)/Cu-30Ni(f) refers to a weld with pure Cu as the base metal and Cu-30Ni as the filler metal.

Figure 1 shows the binary Ni-Cu phase diagram (Ref. 21). For pure Ni the liquidus temperature is its melting point 1455°C. Likewise, for pure Cu the liquidus temperature is its melting point 1085°C.

Welds with $T_{LW} < T_{LB}$

Two mechanisms are proposed as follows for macrosegregation in welds made with a dissimilar filler metal that is not completely mixed with the bulk weld pool when it reaches the pool bottom. Mechanism 3, shown in Fig. 2, is for filler metals making $T_{LW} < T_{LB}$. A phase diagram similar to the binary Ni-Cu phase diagram is shown in Fig. 2A for convenience of discussion. The composition of the base metal is C_B and that of the filler metal C_F. The composition of the resultant bulk weld metal is somewhere between C_B and C_F, depending on the extent the filler metal is diluted by the liquid base metal. The liquidus temperature of the bulk weld metal T_{LW} is below that of the base metal T_{LB}. The partially mixed filler metal near the pool bottom may not be exactly uniform in composition. As will be shown subsequently, the composition of the partially mixed filler metal $C_{F'}$ is close to C_F

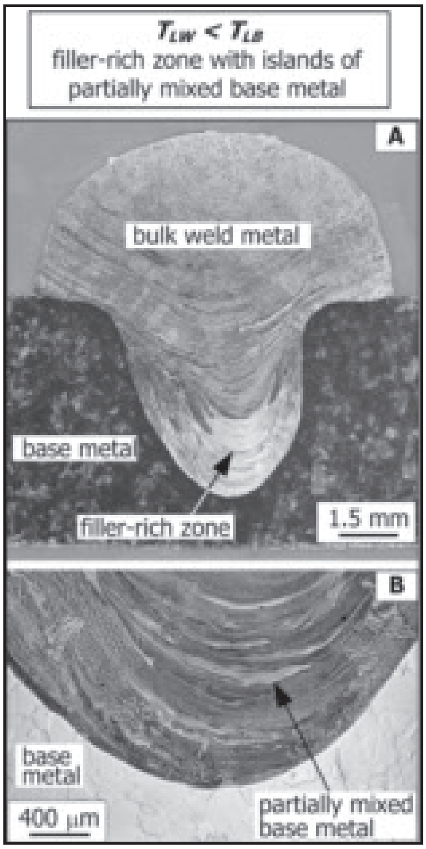

Fig. 8 — Transverse cross section of filler-rich zone formed when $T_{LW} < T_{LB}$. A — Macrograph; B — micrograph. Base metal: Ni; filler metal: Cu-30Ni.

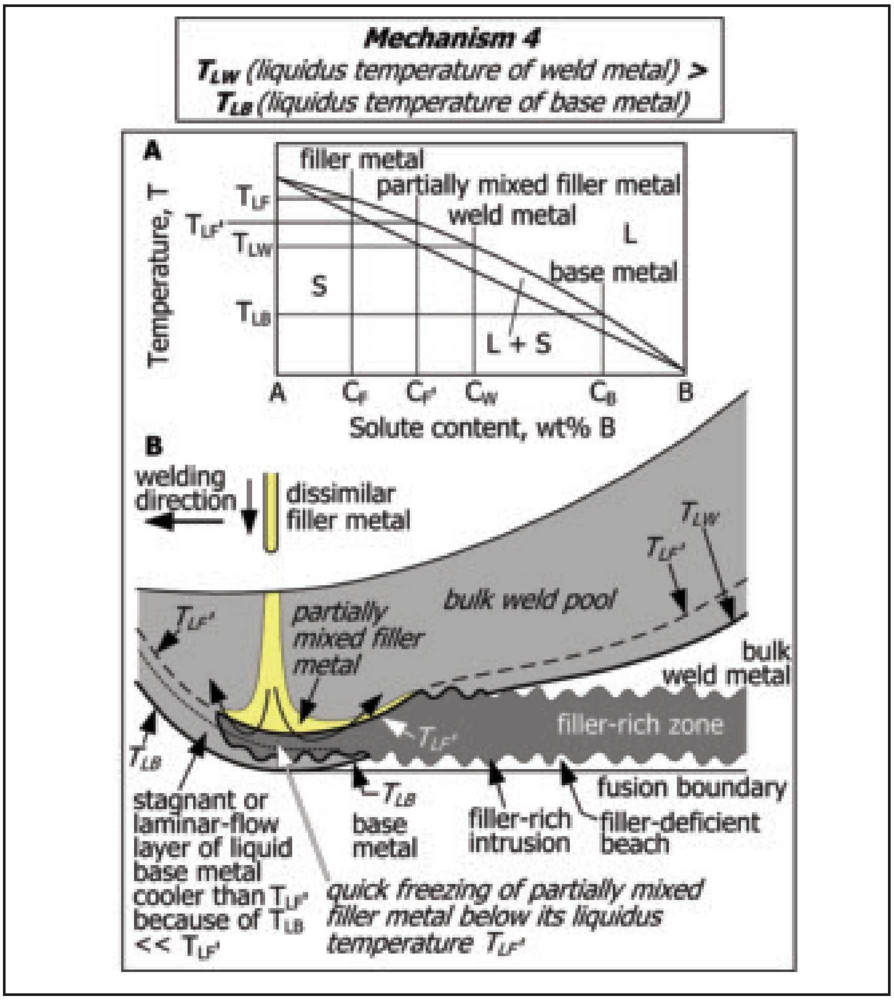

Fig. 9 — Mechanism for macrosegregation formation caused by a partially mixed dissimilar filler metal that makes $T_{LW} > T_{LB}$ (Mechanism 4). A — Phase diagram; B — longitudinal cross section of weld pool.

near the fusion boundary where mixing is most limited and C_W near the bulk weld pool where mixing is complete. Thus, the liquidus temperature of the partially mixed filler metal $T_{LF'}$ is close to T_{LF} near the fusion boundary (where $T_{LF'} << T_{LB}$) and T_{LW} near the bulk weld pool (where $T_{LF'} < T_{LB}$). Thus, $T_{LF'}$ is between T_{LF} and T_{LW}. Therefore, $T_{LF} < T_{LF'} < T_{LW} < T_{LB}$ when the filler metal makes $T_{LW} < T_{LB}$.

As shown in Fig. 2B, in the bulk weld pool the solidification front is at T_{LW} because the bulk weld pool is homogeneous at the composition of C_W (undercooling is usually negligible in most arc welding). Near the pool bottom, however, the solidification front is at $T_{LF'}$ because the filler metal is only partially mixed and the average composition is $C_{F'}$ near the pool bottom. This partially mixed filler metal solidifies into a filler-rich zone along the weld near its bottom.

A stagnant or laminar-flow layer of liquid base metal can exist along the leading portion of the weld pool boundary because of weak convection near the pool boundary as suggested by Savage (Ref. 3). According to fluid mechanics (Ref. 22), the velocity of a moving liquid is zero at a solid wall, that is, the so-called "no-slip" boundary condition for fluid flow.

Since $T_{LF'}$ is well below T_{LB}, there exists a wide region ahead of the solidification front near the pool bottom corresponding to $T_{LF'} < T < T_{LB}$, that is, cooler than T_{LB}. Thus, convection can easily carry the liquid base metal from the layer of base metal near the fusion boundary into the cooler region to freeze quickly before complete mixing occurs. The liquid base metal may break up while being carried. Consequently, partially mixed base metal can scatter as islands in the filler-rich zone. The resultant welds can show numerous islands of partially mixed base metal in the form of streaks or swirls in the filler-rich zone. The composition of the islands can be somewhere between the compositions of the base metal and the bulk weld metal depending on the extent of mixing while freezing.

Since a very thin layer of liquid base metal may still exist near the pool boundary, it can also be carried by convection into the cooler region and solidify as small peninsulas right next to the fusion boundary, as suggested by Mechanism 1. This is also shown in Fig. 2B. The remaining liquid base metal can solidify as a very thin beach.

Figure 3A shows a longitudinal macrograph at the crater end of weld Ni(b)/Cu(f), taken along the weld central plane. The weld crater was longer than the macrograph and its head was thus not included. Since the melting point of pure Ni is 1455°C, the liquidus temperature of the base metal T_{LB} was 1455°C. As shown in Table 1, the dilution was 51.4%. From Equation 1 and the compositions of the base metal and filler metal, the average weld metal composition was Cu-51.3Ni or Ni-48.7Cu. From the Ni-Cu phase diagram, the liquidus temperature of the weld metal, T_{LW}, was 1321°C. Thus, T_{LW} was below T_{LB} and the difference ($T_{LB} - T_{LW}$) was as high as 134°C (1455°–1321°C).

As shown in the macrograph in Fig. 3A,

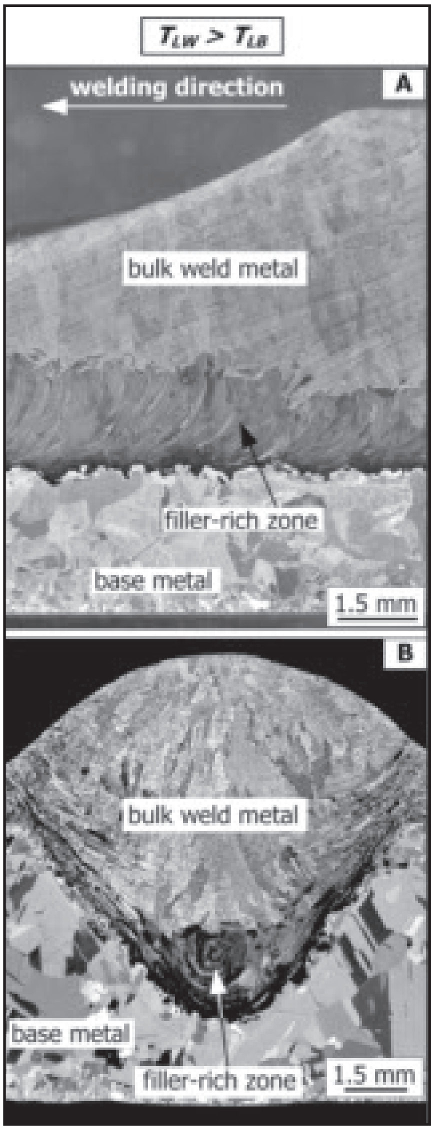

Fig. 10 — Macrographs of filler-rich zone when $T_{LW} > T_{LB}$. A — Longitudinal; B — transverse. Base metal: Cu; filler metal: Ni.

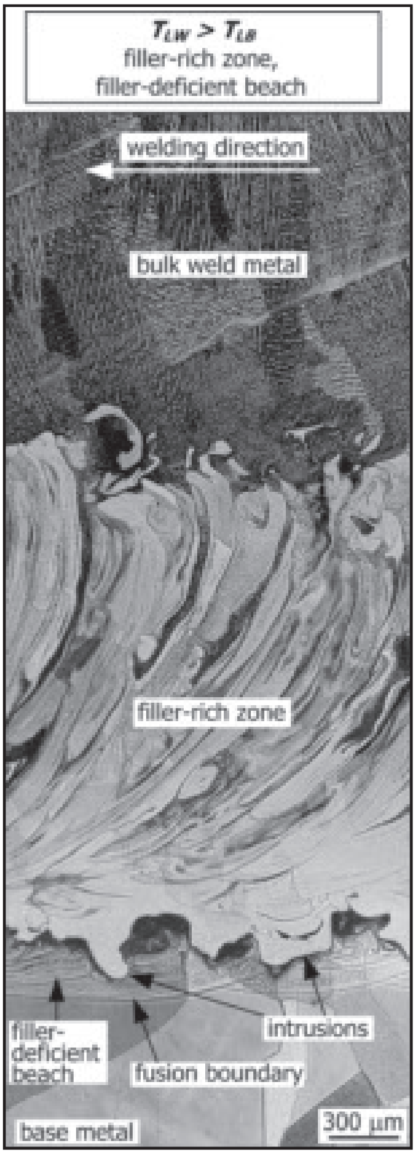

Fig. 11 — Longitudinal micrograph showing filler-rich zone formed when $T_{LW} > T_{LB}$. Base metal: Cu; filler metal: Ni.

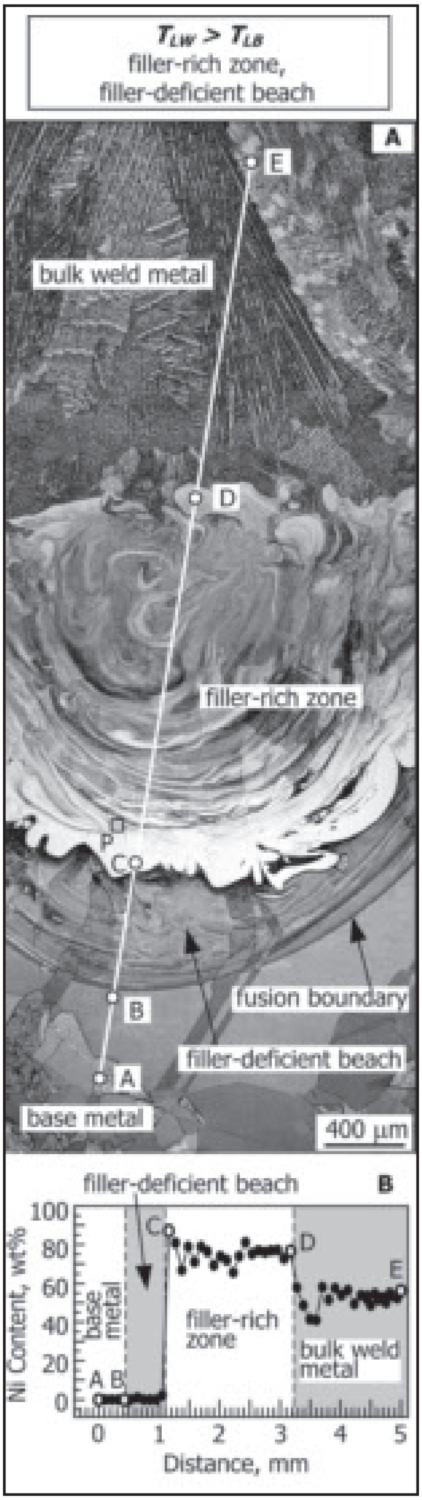

Fig. 12 — Macrosegregation in weld with $T_{LW} > T_{LB}$. A — Transverse micrograph; B — composition profile. Base metal: Cu; filler metal: Ni.

weld Ni(b)/Cu(f) is macroscopically inhomogeneous. A filler-rich zone exists along the bottom of the weld. Figure 3B shows a transverse macrograph of the same weld taken about in the middle of the weld. A filler-rich zone exists near the bottom of the weld.

Figures 4 and 5 are micrographs showing the filler-rich zone in weld Ni(b)/Cu(f). Numerous islands of partially mixed base metal exist in the filler-rich zone, some are more like streaks, and some others more like swirls. These islands were caused by weld pool convection, which can be turbulent and time dependent (Ref. 20). The darker-etching background is the filler-rich metal. A couple of small peninsulas are visible along the fusion boundary in Fig. 5. Their formation, by Mechanism 1, has been described previously (Ref. 18).

Figure 6A shows the transverse micrograph of the filler-rich zone of weld Ni(b)/Cu(f). Numerous lighter-etching islands of partially mixed base metal are surrounded by darker-etching filler-rich metal. The islands were smaller at the zone bottom but became more increasingly spread out and diffused away from it. It appears that mixing was lowest near the fusion boundary and increased away from it.

The results of macrosegregation measurements by energy dispersive spectroscopy (EDS) along path AE in Fig. 6A are shown in Fig. 6B. As shown, the weld bottom is richer in Cu (that is, the filler) than the bulk weld metal (DE) except at islands (points A, B, and C) of partially mixed base metal. This is why the area is called the filler-rich zone. The horizontal line is the average composition of the bulk weld metal of 48.7% Cu calculated based on the dilution ratio. The measured composition of the bulk weld metal fluctuates along DE because of microsegregation across the dendrite arms. It is lower than, but still reasonably close to, the calculated one. A slightly lower value is required by the conservation of Cu because the filler-rich zone is higher than 48.7% Cu. The composition of the filler-rich metal between islands decreases from the weld bottom to the bulk weld metal, that is, from AB to BC to CD and finally DE.

The composition profile measured along path AE in Fig. 6C at smaller intervals than those in Fig. 6A is shown in Fig. 6D. The base metal AB has no Cu from the filler metal, the weld metal BC next to the fusion boundary has about 75% Cu on the average, the island CD has only about 50% Cu, and the weld metal DE just beyond the island has about 70% Cu. Thus, next to the fusion boundary (BC in Fig. 6D, where the composition of the filler-rich metal was about 75% Cu) $T_{LF'}$ = 1220°C. Thus, $T_{LF'}$ (1220°C) << T_{LB} (1445°C) near the fusion boundary.

Figure 7 shows the evidence of quick freezing of the partially mixed liquid base metal in the cooler liquid region ahead of the solidification front. Figure 7A shows the dendritic structure near point E in Fig. 6A, and Fig. 7B shows a much finer dendritic structure of island at point A in Fig. 6A. According to the composition profile shown in Fig. 6B, point E and the island at point A both have a composition of about Ni-48Cu. However, the latter has a much finer dendritic structure than the former, suggesting the latter was cooled much faster than the former — faster than what can be accounted for by the difference in location. This is consistent with the quick freezing of the partially mixed liquid base metal proposed by Mechanism 3.

Figure 8 shows the transverse macrograph of weld Ni(b)/Cu-30Ni(f). As shown in Table 1, the dilution was 38.9%. From Equation 1 and the compositions of the base metal and filler metal, the average weld metal composition was about Cu-57.4Ni or Ni-42.6Cu. From the Ni-Cu phase diagram, the corresponding liquidus temperature of the weld metal, T_{LW}, was 1342°C. Thus, T_{LW} was below T_{LB} and the difference ($T_{LB} - T_{LW}$) was as high as 113°C (1455°–1340°C).

Figure 8A shows a filler-rich zone (lighter-etching) near the bottom of weld Ni(b)/Cu-30Ni(f). This zone is somewhat smaller than that in weld Ni(b)/Cu(f) — Fig. 3B. The temperature difference ($T_{LB} - T_{LW}$) 113°C here is somewhat less than that of 134°C in the pure Ni weld made with pure Cu filler metal. As shown in the micrograph in Fig. 8B, the filler-rich zone contains many islands (light-etching) of partially mixed base metal. As compared to weld Ni(b)/Cu(f) (Fig. 6A), these islands are more like streaks than swirls.

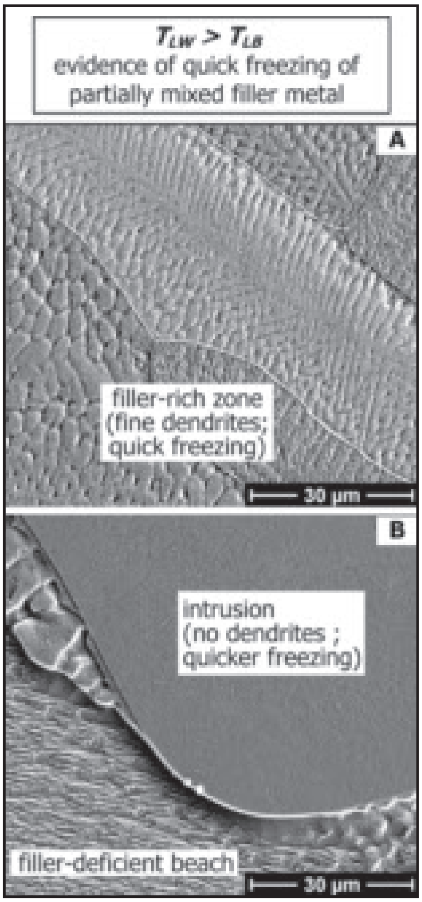

Fig. 13 — SEM images showing evidence of quick freezing of partially mixed filler metal (filler-rich liquid) in cooler layer of liquid base metal suggested by Mechanism 4. A — Filler-rich metal at point P in Fig. 12A; B — filler-rich intrusion near point C in Fig. 12A. Base metal: Cu; filler metal: Ni.

Welds with $T_{LW} > T_{LB}$

Mechanism 4, shown in Fig. 9, is for filler metals making $T_{LW} > T_{LB}$. As shown by the phase diagram in Fig. 9A, the liquidus temperature of partially mixed filler metal $T_{LF'}$ is again between T_{LF} and T_{LW}. Therefore, $T_{LF} > T_{LF'} > T_{LW} > T_{LB}$ when the filler metal makes $T_{LW} > T_{LB}$.

According to Mechanism 2 (Ref. 18), since $T_{LW} > T_{LB}$, the base metal along the outside of the T_{LW} isotherm is above its liquidus temperature T_{LB} and hence must melt completely, as shown in Fig. 9B. Thus, regardless of convection in the bulk weld pool, a stagnant or laminar-flow layer of liquid base metal must exist along the weld pool boundary. The layer solidifies into a continuous filler-deficient beach. This layer is below $T_{LF'}$ and is thus cooler than the liquid weld metal. Thus, the partially mixed filler metal pushed into this cooler layer can freeze quickly into intrusions. Filler-deficient peninsulas or islands can exist in the space formed between the intrusions in random orientation with respect to the weld interface.

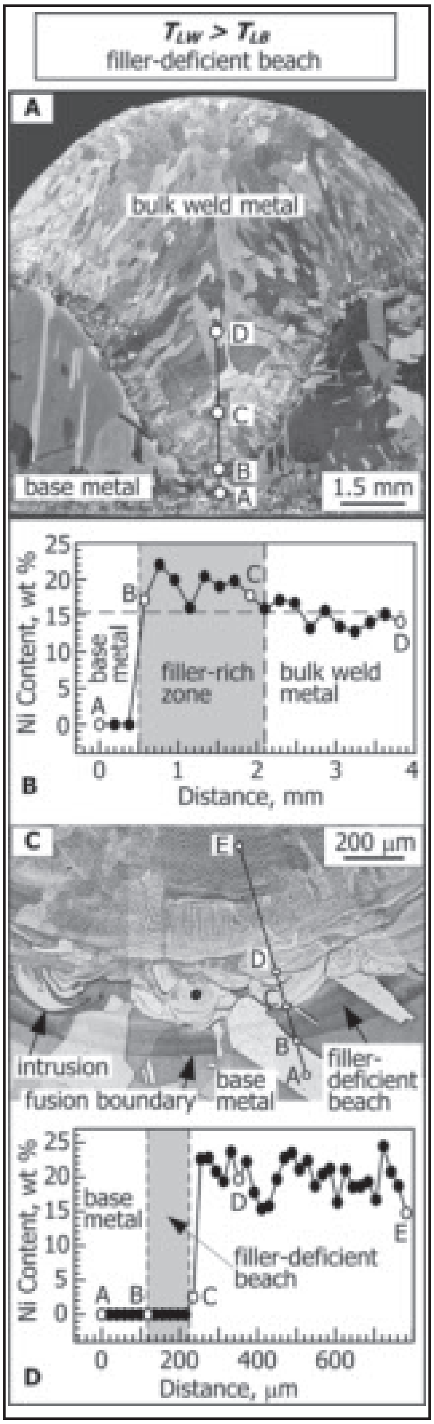

Fig. 14 — Macrosegregation in weld with $T_{LW} > T_{LB}$. A — Transverse macrograph; B — composition profile across weld bottom; C — transverse micrograph near fusion boundary; D — composition profile across fusion boundary. Base metal: Cu; filler metal: Cu-30Ni.

Since the filler metal reaches the pool bottom only partially mixed, it can freeze quickly in the region below its liquidus temperature $T_{LF'}$ near the pool bottom. This results in a filler-rich zone in the form of a core along the bottom of the weld on the longitudinal cross section. On the transverse cross section of the weld, the filler-rich zone often appears as a filler-rich nugget. A filler-deficient beach exists between the filler-rich zone and the fusion boundary, with intrusions from the filler-rich zone.

Figure 10A shows a longitudinal macrograph at the crater end of weld Cu(b)/Ni(f)-1, taken along the weld central plane. The welding direction was from right to left. Again, the crater was longer than the macrograph and its head was thus not included. As shown, weld Cu(b)/Ni(f)-1 is macroscopically inhomogeneous. A large filler-rich zone exists along the bottom of the weld. Since the melting point of pure Cu is 1085°C, the liquidus temperature of the base metal T_{LB} was 1085°C. From Table 1, the dilution was 35.3%. From Equation 1 and the compositions of the base metal and filler metal, the weld metal composition was about Ni-35.3Cu or Cu-64.7Ni. From the Ni-Cu phase diagram, the liquidus temperature of the weld metal, T_{LW}, was 1366°C. Thus, $T_{LW} > T_{LB}$ and the difference ($T_{LW} - T_{LB}$) was as high as 281°C.

Figure 10B shows a transverse macrograph of a similar weld, that is, weld Cu(b)/Ni(f)-2 at a location well behind the crater. From Table 1, the dilution was 44.1%. From Equation 1 and the compositions of the base metal and filler metal, the weld metal composition was about Ni-44.1Cu or Cu-55.9Ni. From the Ni-Cu phase diagram, the liquidus temperature of the weld metal, T_{LW}, was 1338°C. Thus, $T_{LW} > T_{LB}$ and the difference ($T_{LW} - T_{LB}$) was as high as 253°C.

Figure 11 shows a longitudinal micrograph of the filler-rich zone well behind the crater of weld Cu(b)/Ni(f)-1. The transition from the filler-rich zone to the bulk weld metal appears rather sharp, nothing like the islands in the filler-rich zone mentioned previously. The upward and backward flow pattern of the filler-rich liquid during welding is clearly revealed. A filler-deficient beach exists along the fusion boundary between the filler-rich zone and the fusion boundary. The bottom of the filler-rich zone intrudes into the beach at various locations.

Figure 12A is a transverse micrograph of weld Cu(b)/Ni(f)-2. The light-etching, filler-rich nugget corresponds to the darker-etching band along the weld bottom in Fig. 10A and the darker-etching, filler-rich zone in Fig. 10B. A thick filler-deficient beach exists between the nugget and the fusion boundary. As shown, the bottom of the nugget extends into the filler-deficient beach of base metal as intrusions at various locations. These intrusions correspond to those shown in the longitudinal micrograph in Fig. 11. Several very small light-etching islands are also visible in the beach.

Figure 12 shows macrosegregation in weld Cu(b)/Ni(f)-2. The composition profile taken by EDS along path $\underline{AE}$ in Fig. 12A is shown in Fig. 12B. The base metal ($\underline{AB}$ at 0% Ni) is pure Cu, the beach along the fusion boundary ($\underline{BC}$ at 0% Ni) is also pure Cu, and the nugget ($\underline{CD}$ at about 75% Ni) has more Ni (that is, the filler metal) than the bulk weld metal ($\underline{DE}$ at about 52% Ni). Thus, it is clear the nugget was filler-rich and the beach was completely filler-deficient, that is, unmixed base metal (Cu). This confirms the filler-rich zone and the filler-deficient beach along the fusion boundary in the micrographs shown previously in Figs. 10 and 11. The 75% Ni of the filler-rich zone suggests that the filler-metal (originally 100% Ni) was only partially mixed before it started to freeze at a liquidus temperature of nearly 1400°C according to the phase diagram. Thus, $T_{LF'}$ (1400°C) >> T_{LB} (1085°C) near the weld bottom. The 52% Ni of the bulk weld metal was reasonably close to the 55.9% Ni average weld metal composition calculated from the dilution ratio but slightly lower. A slightly lower value is required by the conservation of Ni because the nugget already had a higher Ni content than 55.9%.

Figure 13 shows the evidence of quick freezing of the partially mixed filler metal, that is, the filler-rich liquid, in weld Cu(b)/Ni(f)-2. Figure 13A shows a fine dendritic structure at point P in Fig. 12A, thus indicating the quick freezing of the filler-rich liquid below its liquidus temperature $T_{LF'}$, as suggested by Mechanism 4. The solidification structure near point C in Fig. 12A is shown in Fig. 13B. No dendritic or even cellular structure can be seen, thus indicating an even quicker freezing of the intrusion in the cooler layer of liquid base metal along the pool boundary, as suggested by Mechanism 4. The compositions of the filler-rich metals shown in Fig. 13A and B are both about Cu-75Ni based on the composition measurement shown in Fig. 12B.

Figure 14A shows the transverse macrograph of weld Cu(b)/Cu-30Ni(f). The liquidus temperature of the base metal T_{LB} was 1085°C, the melting point of Cu. From Table 1, the dilution was 49.1%. From Equation 1 and the compositions of the base metal and filler metal, the weld metal composition was about Ni-84.7Cu or Cu-15.3Ni. From the Ni-Cu phase diagram, the liquidus temperature of the weld metal, T_{LW}, was 1168°C. Thus, $T_{LW} > T_{LB}$ and the difference ($T_{LW} - T_{LB}$) was 83°C.

The composition profile along path $\underline{AD}$ in Fig. 14A is shown in Fig. 14B. The horizontal line shows the average 15.3% Ni content of the whole weld calculated based on the dilution ratio and the compositions of the base and filler metals. Although the composition fluctuated due to microsegregation, it still can be seen that the Cu content decreases from above the average value near the weld interface to below it in the bulk weld metal. This indicates the weld bottom was richer in filler-metal than average up to around point C, although a clear filler-rich nugget could not be seen in the weld macrograph.

The filler-deficient beach and the intrusions from the weld metal are still clearly visible, as shown in the transverse micrograph in Fig. 14C. The beach is significantly thinner than that of weld Cu(b)/Ni(f)-2 in Fig. 12A. This is mainly because of the much smaller temperature difference ($T_{LW} - T_{LB}$), that is, 83°C as opposed to 253°C in weld Cu(b)/Ni(f)-2.

The composition profile along path $\underline{AE}$ in Fig. 14C is shown in Fig. 14D. The filler-deficient beach $\underline{BC}$ has no Ni and is thus completely filler-deficient or unmixed. Along $\underline{CE}$ the composition fluctuates due to microsegregation and the average is around 20% Ni, which is higher than the calculated 15.3% Cu average of the entire weld. Thus, again the weld metal near the weld bottom is richer in filler-metal than average.

For both Mechanisms 1 and 2, a filler metal with a large difference from the base metal in the liquidus temperature is more likely to cause more macrosegregation under identical welding conditions. The wire feed rate and the travel speed are likely to affect the extent of macrosegregation as well, but more work will be needed to determine their effect. The liquid viscosity and diffusion coefficient may also have some influence.

Conclusions

The present study builds upon the solidification concepts and macrosegregation mechanisms (Mechanisms 1 and 2) proposed and verified recently by the authors (Refs. 18, 19). The solidification concepts still apply here, but the macrosegregation mechanisms are more complicated because the filler metal can reach the weld pool bottom before mixing completely with the bulk weld pool and cause macrosegregation near the weld bottom. The liquidus temperatures of the bulk weld metal T_{LW}, base metal T_{LB}, filler metal T_{LF}, and partially mixed filler metal near the pool bottom $T_{LF'}$ were all considered in addition to the stagnant or laminar-flow layer of liquid base metal along the weld pool boundary suggested by Savage (Ref. 3). To verify the mechanisms the Ni-Cu binary alloy system was selected and gas metal arc welding was conducted with dissimilar filler metals. The microstructure and macrosegregation in the resultant welds were examined. The conclusions are as follows:

1. Filler metals with a large difference from the base metal in the liquidus temperature can mix partially with the bulk weld pool during welding and cause severe macrosegregation in the bottom of the resultant weld.

2. Two new mechanisms have been proposed for the formation of macrosegregation in arc welds made with dissimilar filler metals that are not mixed with the bulk weld pool completely before reaching the pool bottom. The mechanisms, Mechanisms 3 and 4, explain the formation of two distinctly different forms of severe macrosegregation near the weld bottom well within the fusion boundary.

3. Mechanism 3 is for filler metals that lower the liquidus temperature of the weld metal, that is, $T_{LW} < T_{LB}$. Here, $T_{LF} < T_{LF'} < T_{LW} < T_{LB}$. The partially mixed filler metal forms a filler-rich liquid near the pool bottom, which solidifies at $T_{LF'}$ into a filler-rich zone along the resultant weld. Since the solidification front near the pool bottom is at $T_{LF'}$ and since $T_{LF'}$ is well below T_{LB}, there exists ahead of the front a wide region between T_{LB} and $T_{LF'}$, that is, cooler than T_{LB}. Convection can thus easily carry the liquid base metal from the stagnant or laminar-flow layer into the cooler region and allow it to freeze quickly before complete mixing occurs. This can result in numerous islands of partially mixed base metal in a filler-rich zone along the weld near its bottom.

4. A filler-rich zone has been observed near the bottom of welds made by welding Ni with filler metals Cu (T_{LW} = 1321°C and T_{LB} = 1455°C) and Cu-30Ni (T_{LW} = 1342°C and T_{LB} = 1455°C), where $T_{LW} < T_{LB}$. Islands of partially mixed base metal in the form of streaks or swirls scattered near the weld bottom well within the fusion boundary. The dendritic structure was much finer in an island near the fusion boundary than in the bulk weld metal, suggesting quick freezing of the partially mixed liquid base metal in the cooler liquid region ahead of the solidification front near the weld pool bottom. These experimental results confirm Mechanism 3.

5. Mechanism 4 is for filler metals that raise the liquidus temperature of the weld metal, that is, $T_{LW} > T_{LB}$. Here, $T_{LF} > T_{LF'} > T_{LW} > T_{LB}$. The partially mixed filler metal forms a filler-rich liquid near the pool bottom, which freezes quickly in the region cooler than $T_{LF'}$ and results in a filler-rich zone along the weld near its bottom. The stagnant or laminar-flow layer of liquid base metal solidifies as a continuous filler-deficient beach between the filler-rich zone and the fusion boundary, with filler-rich intrusions penetrating into the beach.

6. A filler-rich zone has been observed near the bottom of a weld made by welding Cu with filler metal Ni (T_{LW} = 1366°C and T_{LB} = 1085°C) and a similar weld (T_{LW} = 1338°C and T_{LB} = 1085°C), where $T_{LW} > T_{LB}$. In the transverse macrograph the filler-rich zone appeared as a nugget near the weld bottom. A filler-deficient beach existed in between the filler-rich zone and the fusion boundary with intrusions from the filler-rich zone. The absence of a discernable dendritic or cellular structure in the filler-rich intrusion suggests very quick freezing of the partially mixed filler metal in the cooler layer of liquid base metal along the pool boundary. These experimental results confirm Mechanism 4.

7. Similar but less macrosegregation has been observed in the transverse macrograph of a weld made by welding Cu with filler metal Cu-30Ni (T_{LW} = 1168°C and T_{LB} = 1085°C), where $T_{LW} > T_{LB}$ again but with a much smaller difference. These results also confirm Mechanism 4.

8. The binary Ni-Cu system is useful for studying macrosegregation in welds made with dissimilar filler metals. Its simple isomorphous phase diagram extending over a wide liquidus-temperature range of 370°C allows dissimilar-filler welds to be made with T_{LW} differing from T_{LB} to various extents.

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Transferring Electron Beam Welding Parameters Using the Enhanced Modified Faraday Cup

An advanced diagnostic tool allowed a set of welding parameters to be quickly and easily transferred between EB welding machines at two widely separated locations

BY T. A. PALMER, J. W. ELMER, K. D. NICKLAS, AND T. MUSTALESKI

ABSTRACT. A procedure for transferring electron beam welding parameters between different machines using the Enhanced Modified Faraday Cup (EMFC) electron beam diagnostic tool is described. Unlike existing qualitative methods based on the transfer of machine settings, this procedure utilizes quantitative measurements of specific beam parameters, which can be correlated to the size and shape of the welds produced by the different welding machines. As a demonstration of this transfer procedure, a sharply focused 100-kV, 10-mA beam produced on one machine at a work distance of 457 mm is replicated on another machine with a defocused beam at a work distance of 210 mm. Measurements made with this diagnostic tool show that the peak power densities of the resulting beams vary by only 2%, while the beam distribution parameters, which are a measure of the beam width, vary by 4 to 7%. Using these well-characterized beams, autogenous welds with similar shapes and depths were then produced on 304L stainless steel samples. The measured depths of these welds vary by only approximately 8%, thus providing evidence for the utility of the use of this diagnostic tool in the transfer of beam parameters between different machines.

Introduction

The process for transferring a set of electron beam welding parameters from one machine to another can be broken down into three consecutive steps: weld development, weld transfer, and production. Each of these categories includes a number of independent operations performed on a dedicated development welding machine and one or more dedicated production welding machine(s). Significant redundancy is introduced into the development and transfer of these welding parameters by the cost and critical nature of the applications. As a result, a series of costly and time-consuming weld development cycles are typically required before the transfer of a set of welding parameters is complete.

A typical weld development study begins with the development of a set of welding parameters on a dedicated development welding machine. The essential electron beam weld parameters include weld power as a combination of beam voltage and current, travel speed, working distance, vacuum level, focus coil current setting, and any unique beam oscillation requirements. The weld parameters are initially chosen based on operator experience and are further refined through a series of parametric weld studies using subsize mock parts, which allow the effects of the weld joint geometry on the weld shape and size to be determined. The selection of acceptable welding parameters is also complicated by the even larger number of possible permutations available for achieving a given weld size and shape. After choosing the most suitable set of welding parameters, a full-size mock part is then welded in order to provide a final test of the acceptability of these parameters.

Once a set of acceptable welding parameters is chosen, the entire process is repeated on the production welding machine. This repetition is necessary in order to take into account any differences in the design of the electron guns in the two machines, the size of the vacuum chambers that affects the placement of the part in each chamber, the capabilities of different welding machines, and general differences in the performance of the welding machines dictated by age and maintenance history. As a result, welding parameters developed on one machine do not easily replicate the weld size and shape produced by the other, making this process more consistent with two distinct weld development operations. This complicated and time-consuming procedure for determining and transferring acceptable weld parameters is in need of replacement by a more quantitative method.

One of the primary areas in need of better quantitative understanding is the measurement and characterization of the electron beam. In recent years, several major advancements have been made in the development of diagnostic tools for characterizing electron beams (Refs. 1–7). These beam probing techniques are primarily based on modifications to a traditional Faraday Cup and utilize direct measurements of the electron beam current to obtain a profile of the beam energy distribution as the beam passes over an edge, slit, or pinhole (Ref. 8). The resulting signal obtained as the beam passes over the edge or slit can provide information about the beam shape and size along with the power density.

Using the data obtained with a given diagnostic system, estimations of the sharp focus setting, the beam diameter, the general beam profile, and the power density distribution can be made, assuming that the machine has been properly calibrated. However, since these rudimentary beam probing systems take only a single profile of the beam, it must be assumed that the beam is radially symmetrical and has a circular cross section for the results to be generally useful. While this assumption may be valid for idealized Gaussian-

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shaped beams, electron beams typically take on elliptical and noncircular shapes or power density distributions, especially when out of focus. Previous research (Ref. 9) has also shown that sharply focused beams can take on non-Gaussian characteristics in different welding machines. Therefore, a means for efficiently producing a complete profile of the beam size, shape, and power density distribution is needed.

An advanced diagnostic tool, which utilizes a variation of the slit detection system, has been developed at Lawrence Livermore National Laboratory (LLNL) to provide quantitative information on the properties of electron beams used in welding (Refs. 4–7). The Enhanced Modified Faraday Cup (EMFC) system collects the beam through a series of radial slits as the beam is oscillated in the shape of a circle over a tungsten disk. Once the radial slit data are collected, computer tomography algorithms are used to reconstruct the power density distribution of the beam. Based on this reconstruction, several important beam parameters, including measures of the peak power density and beam width, are determined.

Given the unique capabilities of this tool, it is envisioned that the EMFC diagnostic tool can be incorporated into the development, transfer, and production aspects of an improved weld transfer procedure. This improved procedure is based on a thorough characterization of the welding machines used in development and production. The steps inherent in characterizing and comparing the performance of different welding machines using this diagnostic tool have been discussed previously (Ref. 9). With this improved understanding of machine performance, the reliance on qualitative measures for choosing welding parameters will decrease as a database of beam characteristics produced by each machine and the resulting weld properties are compiled. As a result, many of the redundant steps described previously can be removed, and a more streamlined process will result.

In this study, the EMFC diagnostic tool is used to characterize the beams produced by welding machines located at the Lawrence Livermore National Laboratory (LLNL) and the BWXT Y-12 National Security Complex (Y-12) over a range of focus settings at different work distances. The effects of these changes on the beams produced by each machine are analyzed, and the characteristics of each welding machine are then compared at the same machine settings. By taking advantage of the knowledge gained through these characterization efforts, beams with similar peak power density and beam width values are produced at widely separated work distances on the two welding machines.

These work distances are based on the typical locations where welds are made in each welding machine. Previous work has emphasized the effect of changing work distance to produce sharply focused beams with similar properties on different welding machines (Ref. 9). This study, though, focuses on the use of changes in the focus settings on one machine to produce a beam equivalent to a sharply focused beam on another. Welds with a similar size and shape are then produced, showing that a significantly streamlined and modernized weld transfer procedure can be utilized with the integration of this advanced EB diagnostic tool.

Experimental

Electron Beam Diagnostic Tool

A photograph of the EMFC device is shown in Fig. 1A. This device has a number of unique features, which are described in more detail elsewhere (Refs. 4–7, 9). During operation, the beam enters the top of the device through a tungsten slit disk containing 17 radial linear slits. Figure 1B shows the interaction between the beam and the radial slits as the beam is deflected in a circular path over the tungsten slit disk. When the beam is deflected along a circular path approximately 25.4 mm in diameter, it passes over each slit, and a portion of the beam current is captured. The signal is then converted into a voltage drop across a known resistor and captured by a fast sampling analog-to-digital (A/D) converter before being transferred to the data acquisition software.

As the beam passes through each slit, it is sampled at a different angle, providing 17 different profiles of the beam shape after each revolution of the beam around the tungsten slit disk. These waveforms are then compiled into a single sinogram. An example of a typical sinogram, containing 17 waveforms, is shown in Fig. 2A. If necessary, a digital filtering routine is applied to the data to remove any electronic noise that may appear. The data are then fed into a computer-assisted tomographic (CT) imaging algorithm in order to reconstruct the power density distribution of the beam (Refs. 7, 10) — Fig. 2B.

Once reconstructed, the peak power density of the electron beam and two distribution parameters are then measured. Figure 2C provides an illustration of how these parameters are determined. The first distribution parameter is the full width of the beam at one-half its peak power density (FWHM). This parameter represents the width at 50% of the beam peak power density. The second parameter is the full width of the beam measured at $1/e^2$ of its peak power density (FWe2). This parameter represents the width of the beam at 86.5% of the beam peak power density. For simplicity, this measurement is considered to be a suitable representation of the beam diameter. Since the cross section of the measured beam is not always circular, the area of the beam at each of these two points in the reconstructed power density distribution curve is measured, and the diameter of a circle having the same area is used to represent both values. These approximations are good for most beams with generally circular cross-sectional shapes, such as the Gaussian-like distributions typically found near the sharp focus setting.

Electron Beam Welding Machines and Integration of Diagnostics

The general characteristics of the LLNL and Y-12 welding machines used in this study are listed in Table 1. Each welding machine is capable of an accelerating

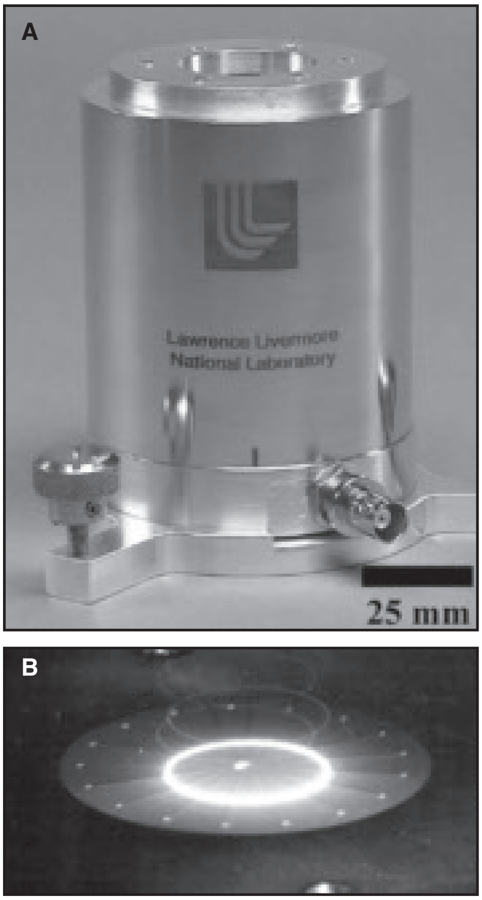
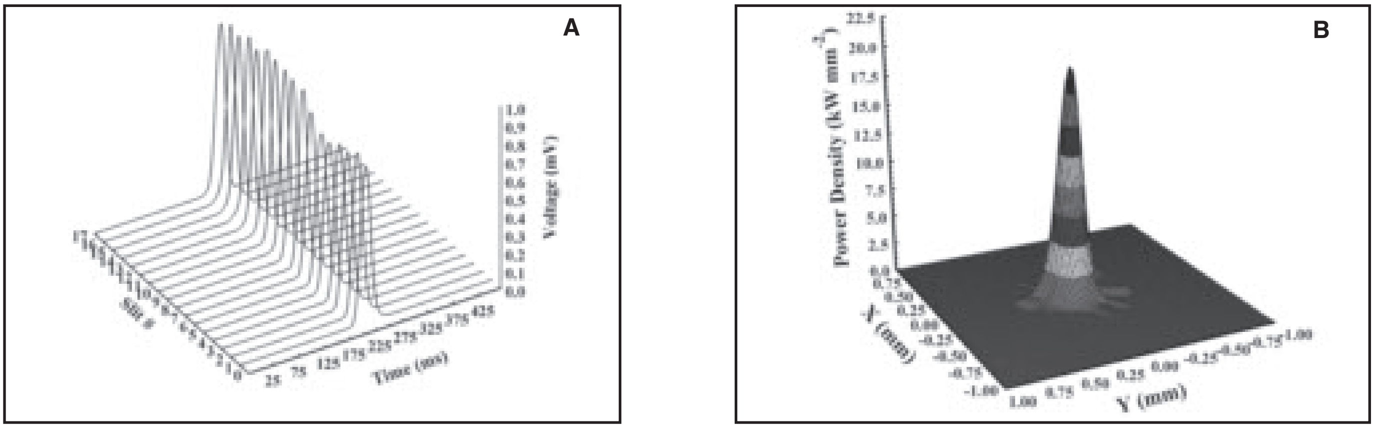


Fig. 1 — A — The Enhanced Modified Faraday Cup; B — an electron beam being deflected in a circular pattern over the radial slits in the tungsten slit disk located on the top of the EMFC.



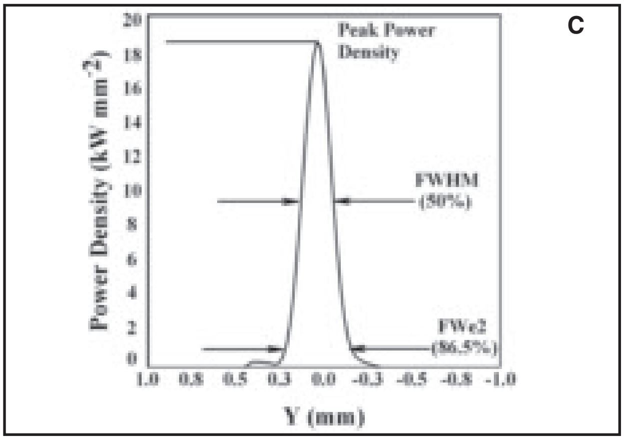


Fig. 2 — Basic overview of operation of the EMFC system beginning with (A) a computed sinogram compiling the profiles seen by all 17 slits; B — a 3D tomographic reconstruction of the power density distribution of the beam; and C — a slice through the center of the reconstructed beam with the peak power density, FWHM, and FWe2 measurements indicated.

voltage of 150 kV and a beam current of 50 mA. However, because of the 20-year difference in the age of the two welding machines, there are differences in the construction of the upper column and electron gun assembly. The two machines also have vacuum chambers that are significantly different in size, with the chamber on the Y-12 welding machine being much larger. As a comparison, the height of the chamber on the Y-12 welding machine is approximately 1070 mm, while that for the LLNL machine is approximately 750 mm. Such a difference in the chamber height can have a direct effect on the size of fixturing used to hold the workpiece and the work distances used during welding. In this case, the work distance typically used in the LLNL welding machine (210 mm) is much smaller than that used for the Y-12 welding machine (457 mm).

The EMFC diagnostic tool was then used to examine the effects of changes in the focus setting on the properties of a 100-kV, 10-mA beam produced by both the LLNL and Y-12 welding machines at a number of work distances. Only a single accelerating voltage and beam current at a vacuum level of 5×10^{-5} Torr are chosen in order to minimize the number of weld parameters being altered and to concentrate on the effects of changes in focus setting and work distance. Gauges measuring the accelerating voltage, beam current, and focus coil current are all within the limits of their respective annual calibrations. Beam currents are verified by using the EMFC as a traditional Faraday Cup (Ref. 10). The focus response for each welding machine is characterized by measuring the beam properties at focus settings both above and below the operator-determined sharp focus setting. Each set of data presented here has been filtered using a high-frequency electronic cut-off filter to remove unwanted electronic noise. Changes in peak power density, FWHM, and FWe2 values are then measured and tracked with changes in the focus settings.

Without diagnostics, the sharp focus setting for a given set of weld parameters is typically determined by the operator directing the beam onto a high melting point target material, such as tungsten, and adjusting the focus coil current setting. As the beam comes in contact with the target, light is emitted. The intensity of this light varies with changes in the focus coil current setting. When the emitted light reaches a maximum intensity, the beam is considered to be at sharp focus (Ref. 11). Different operators may interpret the brightest emission from the target material differently, resulting in different definitions of "sharp focus" for the same settings on the same machine. These differences can become more pronounced when the definition of "sharp focus" involves multiple machines and operators.

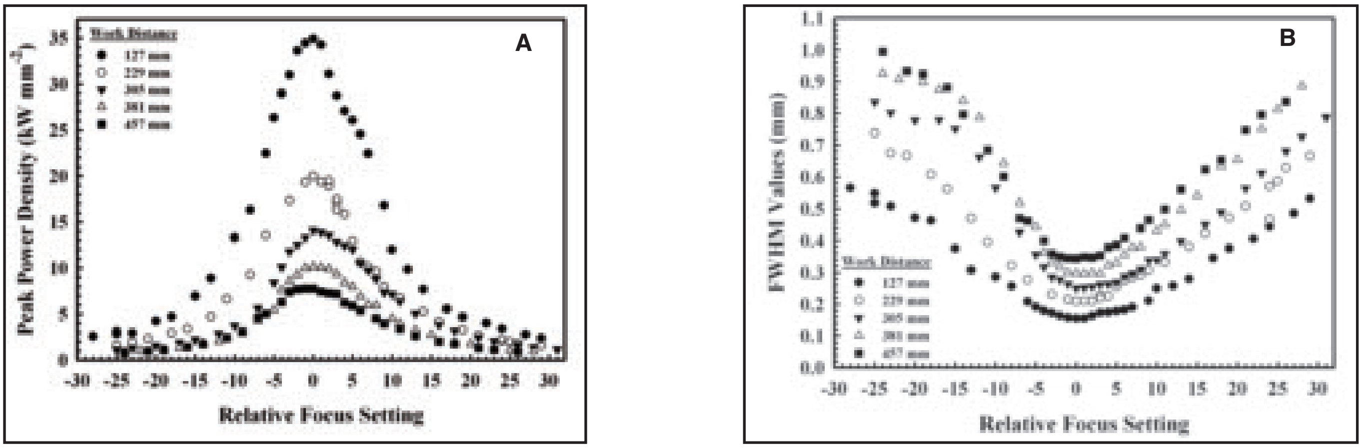
With the aid of the EMFC diagnostic tool, the "sharp focus" setting can be defined in a more quantitative fashion (Ref. 9). This setting corresponds to the focus coil current setting at which the highest peak power density value for a given set of machine settings is obtained. Because the focus coil current settings vary between welding machines, it is necessary to define a relative focus setting so that the same relative focus condition can be achieved on different welding machines. The focus coil current at the sharp focus setting is used as the reference value and is set to a value of zero. Focus coil current settings above this value are given a positive value, while those below are given a negative value, as shown in the following relationship:

Relative Focus Setting = Focus Coil Current – Sharp Focus Coil Current (1)

Table 1 — Characteristics of Electron Beam Welding Machines Used in This Study

	Welding Machine #1	Welding Machine #2
Location	Lawrence Livermore National Laboratory	BWXT Y-12 Plant
Manufacturer	Hamilton Standard	Leybold Herareus
Serial number	175	649
Voltage (kV)	150	150
Current (mA)	50	50
Filament Type	Ribbon*	Ribbon
Electron Gun Type	R167-R	R167-R
Size of Chamber (m^3)	0.393	1.54
Year of Manufacture	1964	1984

* Ribbon filament upgrade made to machine circa 1990.



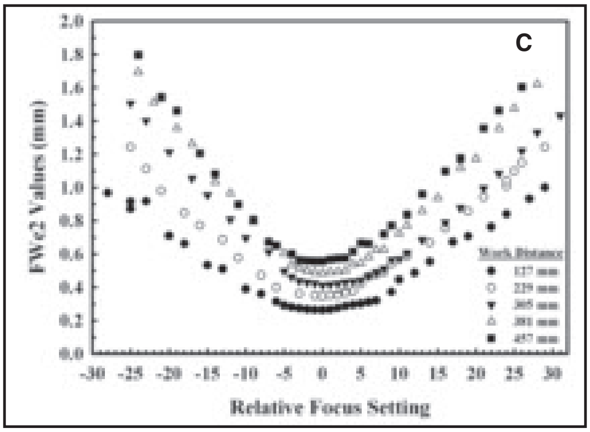


Fig. 3 — Plots comparing the following measured values: A — Peak power density, B — FWHM „ and C — FWe2 with changes in the focus setting for 100-kV, 10-mA beams at different work distances on the LLNL welding machine.

where the focus coil current (mA) is the value for each focus setting and the sharp focus coil current (mA) represents the focus coil current at which the highest peak power density is obtained. The machine focus setting corresponds to the amount of defocus above (positive) or below (negative) the point of sharpest focus. A more in-depth description of the utility of this methodology for defining sharp focus is provided elsewhere (Ref. 9).

Using the EMFC diagnostic tool, the effects of changes in the focus settings at a number of work distances are monitored on each welding machine. Here, the work distance is defined as the distance from the top of the chamber to the top of the tungsten slit disk on the EMFC diagnostic tool. The minimum work distance in this study is limited by the ability of the deflection coils to produce a 25.4-mm-diameter circle. In both welding machines, this minimum work distance is 127 mm. The maximum work distance in each welding machine is limited by the size of the chamber and the positioning systems within the chamber. These work distances correspond to 457 mm on the LLNL welding machine and 508 mm on the Y-12 welding machine. The changes in focus settings at each work distance are varied between values of approximately 25 units above and 25 units below the sharp focus settings.

Particular attention is paid to the work distances at which welds are typically made in each machine. For the LLNL welding machine, a work distance of 210 mm is common, while a work distance of 457 mm is used in the Y-12 welding machine. At these work distances, the effects of positive changes in focus on the peak power density and width of beams produced by both machines are analyzed. Based on these results, the feasibility of producing beams with similar peak power density and beam distribution parameters, as measured by the EMFC diagnostic tool, is determined. In order to produce these similar beam characteristics, a defocused beam is required on the LLNL welding machine in order to match the sharply focused beam produced by the Y-12 welding machine.

As a final step, autogenous welds are made on 9.5-mm-thick 304L samples using nominally equivalent beams on each machine at each work distance using an accelerating voltage of 100 kV and a beam current of 10 mA at a travel speed of 17 mm/s. The weld coupons are fabricated from material taken from a single heat, and the

Table 2 — Chemical Composition of 304L Stainless Steel Samples Used in This Study (All values are in wt-%.)

Fe	Cr	Ni	Mn	Mo	C	N	Si	Co	Cu	S	P
Bal.	18.20	8.16	1.71	0.47	0.020	0.082	0.44	0.14	0.35	0.0004	0.03

Table 3 — Summary of Beam Parameters Made at the Sharp Focus Setting Measured at Each Work Distance on the LLNL and Y-12 Welding Machines for a 100-kV, 10-mA Beam

	Work Distances						
	127 mm	184 mm	229 mm	305 mm	381 mm	457 mm	508 mm
LLNL Welding Machine							
Peak Power Density (kW/mm^2)	34.9	21.6	20.0	14.1	10.2	7.79	—
FWHM (mm)	0.155	0.204	0.210	0.251	0.298	0.344	—
FWe2 (mm)	0.262	0.332	0.346	0.413	0.486	0.557	—
Y-12 Development Welding Machine							
Peak Power Density (kW/mm^2)	50.3	—	27.5	19.4	14.9	11.6	10.2
FWHM (mm)	0.131	—	0.178	0.212	0.240	0.278	0.294
FWe2 (mm)	0.221	—	0.299	0.357	0.408	0.462	0.493

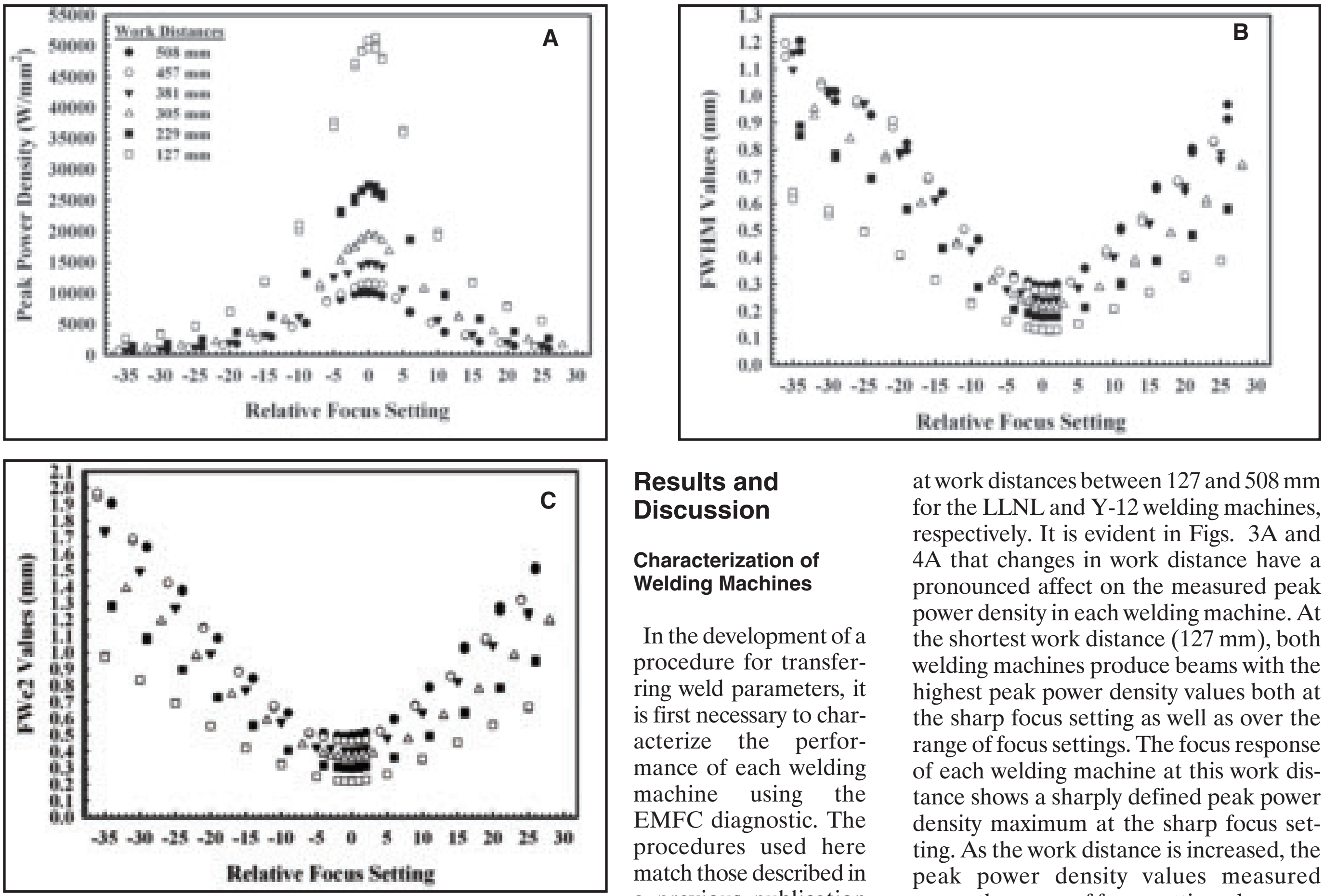


Fig. 4 — Plots comparing the following measured values: A — Peak power density, B — FWHM, and C — FWe2 with changes in the focus setting for 100-kV, 10-mA beams at different work distances on the Y-12 welding machine.

chemical composition is given in Table 2. After welding, a single sample is removed from each weld at a point approximately halfway between the beginning and end of the weld interface. The sample is then mounted in cross section and metallographically prepared and etched using an electrolytic oxalic acid solution to expose the fusion zone. Measurements of the depth, width at the top surface, and melted area are made on each cross section, and the results obtained from the different welding machines are compared. These measurements are made on electronic images of each weld cross section using a commercially available image analysis software package, Image Pro Plus, Version 4.1 from Media Cybernetics, Inc., Silver Spring, Md.

Table 4 — Summary of Linear Regression Coefficients in the Relationships between Beam Distribution Parameters and Work Distance for Both Welding Machines

$$\mathrm{FWHM} = y_0 + m\,(\mathrm{WD})$$

	FWHM		FWe2	
	y_0	m	y_0	m
LLNL Welding Machine	8.97×10^{-2}	5.49×10^{-4}	7.84×10^{-2}	4.30×10^{-4}
Y-12 Welding Machine	7.16×10^{-2}	7.66×10^{-4}	1.34×10^{-1}	7.15×10^{-4}

Results and Discussion

Characterization of Welding Machines

In the development of a procedure for transferring weld parameters, it is first necessary to characterize the performance of each welding machine using the EMFC diagnostic. The procedures used here match those described in a previous publication (Ref. 9). In each welding machine, the effects of changes in focus setting and work distance on the peak power density, FWHM, and FWe2 values of each beam are examined. At each work distance, the machine focus settings are varied between values approximately 25 units above (positive defocus setting) and 25 units below (negative defocus setting) the sharp focus setting. This range of focus settings provides a nearly complete picture of the focus response of each welding machine at a given work distance, accelerating voltage, and beam current. Further changes in the focus settings follow the same trends as the beams continue increasing in width, while the peak power density slowly approaches a minimum value.

Figures 3A–C and 4A–C show the effects of these changes in focus on the peak power density, FWHM, and FWe2 values at work distances between 127 and 508 mm for the LLNL and Y-12 welding machines, respectively. It is evident in Figs. 3A and 4A that changes in work distance have a pronounced affect on the measured peak power density in each welding machine. At the shortest work distance (127 mm), both welding machines produce beams with the highest peak power density values both at the sharp focus setting as well as over the range of focus settings. The focus response of each welding machine at this work distance shows a sharply defined peak power density maximum at the sharp focus setting. As the work distance is increased, the peak power density values measured across the range of focus settings decrease. These changes in work distance also alter the general shape of the curves, with the changes in focus setting having a less pronounced affect on the peak power density, especially at settings near the sharp focus. The resulting curves, therefore, take on a much flatter appearance.

Changes in work distance and focus setting also have an affect on the resulting FWHM and FWe2 values, as shown in Fig. 3B, C for the LLNL welding machine and Fig. 4B, C for the Y-12 welding machine. At the shortest work distance (127 mm), the narrowest FWHM and FWe2 values are observed across the range of focus settings for each welding machine. There are also several differences between the trends observed in these distribution parameters with changes in focus setting and those observed with the peak power density measurements. For example, there is not a well-defined peak in the FWHM and FWe2 values at the sharp focus setting. At each work distance, changes in the focus setting near the sharp focus setting have a rather small affect on the resulting FWHM and FWe2 values. A minimum of five or more focus setting increments in either the positive or negative direction is required in order to produce a substantial change in these values for any work distance.

These changes in the peak power den-

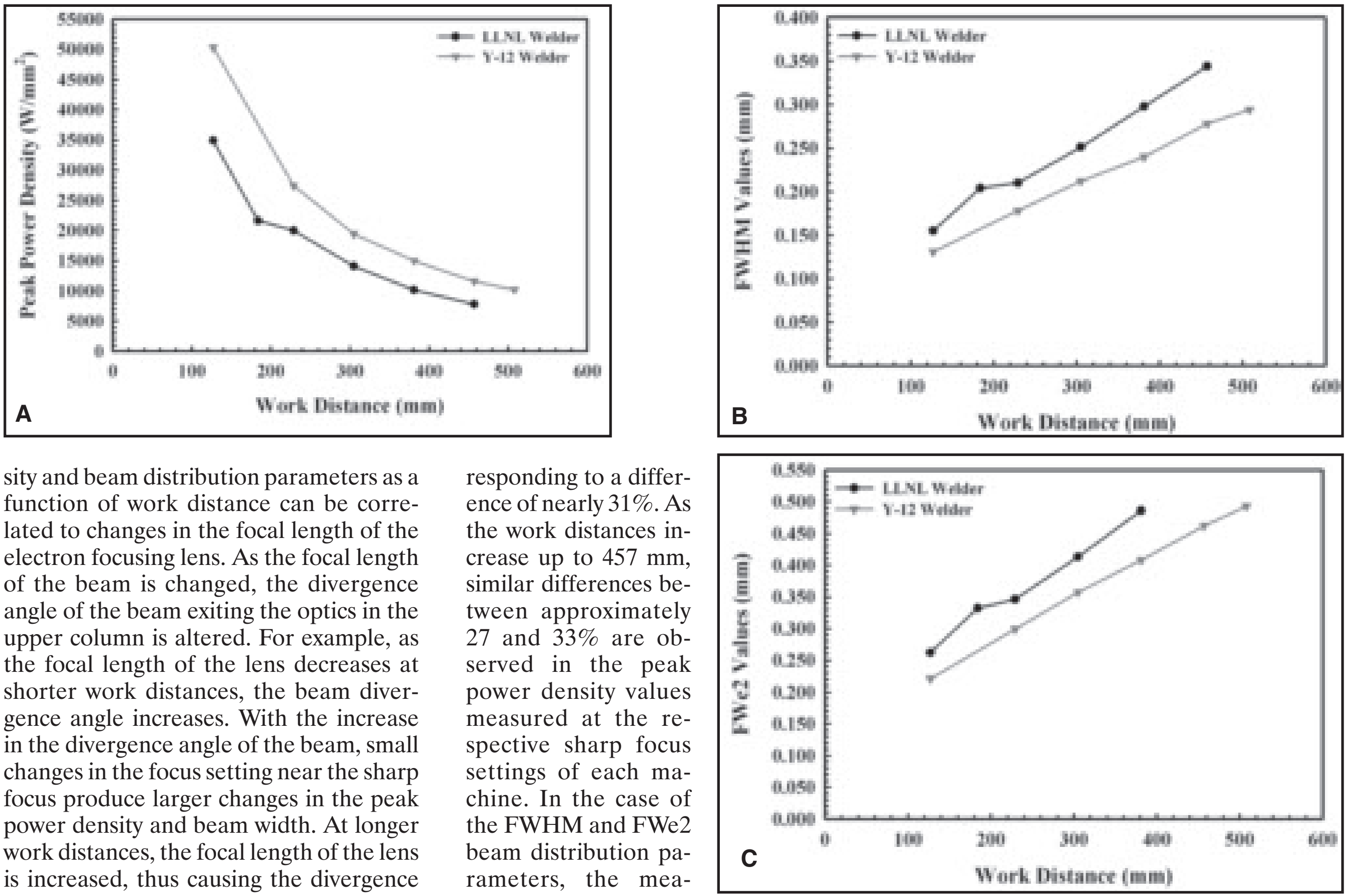


Fig. 5 — Plots showing the comparisons between the measured values of the following: A — Peak power density, B — FWHM, and C — FWe2 measured at the sharp focus settings over the range of work distances for both the LLNL and Y-12 welding machines.

sity and beam distribution parameters as a function of work distance can be correlated to changes in the focal length of the electron focusing lens. As the focal length of the beam is changed, the divergence angle of the beam exiting the optics in the upper column is altered. For example, as the focal length of the lens decreases at shorter work distances, the beam divergence angle increases. With the increase in the divergence angle of the beam, small changes in the focus setting near the sharp focus produce larger changes in the peak power density and beam width. At longer work distances, the focal length of the lens is increased, thus causing the divergence angle to decrease. With this decreased divergence angle, small changes in the focus setting near sharp focus produce only small changes in the peak power density and beam width.

The effects of changes in work distance on the beam properties at the sharp focus setting are of greater interest in providing a quantitative characterization of individual welding machine performance. A summary of the characteristics of sharply focused beams produced at each work distance on both machines is given in Table 3. As shown in this table, changes in the work distance have a marked effect on the resulting beam parameters of the sharply focused beams, with the shorter work distances displaying significantly higher peak power density values and narrower beam distribution parameters.

It is also apparent that beams produced at the same work distance on the two welding machines display different peak power density and beam width values. In general, the sharp focus beams produced by the Y-12 welding machine display a higher peak power density and narrower FWHM and FWe2 values than the LLNL welding machine over the range of work distances studied here. For example, at a work distance of 127 mm, the measured peak power density values for the LLNL and Y-12 welding machines are 34.9 and 50.3 kW/mm^2, respectively, corresponding to a difference of nearly 31%. As the work distances increase up to 457 mm, similar differences between approximately 27 and 33% are observed in the peak power density values measured at the respective sharp focus settings of each machine. In the case of the FWHM and FWe2 beam distribution parameters, the measured values for the beams produced by the LLNL welding machine at the sharp focus setting are typically between 15 and 19% higher than those measured on the Y-12 welding machine over the range of work distances.

Direct comparisons between the peak power density, FWHM, and FWe2 values measured on each welding machine at the sharp focus setting at each work distance are plotted in Fig. 5A–C. Even though the measured values differ, both welding machines show similar trends in how these beam parameters change with work distance. For example, both the FWHM and FWe2 values measured at the sharp focus settings over a range of work distances in the LLNL welding machine decrease linearly with decreasing work distance, as shown in Fig. 5B, C. On the other hand, the peak power density trends for the two welding display machines similar nonlinear behavior.

These results obtained using the EMFC device can also be used to determine unique characteristics of each welding machine (Ref. 9). The FWHM-Work Distance relationships for both machines are plotted in Fig. 6A, while the FWe2-Work Distance relationships are plotted in Fig. 6B. The coefficients corresponding to the linear regressions for the LLNL and Y-12 welding machines, respectively, are summarized in Table 4. In the relationship shown in this table (FWHM = y_0 + m*WD), WD represents the work distance measured from the top inside of the vacuum chamber to the top of the diagnostic. The slopes (m) of the FWHM relationships vary by a factor of approximately 1.4, with the Y-12 welding machine displaying the higher values. With these two relationships, the work distances on the two machines can be adjusted to produce beams with the same FWHM and FWe2 values, thus allowing the work distance to be used as a variable to produce similar welds on different welding machines.

A comparison between the peak power density measurements of the beams produced by each welding machine at the sharp focus setting and the various work distances is shown in Fig. 7. Overlaid on these experimental measurements are curves of the predicted peak power density, based on the FWHM relationships as a function of work distance, as defined in Table 4. The following relationship for the peak power density (PPD) of the beam is

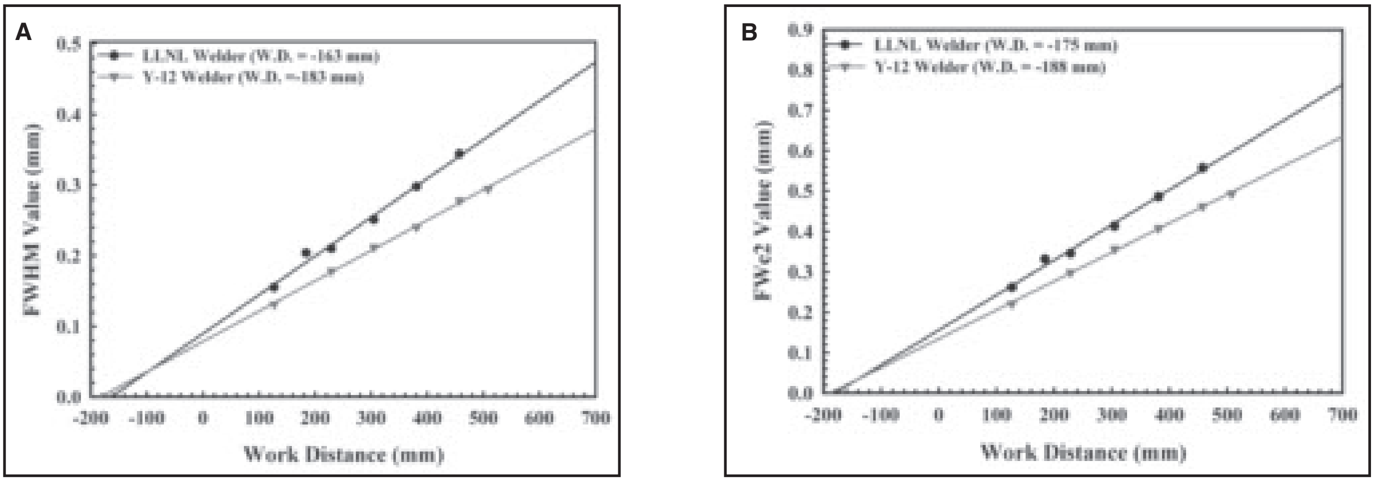


Fig. 6 — Comparisons between the following measured values A — FWHM; and B — FWe2 measured at sharp focus settings for both welding machines as a function of work distance for 100-kV, 10-mA beams.

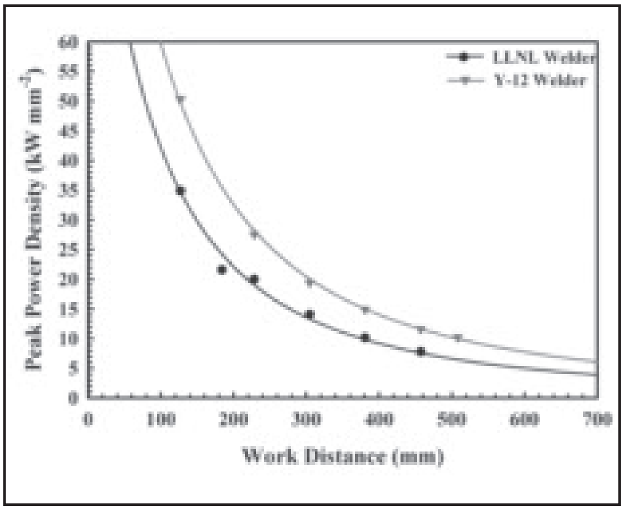


Fig. 7 — Comparison between peak power density values measured on both welding machines at their respective sharp focus settings as a function of work distance for 100-kV, 10-mA beams. The theoretical peak power density for each welding machine is also plotted as a function of the work distance.

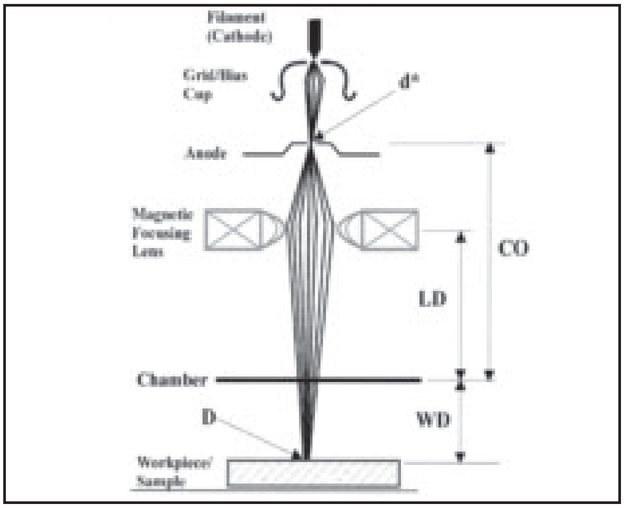
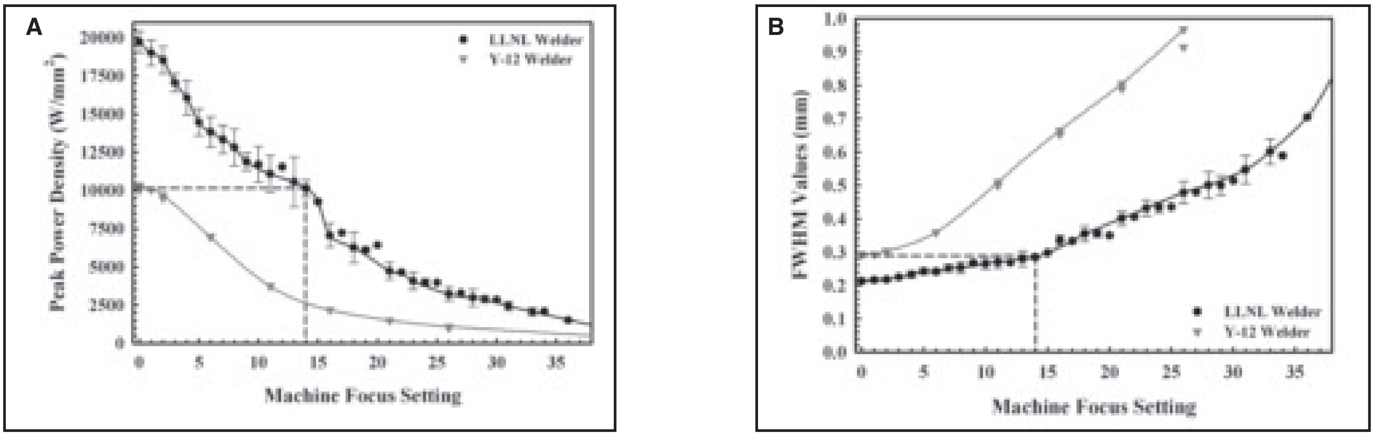


Fig. 8 — Schematic drawing showing the major components found in the upper column of an electron beam welding machine. The location of the focus coils and the beam crossover location are also highlighted.

Table 5 — Overview of Beam Crossover Locations in the Two EB Welding Machines

Work Distance (mm)	Lens Distance (mm)	Lens to Workpiece Distance (mm)	Crossover Distance* (mm)	Lens to Crossover Distance (mm)	Magnification	Crossover to Workpiece Distance (mm)	Peak Power Density (kWmm^{-2})	FWHM (mm)	d*(mm)
LLNL Welding Machine									
127	115	242	163	48	5.04	290	34.9	0.155	0.031
184	115	299	163	48	6.23	347	21.6	0.204	0.033
229	115	344	163	48	7.17	392	20.0	0.210	0.029
305	115	420	163	48	8.75	468	14.1	0.251	0.029
381	115	496	163	48	10.33	544	10.2	0.298	0.029
457	115	572	163	48	11.92	620	7.79	0.344	0.029
Y-12 Welding Machine									
127	130	257	183	53	4.85	310	50.3	0.131	0.027
229	130	359	183	53	6.77	412	27.5	0.178	0.026
305	130	435	183	53	8.21	488	19.4	0.212	0.026
381	130	511	183	53	9.64	564	14.9	0.240	0.025
457	130	587	183	53	11.08	640	11.6	0.278	0.025
508	130	638	183	53	12.04	691	10.2	0.294	0.024

* Calculated based on FWHM measurements.



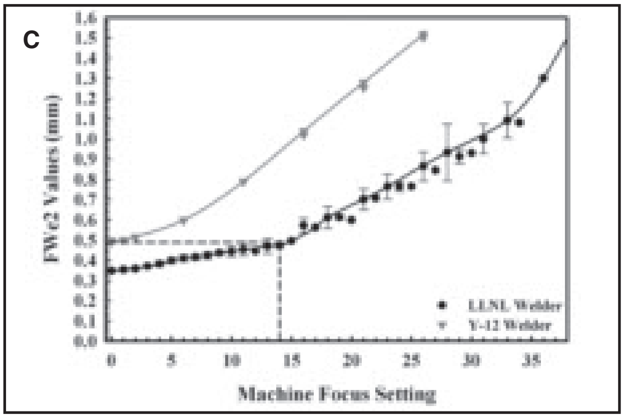


Fig. 9 — Plots comparing the following measured values: A — Peak power density; B — FWHM; and C — FWe2 measured in the LLNL and Y-12 welding machines for 100-kV, 10-mA beams at work distances of 210 and 457 mm, respectively. Results from the LLNL welding machine are representative of multiple measurements made at each focus setting. Error bars represent the standard deviation of the results around an average value. The dashed lines show the amount of defocus required on the LLNL machine in order to match parameters on the Y-12 machine.

then used to fit the experimental data (Ref. 10).

$$PPD\left(W/mm^2\right) = \frac{kV * mA}{2\pi\left(\frac{FWHM}{2.35}\right)^2} \qquad (2)$$

where kV is the beam voltage and mA is the beam current. This relationship is based on the assumption that each welding machine produces a Gaussian-shaped beam at each work distance. The factor of 2.35 originates from the relationship between the FWHM value for an ideal Gaussian beam and its standard deviation (Ref. 11).

Using this relationship, the work distance corresponding to a desired peak power density at the sharp focus can be predicted for each welding machine. The plot shows that equivalent peak power density values at different work distances for two or more welding machines can also be predicted. This plot also points out the differences in the performance of the two welding machines, indicating that at a given work distance, the two machines produce sharply focused beams with different peak power densities. Overall, though, beams produced by different machines can be matched by changes in either the work distance or focus settings.

Estimation of the Beam Crossover Location

The work distance, as defined up to this point, is the distance from the top of the chamber to the surface of the workpiece. This definition of the work distance provides a means for consistently placing the workpiece at the same location in the chamber of each welding machine. However, this measurement is really only applicable on the welding machine on which it is made and cannot be transferred to a different welding machine that may have a different construction of the upper column. The effects of variations in the construction of the two welding machines studied here can be at least partly responsible for differences in the measured peak power density and beam distribution parameters at the sharp focus condition for each work distance.

Given the differences in the age, maintenance records, and construction of the upper columns of the two welding machines, it becomes difficult to attribute differences in performance to specific characteristics of each machine. In order to compare the performance differences of these two electron beam welding machines more easily, a simplified upper column construction is used here. Using this simplified design as a baseline, general performance characteristics of the two welding machines can then be compared. A schematic diagram of this simplified upper column is shown in Fig. 8. For this discussion, only the location of the magnetic focusing lens, where the beam is at its widest, and the beam crossover location, where the size of the beam is at its narrowest (d*), are considered in order to simplify the analysis. Of these two, the location of the magnetic focusing lens in the upper column can be physically measured, while the beam crossover location and d* value are determined using results obtained by the EMFC diagnostic.

Physical measurements made in the upper column of each welding machine show that the focus lens in the LLNL machine is located approximately 115 mm above the top of the vacuum chamber, while the focus lens in the Y-12 machine is located approximately 130 mm above the top of the chamber. These measurements represent only general locations for the focus coil and do not discriminate between the top, center, or bottom of the focus lens. The performance of the electron focus lens can also vary due to differences in construction or degradation over time. Such unique internal characteristics are difficult to quantify when comparing different welding machines and may affect the beam properties in unknown ways even under the same experimental conditions. Since the location of these coils and their performance varies between welding machines, they are not suitable for defining a standard work distance to be used between machines. Therefore, it becomes necessary to develop a means for taking into account other more difficult to quantify differences in machine performance.

The beam crossover location depends, in part, on the gun design and can be correlated with the location of the anode. However, the electron guns used on the two systems are different, with the anodes in the upper columns mounted at different distances from the cathode in the electron gun (Ref. 12), and physical measurements of the anode are difficult. The the-

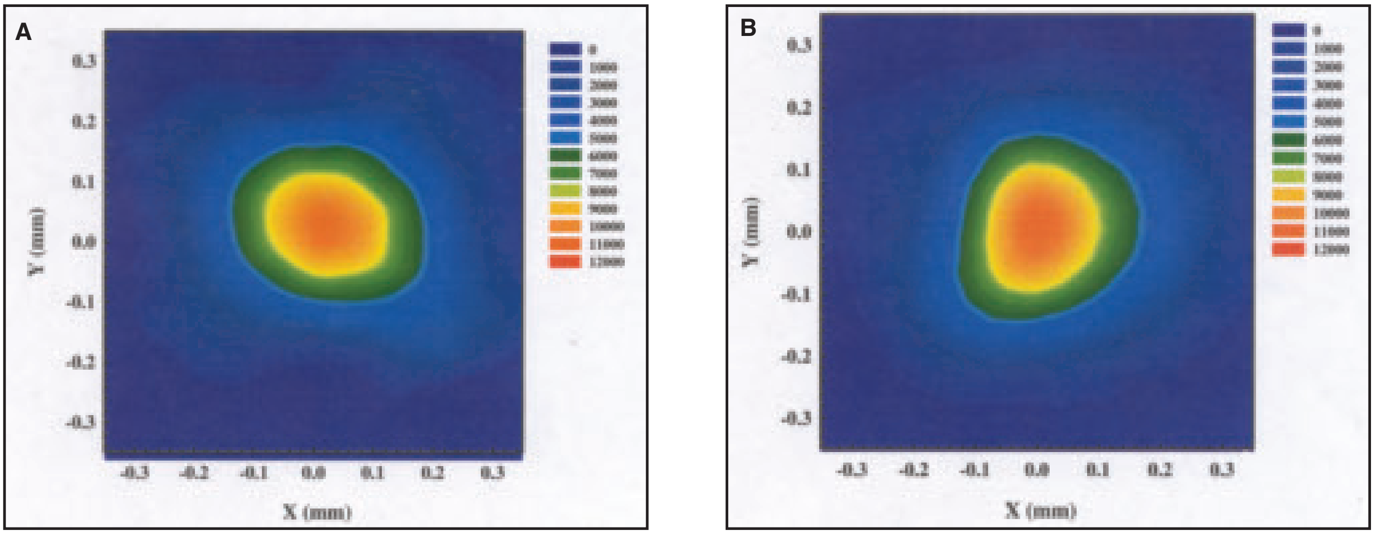


Fig. 10 — Plots showing the reconstructed beams made at a constant voltage of 100 kV and current of 10 mA on the following: A — The LLNL welding machine at a defocus setting of +11 and a work distance of 210 mm (PPD = 11.9 kW/mm²); and B — the Y-12 welding machine at the sharp focus setting and a work distance of 457 mm (PPD = 11.6 kW/mm²).

oretical beam crossover location can be estimated using the results obtained with the EMFC on sharply focused beams at different work distances. It corresponds to the work distance where the electron gun would theoretically produce a sharply focused beam with a FWHM or FWe2 of zero. In Fig. 6A, B, the linear regressions of the measured beam distribution parameters are extended to FWHM and FWe2 values of zero. The two distribution parameters produce slightly different results for both machines. With the FWHM values, the beam crossover location is approximately 163 mm above the top of the chamber for LLNL welding machine and 183 mm above the top of the chamber for the Y-12 welding machine. Measurements of the FWe2 values provide beam crossover locations of approximately 175 and 188 mm above the top of the chambers on the LLNL and Y-12 welding machines, respectively. Unlike physical measurements of the focus lens location, the estimation of this crossover point takes into account the performance of the welding machine and gives some meaning to difficult-to-define variables.

The fundamentals of electron beam optics are analogous to those of traditional optics (Refs. 13, 14), thus allowing the analysis of machine performance to be estimated using traditional geometric optics relationships. As shown in the schematic diagram of the upper column in Fig. 8, there are several important measurements that define the performance of the electron optics on each machine. Starting at the surface of the workpiece and proceeding up to the top of the vacuum chamber, there are three important measurements: the work distance (WD), the lens distance (LD), and the crossover distance (CO). These measurements define the distances between the surface of the workpiece and the top of the vacuum chamber (WD), the magnetic focusing lens and the top of the vacuum chamber (LD), and between the beam crossover point and the top of the vacuum chamber (CO), respectively. In addition, the diameter of the electron beam at the crossover point (d*) is required to determine the diameter of the beam at the surface of the workpiece (D).

Measurements of these distances have been made on each machine and are listed in Table 5. Whereas LD and WD are physical measurements, the CO measurement is determined from measurements of the FWHM values of sharply focused beams at each work distance made using the EMFC diagnostic tool. In practice, the WD measurement is the only one that can be varied by the operator. With these measurements, it becomes possible to use the results obtained with the EMFC to better understand the characteristics of each welding machine. The calculation of the lens magnification, which is described in the relationship shown below, is one means for characterizing the performance of both machines.

$$M = \frac{D}{d^*} = \left(\frac{WD + LD}{CO - LD}\right) \tag{3}$$

This relationship is based on standard optics equations available in standard references (Ref. 15). Equation 3 states that the magnification is the ratio of the beam diameter at the surface of the workpiece (D) to the beam diameter at crossover (d*) in the upper column, which is a function of the machine settings, construction of the upper column, and cathode design. As shown in Table 5, the calculated magnifications for the LLNL welding machine are approximately 4 to 7% higher than those for the Y-12 welding machine.

Such differences in magnification can be the result of variations in the d* values in each machine. These d* values can be determined using the physical and diagnostic measurements described in the sections above. Using the data in Table 5, the d* values at each work distance are calculated using Equation 3 and the magnification and FWHM values, which are consid-

Table 6 — Summary of Beam Parameters and Weld Dimensions Produced by the LLNL Welding Machine and the Y-12 Welding Machine in the Transfer of Beam Parameters for a 1-kW (100-kV, 10-mA) Beam at Work Distances of 210 and 457 mm, Respectively (All welds were made at a travel speed of 17 mm/s.)

	LLNL Welding Machine (S/N 175)		Y-12 Welding Machine
	Sharp	+11 Defocus	Sharp
Peak Power Density (kW/mm²)	19.9	11.0	11.6
FWHM (mm)	0.212	0.259	0.278
FWe2 (mm)	0.346	0.444	0.461
Weld Depth (mm)	4.08	2.89	2.64
Weld Width at Top Surface (mm)	1.34	1.93	1.46
Weld Width at Half Depth (mm)	0.62	0.67	0.60
Aspect Ratio	3.04	1.50	1.80
Cross-sectional Area (mm²)	2.51	2.64	2.16

ered to be the beam width (D). As shown in Table 5, each welding machine displays a different d* value over the range of work distances, with the LLNL welding machine displaying an average value of 0.030 ±0.002 mm and the Y-12 welding machine displaying an average value of 0.026 ±0.001 mm. The observed variations in the calculated d* values are small and the result of experimental variations in the measurement of the FWHM values.

This difference in d* values between the two welding machines, most likely caused by the differences in the anode noted previously, explains the differences in beam characteristics over the range of work distances studied here. Additional factors, such as the alignment and vacuum level of the upper column and differences in the characteristics of the focus lenses, can also contribute to variations in beam properties but are difficult to quantify. With this knowledge, though, it is now possible to produce beams with similar characteristics at different work distances in these two welding machines, thus providing the basis for developing modern transfer procedures for electron beam welding.

Transferring Weld Parameters

Based on the results detailed above, it is apparent that these two welding machines produce beams with different characteristics at the same machine settings and work distances. These performance differences, as defined by the characteristics of the beams produced by each welding machine, are the reason that existing qualitative means for weld transfer are lacking. With the characterization of the two welding machines described above, it is possible to produce similar beams at different work distances on the two welding machines by taking into account differences in d* and beam magnification that result from differences in the construction of the upper columns. However, in many cases, the work distances, particularly in production welding machines, are fixed by either the size of the weld fixturing or the requirements of the appropriate Weld Process Specification. Under these conditions, it thus becomes necessary to use changes in focus to obtain similar beams.

In this case, the work distances are fixed, with the LLNL welding machine having a work distance of 210 mm and the Y-12 welding machine with a work distance of 457 mm. The EMFC diagnostic tool, with its ability to provide quantitative information on the beams produced by each welding machine, is used to measure differences in the performance of the two machines at their respective work distances. Because of the shorter work distance employed on the LLNL welding machine, the beam must be defocused in order to replicate that produced by the Y-12 welding machine. The amount of defocusing required for the LLNL welding machine is determined by characterizing the focus response of this machine and comparing it with that for the Y-12 welding machine at their respective work distances.

Comparisons between the peak power density, FWHM, and FWe2 values measured at work distances of 210 mm for the LLNL welding machine and 457 mm for the Y-12 welding machine are shown in Fig. 9A–C. In these figures, the effects of positive changes in the focus settings on each welding machine are shown. A positive defocus setting is desirable for partial penetration welds because the crossover point for the beam, where the peak power density would be at its maximum, is located above the surface of the part to be welded. With the crossover point above the part, the beam is diverging by the time it reaches the part, making the potential for weld overpenetration less likely. Dashed lines on each figure also represent the defocus required on the LLNL welding machine in order to produce a beam with similar parameters to those produced at sharp focus on the Y-12 welding machine.

Table 6 provides a summary of the measured beam parameters at the respective sharp focus settings for the LLNL and Y-12 welding machines at work distances of 210 and 457 mm, respectively. The sharply focused beam produced by the LLNL welding machine displays a peak power density nearly 42% larger than that produced by the Y-12 welding machine. In turn, the FWHM and FWe2 values for this sharply focused beam are both approximately 25% smaller than those measured for the sharply focused beam on the Y-12 welding machine.

In order to replicate the beam produced by the Y-12 welding machine on the LLNL machine, the beam is defocused. With a +11 change in the focus setting, the peak power density for the LLNL welding machine decreases by 40% and the FWHM and FWe2 values increase by approximately 22 and 28%, respectively. After the defocus correction is made to the beam produced by the LLNL welding machine, the resulting peak power density values vary by only approximately 2%, while the difference in the beam distribution parameters is 7% for the FWHM values and 4% for the FWe2 values.

Reconstructions of the power density distribution for the defocused beam on the LLNL welding machine and the sharp focused beam on the Y-12 welding machine are shown Fig. 10A, B. These figures provide a great deal more information concerning the power density distribution and the orientation of the beams than available in the measurements given in Table 6. For example, the defocused beam produced by the LLNL welding machine is slightly elongated along the x-axis. Such variations from the circular-shaped beams observed at sharp focus conditions are typical for defocused beams. On the other hand, the sharply focused beam produced by the Y-12 welding machine is round, consistent with that typically observed with beams at sharp focus. Even though the orientations of the beams differ, the power density distribution and general size of the beams produced by the two welding machines are very similar.

Cross sections of the welds made on the LLNL and Y-12 welding machines using the beams described above are shown in Fig. 11A, B. Table 6 also includes a summary of

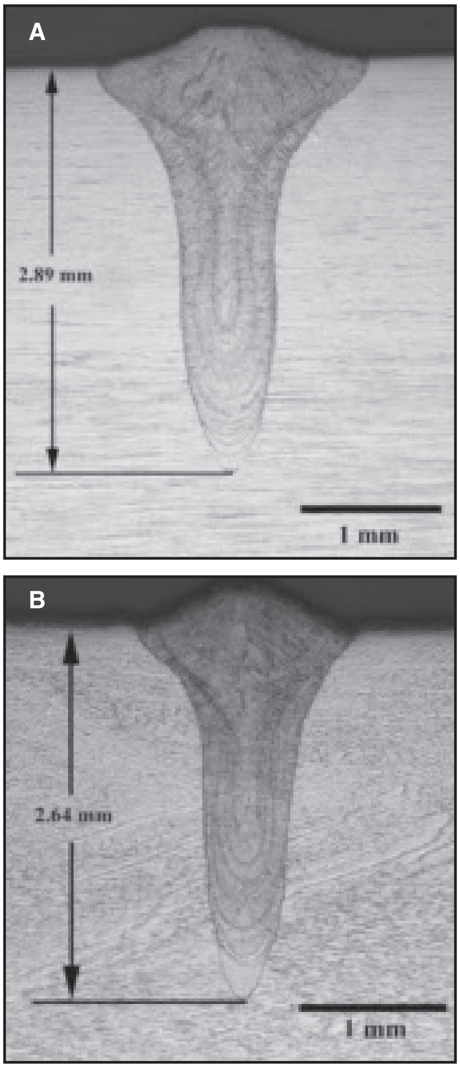


Fig. 11 — Micrographs showing the weld cross sections in 304L stainless steel produced by the following: A — The LLNL welding machine at a work distance of 210 mm and a focus condition of +11; and B — the Y-12 welding machine at a work distance of 457 mm and at the sharp focus setting for 100-kV, 10-mA beams at a travel speed of 17 mm/s.

the measurements of the weld depth, width, and cross-section area. In general, the two welds display similar depths, differing by only 0.30 mm or approximately 8%, with the weld produced by the LLNL welding machine being the deeper of the two. Even though the width of the beam produced by the Y-12 welding machine is larger, the width of the weld produced by the LLNL welding machine, as measured at the top surface of the weld, is approximately 0.5 mm wider than that produced by the Y-12 welding machine, corresponding to a difference of nearly 25%. This difference in width can be attributed, in part, to the orientation of the beam produced by the LLNL welding machine, which is elongated along the axis lying parallel to the direction of welding. On the other hand, the widths of the welds, as measured at the half-depth level, are fairly similar, varying by only approximately 10%.

The above experiments show that it is possible to produce welds that are similar in shape and size by considering the differences in the performance of two machines determined using the EMFC diagnostic tool. With this tool, the characteristics of the electron beam are quantified to a level that allows similar beams to be reproduced with ease on different welding machines. Using these results as a baseline, a procedure for the transfer of electron beam welding parameters between two machines can be adapted to specific needs. In any modified procedure, the EMFC diagnostic tool is integrated into each step of this procedure. Beginning with the weld development stage, the EMFC diagnostic tool provides a means for quantitatively characterizing the beam and ensuring that it exhibits the same characteristics each time that it is used. During the transfer of weld parameters, the use of the EMFC diagnostic tool significantly streamlines the process by removing redundant test welds on each machine and minimizes the time and cost required to move a part from development to production. Therefore, traditional methodologies that rely on multiple test welds to transfer welding parameters from development to production can be replaced by one based on a thorough knowledge of machine performance.

Summary

With the use of an advanced electron beam diagnostic tool, a means for quickly and easily transferring a set of welding parameters between electron beam welding machines at two widely separated locations has been demonstrated. The EMFC diagnostic tool is first used to characterize the beams produced by each welding machine over a range of focus settings at work distances spanning the height of the vacuum chamber on each welding machine. The characterization of these beams generally shows that increases in the work distance can significantly decrease the resulting peak power density and increase the beam width of sharply focused beams. These effects, though, are not consistent across the two welding machines, with the Y-12 machine producing sharply focused beams with higher peak power density and lower FWHM and FWe2 values at the same work distance, accelerating voltage, and beam current.

Because the two machines have vacuum chambers of different sizes, the weld is made at a longer work distance in the Y-12 welding machine (457 mm) than the LLNL welding machine (210 mm). Using the EMFC tool, the effects of changes in focus settings on the beams produced by the two machines at these work distances are examined. Based on these results, a machine focus setting of +11 on the LLNL welding machine is found to produce a beam very similar to the sharply focused beam produced by the Y-12 welding machine at a work distance of 457 mm. Welds have been made using these well-characterized beams. The resulting weld cross sections are similar in appearance and size.

Overall, the results of this weld transfer exercise show that with minimal effort, a weld produced on one electron beam welding machine can be repeated on a second machine at a significantly different work distance using diagnostics. Transferring weld parameters from one machine to another utilizing the EMFC diagnostic tool results in a significant decrease in the time, effort, and money required to develop weld parameters on two or more machines. It also represents a significant advance by utilizing quantitative measures of the beam parameters produced by each welding machine and correlating these values to the resulting weld dimensions.

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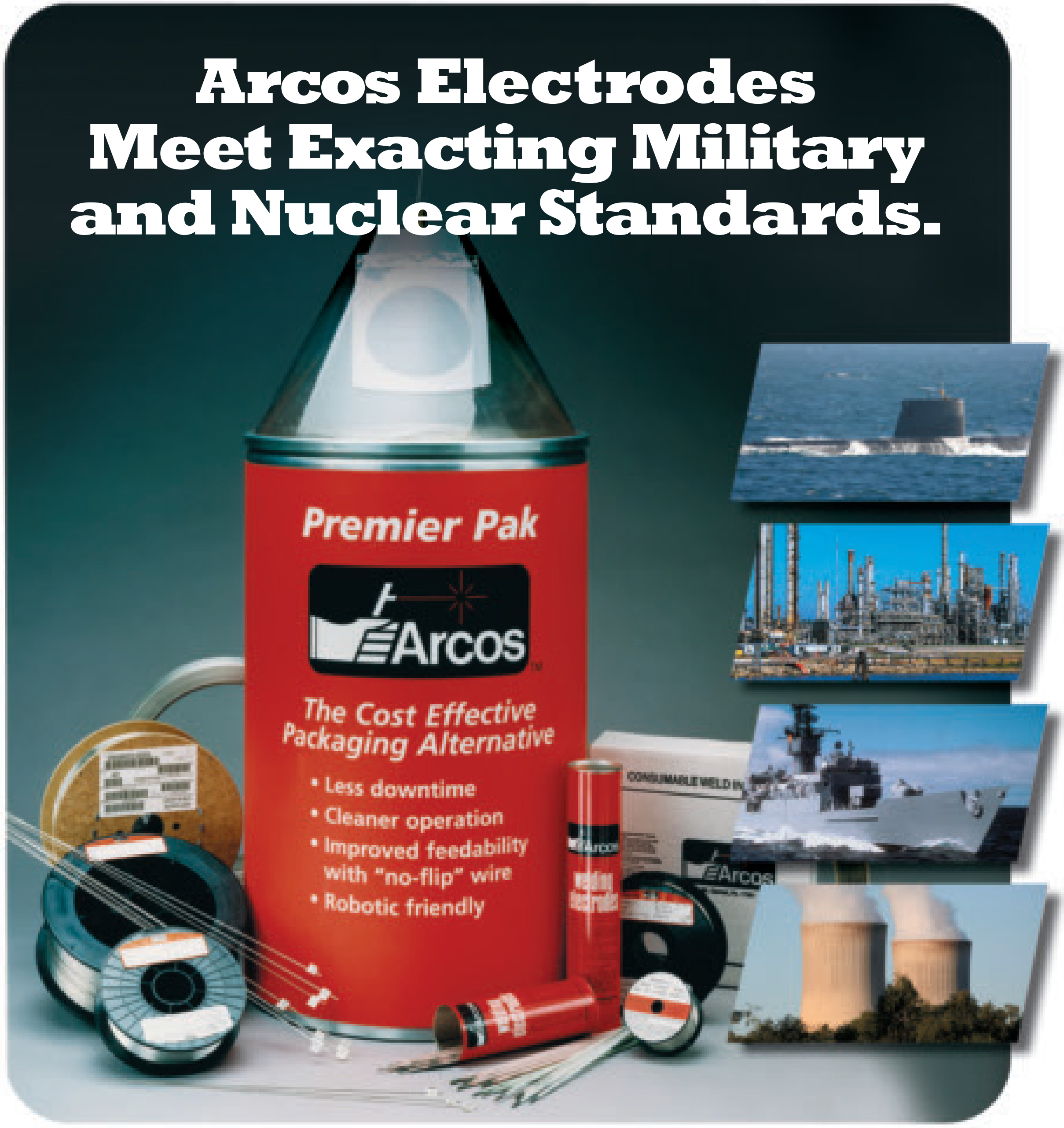

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