January 2008

- Gas Tungsten Arc Welding on the Navy’s Hovercraft
- Innovative Torch for GTAW
- Advice for Proper Weld Finishing

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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American Welding Society Acquires Weldmex

The American Welding Society (AWS), Miami, Fla., has recently entered into an agreement with Trade Show Consulting LLC (TSC), a trade show and conference production company, to purchase Weldmex, the largest welding trade show in Latin America.

AWES will maintain primary ownership of Weldmex, and assumes the rights to organize, promote, produce, and manage Weldmex under the new name, AWS Weldmex. TSC will continue to provide support services in the production, marketing, and management of the show.

“We are very pleased to join Mexico’s premier welding event and expand AWS further into the Latin American market,” said AWS Executive Director Ray Shook. “Mexico’s welding and fabrication industries have experienced impressive growth and the country remains an important trading partner in North America. We believe that AWS Weldmex will broaden AWS’s reach and provide exciting additional benefits and opportunities to our more than 50,000 members.”

This year, AWS Weldmex is scheduled to take place on January 29–31 at the new Centro Banamex in Mexico City.

Westinghouse Obtains Carolina Energy Solutions

Westinghouse Electric Co. has acquired Carolina Energy Solutions (CES), Rock Hill, S.C., a supplier of welding and machining services to the nuclear, fossil, and hydropower-generation, waste-to-energy, petrochemical, gas, and general fabrication industries.

CES and its approximately 60 employees will become part of the company’s newly established subsidiary company, WEC Welding and Machining, which holds PCI Energy Services, a supplier of specialty welding and machining services to the nuclear power industry.

The acquisition also includes the following CES affiliates: Aggressive Equipment, now WEC Machining, which manufactures and distributes a line of field machining tools; Construction Institute of America, now WEC Welding Institute, which operates a welding school serving the North and South Carolina areas; and Carolina United Services, now WEC Machining, which manufactures and distributes a line of field machining tools.

Viking Power Services Subsidiary Secures $800,000 Purchase Order

Viking Power Services, Inc., Manalapan, N.J., recently announced the company’s American Boiler and Pipe subsidiary is currently providing services for an $800,000 purchase order received from an international nuclear energy company.

American Boiler and Pipe is providing expert welding services at one of the customer’s Pennsylvania operating facilities. These services are currently ongoing, and to date, the company has booked revenues of approximately $170,000 from services performed in connection with this purchase order, with the project expected to be completed this year.

Airgas Purchases Wright Welding, Basin Welding, and Mainland Welding

Airgas, Inc., Radnor, Pa., has acquired Wright Welding Supply, Inc., Des Moines, Iowa, an industrial gas and welding supply distributor. In addition, the company has acquired Basin Welding Supply in Odessa, Tex., and Mainland Welding Supplies Ltd., based in Surrey, BC, near Vancouver, Canada.
A Changing Welding Environment Brings Opportunities

It was my pleasure to address the 2007 Annual Assembly at the FABTECH International & AWS Welding Show in Chicago. I am pleased to report that the welding exhibit space alone was 20% greater than at the 2006 show in Atlanta and nearly double that of the 2005 show in Chicago.

As your president, my mission is to help bring about another successful year. My hope is that 2008 will see additional members, an even stronger foundation at the local level, and a positive image of the welding industry.

I would like to begin with our ongoing goal of expanding AWS membership. With more than 52,000 members worldwide, AWS continues to reach record membership levels and has shown time and again that we are an unstoppable force. The industry attention raised due to the shortage of welders and the need to rebuild much of our infrastructure has provided us with new opportunities to reach many more prospective members, not only within the United States, but also abroad.

Countries all over the world are reporting serious shortages of skilled welders and require immediate solutions to keep pace with their infrastructure and manufacturing needs. According to the latest Manpower Survey (of nearly 37,000 employers in 27 countries), 41% of employers across the globe are finding it more difficult to fill jobs in trades like welding, carpentry, and plumbing. The interesting part is that employers are not just looking for welders, but are posting signs that read “certified” welders wanted.

The welder shortage outside of the United States can mean great opportunities for AWS with the focus on quality, standards, and certification across the globe. For example, in Calcutta a “certified welder” can earn more than ten times the average wage in India. The connection is that 13% of our membership is international, presently 7000 AWS members. You can see where this is a great opportunity for new members.

AWS has recently taken positive steps toward furthering our exposure in key international markets. These include our recent partnership with, the Indian Welding Journal, the official publication of the Indian Institute of Welding, and an abbreviated version of our Welding Journal titled Welding Journal en Español.

My second goal is outreach at the local level. I believe this is important because our Sections are the roots of AWS. The men and women within the Sections are the voices and the messengers that can affect industry. Without strength at our Sections, AWS would not be able to grow. I will be traveling to India, China, and Europe this year as well as several Sections around the country, but I am still an officer in the Los Angeles/Inland Empire Section and will stay as involved as I can.

Lastly, it’s all about raising the image of the welding industry. Are we doing enough? Well, we are certainly off to a good start. AWS and the AWS Foundation have established a Welder Workforce Development Program. In concert with this program, AWS in 2006 inaugurated the Welding for the Strength of America Capital Campaign to add financial support to assist with the critical shortage of welders in the U.S. workforce. These endeavors are important to make the image of welding positive and it’s our responsibility to advocate to our local businesses to let it be shown through them. They can make easy changes to help us in our mission by cleaning up shops and donating some materials to local schools. We all need to work together to make it happen.

I’m looking for 2008 to be an exciting year of growth and improving image.
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ABB Robotics Joins Forces with ESAB

ABB Robotics, Auburn Hills, Mich., has developed a partnership with ESAB Welding & Cutting Products, Florence, S.C. The companies have agreed to jointly develop and market robotic welding packages and systems. Particularly, the alliance relates to the incorporation of ABB robots with ESAB robotic gas metal arc welding automation products, specifically wire feeders, welding power units, and other related equipment.

RTI and Boeing Enter into Long-Term Supply Agreement

RTI International Metals, Inc., Niles, Ohio, has signed a ten-year agreement with The Boeing Co. to supply extruded, welded, and fully machined value-added structural titanium components for the Boeing 787 Dreamliner. In addition, the contract is estimated to generate in excess of $900 million in revenue over its term, which commences this year and runs through 2017.

RTI will act as the lead integrator on the PAX Floor Pi-Box Seat Track program through its Fabrication & Distribution Group. The company’s Houston and Montreal facilities, as well as multiple supply chain partners, will support the production of the finished titanium components used for the seat tracks in the floor structure of the Boeing 787.

ThyssenKrupp Breaks Ground for New Carbon and Stainless Steel Facility

ThyssenKrupp Steel USA, LLC, and ThyssenKrupp Stainless USA, LLC, recently broke ground on the site of their $3.7 billion carbon and stainless steel processing facility in Calvert, Ala. This marked the beginning of construction of the 3500-acre plant.

The facility will include a hot strip mill. Also, it will feature cold rolling and hot-dip coating capacities for high-quality end products of flat carbon steel. The facility will have an annual capacity of 4.1 million metric tons of carbon steel end products.
Additionally, a stainless steel melt shop will be built with an annual capacity of up to one million metric tons of slabs. The company remains on schedule for the commencement of operations in March 2010. When fully operational, 2700 permanent jobs are expected to be created.

Frank Phillips College Receives $1.3 Million for Welding and Safety Center

A Skills Development Fund check for $1.3 million was recently presented for a new welding and safety center at Frank Phillips College in Texas. From left are Larry Jones, Workforce Development Division director, Texas Workforce Commission; Diane D. Rath, chair and commissioner representing the public, Texas Workforce Commission; Dr. Herbert J. Swender Sr., Frank Phillips College president; Kel Seliger, state senator, Texas 31st District; Conny Moore, chair, FPC board of regents; and Warren Chisum, state representative, Texas 88th District. (Photo courtesy of Frank Phillips College.)

Frank Phillips College will receive $1.3 million for a welding and safety center due to a workforce training grant from the Skills Alabama Governor Bob Riley and Ekkehard D. Schulz, chairman of the executive board of ThyssenKrupp AG, Karl-Ulrich Koehler, chairman of the executive board of ThyssenKrupp Steel, and Jurgen H. Fechter, chairman of the executive board of ThyssenKrupp Stainless, broke ground on the site of ThyssenKrupp’s new $3.7 billion carbon and stainless steel processing facility in Calvert, Ala., on November 2, 2007. (Photo courtesy of ThyssenKrupp.)
Development Fund program that the Texas Workforce Commission administers.

“The expansion of welding training at Frank Phillips College will provide high-demand, skilled workers to Panhandle-area employers,” said state Senator Kel Seliger. It will help to assist the welder shortage in Texas as well.

To be called the Warren Chisum Welding and Safety Center, named after State Representative Warren Chisum, the new facility is going to be 14,600 sq ft and include a welding lab and safety education classroom. Construction will begin within the first months of this year, and the project will take 12 to 14 months to complete.

Williamsburg Technical College Gets Stainless Steel Pipe Donation

The welding department at Williamsburg Technical College, Kingstree, S.C., has received a donation of 250 ft of 6-in. stainless steel pipe from International Paper Co. in Georgetown.

The concept of the donation came from an idea by Andy Baker with BE&K Construction, who serves on the college’s welding advisory board. After speaking with welding instructors Jeff Ball and Jason Kinder, he learned that training students on stainless steel was cost-prohibitive under current state budget constraints.

He contacted Ruben Williams at International Paper, explained the situation, and Williams was instrumental in encouraging the company to donate the piping.

Now the college’s welders are able to learn to work on the nonferrous metal and will be more hirable upon graduation.

Lincoln Electric Donates Equipment for Boilermakers Apprenticeship Awards

The International Brotherhood of Boilermakers, Iron Ship Builders, Blacksmiths, Forgers and Helpers recently opened a new national training facility near its Kansas City, Kansas, headquarters. As a part of the grand opening, the center served as host to the 2007 Boilermakers Apprenticeship Awards. Lincoln Electric, the outfitter of welding equipment, consumables, and fume removal systems for the facility, donated prizes for the competition. Shown (from left) are the following Lincoln representatives and Boilermakers welding instructors: Carl Peters (Lincoln Electric), John Standish (Boilermakers), Jason Schmidt (Lincoln Electric), Louis Lombardi (Boilermakers), Bob Simmons (Lincoln Electric), and Mark Branscum (Boilermakers).
Alfalight Receives $1.2 Million Contract to Develop Advanced Fiber Laser Pump Sources

Alfalight, Inc., Madison, Wis., a manufacturer of high-power diode lasers, has received a $1.2 million contract from the Army Research Laboratory in Adelphi, Md. This 12-month program, “High Brightness Diode Sources,” will enable the company to leverage the results of two previous programs to create laser diode modules. The new laser design will have less-demanding manufacturing tolerance requirements as well.

Results of this program will allow power scaling into kilowatt-class arrays for pumping fiber lasers and solid-state gain media, and as direct diode sources for applications such as welding.

Industry Notes

• Valley National Gases, LLC, Washington, Pa., has acquired Allegheny Welding and Industrial Supply Inc., an industrial gas and welding supply distributor with locations in Pennsylvania.
• When the latest version of the ASME Boiler and Pressure Vessel Code is published, it will signify an advance in how industry addresses weld fatigue, as Section VIII, Division 2, will include Battelle’s Mesh-Insensitive Structural Stress method. Also, it marks an achievement for scientist Dr. Pingsha Dong.
• TRUMPF Inc., Farmington, Conn., has recently acquired 100% of Advanced Fabricating Machinery, Canada.
• The integrated BOC Gases and Linde Gas organizations in North America are now branded as Linde. Linde AG acquired The BOC Group, PLC, in 2006 to form The Linde Group.
• TWI, Cambridge, UK, recently announced the European Patent Office upheld a patent relating to the laser welding of plastics following proceedings held in Munich, Germany.
• Flomerics, Marlborough, Mass., is providing its EFD Pro™ software free to schools in Canada. The aim is to help students in the F1 in Schools™ CAD/CAM Design Challenge.
• Privately held Jackson Safety, Fenton, Mo., has acquired the assets of Wilson Industries, Pomona, Calif., a manufacturer of welding curtains and blankets.
• Applied Robotics Inc., Glenville, N.Y., has added a new distributor, Automated Micron Assembly Pte Ltd, Singapore, to its line-up of partners.
• Lucas-Milhaupt, Inc., Cudahy, Wis., has acquired Omni Technologies Corp. of Danville, a N.H.-based company specializing in the manufacture and distribution of aluminum-based brazing and soldering materials.
• Dave’s Welding and Metal Fabrication, Inc., and Lynnes Welding Training have moved to a new 17,000-sq-ft location in Fargo, N.Dak.
• Jim Tetreault, vice president of the Ford Motor Co., recently presented one of 2007’s Henry Ford Technology Awards to a team of engineers from the company’s plant in Cologne, Germany. With welding experts from Fronius, they have come up with a solution for producing a spatter-free brazed joint.
• Airgas, Inc., Radnor, Pa., has acquired Central Welding Supply, Inc., an industrial packaged gas distributor with three locations south of Dallas, Tex.
• Select-Arc, Inc., Fort Loramie, Ohio, plans to open a new warehouse and distribution center in Houston, Tex. The 20,000-sq-ft facility is scheduled to open its doors this month.
• Sonics & Materials, Inc., Newtown, Conn., is expanding its line of ultrasonic assembly equipment to include metal welding systems.
German Manufacturer to Build Its Largest Gantry CMM Ever

Wenzel GmbH of Germany recently received an order for the largest coordinate measuring machine (CMM) it has ever produced. The 32-ft-long Model LHF 3020 gantry CMM will be delivered to Emraer, a Brazilian aircraft manufacturer. The machine has a measuring range of $9.8 \times 32.8 \times 6.5$ ft.

The LHF series was designed and developed to solve problems associated with the inspection of large parts. The machines are characterized by easy accessibility and maximum freedom of movement. Their flexible configuration provides for full integration of Renishaw scanning solutions.

Dynamic Materials Purchases German Explosion Welding Company

Dynamic Materials Corp. (DMC), Boulder, Colo., a leading provider of explosion-welded plates, recently purchased privately held DYNAenergetics, a Germany based manufacturer of clad metal plates and various explosives-related oil-field products.

The acquisition was completed for $96.6 million, excluding transaction costs, consisting of $83.4 million in cash and 251,041 shares of common stock. DMC also assumed approximately $2.8 million of DYNAenergetics' debt. DYNAenergetics recorded sales of approximately $73.3 million for its fiscal year ended September 30, 2007. It operates two business units: DYNAplating and DYNAwell.

DYNAplating has a 40-year history as one of Europe’s leading explosion welding companies. It operates manufacturing facilities in Germany and primarily serves European and Asian industrial fabrication customers. DYNAwell utilizes both explosive and metalworking technologies to manufacture a wide range of proprietary and nonproprietary products for the global oil-field production and decommissioning industries.

Rolf Rospek, who has been chief executive of DYNAenergetics since 2001, will continue to serve in that capacity and has also been named to the DMC board of directors.

“DYNAenergetics is widely regarded as one of the world’s top-tier explosion welding businesses,” said Yvon Cariou, president and CEO of DMC. “Its addition to the DMC family enhances our ability to address growing worldwide demand for clad metal plates, brings new depth and talent to our management and operations teams, and expands our already leading position in the global explosion welding market.”

Aker Yards to Build More Offshore Vessels for ‘K’ Line

Aker Yards, headquartered in Oslo, Norway, has signed a contract with “K” Line Offshore AS to build four Platform Supply Vessels of Aker Yards design. The contract is valued at approximately 1.4 billion NOK. Delivery of the four vessels is scheduled between fourth quarter of 2010 and third quarter of 2011.

“K” Line Offshore AS is a subsidiary of Kawasaki Kisen Kaisha Ltd. of Japan. It had previously ordered two large-sized Anchor Handling Tug and Supply Vessels from Aker.

The 95-m-long Platform Supply Vessels have a deadweight of 5100 tons and are used for transport of cargo to and from offshore installations. They can accommodate a 25-person crew. The Anchor Handling Tug and Supply Vessels have a deadweight of 4800 tons and can handle 70 people. They are dual-purpose tugs not only capable of transporting cargo, but of performing anchor handling and towing duties for floating rigs such as jack-ups and semisubmersibles.

The hulls for the vessels will be built at Aker Yards in Romania. The company has shipyards in Braila (see figure) and Tulcea, Romania. The ships will be outfitted at Aker Yards in Norway.

Dubai to Purchase 1616 Buses

The Roads & Transport Authority (RTA) of Dubai, United Arab Emirates, announced the purchase of 1616 buses of various sizes and models, a move that will increase the number of buses the authority operates by 2009 to 2500. The deal is thought to be the world’s biggest bus purchase transaction.

H. E. Mattar Al Tayar, chairman of the board and executive director of RTA, announced the purchase in November during the opening session of the International Association of Public Transport 1st Middle East & North Africa Congress.

Wenzel will build its largest ever gantry CMM, similar to the one shown here, for a South American aircraft manufacturer.

The steel hulls for most of Aker Yards’ new-build projects, such as the vessels for “K” Line, are being built by Aker Braila and Aker Tulcea in Romania. Shown is the Aker Braila yard.
You Think Their Names Are Thought-Provoking?

Tony the TIG’er
Man of Steel
PipePrincess
Long Haired Hippie Welder
Da Welda
Carmen Electrode

You Should Read Their Viewpoints.

Check out the Viewpoints blog at MillerWelds.com/Results—the industrial welding site where real people gather to discuss real issues, share insights and explore the industry’s most challenging topics.

Viewpoints—The Blog That’s Got Everyone Talking

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Real Issues. Real Answers.


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Q: We need to make, by welding, some modifications to a 304L stainless steel tank that is in an environment where the ambient temperature is around 0°F. Questions have been raised about the minimum preheat temperature needed to avoid cracking. In the area where we need to weld, the wall thickness is about ½ in. Would preheat to 32°F be sufficient to avert cracking, or should we preheat to 70°F?

A: Application of preheat before welding can have several functions. One is to dry the surface. Surface moisture, whether in the form of liquid water, snow, ice, or frost, can either be frozen in the arc into hydrogen and oxygen. Hydrocarbons (oil, grease, etc.) are also potential contributors to hydrogen in the arc. The hydrogen dissolves in the liquid weld metal where it has the possibility of creating mischief. There is an abrupt reduction in solubility of hydrogen in the weld metal when it transforms from the liquid state to the solid state, which can produce porosity in the weld metal. This concern applies to carbon steel, low-alloy steel, stainless steel, nickel-based alloys, aluminum alloys, and a host of other metals.

Hydrogen in the weld metal can also remain in solution in the weld metal after it freezes and can also diffuse into the weld heat-affected zone (HAZ). Metals with body-centered cubic (BCC) crystal structure or body-centered tetragonal (BCT) crystal structure can be severely embrittled by this hydrogen and may crack due to weld residual stresses interacting with this diffusible hydrogen. Higher-strength material tends to be more susceptible to this form of cracking. Martensite in steels is BCT and is most susceptible to hydrogen-induced cracking (HIC), but ferrite and bainite are BCC and can also be susceptible. Higher-carbon steels, low-alloy steels, and martensitic stainless steels are all susceptible. Duplex stainless steels, consisting of approximately equal amounts of ferrite and austenite, have also been shown to be susceptible to HIC when the ferrite content exceeds about 60 FN. However, austenitic stainless steels, nickel-based alloys, and aluminum alloys have a face-centered cubic (FCC) crystal structure that is virtually immune to HIC, at least at levels of hydrogen that will not produce porosity. Type 304L stainless steel, and its matching 308L weld metal, have predominantly FCC crystal structures. With ferrite content on the order of 10 FN as might be found in 308L weld metal, HIC is unknown.

A second function of preheat is to reduce the cooling rate of alloys that transform from austenite to ferrite, bainite, or martensite. A reduced cooling rate tends to produce lower hardness, which is less susceptible to HIC. In the extreme, a preheat temperature higher than the martensite start temperature has been successfully used for welding tool steels and martensitic steels like 420. Happily, 304L base metal and 308L weld metal do not transform from austenite to any other crystal structure, except under conditions of severe cold working or refrigeration to cryogenic temperatures such as –320°F (–196°C). Otherwise, 304L base metal and 308L weld metal are unaffected by cooling rate as regards HIC.

A third function of preheat is to raise the temperature of the weldment above any ductile-to-brittle fracture transition temperature (DBTT). This prevents fracture in the presence of a flaw such as an incomplete fusion defect or a preexisting crack. Martensitic steels may have a DBTT above normal room temperature, while many structural steels have a DBTT below 0°F (–18°C). But austenitic stainless steels like 304L and 308L weld metal do not generally have a definable DBTT. They are capable of ductile fracture even at cryogenic temperatures. Brittle fracture is generally unknown in austenitic stainless steel base metal or weld metal.

A fourth function of preheat is to reduce residual stresses caused by welding. These residual stresses arise because the weld metal and HAZ shrink due to thermal contraction during cooling. The colder base metal opposes this shrinkage and the result is tensile residual stress in the weld metal and often in the HAZ. This tendency to greater differential thermal contraction and correspondingly higher residual stresses is greater when the temperature difference between the base metal mass and the solidifying and cooling weld metal is greater. Preheat of the mass of the base metal can reduce this differential thermal contraction. This has been used successfully for welding martensitic stainless steels such as 420, where a preheat of 600°F (315°C) reduces the temperature differential between the mass of base metal or previously deposited weld metal and the newly deposited weld metal and thereby reduces residual stresses. For austenitic stainless steels like 308L weld metal, the important temperature differential is that between about 1500°F (815°C), where the weld metal develops appreciable yield strength, and the base metal preheat temperature. An increase in base metal temperature from 0°F (–18°C) to 70°F (21°C) amounts to a reduction of less than 1% of the temperature differential between the base metal and the weld metal when the weld metal starts to develop appreciable yield strength. Accordingly, increasing the base metal temperature from 0°F to 70°F before welding will have a negligible effect on residual stresses in a 304L weldment.

In summary, only one of the various reasons for preheating base metals before welding would generally be applicable to 304L stainless steel welding in your situation. That reason is to help ensure dryness of the surface before welding, in order to avoid porosity due to hydrogen. If you are careful to remove any moisture (water, ice, snow, or frost) and hydrocarbons (oil, etc.) from the surface by means other than preheat, and if you use low-hydrogen practices, you should eliminate any porosity due to hydrogen. Cracking should not be an issue so long as the filler metal is chosen to provide some ferrite in the weld metal, and in any event is not going to be affected by preheating. I suggest that you be careful to maintain dry surfaces in the joint area and weld the 304L without preheat.

Be aware that preheat to only 70°F (21°C) will not decompose or remove any hydrocarbons, nor will it remove water. Also, be aware that preheat with an oxy-fuel torch or air-fuel torch to a peak temperature lower than 212°F (100°C) can allow the combustion products (water vapor) from the flame to condense on the base metal, and may actually do more harm than good by promoting porosity. So if you do choose to preheat to a low temperature like 70°F, I suggest that you use infrared heaters or electric resistance strip heaters, but not an oxyfuel air-fuel torch.

DAMIAN J. KOTECKI is president, Damian Kotecki Welding Consultants, Inc. He is a past president of the American Welding Society, a past vice president of the International Institute of Welding, and a member of the AWS ASD Subcommittee on Stainless Steel Filler Metals, and the AWS D1K Subcommittee on Stainless Steel Structural Welding. He is a member and past chair of the Welding Research Council Subcommittee on Welding Stainless Steels and Nickel-Based Alloys. Send your questions to Dr. Kotecki at damian@dami-ankotecki.com, or to Damian Kotecki, c/o Welding Journal, 550 NW LeJeune Rd., Miami, FL 33126.
Think about the challenges of welding new alloys and at the same time meeting stricter quality standards. Think about having to weld more for less.

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Friends and Colleagues:

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

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

Sincerely,

Nancy C. Cole
Chair, AWS Fellows Selection Committee
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Welding Journal
Weld Curtain Transports with Ease

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Are you interested in weld finishing, but unfamiliar with the tools and accessories needed to get the job done successfully? Well, you’ve come to the right place. Read on for tips and hints to help you conquer your weld finishing jobs as easily as possible.

Just grabbing any old tool and embarking on a weld finishing project could lead to disaster with poor, weak joints and wear and tear on both the tool and the operator. Prior to weld finishing, the user must be familiar with the safety requirements and the tools commonly used for this technique, including burnishers, die grinders, and angle grinders as well as their related accessories and abrasives.

**Warming Up**

If you want to survive the job in one piece, first start by properly equipping yourself with the personal protective equipment (PPE) needed. Grinding creates hazards that include sparks and flying debris, so safety glasses or a full-face shield are needed. Grinding is also a noisy job, so hearing protection is required. To protect yourself from sparks and debris, leather work gloves as well as a leather apron or full shop coat are recommended. Depending on the material being ground, a dust mask or respirator should also be used. Always be sure the tool has been properly maintained, and read and understand the instruction manual that comes with the tool. Never operate the tool without guards and side handles in place.

**Basic Training**

For optimum performance, greatest efficiency, and quickest throughput for weld finishing, you must choose the proper grinder for your welding application. Many manufacturers offer an array of grinder models. Grinders come in many sizes — 4 1⁄2, 5, 6, 7, and 9 in. — and in different switch configurations: top-locking switch, side-locking switch, rear-locking paddle switch, or a “dead man” non-locking paddle switch. Ergonomics and your
shop rules will determine which type suits you best.

Grinders also come in various power ratings and speeds that allow you to match the ideal tool with an application. For example, a 9-in. angle grinder may be too cumbersome in tight situations, and a 4½- or 5-in. grinder could be too lightweight to grind stainless steel welds; therefore, an all-purpose 6- or 7-in. angle grinder in would be an ideal fit.

Most shops own some finishing tools such as a small angle grinder (4½ in.) for light grinding, deburring, and sanding applications as well as a large angle grinder (7 or 9 in.) for heavy material removal applications. Be aware, however, the weight of the grinder should be considered when selecting one that is suitable for the welding application. Grinders can weigh as little as 4.5 lb and as much as 19 lb, which makes a drastic difference when working on a ladder or removing welds on a vertical surface.

**Hitting Your Stride**

**Burnishers**

The burnisher is a useful tool for weld and surface finishing with its exceptional ability to grind/blending welds as well as to create a brushed or polished look on bronze, steel, nickel, silver, and stainless steel. Standard features on many available burnishers include durable sanding and abrasive belts that are utilized for sanding, smoothing, buffing, and polishing metal — Fig. 1. More upscale burnishers offer advanced features; for example, Metabo’s SE 12-115 burnisher provides electronic speed stabilization and spiral bevel gears, ensuring consistent results and an efficient transfer of power when finishing welds. Many manufacturers also offer an accessory line to complement their burnishers, further optimizing the tool for each specific application.

**Die Grinders**

The die grinder is a versatile tool that can be used for situations such as deburring and cutting as well as for finishing and light grinding of welds. With higher revolutions per minute (rev/min), single-speed die grinders featuring no-load speeds from 20,000 to 30,000 rev/min are best for deburring using mounted abrasive points or carbide burrs. Variable speed die grinders, with ranges from 7000 to 27,000 rev/min, can tackle various applications like delicate finishing and blending by using a lower speed and 2- to 3-in. wafer cutting wheels. Some die grinders also feature geared-down construction that provides higher torque and, along with larger accessories, are ideal for covering more surface area when finishing and blending welds.

Typical accessories for die grinders include abrasive mounted points that are ideal for grinding applications and are available in a large variety of shapes, such as cylindrical and cone, mounted to a ½- or ⅛-in. steel shaft. Carbide burrs, used for metal removal and deburring, also come in a variety of shapes and sizes, typically with ⅛-in. shank size. Other accessories for die grinders include flap wheels offered in standard, nonwoven, and interleaved versions. Standard flap wheels are ideal for material removal, but leave a rougher finish; nonwoven wheels provide a nicer finish, but do not do a good job in removing stock; and interleaved wheels provide a smoother finish when used for surface conditioning and blending — Fig. 2.

It is critical to choose the proper accessory when weld finishing. For example, if you are trying to remove a hard metal by using an accessory meant for lighter-duty applications, this accessory will not hold up well under pressure and may damage the project, or even worse, result in injury. When the proper accessory is chosen, the life of the accessory and the efficiency of the operator increase dramatically, saving both time and money.

Fig. 2 — The variety of accessories available for a die grinder enable its use in a multitude of weld finishing applications.
Angle Grinders

Angle grinders offer an array of features that enhance tool performance as well as user comfort and safety. For example, one model offers a two-position ergonomic side handle, lock-on switch, easy-to-use accessible spindle lock, low-profile aluminum die cast gear housing, and high-efficiency cooling vents with front exhaust.

Electronics can also enhance the performance and add safety features to these tools. Electronic speed stabilization keeps the grinding wheel spinning at the optimum speed, even under full load, saving time and effort in the grinding job. Overload protection warns the operator of impending overload and prevents the tool from burning up. A power interruption feature also disables the tool in the event of a power outage while in operation, preventing unexpected restart when power is restored.

With its ergonomic design, the small angle grinder is ideal for weld finishing in hard-to-reach places. Angle grinders are available in many sizes, and more specifically, a smaller grinder, measuring 4½, 5, or 6 in., is perfect for grinding out welds in odd positions such as from atop a ladder or inside a vessel — Fig. 3.

Prior to choosing your angle grinder, you must first consider the various performance specifications of each model. For example, Metabo’s 6-in. W14-150 and 9-in. W25-230 models share many features, such as an ergonomic rear handle that pivots 90 deg left and right, a three-position side handle, auto-stop carbon brushes, and tool-less guard adjustment. However, the available torques are 44 lb in the 6-in. model and 150 lb in the 9-in. model. You should compare the different models in order to choose the right tool for the application.

An assortment of specialized abrasive wheels is also available to grind, blend, or clean any welding application. When choosing a wheel, the wheel size must match the grinder size and its maximum rev/min should always be rated at or above the no-load speed of the angle grinder to ensure maximum performance and safe operation. To ensure safety, the user should consult the grinder manufacturer so the right abrasive is used based on the grinder model.

The Finish Line

The angle grinder’s abrasive wheels are the working force behind all weld-finishing applications. Using the correct grinder/wheel combination will ensure the greatest efficiency, performance, and results. Abrasive wheels fall into two broad categories: grinding wheels and slicing (cut-off) wheels. A grinding wheel is thicker, sturdier, and designed to grind down and blend welds, so the wheel is typically applied at an angle of 15–30 deg to the surface being ground. In contrast, a slicing or cutting wheel is always used perpendicular to the material being cut.

To choose the best abrasive for weld finishing, the user must understand the different types of abrasives and their uses. It is also important to match the wheel carefully to the stock being ground.

There are three major types of abrasives to choose from, which are determined by the application’s surface.

* Aluminum oxide is a general-purpose abrasive for use on ferrous metals. It offers good wheel life, good material removal rates, and comes in varying degrees of hardness for job-matched performance. For hard materials such as stainless steel, users should select a softer grade abrasive, while a harder grade abrasive is suitable for softer metals because it will not dull the grains as readily.

* Zirconia alumina is used for ferrous metals, stainless steels, and high tensile strength alloys. It offers superior wheel life and superior material removal rates.

* Silicon carbide is used for nonferrous metals such as copper, aluminum, bronze, and masonry materials.

Grasping the Silver Metal

Overall, when selecting a tool, abrasive, or accessory for weld finishing you must first consider the application at hand, including the type of metal you’re working with, desired finish, and working conditions. The weld finishing tips found here will help you choose the proper tools, abrasives, and accessories that will complement your application and provide you with the ability to get the most out of grinding and finishing welds.
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HODGSON CAN HELP SOLVE YOUR PROBLEMS
“No beach out of reach” is the Assault Craft Unit Five’s (ACU-5 — “The Swift Intruders”) motto.

Commissioned in 1983, ACU-5 has been tasked with the high-speed transfer of personnel, equipment, and supplies from ship to shore and inland to designated landing areas. To accomplish this, the unit relies on a unique hovercraft, the Navy’s Landing Craft, Air Cushion (LCAC) — Fig. 1.

Riding four feet above the surface on a cushion of air, the LCAC can transport an M1A1 tank, 24 Marines, or other 75-ton payload at speeds of up to 40 knots for distances of 200 miles — Fig. 2. A traditional landing craft traveled at 8 knots, could access only about 17% of the world’s beaches, and delivered its cargo or troops at the beach. An LCAC, on the other hand, can access about 80% of the world’s beaches and can carry its cargo far inland, clearing obstacles of up to 4 ft high.

With their high speed and increased range, LCACs can launch from their parent ship, which remains out of sight over the horizon, and quickly make their way inland. This maximizes the element of surprise, reduces exposure to enemy fire, and, because of their high speed, allows them to coordinate with helicopters during an amphibious assault. LCACs have deployed in Operation Desert Storm, Operation Iraqi Freedom and Somalia. They have also conducted humanitarian missions of tsunami and Hurricane Katrina relief and supported firefighting efforts on Catalina Island, Calif.

There are 80 LCACs in service, each operated by a crew of five enlisted personnel and powered by four TF40B gas turbine engines that produce 4000 hp each. Constructed by Textron Marine and Land Systems and Avondale Gulfport Marine, LCACs were designed with a 20-year service life. Now, with the LCACs having reached the 20-year mark and with no additional craft being manufactured, the Navy has undertaken a Service Life

BY JOHN LUCK

Extension Program to extend the life of the craft by 10 years.

The work might consist of upgrading systems, replacing engines, and repairing structural components, including replacing damaged areas on the underside of the deck or “buoyancy box.”

Contracted through L-3 Communications Unidyne, Walashek Industrial & Marine are performing the work at Camp Pendleton, Calif., for the U.S. Navy. With headquarters in Seattle, Wash., and locations around the country, Walashek has a reputation for performing complete overhaul and repair of marine boilers, structural and piping system fabrication, and other specialized ship repair, including work on the aircraft carrier USS Nimitz.

“The LCAC takes quite a beating,” said Paul Hicks, program manager for Walashek — Fig. 3. “They transition from being on-cushion over water, land, and various beach environments, and parking in support ships under varying sea conditions. They can adjust to the operating environment and are constantly battered about by the seas.”

A peripheral skirt system holds the cushion of air and connects to the LCAC’s buoyancy box, which is designed to keep the craft afloat even if it goes “off-cushion” and the skirt is deflated. The buoyancy box receives a majority of the attention due to the effects of the corrosive ocean environment and vibration-related cracks.

Everyone concerned with maintaining the LCACs is acutely aware that United States military personnel lives are at stake each time the crafts head to sea, and they perform their tasks accordingly. Every inch of the craft is inspected, and suspect areas are marked for repair or removal and replacement.

While Walashek works to extend the service life of the crafts, nearby on the base, Navy hull technicians (HTs) perform the pre- and postdeployment maintenance that keeps the LCACs running on a regular basis — Fig. 4. Gary Wheeler, ACU-5’s onsite representative from CACI, trains the HTs in the fine art of gas tungsten arc welding (GTAW) the aluminum craft.

Regardless of prior welding experience, when HTs enter the program, it’s Wheeler’s job to start from the beginning and teach them the theory, machine operation, metallurgy, and welding techniques they’ll need to earn their Navy certification to weld on the aluminum LCACs. These efforts save the command up to $1 million each year since ACU-5’s personnel can perform welding and maintenance that would otherwise be contracted out.

Walashek draws on its many years of welding experience and skilled workforce to perform the service life extension work.

“With our experience in boiler work and other welding-critical projects, we’ve got pipe fitters, boiler makers, steam fitters, and some top-of-the-line welders working for us,” said Hicks. Yet, regardless of an individual’s previous experience, to qualify for working on the LCAC, Walashek’s welding operators must pass overhead, horizontal, and vertical x-ray welding tests — Fig. 5. Each completed production weld is tested using dye penetrant.

To meet the challenge, the Miller Dy-
nasty 300 DX AC/DC GTAW machine was chosen for its advanced squarewave output and aluminum welding capabilities.

The Problem with Aluminum

“Aluminum is a unique alloy that presents some special welding challenges,” said Wheeler. “For instance, steel changes color as it heats up; however, aluminum maintains the same color whether it’s solid or liquid, making it difficult to determine the temperature of the alloy. This means it’s easier to put too much heat into the weld and burn through the material.

“Aluminum also has a thick, heavy oxide on it, which melts at about 3600°F, while the aluminum itself melts at about 1075°F. This requires the welder to disrupt the oxide by mechanical abrasion and the welding arc (electrode positive part of the AC welding current). If it’s done correctly, after the weld is complete, the oxide will reform within eight hours to protect the weld and the plating for the rest of its life cycle.”

If the oxide is not removed properly, the aluminum will melt below the oxide and the fusion will not be sufficient to carry the LCAC. So AC output is necessary for GTAW aluminum because it combines the cleaning action of electrode positive (EP) to remove the oxide layer on the metals with the penetration of electrode negative (EN).

Weapon of Choice

With an AC gas tungsten arc inverter that allows the user to precisely control the arc characteristics and the amount of heat put into the weld, those working on the LCACs are better able to prevent the melt-through and warping that might occur on thin material and can also ensure better penetration.

The welding inverter chosen for the project provides a 5- to 300-A output range (250 A at 40% duty cycle), and permits adjusting frequency from 20 to 250 Hz and adjusting EN duration from 50 to 90%. By fine tuning EN duration and AC frequency, operators can stabilize the arc, reduce arc wandering, obtain excellent directional control over the arc and pool, establish the weld pool faster, precisely place the filler, and control bead width.

The desired arc cone shape and weld bead profile determine the frequency to be used. An arc cone at 200 Hz is much tighter and more focused than an arc cone operating at 60 Hz. At higher frequency, there is significantly improved arc stability and increased penetration, making it ideal for fillet welds and other fit ups requiring deep, precise penetration.

Pieces with wider root openings to fill or that require buildup will benefit from decreasing the frequency. The longer the arc spends in each polarity, the longer it has to spread itself out to the nearby metal and the softer and wider the arc cone that results.

“On fillet welds and lap weld joints we change the frequency to 200 Hz,” Wheeler said. “This minimizes some challenges for the welding machine operator in that it minimizes melt through, burn through, and some other defects. On a butt weld, where we’re putting two pieces together, we change the frequency to 60 Hz, keeping the arc on longer and getting adequate fusion.”

Hicks offers the following tip: “A lot of guys will think that if you want to put less heat on something, you need to turn your amperage down. Well, it’s actually the opposite. To decrease the heat transferred to the metal, increase your amperage so you can increase your travel speed.”

When it comes to balance control, more cleaning action is not necessarily better. A good weld requires only 0.1-in. etched zone surrounding the weld, although different joint configurations may have different requirements. Using the least amount of cleaning action necessary (setting the bal-
ance at the highest practical EN) helps maintain the tungsten point, reduces balling, and provides for deeper, narrower penetration. Insufficient cleaning action results in a “scummy” weld pool. Too much cleaning action can lead the tungsten tip to ball and reduce penetration.

“We set the electrode to 70% EN,” said Wheeler. “At that setting, we get good cleaning action while extending tungsten life, since it puts more heat in the base material than in the electrode.”

Navy HTs and Walashek welders will continue do their part to ensure that no beach remains out of reach. ♦

Fig. 5 — Every Walashek welder working on the LCACs must be certified in overhead welding and pass an x-ray test to prove it. Each actual weld is tested with dye penetrant.
Friends and Colleagues:

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

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

Sincerely,

Alfred F. Fleury
Chair, Counselor Selection Committee
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Abstract Deadline: April 30, 2008
Manuscripts Due: July 31, 2008

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

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

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

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

Below are some of the topical areas covered at IBSC

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

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

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

Endorsing Sponsors:
Innovative Process Improves Welding of Sheet Metal Parts

A welding process combines the quality of gas tungsten arc with the speed and penetration characteristics of gas metal arc

BY JEAN-MARIE FORTAIN, LAURENT RIMANO, AND VIWEK VAIDYA

Gas tungsten arc welding (GTAW) is widely used in manufacturing for manual, automatic, and robotic applications. The main advantage of this process resides in the fine quality of the welds it produces. However, on the downside, GTAW is limited in terms of welding speed and penetration compared to other robotic welding processes.

A new welding process has been developed that improves on the robotic cold wire GTAW process by combining GTA quality with gas metal arc welding (GMAW) productivity. The key part of this technology is an original torch design concept where the wire is fed through the torch gas nozzle side with a very tight angle relative to the torch axis. This configuration reduces the torch’s overall dimensions and thus enhances part accessibility in robotic welding of complex geometries. Further, it eliminates the need for keeping the wire aligned with the joint axis; the robot’s sixth axis is thereby freer, which facilitates programming and allows optimized robotic motion.

This new process, named TOPTIG, can also be used with peripheral equipment such as an automatic tungsten electrode changer and a push-pull wire feeder. The process has already been implemented successfully into applications ranging from thin galvanized steel spatter-free brazing with silicon bronze to welding stainless steel and aluminum for the food processing, metal furniture, and cycle industries.

Introduction of the New Process

The automotive industry tends to take more and more advantage of the performance increases from using deep formability, and high tensile and yield strengths by using thinner sheet metals in order to reduce the vehicle body-in-white weight. But at this point, the welding processes used on some production lines have not followed this material’s evolution and some undesirable characteristics of the conventional GMAW process, such as excessive penetration, poor arc stability, short weld efficiency, and bead morphology, are problematic for welding engineers.

The new materials used in body-in-white manufacturing as well as other usual manufacturing constraints require the following:
- Energy dissociation from the workpiece and the welding wire, for example, cold wire GTA or plasma processes
- High welding speed
- Use of an automatic process that allows smooth and optimized robot motion
- Minimum consumable replacement downtime

Conventional GTAW Torches Used in Robotic Welding

With robotic GTA processes, the center element of a welding system is the torch. On some commercially available robotic GTA and plasma welding systems (Refs. 1, 2), the wire feeding system is installed as an add-on feature and is not necessarily installed optimally for automatic operation. As shown in Fig. 1, the wire is oriented at 90 deg relative to the electrode and is thus aligned with the joint, which is an important drawback in terms of overall size and positioning reliability. The orientation of the wire also requires the torch to be positioned with the same orientation at all times, which overuses the robot’s sixth axis, complicates programming, and results very often in slower and irregular motion. Furthermore, the tungsten electrode must be changed manually, inducing significant machine downtime, possible tip shape and electrode-to-workpiece distance variations that strongly affect the electrical parameters and the bead morphology (Ref. 3).

The New Torch Concept

The conventional cold wire robotic GTAW process allows energy dissociation from the workpiece and the welding wire, but it does not offer the wire melting rate with partial transfer through the arc required in order to comply with the previously listed welding speed constraint.

The new process is based on a patented welding torch. Its active element includes an integrated wire-feeding system shown in Fig. 2. The wire (2) passes through the gas nozzle (5) at an angle of about 20 deg relative to the electrode (1) axis, and is parallel to the machined electrode tip cone. Thanks to this configuration, the filler metal (4) is brought through very close to the electrode tip — the hottest area of the arc — making it melt faster and thus allowing a higher deposition rate and welding speed.

This configuration makes the use of a GTA torch possible with the same flexibility as a GMAW torch since its orientation is not critical. The electrode-to-workpiece distance is less critical since the molten metal is stubbed through the arc toward the weld pool. The wire guide is permanently attached to the nozzle so there is neither need nor possibility to modify its position. This configuration also leads to a very particular fusion type and allows two different metal transfer modes.

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Two Metal Transfer Modes

The wire passing through the hottest arc area can be melted and brought to the weld pool using two different transfer modes, depending on wire feed speed, as shown in Fig. 3. The modes are 1) droplet transfer, and 2) uninterrupted bridge (or molten metal stream) transfer. In 2004, the Japanese Welding Research Institute studied the oscillation of the weld pool surface with different types of metal transfer (Ref. 4). It concluded that the uninterrupted bridge metal transfer mode permits optimum penetration control and minimizes weld pool oscillation.

Uninterrupted Metal Bridge Transfer

When the wire feed speed and the arc fusion energy reach equilibrium, a continuous contact is established between the melted filler metal and the workpiece. The video snapshots shown in Fig. 4 were obtained using a laser strobe vision system that eliminated the arc radiation effect from the images. They are representative of a complete welding cycle from arc strike to slope down and arc extinction.

The main advantages of this transfer mode are as follows:
• Very stable transfer with high deposition rate combined with maximum welding speed
• Narrow and smooth weld bead
• Reduced risk of tungsten electrode contamination

Droplet Metal Transfer

The droplet transfer mode is characterized by a repetitive sequence starting with the formation of a droplet at the end of the wire tip. This droplet grows until it is detached by gravity and the surface tension effect. This mode is similar to a short arc transfer in GMAW welding, and has the following advantages:
• Improved weld pool degassing and fine and regular bead microstructure by forcing weld pool oscillations with repetitive droplet contact on the liquid surface
• Extended system operation range to lower current values
• Produces larger weld beads.

The video snapshots shown in Fig. 5 were obtained using the same technique as described in the uninterrupted bridge transfer mode section.

The droplet size is larger at lower wire feed speed (three to four times the wire diameter) and is very similar to short arc droplet in globular transfer. This transfer mode gives good results for welding aluminum alloys.

Conclusion on Transfer Modes

The droplet transfer mode main variables are droplet size and frequency. A higher wire feed speed leads to a higher droplet frequency and a smaller droplet size. Figure 6 shows the influence of wire speed at constant welding current on the frequency of droplet transfer. This phenomenon has been observed using a laser strobe vision system giving the same image type as those shown in Figs. 4, 5. The transition zone from the droplet transfer to the uninterrupted bridge transfer is very narrow. A distinct and characteristic noise is produced by each of the transfer modes, making the transition easy to detect.
Key Parameters

Setting the correct torch electrode-to-wire distance (EWD) is very important in this process. The EWD should be set at 1 to 1.5 times the wire diameter. The electrode tip must be machined in order to keep its shape constant, since any variation may impact on the electrical parameters and the weld profile.

Electrode Diameter and Grade

Most DC applications are carried out with EWCe2 electrodes, 2.4 or 3.2 mm (¾ in.) diameter, with current limits of 230 and 300 A, respectively. The GTA standard recommendations are applicable for the new process. These electrodes can be used in DC and AC welding modes. The 1.8-mm (½-in.) electrodes can also be used for specific applications with very thin sheet metal in order to ease arc strike and stability at low current. However, the use of a 1.8-mm electrode can result in an electrode axial thermal deformation that will have an impact on the electrode-to-workpiece distance, one of the key process parameters.

Wire Diameter

The wire diameter depends on the base metal thickness (BMT). The following are guidelines for carbon and stainless steel:

• BMT < 1 mm (½ in.) — use 0.8-mm (0.030-in.) diameter wire
• 1.0 mm < BMT < 1.5 mm (½ in.) — use 1.0-mm-diameter wire
• 1.5 mm < BMT < 4.0 mm (½ in.), use 1.2-mm (0.045-in.) diameter wire.
• For aluminum welding and steel brazing (with CuAl and CuSi wires), the diameter size must be one step higher. The wire diameter influences the process deposition rate and the weld pool wetting.

Essential and Secondary Parameters

The various welding parameters’ influences on the process are summarized in Tables 1 and 2. Table 1 shows the interaction between the parameters (variation of one parameter only, the others being kept constant), and Table 2 shows their influences on the molten pool behavior.

Current: The welding current influences weld penetration, wetting, and melting rate of the wire. The current must be adapted to the base metal type, thickness, and welding speed.

Voltage: The voltage depends on the electrode-to-workpiece distance and the shielding gas. It is also related to the welding speed, since the arc might be slightly deflected backward at higher welding speeds. The arc voltage influences the weld penetration, the droplet size in droplet transfer mode, and the weld pool wetting. The typical value of electrode-to-workpiece distance is about 3 mm (¼ in.). As shown in Table 1, the arc length can be reduced to force an uninterrupted metal bridge transfer mode, or increased to force droplet transfer mode. This parameter has to be adjusted according to the workpiece thickness and in accordance with the welding current value.

Wire Feed Speed

The wire feed speed can be adjusted independently from all other parameters. At a given current value and welding speed, the transfer mode changes from the droplet transfer mode to the continuous bridge transfer mode with a distinctive sound.
Torch/Wire Orientation and Welding Speed

On thin galvanized sheet, the torch can be oriented following two angles: the lead angle and the lateral angle as defined by Fig. 7. On very thin sheet metal, the torch can be perpendicular to the workpiece. More often, and especially with thicker metals, the torch is oriented toward the joint with a lateral angle of 10 to 20 deg. The electrode-to-workpiece distance is generally 3 mm (1/8 in.) from the lap joint assembly lower plate, and the distance between the torch axis and the joint center point is 0 to 1 times the wire diameter.

The welding speed has a strong influence on arc length stability, weld penetration, and weld pool wetting. For galvanized sheet metal welding, decreasing the nominal welding speed facilitates the zinc evaporation from the liquid metal pool while increasing speed tends to trap fine zinc particles in the lower part of the weld pool. For a given set of other welding parameters, a faster travel speed will also result in lower linear energy, and thus lower distortion, which is critical in welding thin metal sheet or brazing applications.

Application of the Process to Thin Galvanized Sheet Metal

First, it is important to notice that the new process was developed to weld very thin sheet metal plates for which GMA welding is not applicable and more generally for galvanized sheet metal frequently used in automotive arc welding or brazing applications. The following sections de-
scribe results obtained with the process used on body-in-white and other automotive components.

Table 3 summarizes the optimum parameters determined for galvanized and electrogalvanized steel lap joints arc brazing and, by extension, also gives an indication of which parameter sets would be required to adapt this process to other steel gauges.

These parameters are valid for the test joint configuration and eventually need to be adapted for other joint and fixture types since the welding current and wire feed speed depend on the joint preparation and tooling device.

All welds were performed using DC without pulsing, a 3.2-mm EWCe2 electrode, and with ARCAL™ 10 argon-hydrogen gas mixture. The hydrogen in the gas mixture helps stabilize the arc at low energy, increases weld pool wetting, and improves weld bead appearance by reducing surface oxides.

**Typical Galvanized Sheet Metal Arc Brazing Applications**

Table 4 illustrates the results obtained during brazing tests performed on different types of 0.8 to 1.5 mm (1/32 to 1/16 in.) thick lap or fillet joints that are typically found in body-in-white manufacturing.

The process allows welding speeds of about 1 m/min with good-looking weld beads. It is possible to use a weaving technique to compensate for part fitup variations; consequently, the welding speed may be slightly reduced. Another advantage is the process capability to produce short beads (Fig. 8) with acceptable repeatability in terms of welding efficiency (bead length with sufficient penetration/total length of the bead). It is usually more difficult with the GMAW process to ensure repetitively sufficient penetration on the first 10 mm of a weld bead.

The forgiveness capability of the new process has also been evaluated on lap joint brazing during these tests. Table 5 summarizes the impact of wire lateral offsets, electrode vertical offsets, arc length variations, and joint clearances on brazing quality.

These tests have clearly shown that the maximum arc length variation on a lap joint is possible when the wire is located on the lower plate along the joint at a distance equivalent to the wire diameter. The dilution of the upper sheet metal in the molten pool depends on the wire position in the lap joint (it decreases continuously from X = –1 to X = 1 mm).

Figure 9 shows a transversal cut of a 1-mm-thick electrogalvanized, 1-mm joint clearance lap joint brazed with the new process. It proves that the process’s performance with such a joint clearance is
similar to GMA brazing, but that it offers superior bead morphology.

The second step of these tests was to validate the initial test results on actual parts: a coupe model windshield frame assembly (Fig. 10) was selected. The sample provided an all-position welding test under actual industrial conditions (mismatch, joint clearance and dimensional tolerances, and no cleaning before arc brazing).

During the operations, the wire orientation was kept constant. On some occasions, when the initial pass resulted in critical defects or cosmetic problems, a remelting second pass was carried out immediately.

During this brazing test campaign with CuAl and CuSi solid wires, the analysis of some mechanical tensile samples and corresponding microscopic examination showed a narrow border (a few microns) of FeCuSi compound brittle (Ref. 5) in the CuSi braze interface. This braze interface is very different from the one found on CuAl samples. It could explain, at least partially, why CuSi short bead properties are lower than CuAl short bead properties in static conditions.

**Carbon Steel Industrial Applications**

Welding was performed on 1-mm-thick electrogalvanized carbon steel — Fig. 11. The purpose of this trial was to weld the part with a standard solid wire, and to produce weld beads free of surface spatter with low reinforcement. These stringent specifications were required because the welded part had to be installed directly on other components without further cleaning or grinding. The welding operation was performed in the flat and downhill positions with minimum zinc coating degradation.

**Carbon Steel Steering Column**

Another interesting application for the process is welding carbon steel steering column components — Fig. 12. The main requirement is minimum distortion and no spatter, since this part is mounted in a steering column assembly, without subsequent cleaning or grinding.

After satisfactory preliminary tests, the production was launched with very significant cost savings due to improvement of the bead profile and absence of spatters and the elimination of postweld operations.

**The Welding Equipment**

The welding equipment (Fig. 13) consists of the following:

- A dedicated GTA transistorized power source (220 A, 100% DC and DC pulsed current) matched to the torch capacity.

![Table 4 — Galvanized and electrogalvanized sheet metal arc brazing tests results.](image_url)

Table 4 — Galvanized and electrogalvanized sheet metal arc brazing tests results.

<table>
<thead>
<tr>
<th>Joint and wire direction</th>
<th>1 (3/64)</th>
<th>CuAl0.040”</th>
<th>115A</th>
<th>600/min (weaving)</th>
<th>Gas</th>
<th>Appearance</th>
</tr>
</thead>
<tbody>
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<td>Wire behind the electrode</td>
<td>1.5</td>
<td>CuAl0.040”</td>
<td>110A</td>
<td>Arcal 10</td>
<td>80GPM</td>
<td>120A</td>
</tr>
<tr>
<td>Wire in front of the electrode</td>
<td>1.5</td>
<td>CuAl0.040”</td>
<td>110A</td>
<td>Arcal 10</td>
<td>80GPM</td>
<td>120A</td>
</tr>
</tbody>
</table>

![Table 5 — 1-mm (3/32-in.) thick electrogalvanized steel lap joint, 120 A; 1 m/min (40 in./min), ARCAL 10 gas, wire located behind the electrode.](image_url)

Table 5 — 1-mm (3/32-in.) thick electrogalvanized steel lap joint, 120 A; 1 m/min (40 in./min), ARCAL 10 gas, wire located behind the electrode.
The power source remote control allows on-the-fly parameter adjustment.

- The torch and harness linked to the push-pull wire feeder unit through a quick Euro connector
- The push-pull wire feeder unit (wire feed speed up to 10 m/min in constant or pulsed wire)
- The equipment is high-frequency protected and fully insulated from the robot, the wire feeder, and the interface signals with opto-couplers.

**The Torch Design**

The torch body (Fig. 14) is water cooled with specifications established in compliance with European Standard EN 60974-7 at a nominal current of 220 A DC, 100% duty cycle, for wire diameters from 0.8 up to 1.2 mm. A new version with improved gas nozzle wire guide rated at 350 A, 100% duty cycle, is also available. The gas nozzle can be removed easily from the torch without opening the liquid coolant circuit. An optional water-cooled gas nozzle is available for high-temperature environments.

Gas flow homogeneity of the torch has been evaluated using the hot wire anemometry test. The electrode is clamped into an electrode holder. It can be replaced automatically within 15 s by the robot using an optional electrode holder changer. This equipment is driven via an on-board PLC control that can be connected to any robot. It contains up to seven electrode holders on its rotary tray.

**Conclusions**

The process offers a new alternative for complying with thin sheet metal robotic welding requirements. The torch concept offers excellent accessibility to complex components; it doesn’t need any complex and dedicated automated system and can be installed on any standard GMAW robot.

Additional features such as an automatic electrode changer and the quick-connect wire feeder torch increase the robot arc welding efficiency significantly. Several tests campaigns with partner customers showed some interest for body-in-white brazing applications. For these applications, the use of CuAl wire allows exceptional mechanical properties without any brittle weld interface and without the difficult-to-remove spatter that has been a main drawback of this type of wire in GMA applications.

The process offers lower distortion on long joints with adequate penetration.

The evolution of new welding power sources, particularly for pulse current control and wire pulsing, promises new applications for the process. These new technologies should, in the near future, allow the process to be used in a larger variety of new welding and possibly surfacing applications.

**References**

2. Panasonic literature
3. Welding Handbook, Vol. 2, Fig. 3.5, Arc shape and fusion zone profiles as a function of the electrode tip geometry in pure argon.
5. Air Liquide internal document expertise 4183.
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Classification of Electrodes for GTAW

Tungsten electrode classifications are based on the chemical composition of the electrode, as noted in Table 1. The table also shows the color identification system for the various classes of tungsten electrodes.

Electrodes must be free of surface impurities or imperfections; therefore, they are produced with either a chemically cleaned finish, in which surface impurities are removed after the forming operation, or a centerless ground finish, in which surface imperfections are removed by grinding.

Following are some brief descriptions of the electrode classifications.

**EWP Electrode Classification.** Pure tungsten electrodes (EWP) contain a minimum of 99.5% tungsten, with no intentional alloying elements. They are considered low-cost electrodes and are normally used for welding aluminum and magnesium alloys. The current-carrying capacity of pure tungsten electrodes is lower than that of the alloyed electrodes. They provide good arc stability when used with alternating current, either balanced-wave or continuous high frequency. The tip of the EWP electrode maintains a clean, balled end that promotes good arc stability. EWP electrodes may be used with DC, but they do not provide the arc initiation and arc stability characteristics offered by thoriated, ceriated, or lanthanated electrodes.

**EWTh Electrode Classification.** In these electrodes, the thermionic emission of tungsten can be improved by alloying the tungsten with metal oxides that have very low work functions. As a result, these electrodes can be used with higher welding currents. Thorium oxide (ThO₂), called thoria, is one such additive. Two types of thoriated tungsten electrodes are available. EWTh-1 and EWTh-2 electrodes contain 1% and 2% thoria, respectively, evenly dispersed through the entire length of the electrodes.

When compared to pure tungsten (EWP) electrodes, thoriated tungsten electrodes provide a 20% higher current-carrying capacity, generally have a longer life, and provide greater resistance to contamination of the weld. Arc starting is easier and the arc is more stable than with pure tungsten or zirconiated tungsten electrodes.

The EWTh-1 and EWTh-2 electrodes were designed for DCEN applications because they maintain a sharpened tip configuration during welding, the desired geometry for DCEN welding operations.

While thorium is a very low-level radioactive material, if welding is to be performed in confined spaces for a prolonged period, or if dust from grinding the electrode might be ingested, special ventilation precautions should be considered.

**EWCe Electrode Classification.** First introduced into the U.S. market in the early 1980s, these electrodes were developed as possible replacements for thoriated electrodes because cerium is not a radioactive element. The EWCe-2 electrodes contain 2% cerium oxide (CeO₂), referred to as ceria. Compared with pure tungsten, the ceriated electrodes facilitate arc starting, improve arc stability, and reduce the rate of vaporization or burn-off. The advantages of ceriated electrodes improve in proportion to increased ceria content. EWCe-2 electrodes operate successfully with AC or DC of either polarity.

**EWLa Electrode Classification.** Electrodes with lanthanum oxide additions were developed at about the same time as the ceriated electrodes and for the same reason — lanthanum is not radioactive. The advantages and operating characteristics are similar to those of the EWCe-2 electrodes.

Three types are available: EWLa-1, EWLa-1.5, and EWLa-2. The EWLa-1 electrodes contain 1% lanthanum oxide (La₂O₃), referred to as lantha. The advantages and operating characteristics of these electrodes are very similar to the ceriated tungsten electrodes. EWLa-1.5 electrodes contain 1.5% of dispersed lanthanum oxide, which enhances arc starting and stability, reduces the tip erosion rate, and extends the operating current range. EWLa-2 electrodes contain 2% dispersed lanthanum oxide; this is the highest volume of oxide of any of the specific, single-additive, AWS-specified electrode types. The high oxide content enhances arc starting and stability, reduces the tip erosion rate, and extends the operating current range.

**EWZr Electrode Classification.** Zirconiated tungsten electrodes (EWZr) contain 0.25% zirconium oxide (ZrO₂). They have welding characteristics that generally fall between those of pure tungsten and thorialed tungsten electrodes. With AC welding, EWZr combines desirable arc stability characteristics and a balled end typical of pure tungsten, with the current capacity and starting characteristics of thorialed tungsten. They have higher resistance to contamination than pure tungsten and are preferred for radiographic-quality welding applications where the tungsten contamination of the weld must be minimized.

**Table 1 — Color Code and Alloying Elements for Various Tungsten Electrode Alloys**

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<tr>
<th>AWS Classification</th>
<th>Color(a)</th>
<th>Alloying Element</th>
<th>Alloying Oxide</th>
<th>Alloyng Oxide %</th>
</tr>
</thead>
<tbody>
<tr>
<td>EWP</td>
<td>Green</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>EWCe-2</td>
<td>Orange</td>
<td>Cerium</td>
<td>CeO₂</td>
<td>2</td>
</tr>
<tr>
<td>EWLa-1</td>
<td>Black</td>
<td>Lanthanum</td>
<td>La₂O₃</td>
<td>1</td>
</tr>
<tr>
<td>EWLa-1.5</td>
<td>Gold</td>
<td>Lanthanum</td>
<td>La₂O₃</td>
<td>1.5</td>
</tr>
<tr>
<td>EWLa-2</td>
<td>Blue</td>
<td>Lanthanum</td>
<td>La₂O₃</td>
<td>2</td>
</tr>
<tr>
<td>EWTh-1</td>
<td>Yellow</td>
<td>Thorium</td>
<td>ThO₂</td>
<td>1</td>
</tr>
<tr>
<td>EWTh-2</td>
<td>Red</td>
<td>Thorium</td>
<td>ThO₂</td>
<td>2</td>
</tr>
<tr>
<td>EWZr-1</td>
<td>Brown</td>
<td>Zirconium</td>
<td>ZrO₂</td>
<td>0.25</td>
</tr>
<tr>
<td>EWG</td>
<td>Gray</td>
<td>Not Specified(b)</td>
<td>—</td>
<td>—</td>
</tr>
</tbody>
</table>

(a) Color may be applied in the form of bands, dots, or other, at any point on the surface of the electrode.

(b) The manufacturer must identify the type and nominal content of the rare earth or other oxide additions.

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

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


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


Educational Opportunities


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

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

CWI/CWE Prep Course and Exam and NDT Inspector Training Courses. An AWS Accredited Testing Facility. Courses held year-round in Allentown, Pa., and at customers’ facilities. Contact: Welder Training & Testing Institute (WTTI). Call (800) 223-9884, e-mail info@wtti.edu, or visit www.wtti.edu.


CWI Preparatory and Visual Weld Inspection Courses. Classes presented in Pascagoula, Miss., Houston, Tex., and Houma and Sulphur, La. 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.augustomack.com/Web%20Seminars.htm.

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

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


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

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

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

### Certification Seminars, Code Clinics and Examinations

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

#### Certified Welding Inspector (CWI)

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

For information on any of our seminars and certification programs, visit our website at [www.aws.org/certification](http://www.aws.org/certification) or contact AWS at (800/305) 443-9353, 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

<table>
<thead>
<tr>
<th>Location</th>
<th>Seminar Dates</th>
<th>Exam Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denver, CO</td>
<td>Feb. 11-16</td>
<td>NO EXAM</td>
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<tr>
<td>Dallas, TX</td>
<td>Mar. 10-15</td>
<td>NO EXAM</td>
</tr>
<tr>
<td>Sacramento, CA</td>
<td>Apr. 14-19</td>
<td>NO EXAM</td>
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<tr>
<td>Pittsburgh, PA</td>
<td>May 19-24</td>
<td>NO EXAM</td>
</tr>
<tr>
<td>San Diego, CA</td>
<td>Jun. 9-14</td>
<td>NO EXAM</td>
</tr>
<tr>
<td>Orlando, FL</td>
<td>Sept. 8-13</td>
<td>NO EXAM</td>
</tr>
<tr>
<td>Dallas, TX</td>
<td>Oct. 20-25</td>
<td>NO EXAM</td>
</tr>
</tbody>
</table>

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

### Certified Welding Supervisor (CWS)

<table>
<thead>
<tr>
<th>Location</th>
<th>Seminar Dates</th>
<th>Exam Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Houston, TX</td>
<td>Jan. 28-Feb. 1</td>
<td>Feb. 2</td>
</tr>
<tr>
<td>Baton Rouge, LA</td>
<td>Mar. 31-Apr. 4</td>
<td>Apr. 5</td>
</tr>
<tr>
<td>Atlanta, GA</td>
<td>Apr. 28-May 2</td>
<td>May 3</td>
</tr>
<tr>
<td>Columbus, OH</td>
<td>May 19-23</td>
<td>May 24</td>
</tr>
<tr>
<td>Minneapolis, MN</td>
<td>Jun. 23-27</td>
<td>Jun. 28</td>
</tr>
<tr>
<td>Atlanta, GA</td>
<td>Jul. 14-18</td>
<td>Jul. 19</td>
</tr>
<tr>
<td>Philadelphia, PA</td>
<td>Aug. 18-22</td>
<td>Aug. 23</td>
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<tr>
<td>Atlanta, GA</td>
<td>Sept. 15-19</td>
<td>Sept. 20</td>
</tr>
<tr>
<td>Tulsa, OK</td>
<td>Oct. 20-24</td>
<td>Oct. 25</td>
</tr>
<tr>
<td>Atlanta, GA</td>
<td>Nov. 17-21</td>
<td>Nov. 22</td>
</tr>
</tbody>
</table>

CWS exams are also given at all CWI exam sites.

### Certified Radiographic Interpreter (CRI)

<table>
<thead>
<tr>
<th>Location</th>
<th>Seminar Dates</th>
<th>Exam Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indianapolis, IN</td>
<td>Feb. 11-15</td>
<td>Feb. 16</td>
</tr>
<tr>
<td>Houston, TX</td>
<td>Mar. 10-14</td>
<td>Mar. 15</td>
</tr>
<tr>
<td>Philadelphia, PA</td>
<td>Apr. 14-18</td>
<td>Apr. 19</td>
</tr>
<tr>
<td>Nashville, TN</td>
<td>May 19-23</td>
<td>May 24</td>
</tr>
<tr>
<td>Manchester, NH</td>
<td>Jun. 9-13</td>
<td>Jun. 14</td>
</tr>
<tr>
<td>St. Louis, MO</td>
<td>Aug. 18-22</td>
<td>Aug. 23</td>
</tr>
<tr>
<td>Denver, CO</td>
<td>Sept. 15-19</td>
<td>Sept. 20</td>
</tr>
<tr>
<td>Seattle, WA</td>
<td>Nov. 17-21</td>
<td>Nov. 22</td>
</tr>
</tbody>
</table>

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

### Certified Welding Educator (CWE)

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

### Senior Certified Welding Inspector (SCWI)

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

### Certified Welding Fabricator

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

### Code Clinics & Individual Prep Courses

The following workshops are offered at all sites where the CWI seminar is offered (code books not included with individual prep courses): Welding Inspection Technology (general knowledge and code books not included with individual 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.
The American Welding Society elected its new slate of national officers Nov. 12 at the AWS Annual Meeting held at the FABTECH International & AWS Welding Show in Chicago, Ill. The officers took their posts on Jan. 1.

Gene E. Lawson was elected president. Lawson is senior territory sales manager for ESAB Welding and Cutting Products. He represents the company’s southern California, Arizona, and Hawaii territory.

Victor Y. Matthews, an AWS Distinguished Member and past District 10 director, was elected to his third term as an AWS vice president. He has been a member of the Cleveland Section for 39 years.

John C. Bruskotter was elected to his second term as an AWS vice president. He operates Bruskotter Consulting Services, working for an independent oil and gas operator. He has been a chairman of the New Orleans Section and served as a past District 9 director.

John L. Mendoza was elected to his first term as an AWS vice president. Mendoza, a past District 18 director, is a journeyman welder, AWS Certified Welding Inspector, and Certified Welding Educator. He has performed power plant maintenance for CPS Energy, San Antonio, Tex., for 32 years.

Bruce Albrecht was elected to his second term as an AWS director-at-large. He has worked with Miller Electric Co. and other ITW welding companies since 1984, involved with product design, manufacturing, and product sales. Currently, he is vice president and managing director, ITW Welding Technology Center, and serves as vice chairman of the board of trustees at Edison Welding Institute, and chairman of the arc welding section of the National Electrical Manufacturers Association.

David L. McQuaid has been elected to his first term as an AWS director-at-large. He has operated D. L. McQuaid & Associates in Pittsburgh, Pa., since 1999, providing consulting services for the structural, bridge, and pressure vessel industries.
Ken Stockton has been elected to serve a second term as District 2 director. He received his AS degree in mechanical drafting from Middlesex County College, N.J., in 1975 and continued his education at the General Technical Institute of Welding in Linden, N.J. In 1994 he attended the Hobart Institute of Welding Technology, and in 1996 the Hellier NDT Institute. He has been an active AWS Certified Welding Inspector and an AWS Certified Welding Educator since 1994.

Steve Mattson has been elected District 5 director. Mattson began his career in the welding industry in 1986 after serving in the military. He started a welding equipment service and repair facility business in Jacksonville, Fla., that has operated for more than 20 years. Mattson has been active in the North Florida Section for more than 20 years where he has served in all levels of the Section executive committee. Currently, he is Section secretary.

Joe Livesay was elected District 8 director. Livesay, an AWS Certified Welding Educator (CWE), is an instructor at the Tennessee Technology Center welding program. He has hosted numerous welding competitions. His teams have ranked high in the SkillsUSA contests.

Efthios T. (F.T.) Siradakis has been elected to serve a second term as District 11 director. He has been a member of the AWS Saginaw Valley Section since 1982, where he has held all Section offices. He has been employed by Airgas Great Lakes, a regional company of Airgas Inc., for 24 years, serving as sales representative, branch manager, and strategic account manager.

Tully Parker has been elected to serve a second term as District 14 director. An AWS Senior Welding Inspector, he has served as a district manager for Miller Electric Mfg. Co., in St. Louis, Mo., since 1990. Parker has been an AWS member since 1971, serving the St. Louis Section in many offices, including chairman (1997–1998).

J. J. Jones has been elected District 17 director. Jones worked 20 years as a welding instructor with industry, secondary, and higher-education institutes. He is currently a technical sales manager for region 300 of Thermadyne Industries, where he is responsible for assisting distributors and end users with the company’s complete line of welding products. He contributed to the AWS Welding Handbook, ninth edition, where he authored welding processes.

John Bray has been elected District 18 director. Since 1996, Bray has served as president of Affiliated Machinery, Inc., Pearland, Tex., one of the Associated Equipment LP companies. An AWS member since 1988, Bray was elected to the Houston Section Membership Committee in 1989 and has since served in most posts including Section chairman.

William A. Komlos has been elected District 20 director. An AWS member since 1979, he is an AWS Senior Certified Welding Inspector and a Certified Welding Educator. Komlos launched Arc Tech, LLC, Salt Lake City, Utah, in 1999 where he provides project support to manufacturing and steel-erection companies and presents training seminars to manufacturing personnel and engineers.
New AWS Supporters

Sustaining Company
Fan Equipment Co., Inc.
3925 W. Sunset Rd.
Las Vegas, NV 89118
www.fanequipment.com
Representative: Timothy J. Harris
Fan Equipment Co., Inc., has been designing and manufacturing heavy-duty air-moving equipment for more than 40 years. It provides engineering support and product reliability for applications serving the power-generation, petrochemical, pulp and paper, pharmaceutical, pollution control, synthetic fibers, and other industries. Visit the Web site or e-mail info@fanequipment.com for more information and quotes.

Supporting Companies
Control Total de Calidad en
Procedimientos de Soldadura SA de CV
Calle Fuente de Diana #165, Colonia Metropolitana Segunda Sección
Cd. Nezahualcoyotl, DF 57740, Mexico
Fenestration Testing Laboratory, Inc.
8148 NW 74th Ave.
Medley, FL 33166
Lake Welding Supply
363 Ottawa St.
Muskegon, MI 49442
Zamil Steel Industries, SSD/PEG
2nd Ind. City, Al Hasa St. Ext.
Dammam, Eastern 31421
Kingdom of Saudi Arabia

Affiliate Companies
A Ultimate Fabrication & Welding Services, Inc.
8011 Monetary Dr., Unit A-4
Riviera Beach, FL 33404
Champion Welding Alloy, Inc.
7619 Detour Ave.
Cleveland, OH 44103
Collado Ryerson S.A.
PO Box 6140
Brownsville, TX 78521
Iron Star Welding
13827 84th St. NE
Lake Stevens, WA 98258
Isolux Ingenieria S.A. Emesa
Parque Empresarial De Coiros
15316 Spain
Magnetic Radiation Labs, Inc.
690 Hilltop Dr.
Itasca, IL 60143
Quantum Structure & Design
d.b.a. Clear Channel Outdoor
2145 S. Moen Ave #3, Joliet, IL 60436
Scully Steel
12 Cash Dr.
Carson City, NV 89706
Standard Machine Co.
PO Box 10464
Albuquerque, NM 87184
TNT Ironworks, LLC
3675 E. Post Rd., Ste. B
Las Vegas, NV 89120
Viking Diving Services
PO Box 9487
Port Saint Lucie, FL 34985
Welder Supply Co., Inc.
139 Castle Coakley, PO Box 1129
Christiansted, St. Croix, VI 00821

Welding Distributors
Forney Industries, Inc.
1830 Laporte Ave.
Fort Collins, CO 80521

Educational Institutions
Advanced Technology Institute
5700 Southern Blvd.
Virginia Beach, VA 23462
Clearfield Job Corps Center
20 W. 1700 S.
Clearfield, UT 84016
Sequel Youth Services of Iowa
1820 N. 16th St.
Clarinda, IA 51632
St. Johns Institute of Welding Technology
Merryland Bldgs., near Head Post Office
Pathanamthitta, Kerala 689645, India
Walters State/GRV Center for Technology
1121 Hal Henard Rd.
Greenville, TN 37743

Nominees Solicited for Robotic Arc Welding Awards

Nominees are solicited for the 2009 Robotic and Automatic Arc Welding Award. December 31 is the deadline for submitting nominations.

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

Send your nomination package to Wendy Sue Reeve, awards coordinator, 550 NW LeJeune Rd., Miami, FL 33126. For more information, contact Reeve at wreeve@aws.org, or call (800/305) 443-9353, ext. 293.

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

Prof. Koichi Masubuchi Award Nominees Sought

October 10, 2008, is the deadline for submitting nominations for the 2009 Prof. Koichi Masubuchi Award, sponsored by the Dept. of Ocean Engineering at Massachusetts Institute of Technology.

It is presented each year to one person who has made significant contributions to the advancement of materials joining through research and development. The candidate must be 40 years old or younger, may live anywhere in the world, and need not be an AWS member. The nomination should be prepared by someone familiar with the research background of the candidate. Include a résumé listing background, experience, publications, honors, awards, plus at least three letters of recommendation from researchers. This award was established to recognize Prof. Koichi Masubuchi for his numerous contributions to the advancement of the science and technology of welding, especially in the fields of fabricating marine and outer space structures.

Submit nominations to Prof. John DuPont at jndl@lehigh.edu.
Tech Topics

A2.4 Inquiry
Re: A2.4, Standard Symbols for Welding, Brazing, and Nondestructive Examination

Inquiry: Please review the welding symbols indicated in the figure and post the AWS interpretation for them, including how to measure the groove weld size.

Note: The figure has been redrawn by the Committee members for clarity.

Official Committee Response

1. The drawing shows three welding symbols, one with a combination weld with a fillet weld of unspecified size on the arrow side and a 0.2 in.-deep 45-deg bevel groove preparation with zero root opening on the other side for the web of the attaching channel. The other two welding symbols have combination welds with fillet welds of unspecified size on the arrow side and a 0.2 in.-deep bevel groove preparation with no specified bevel angle or root opening on the other side for the web of the attaching channel.

2. The welding symbols are improper. Contrary to subclause 5.16 of AWS A2.4:2007, U.S. Customary and SI Units, the same system that is the standard for the drawings shall be used on welding symbols. Dual units shall not be used on welding symbols. If it is desired to show conversions from U.S. Customary Units to SI Units, the same system that is the AWS interpretation for them, include them on the drawings.

3. Four other items need discussion:
   a) The fillet weld size is not described. However, as noted in subclause 7.1.3, Drawing Notes, the dimensions of fillet welds covered by drawing notes need not be repeated on the welding symbols. Fillet welds may be sized by other means not apparent in the inquiry.
   b) The groove angle and root opening are missing from the two upper welding symbols. While it is not mandatory to have groove dimensions on the welding symbols, the committee notes that the lack of dimension information can lead to misinterpretation of the groove welding requirements.
   c) As noted by subclause 6.27, Depth of Bevel Specified, Groove Weld Size Not Specified. A welding symbol with a depth of bevel specified, and the groove weld size not included and not specified elsewhere, may be used to specify a groove weld size not less than the depth of the bevel. In regard to the size of the bevel groove weld, the Committee notes that the “specified elsewhere” provision needs further exploration. For example, the code or specification referenced on the drawing may have a size provision for prequalified partial penetration bevel groove joints that defines the groove weld size as being a specified dimension less than the bevel preparation. (e.g., AWS D1.1, Fig. 3.3).
   d) Finally, the inquirer requested “how to measure” groove weld size. AWS A2.4 does not have a provision for measurement of welds. Rather, it’s a method of conveying welding information. The provisions of the various fabrication standards describe the specification of welding requirements including nondestructive examination that includes the measurement of welds.

Technical Committee Meetings

All AWS technical committee meetings are open to the public. Call the staff secretary listed at (305) 443-9353.

D1.1 Interpretation
D1.1, Structural Welding Code — Steel

Subject: Visual Inspection of Studs
Code Edition: D1.1:2004
Code Provision: Subclause 7.5.5
AWS Log: D1.1-04-I03

Inquiry: Are studs that are welded using the SMAW, GMAW, or FCAW processes subject to the visual inspection requirements of paragraph 5.26, Fig. 5.4, and the visual acceptance criteria listed in Table 6.1?

Response: Studs welded using an approved welding process as listed in Clause 7.5.5 must meet the fillet weld profile requirements of Clause 5.24 and the requirements of Table 6.1. Visual Inspection Acceptance Criteria for the applicable service conditions (static, cyclic, or tubular). Visual inspection of hand-welded studs is specified in Clause 7.5.5.7 (this clause in turn refers to Clause 6.6.1, which refers to Table 6.1 which references to Clause 5.2.4).

New Standard Project
Development work has begun on the following new standard. Directly and materially affected individuals are invited to contribute to the development of this standard. Those wanting to participate on the committee should contact staff engineer Brian McGrath, ext. 311.
D10.18M/D10.18:200X, Guide for Welding Ferritic/Austenitic Duplex Stainless Steel Piping and Tubing. This standard presents a detailed discussion of the metallurgical and welding characteristics and weldability of duplex stainless steel used in piping and tubing. A number of tables and graphs are presented to illustrate the text. Stakeholders: DSS and SDSS pipe and tube fabricators, and educators.

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 the following standard may be obtained from Rosalinda O’Neill, ronell@aws.org; (305) 443-9353, ext. 451.

ISO Drafts for Public Review
Copies of the following Draft Inter-
national Standard 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 5171, Gas welding equipment — Pressure gauges used in welding, cutting, and allied processes.

Standards Approved by ANSI


This year, for the first time, a new program instituted by the AWS board of directors, whereby members who achieved 25, 35, and 50 years of service during the calendar year, were offered the option to receive their certificates from the AWS president.

The recognition ceremony took place during the Section Appreciation Lunch, held in conjunction with the recent FABTECH International & AWS Welding Show. The Years-of-Service recognition ceremony will be an annual event. President Gerald Uttrachi made the presentations.

Life Member Certificates (for 35 years of service) were presented to John A. Beyer Jr., Richard W. Connelly Sr., Richard J. Davis, Louis M. Dumez, Douglas M. Kloss, Kevin A. Lyttle, Michael T. Merlo, Ralph M. Nugent Jr., Slavko Panezic, Thomas A. Stewert, and Carl E. Walter.

Silver Member Certificates (for 25 years of service) were presented to James E. Davis, William P. Dawson, Philip O. DeSouza, Danny I. Moore, Michael J. Morlock, Richard G. Peck, Johnyeng Peng, Grahame L. Savage, Mike Skiles, and Michael Young.

Member certificate awards were presented to AWS Life Members (top photo) for 35 years of service, and Silver Membership Certificates to members (bottom photo) with 25 years. The presentations were made by AWS President Gerald Uttrachi (far right, bottom photo) at the FABTECH International & AWS Welding Show in Chicago.
Listed are the members participating in the 2007–2008 AWS Member-Get-A-Member Campaign for the period between June 1, 2007, and May 31, 2008. For campaign rules and a prize list, see page 69 of this Welding Journal. Standings are as of 11/16/07. If you have any questions regarding your member proposer points, call the Membership Department, (800) 443-9353, ext. 480.

**Winner’s Circle**

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

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

**President’s Guild**

Members sponsoring 20 or more Individual Members.

- L. Taylor, Pascagoula — 88

**President’s Club**

AWS Members sponsoring 3–8 new Individual Members.

- E. Ezell, Mobile — 8
- S. Christensen, Nebraska — 7
- R. Ellenbecker, Fox Valley — 7
- A. Castro, South Florida — 6
- K. Kotter, Utah — 4
- D. Wright, Kansas City — 4
- L. Garner, Mobile — 3
- C. Gilbert, East Texas — 3
- P. Hanley, Peoria — 3
- T. Nielsen, Pittsburgh — 3

**Member-Get-A-Member Campaign**

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

- J. Compton, San Fernando Valley
- D. Daugherty, Indiana
- R. Gaffney, Tusla
- W. Galvery Jr., Long Beach/Or. County
- H. Jackson, L.A./Inland Empire
- C. Johnson, Northern Plains
- J. Johnson, Northern Plains
- D. Landon, Iowa
- F. Schmidt, Niagara Frontier
- A. Sumal, British Columbia
- R. Wright, San Antonio
- P. Zammit, Spokane

**Student Member Sponsors**

Members sponsoring 3 or more new AWS Student Members.

- D. Berger, New Orleans — 38
- G. Euliano, Northwestern Pa. — 34
- R. Evans, Siouxland — 34
- T. Zablocki, Pittsburgh — 28
- M. Anderson, Indiana — 26
- G. Seese, Johnstown-Altoona — 19
- C. Kipp, Lehigh Valley — 18
- M. Arand, Louisville — 16
- T. Moore, New Orleans — 15
- C. Overfelt, SW Virginia — 14
- A. Stute, Madison-Beloi — 14
- R. Munns, Utah — 12
- T. Buchanan, Mid-Ohio Valley — 10
- R. Tully, San Francisco — 10
- P. Bedel, Indiana — 9
- R. Hutchinson, Long Beach/Or. Cty. — 9
- D. Williams, North Texas — 9
- A. Badeaux, Washington D.C. — 8
- W. Komlos, Utah — 8
- C. Schiner, Wyoming Section — 8
- J. Boyer, Lancaster — 7
- H. Hughes, Mahoning Valley — 7
- R. Hutchison, Long Beach/Or. Cty. — 7
- L. Smerglia, Cleveland — 7
- W. Troutman, Cleveland — 7
- J. Boyer, Lancaster — 6
- D. Kowalski, Pittsburgh — 6
- E. Norman, Ozark — 6
- B. Wenzel, San Francisco — 6
- B. Hardin, San Francisco — 5
- D. Vranich, North Florida — 5
- J. Angelo, El Paso — 4
- J. Craiger, Indiana — 4
- S. Robeson, Cumberland Valley — 4
- T. Shirk, Tidewater — 4
- L. Taylor, Pascagoula — 4
- N. Carlson, Idaho/Montana — 3
- A. Kitchens, Olympic Section — 3
- W. Galvery Jr., Long Beach/Or. Cty. — 3
- J. Geesey, Pittsburgh — 3
- R. Olesky, Pittsburgh — 3
- C. Rossi, Washington D.C. — 3
- L. Taylor, Pascagoula — 2

**Standings**

<table>
<thead>
<tr>
<th>Standings</th>
<th>Members</th>
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<tbody>
<tr>
<td>Individual</td>
<td>47,034</td>
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<tr>
<td>Student + transitional</td>
<td>5,620</td>
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<tr>
<td>Total members</td>
<td>52,654</td>
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<tr>
<td>Corporate members</td>
<td>3,654</td>
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<tr>
<td>Total corporate members</td>
<td>1,673</td>
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</tbody>
</table>

**Total Membership Counts**

- Total members: 52,654
- Student + transitional members: 5,620
- Individual members: 47,034
- Corporate members: 1,673
- Welding distributor: 50
- Affiliate: 419
- Educational: 442
- Supporting: 292
- Sustaining: 470
- Grades: 470
Three Sections Cited for Their Scholarship Achievements

The AWS Detroit, Houston, and Santa Clara Valley Sections were recognized at the recent FABTECH International & AWS Welding Show with “Proud sponsor of Welding for the Strength of America” banners for establishing Named Scholarships.

The new scholarships are Detroit Arc Welding — District 11 Named Scholarship; Detroit Resistance Welding — District 11 Named Scholarship; Ron Theiss — Houston Section Named Scholarship; and Lou DeFreitas — Santa Clara Valley Named Scholarship.

Ron Pierce, chairman, AWS Foundation board of trustees, and Sam Gentry, executive director, presented the banners to Detroit representatives Don DeCorte and Chairman David Beneteau; Houston Section Chair John Husfeld and Gerald Koza Jr.; and to District 22 Director Dale Flood, representing the Santa Clara Valley Section.

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

BOSTON
November 5
Activity: The Section members toured the Pipefitters Association Local Union 537 training facility in Dorchester, Mass. James Walsh, training coordinator, and his assistant, Tim Gilligan, led the program. The facility runs a five-year apprenticeship program in conjunction with on-the-job training in the heating, ventilation, air-conditioning, and refrigeration (HVACR) industry for about 400 students. Following the tour, the members met at Harp & Bard Restaurant in Boston. Russ Norris, District 1 director, and students from Plymouth Tech High School attended the program.

Tim Gilligan (far right) describes pipe welding for Plymouth Tech High School students at the Boston Section program.

Shown at the Boston Section program are (from left) presenter Tim Gilligan, Section Chair Tom Ferri, and presenter Jim Walsh.
Bob Wlazlowski, hospitality chair, is shown at the New Jersey Section program.

NEW JERSEY
OCTOBER 16
Speakers: Rich Jordan and Randall Dry with Orgo-Thermit, Inc., and Roger Hornberger with Tempil. Topics: The thermit welding process and temperature-indicating devices
Activity: The Section voted to donate $200 to the USO to purchase phone cards for service personnel overseas. The program was held at L’Affaire Restaurant in Mountainside, N.J.

PHILADELPHIA
NOVEMBER 15
Activity: The Section members met at the Miller Electric Mfg. Co. facility in Swedesboro, N.J. Charlie Minnick presented a PowerPoint® review and a video detailing several welding processes. Following the talk, Minnick and Tim Stot conducted the group on a plant tour.

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

LANCASTER and READING
OCTOBER 9
Activity: Members of the Lancaster and Reading Sections met at G/S/M Industrial, Inc., in Lancaster, Pa., for a tour of its new facilities. The company provides custom metal fabrications for air-pollution control, and the quarry and ethanol-production industries.

YORK-CENTRAL PA. and LANCASTER
NOVEMBER 1
Activity: The York-Central Pennsylvania and Lancaster Sections jointly held a golf outing and meeting at Heritage Hills Golf & Conference Center in York, Pa. The meeting featured a DVD, handouts, and photographs of the Alaskan pipeline with a presentation by Dave Herr, York Central Pa. chairman. The winning golfers were Tony Kaz, Johnstown Section Chair Bart Sickles, District 7 Director Don Howard, and Tyler Williams.

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

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

FLORIDA WEST COAST
NOVEMBER 14
Activity: James McLeod, president, SEACO Mfg. Co., and Tom Christ, manufacturer’s representative, All-State Prest-O-Lite, demonstrated several thermal spray restoration, wear, and corrosion protection techniques. The meeting was held in Tampa, Fla.

SOUTH CAROLINA
OCTOBER 18
Activity: The Section members toured Alpha Sheet Metal Works in Ladson, S.C. Joe Schady, president and owner, conducted the program for the 36 attendees.

NOVEMBER 15
Speaker: Carl Matricardi, Atlanta Section chairman
Affiliation: Welding Solutions, Inc., president
Topic: Billboard weld failures
Activity: This South Carolina Section program was held at Trident Technical College in Charleston, S.C.

DISTRICT 6
Director: Neal A. Chapman
Phone: (315) 349-6960
Members of the Lancaster and Reading Sections are shown at their joint meeting at G/S/M Industrial, Inc., in October.

Members of the York-Central Pennsylvania and Lancaster Sections are shown at their joint meeting in November.

Shown at the Florida West Coast Section program are Chairman Al Sedory (center) with speakers Tom Christ (left) and James McLeod.

Atlanta Section Chair Carl Matricardi (right) receives a speaker award from Odell Haselden, South Carolina Section treasurer, at the November 15 South Carolina Section meeting.

Shown at the October 18 South Carolina Section program are (from left) Joey Schady, Robert Harrison, Alpha Sheet Metal Works President Joe Schady, Section Chairman Gale Mole, and Richard Temple.

Florida West Coast Section members are shown at their Nov. 14 program.
Mark Dryjka (left) and John Sullivan set up a spool gun at the Niagara Frontier Section program.

Jack Melsom (right) accepts a speaker gift from Bruce Lavalle, chairman of the Northern New York Section, following the tour of the AWESCO facilities in October.

Shown at the November Northern New York Section program are (from left) Chair Bruce Lavalle, speaker Dale Kapuscinski, and Keith Flood, treasurer.

NIAGARA FRONTIER
OCTOBER 30
Activity: The Section members met at QIS Services in Buffalo, N.Y., for a students’ night program. Tom Matecki, welding instructor, discussed the AWS SENSE program and student concerns. Mark Dryjka and John Sullivan assisted with setting up the equipment.

NORTHERN NEW YORK
OCTOBER 2
Activity: The Section members toured AWESCO in Albany, N.Y., to study the manufacture of welding equipment and materials. Jack Melsom conducted the program, including visits to the company’s new specialty gas lab, fill plant, and facilities for cylinder repair and maintenance.

OCTOBER 6
Speaker: Dale Kapuscinski, district manager
Affiliation: The Lincoln Electric Co., Syracuse, N.Y.
Topic: Power supply waveform technology
Activity: Northern New York Section Chairman Bruce Lavalle received the Section Meritorious Award from Bob Christoffel in recognition of his establishment and maintenance of the Donald C. Scarborough Student Chapter at Coxsackie Correctional Facility. Lavalle also serves as advisor to the Student Chapter.

DISTRICT 7
Director: Don Howard
Phone: (814) 269-2895
DAYTON
OCTOBER 5
Activity: The Section hosted its annual golf outing at Sugar Isle Golf Course in New Carlisle, Ohio. The event, held for 26 participants, raised more than $700 for its Les Vesey Scholarship Fund. The Section sponsors fall scholarships to support students attending the Hobart Institute of Welding Technology, and spring scholarships awarded to Section members enrolled in two- or four-year welding programs at local colleges.

DISTRICT 8
Director: Joe Livesay
Phone: (931) 484-7502
CHATTANOOGA
OCTOBER 23
Speaker 1: Buster Hales, head design engineer at Specialty Welding & Machining
Speaker 2: Franklin Turner, chief formulator at Electrode Engineering/Euroweld
Topic: Strip cladding and manufacturing of coated electrodes
Activity: The talks included demonstrations and technical information of the submerged arc strip cladding process and explanation of electrode formulation and extrusion techniques. Richard Daffron of Holston Gases was awarded the AWS Silver Membership Certificate for 25 years of service to the Society. Ted Ward was recognized for his 50 years of service and direction in the U.S. power industry.

HOLSTON VALLEY
NOVEMBER 13
Speaker: Charlie Tiller, apprentice ship coordinator
Affiliation: Eastman Chemical Co. (ECC), Kingsport, Tenn.
Topic: Welding careers and the apprenticeship programs offered at ECC
Activity: Discussed was how the ECC training works with Northeast State College and other schools to coordinate with its degree programs. The meeting was held at Ryan’s Steak House Restaurant in Kingsport, Tenn.

NE MISSISSIPPI
SEPTEMBER 20
Activity: The Section members toured the Weavexx facility in Starkville, Miss., a supplier of forming fabrics, press felts, and dryer fabrics for the pulp and paper industry.

OCTOBER 18
Activity: The Northeast Mississippi Section members toured the Tower Automotive plant in Canton, Miss. The company is a supplier of car and truck frames for Nissan North America.
Shown in October, the NE Mississippi Section members pose during their tour of the Tower Automotive plant in Canton, Miss.

Richard Daffron received his Silver Membership Certificate at the Chattanooga Section meeting.

Ted Ward (left) was recognized for his 50 years of contributions to industry by Buster Hales at the Chattanooga Section program.

The NE Mississippi Section members are shown during their tour of the Weavexx facility in September.

Educator Patricia Merrick accepts a speaker gift from Barry Carpenter, Baton Rouge Section chairman.

Franklin Turner (far right) discussed formulating shielded meal arc electrodes for Chattanooga Section members.

WESTERN CAROLINA
OCTOBER 16
Speaker: Jim Leylek, a professor and director, Computational Center for Mobility
Affiliation: Clemson University
Topic: The ICAR wind tunnel under construction in Greenville, S.C.
Activity: In attendance were John Bowman from ASNT, Warren Miglietti from ASM Int’l, and Eric Eberius, chairman of the ASNT Piedmont Chapter. The program was held at Holiday Inn in Greenville, S.C.

DISTRICT 9
Director: George D. Fairbanks
Phone: (225) 673-6600

BATON ROUGE
OCTOBER 25
Activity: The Section members met at Louisiana Tech College in Baton Rouge,
La., for a program airing educational issues in the community. Patricia Merrick, educational director for Louisiana high schools, and John Easley, educational director, Louisiana technical colleges, made presentations on welding and craft education in Louisiana high schools and technical colleges. The talks were followed by an hour of questions and comments from the audience. Anthony Blakeney, Baton Rouge Section Image of Welding chairman and Southeastern Louisiana University Student Chapter advisor, gave a presentation titled ‘Sections and the Shortage of Welders’ at the Section Appreciation Luncheon held during the FABTECH International & AWS Welding Show in Chicago.

NEW ORLEANS
OCTOBER 16
Speaker: Bree Allen
Affiliation: Bocage
Topic: Portable x-ray fluorescence (XRF) testing units
Activity: The meeting was held at the Boomtown Casino in New Orleans, La. Section Chair Travis Moore presented a host award plaque to Allen Gibbs and a speaker plaque to Bree Allen. Martin Kafferburger won the 50-50 raffle prize.

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

CLEVELAND
OCTOBER 9
Speaker: Omer W. Blodgett, P.E.
Affiliation: The Lincoln Electric Co.
Topic: Lessons I have learned
Activity: Dennis Klingman, Section Treasurer Harry Sadler, and Dan Harrison were presented District 10 Director Awards for their work and achievements in the welding industry. The District CWI of the Year Award was presented to Section Secretary Mark Demchak. Ryan Ebanks, Auburn Career Center, was cited for his students winning top spots in the Ohio and national welding competitions.

DRAKE WELL
NOVEMBER 6
Activity: The Section members toured the Joy Mining Machinery facility in Franklin, Pa. The company employs more than 200 welders to fabricate machinery used for underground mining. Michael Owens, CWI, CWE, senior welding engineer, detailed the company’s manufacturing operations at the meeting following the tour.

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

DETROIT
NOVEMBER 8
Speaker: Rob Cunningham, consulting engineer
Topic: Techniques for joining plastics to metal
Activity: The meeting was held at Ukrainian Cultural Center in Warren, Mich.

DISTRICT 12
Director: Sean P. Moran
Phone: (920) 954-3828
Shown at the Chicago Section board meeting are (from left) Chairman Craig Tichelar, Cliff Iftimie, Vice Chair Hank Sima, Pete Host, and Eric Krauss.

Welding students present their instructor Charlie Smith a certificate of appreciation at the Chicago Section meeting.

Welding instructor Mike Pellegrino (far right) receives a certificate of appreciation from his students at the Chicago Section program.

The St. Louis Section members toured St. Louis Testing Labs in October.
Shown at the Northwest Section clay shoot are (seated, from left) Todd Bridigum, Tom Laberda, Tom LaVenture, and Rick Laberda; (standing, from left) Duane Pederson, Chairman Dale Szabla, District 15 Director Mace Harris, Michael Affeldt, Austin Harris, and Dwight Affeldt.

Shown at the East Texas Section program are LeTourneau University Student Chapter officers (from left) Jerica Cadmen, vice chair; Nathaniel Horton, publicity chair; Chairman Richard Baumer; Ken Bean, secretary; and Advisor Robert Warke.

Presenters at the East Texas Section program included (from left) Prof. Robert Warke and LeTourneau University students Devin Hartshorn, Ken Bean, and Ben Lacy.
sidered titanium. Prof. Warke followed with an in-depth address on weld cracking mechanisms with supporting case histories. Among the 87 attendees were members of the LeTourneau University Student Chapter. Introduced were Chapter Chair Richard Baumer, Vice Chair Jerica Cadmen, Secretary Ken Bean, and Nathaniel Horton, publicity chair. Robert Warke is the faculty advisor.

NORTH TEXAS
NOVEMBER 13
Speaker: Firdosh Mehta, director of engineering
Affiliation: Perry Equipment Corp.
Topic: Welding duplex stainless steel in the heat exchanger industries
Activity: The Section has modified its door prize to benefit the Dallas food bank. Attendees must donate a can of food to receive a door prize ticket. The Section also announced a silent auction to raise funds for its scholarship program. At this meeting, the door prize winner was Curtis Jenkins, an instructor at ATI Career Training Center. The meeting was held at Golden Coral in Irving, Tex.

TULSA
SEPT. 27–OCT. 7
Activity: Section members manned an inside booth displaying and an outside location promoting welding at the Tulsa State Fair. Among the presenters donating their time and expertise were Mike Thurber from Tulsa Welding School, Paul Morgan, retired, and Doug Sewell and Mike Hacker from Linde BOC process plants.

DISTRICT 18
Director: John Bray
Phone: (281) 997-7273

HOUSTON
OCTOBER 21
Activity: The Section hosted a special program to celebrate its 70th anniversary. Doug Kloss received his AWS Life Membership Certificate Award for 35 years of service to the Society. Kenneth Wagner was presented the AWS Silver Certificate Award for 25 years of service. The event was held at Brady’s Landing in Houston, Tex.

SAN ANTONIO
OCTOBER 10
Speaker: Morris Weeks, president
Affiliation: Weeks Welding Labs
Topic: Welding procedure development
Activity: District 18 Director John Mendoza presided over the election of officers for the new AWS Alamo Student Chapter. Mendoza presented the District Society News Jan.:Layout 1 12/10/07 3:32 PM Page 65
Shown at the San Antonio Section meeting are the students interested in forming the new Alamo Student Chapter.

Displaying their awards received at the San Antonio Section program are (from left) Cornelio Ontiveros, Howard Thomas, and John Mendoza Jr.

Displaying their speaker awards at the Northern Alberta Section seminar are John Bringas (left) and Barry Patchett.

Director Award to Cornelio Ontiveros, and San Antonio Section Meritorious Awards to Howard Thomas and John Mendoza Jr.

PUGET SOUND
During the FABTECH International & AWS Welding Show in Chicago, District 19 Director Neil Shannon presented Chuck Daily with special recognition plaques for the three Student Chapters in the Puget Sound Section. Daily, in turn, will present the awards to the Chapter advisors of the Cedarcrest, Mount Vernon, and Stanwood High School Student Chapters who were unable to attend the program.

Stanwood High School Student Chapter
District 19 Director Neil Shannon presented Lena Rink the Outstanding Student Chapter Member Achievement Award following her presentation at the FABTECH International & AWS Welding Show Section Appreciation Luncheon. Rink discussed her Chapter’s activities, fund-raising initiatives, and volunteer work.

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

NORTHERN ALBERTA
OCTOBER 19
Activity: The Section hosted a seminar on welding procedure development and qualification requirements for pressure equipment and pipelines for 90 attendees. The presenters included Barry Patchett (Maglyn Engineering), Bob Roseberg (ABSA), Chris Vrolyk (Qualimet, Inc.), John Bringas (CASTI), Ron Peters (Ludwig & Associates), Rob Lazor (TransCanada Pipelines), and Jacek Mielczarek (Husky Energy). The program was hosted at the Edmonton branch of the Alberta Research Council in Edmonton, Alb., Canada.

COLORADO
OCTOBER 11
Activity: The Section members toured
Harsh International, Inc., in Eaton, Colo., to study the manufacture of truck hoists and cattle feeding trucks. Bob Brown, owner and president, and Orven Adolph, plant superintendent, conducted the program. Peter Jorgenson, a CWI, received his AWS Silver Membership Award for 25 years of service to the Society. Jeff Klein, a CWI/CWE, was presented the Section Educator of the Year Award.

Chuck Daily (left) was honored for his outstanding achievements in building the three Student Chapters in the Puget Sound Section. District 19 Director Neil Shannon presented the award at the FABTECH International & AWS Welding Show in Chicago.

Harsh International, Inc., in Eaton, Colo., to study the manufacture of truck hoists and cattle feeding trucks. Bob Brown, owner and president, and Orven Adolph, plant superintendent, conducted the program. Peter Jorgenson, a CWI, received his AWS Silver Membership Award for 25 years of service to the Society. Jeff Klein, a CWI/CWE, was presented the Section Educator of the Year Award.

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

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

FRESNO
SEPTEMBER 26
Speaker: James Gebert, district manager
Affiliation: Thermadyne
Topic: Plasma arc cutting
Activity: Following the technical presentation, James Gebert displayed the Thermal Dynamics’ mobile demo vehicle, then helped the attendees try their skills using the Cutmaster hand-held plasma arc cutting system. Chairman Brad Bosworth presented the District Director Award to Fred Mattern, Section secretary. The Section Dalton E. Hamilton Memorial CWI of the Year Award was presented to Brian Visher, accepted in his absence by William Kates, Section vice chair.

SAN FRANCISCO
OCTOBER 24
Speaker: Gerald Utrachi, AWS president
Affiliation: WA Technology, LLC, president
Fresno Section Chair Brad Bosworth is shown with speaker James Gebert.

San Francisco Section Chair Tom Smeltzer presents an appreciation award to Past Chair Richard Hashimoto.

Shown at the October San Francisco Section program are (from left) Mark Bell (San Diego chair), Tom Erichsen (Santa Clara chair), Tom Smeltzer (San Francisco chair), Gerald Uttrachi (AWS president), Dale Flood (District 22 director), and Brad Bosworth (Fresno Section chairman).

Fred Mattern (left) receives the District Director Award from Fresno Section Chair Brad Bosworth.

Fresno Vice Chair William Kates (left) accepts Brian Visher’s CWI award from Chairman Brad Bosworth.

Shown at the October San Francisco Section program are (from left) Tom Smeltzer, Rich Hashimoto, Dale Phillips, Liisa Pine Schoonmaker, District 22 Director Dale Flood, Mark Bell, Brad Bosworth, Doug Williams, Corky Bates, AWS President Gerald Uttrachi, Tom Erichsen, Jose Bohorquez, and Jerry Azzaro.

San Francisco Section Vice Chair Liisa Pine Schoonmaker welcomes speaker Paul Tibbals to the lectern.

Topic: Welding race cars
Activity: District 22 Director Dale Flood presented District Dalton E. Hamilton Memorial CWI of the Year Awards to Brad Bosworth (Fresno), Mark Bell (Fresno), Jose Bohorquez (Santa Clara Valley), and Doug Williams (San Francisco). Corky Bates (San Francisco) received the Section Dalton E. Hamilton Memorial CWI of the Year Award. Jerry Azzaro (San Francisco) received the District Meritorious Certificate Award. Tom Erichsen (Santa Clara) and Tom Smeltzer (San Francisco) received District Director’s Awards. Liisa Pine Schoonmaker and Richard Hashimoto (San Francisco) received District Educator Awards. Dale Phillips (San Francisco) accepted the District Private Sector Instructor Membership Award. San Francisco Section Chair Tom Smeltzer presented Rich Hashimoto the Section Meritorious Certificate Award in appreciation for his service as chairman. The event was held at Spencer’s Restaurant in Berkeley, Calif.

November 7
Speaker: Paul Tibbals, metallurgical engineer
Affiliation: Pacific Gas & Electric Co.
Topic: Failures that weren’t the welder’s fault — surprising findings by a metallurgist
Activity: The program was held at Spencer’s Restaurant in Berkeley, Calif.
**Guide to AWS Services**

AWS PRESIDENT  
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(252)

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

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

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

**Administrative Services**  
Managing Director  
Jim Lankford  
jlankford@aws.org  
(214)

IT Director  
Armando Campana  
acampa@aws.org  
(296)

Director  
Hidal Nuñez  
hidal@aws.org  
(287)

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

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

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

**INT’L INSTITUTE OF WELDING**  
Senior Coordinator  
Sissibeth Lopez  
sst@aws.org  
(319)

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

**GOVERNMENT LIASON SERVICES**  
Hugh K. Webster  
hwebster@wc-b.com  
25108 Margurite Pkwy, #165,  
Mission Viejo, CA 92692  
(210) 666-2976; FAX (210) 835-0243

Identifies funding sources for welding education, research, and development. Monitors legisliative and regulatory issues to affect the industry.

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

RWMA — Resistance Welding  
Manufacturing Alliance  
Susan Hopkins  
susan@aws.org  
(205)

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

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

Corporate Director, Exhibition Sales  
Joe Kral  
jkral@aws.org  
(297)

Organizes the annual AWS Welding Show and Convention, regulates space assignments, registration items, and other Expo activities.

**PUBLICATION SERVICES**  
Department Information  
Andrew Cullison  
cullison@aws.org  
(249)

Welding Journal  
Annette O’Brien  
aobrien@aws.org  
(303)

Welding Handbook Editor  
Rob Saltzman  
salty@aws.org  
(296)

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

**MARKETING COMMUNICATIONS**  
Ross Hancock  
rhancock@aws.org  
(226)

Assistant Director  
Adrienne Zalkind  
aazalkind@aws.org  
(416)

**MEMBER SERVICES**  
Department Information  
(480)

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

Director  
Rhenda A. Mayo  
rhenda@aws.org  
(260)

Serves as a liaison between Section members and AWS headquarters. Informs members about AWS benefits and activities.

**CERTIFICATION SERVICES**  
Department Information  
(273)

Managing Director, Certification Operations  
John Filippi  
jfiliippi@aws.org  
(222)

Directs the financial and general operations of the department and provides Committee support.

Managing Director, Technical Operations  
Peter Howe  
phowe@aws.org  
(309)

Manages and oversees the development, integrity, and technical content of all certification programs.

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.

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

Director, Education Services Administration  
John Ospina  
jospain@aws.org  
(462)

Coordinates in-plant seminars and workshops. Administers the SENSE program. Assists Government Liaison Committee and Education Committee. 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  
wwreeve@aws.org  
(293)

Coordinates AWS awards and AWS Fellow and Counselor nominees.

**TECHNICAL SERVICES**  
Department Information  
Andrew R. Davis  
advasis@aws.org  
(466)

Int’l Standards Activities, American Council of the Int’l Institute of Welding (IIW)  
John L. Gayler  
gayler@aws.org  
(472)

Manager, Safety and Health  
Stephen P. Hedrick  
shedrick@aws.org  
(305)

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

**DOMESTIC OFFICES**  
350 NW LeJeune Rd., Miami, FL 33126  
http://www.aws.org  
Phone (800) 235-9353; FAX (305) 443-7559  
(Phone extensions are shown in parentheses.)

**WELDING JOURNAL**  
71
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, or to Damian J. Kotecki, chair, National Nominating Committee.

The next meeting of the National Nominating Committee is scheduled for October 2008. The terms of office for candidates nominated at this meeting will commence January 1, 2010.

Honorary Meritorious Awards

The Honorary-Meritorious Awards Committee makes recommendations for the nominees presented for Honorary Membership, National Meritorious Certificate, William Irgang 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 Irgang Memorial Award: This award is administered by the American Welding Society and sponsored by The Lincoln Electric Co. to honor the late William Irgang. 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

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; vpmyky@aws.org

AWS Mission Statement

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

It is the intent of the American Welding Society to build AWS to the highest quality standards possible. The Society welcomes your suggestions. Please contact any staff member or AWS President Gene E. Lawson, as listed on the previous page.
Aluminum lends itself to a wide variety of industrial applications, but because its chemical and physical properties set it apart from other metals, welding of aluminum requires special processes, techniques, and expertise. At this conference, a distinguished panel of aluminum-industry experts will survey the state of the art in aluminum welding technology and practice.

For more information, please call 1-800-443-9353, ext. 455, or visit us online at www.aws.org/conferences
Multipurpose Welding Machines Pictured

A brochure describes the features of the company’s Multimaster® Models 160 and 260 portable welding machines. Detailed are the units’ abilities for switching easily between gas metal arc, DC gas tungsten arc, or shielded metal arc welding processes, as needed. The brochure may be ordered by phone. Product information sheets may be viewed on the Web site.

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

Stylish Protective Clothing Illustrated in Brochure

A brochure illustrates the company’s new line of BSX (Black Stallion® Xtreme) welding protection gear, including fire-resistant jackets, sweatbands, FireCut™ GTAW and Vulcan™ GMAW gloves, caps, doorags, and sleeve extenders. The products, introduced at the recent FABTECH Int’l & AWS Welding Show, feature a signature black with red-flame design.

Revco Industries, Inc.
www.bsxgear.com
(800) 527-3826

Publication Features Laser Safety Products


Laser Institute of America
www.laserinstitute.org/store
(800) 345-2737

Welder Training Using Virtual Reality Explained

---Continued on page 76
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.

Send in your acceptance form today! (Fee covers printing and shipping costs).

---

☐ YES! I’m an AWS Individual Member, and would like this discounted publication.

AWS Member #  
Name  
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Country  
Phone (  )  
FAX (  )  
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PAYMENT INFO  
$25 fee applies to Domestic AWS Individual Members. International Members will be charged $75 for book selection (note: $50 is for international shipping).

Payment can be made (in U.S. dollars) by check or money order (international or foreign), payable to the American Welding Society, or by charge card

☐ Check  ☐ Money Order  ☐ Bill Me

☐ American Express  ☐ Diners Club  ☐ Carte Blanche  ☐ MasterCard  ☐ Visa  ☐ Discover  ☐ Other

Your Account Number  
Expiration Date (mm/yy)  
Signature:  
Date:  

THREE WAYS TO RESERVE YOUR COPY

☐ Mail this form, along with your payment, to AWS, Attn. Membership Dept., 550 N.W. LeJeune Rd., Miami, FL 33126
☐ Call the Membership Department at (800) 443-9353, ext. 480, or  ☐ Fax this completed form to (305) 443-5647

Office Use Only

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* IMPORTANT: $25 fee applies to Domestic AWS Individual Members. International Members add $75 for book selection (note: $50 is for international shipping). Books will be delivered to the same address as your Welding Journal. Please allow 6-8 weeks for delivery from date of publish (11/07 expected). Offer applies to AWS Individual Members only. Limit of one book per AWS Individual Member. To upgrade your membership, please call (800) 443-9353, ext. 480.
A brochure describes the company’s ARC+ equipment designed to give student welders a three-dimensional virtual reality training experience. Included is information to assist welding instructors in identifying weld defects and keeping a detailed record of students’ progress according to various industry code requirements.

123 Certification Inc.
www.123certification.com
(514) 932-7273

New Products Featured in 2008 Catalog

The company’s 325-page, full-color 2008 catalog features 40 new products. The new machines include electrical discharge machines, machining centers, milling machines, lathes, bandsaws, shears, presses, and ironworkers. Other products displayed include injection molding machines, sheet metal working machines, and tools and accessories for turning, sawing, drilling, and grinding.

Knuth Machine Tools USA, Inc.
www.knuth-usa.com
(866) 665-6884

High-Alloy Consumables Detailed in Catalog

The 72-page Blue Max® and Red Baron® Product Catalog — Stainless Steel and High Alloy Consumables, Bulletin C6.10, features the company’s complete lines of shielded metal arc, and flux and metal cored electrodes. A full-page color-coded selection guide details base materials and welding consumables. Products are keyed to the AWS designation and ISO number where available. Each electrode is detailed with product descriptions, recommended welding positions, advantages, and typical applications for each product. Included are mechanical properties, operating procedures, and packaging information. The back page lists contact information for the company’s North American district sales offices and international headquarters locations.

The Lincoln Electric Co.
www.lincolnelectric.com
(216) 481-810

Self-Aligning Fixturing Elements Shown

The Amflex® modular work-holding self-aligning fixturing elements catalog features an expanded product line. New items are hydraulic and pneumatic fixtures, modular components, force cartridges, tombstones, and high-density work-holding systems for dedicated or manual fixturing. The 94-page catalog includes detailed technical data with application information, design options, and mounting dimensions.

Advanced Machine & Engineering
www.ame.com
(815) 962-6076

Poster Explains AWS Wire Classification System

A poster explains the AWS classification for four types of tubular wires. Detailed are mild steel flux cored wire, mild steel metal cored wire, low-alloy flux cored wire, and low-alloy metal cored wire, and the suitability of these filler metals for various welding applications is outlined. This is the third in a series of posters designed to increase knowledge of welding terms for students, hobbyists, and professionals. The full-size poster can be ordered by calling the telephone number. A smaller version of the poster may be downloaded from the Web site.

Hobart Brothers Co.
www.hobartbrothers.com
(937) 339-9425

For info go to www.aws.org/ad-index
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...
Rankin Hires Sales Manager

Rankin Industries™, San Diego, Calif., a supplier of hardfacing products, has named Brian Caddell sales manager. Previously, Caddell held positions with Praxair Distribution, and Welders Supply and Equipment Co.

Wall Colmonoy Fills Two Quality Posts

Wall Colmonoy Corp., Madison Heights, Mich., has promoted Rick Rackley to director of quality for its Aerospace Group, and promoted David Amundson to quality assurance manager for its alloy manufacturing facility in Los Lunas, N.Mex. Previously, Rackley served as quality manager/safety officer for the Oklahoma City facility. Amundson most recently served as lab technician, quality engineer, and a member of the ISO certification team.

Wheelabrator Appoints General Manager

Bjorn Tranebo has been promoted to general manager of the Wheelabrator Group Burlington Technology Center in Burlington, Ont., Canada. Prior to this appointment, Tranebo was operations manager at the facility.

NanoSteel® Designates VP of Sales

NanoSteel® Co., Providence, R.I., has designated Kenneth M. Byrne vice president of sales and marketing. Byrne succeeds Michael Breitsameter who has left the company. Previously, Byrne served as vice president, sales and marketing — coatings division, at Liquidmetal Technologies.

Motoman Announces Senior General Manager

Motoman Inc., Dayton, Ohio, has announced Trever Jones will join the company as senior general manager of Yaskawa Motoman Canada, Mississauga, Ont., Canada. Jones, who is also president of the Robotics Industries Assn., has 23 years of experience holding a number of key posts at CRS Robotics.

Two Key Posts Filled at Paratherm

Paratherm Corp., West Conshohocken, Pa., has named Jim Oetinger to the newly created position as director of technology. Previously, Oetinger served as head of the company’s sales and technical functions. Rich Clements has been hired as sales manager. Clements has more than 20 years of executive-level sales management experience.

PMA Elects Hardt Chairman

Precision Metalforming Association (PMA), Cleveland, Ohio, has named Ralph Hardt 2008 chairman of the board of directors, for a one-year term. Hardt is president of North American operations for Feintool, Inc., Cincinnati, Ohio.

Mathey Dearman Names VP

Mathey Dearman, Inc., Tulsa, Okla., has promoted Darrin Hanby to company vice president. Hanby, with the company since 2002, most recently served as international sales and marketing manager.

Sales VP Appointed at Gas Innovations

Gas Innovations, Inc., Houston, Tex., has appointed Jim Hoffmann vice president of sales. Previously, Hoffmann worked for 30 years at Praxair, and most recently in branch operations with Airgas.

Bosch Rexroth Designates VP for Technologies Group

Bosch Rexroth Corp., Charlotte, N.C., has appointed Erwin Wieckowski as vice president and general manager for its Linear Motion and Assembly Technologies Group. Wieckowski previously was with Bosch Rexroth Canada where he served both as general manager of the automation business unit, and national sales and marketing director.

LIA Taps Four New Fellows

Laser Institute of America (LIA), Orlando, Fla., has elected four of its members to be honored as Fellows of the Institute. Named were Lin Li, professor of laser engineering, University of Manches-
We would like to thank the following who have supported the Welding for the Strength of America Campaign with their donations. Their contributions will benefit the workforce development initiative.

**Major Sponsor ($5,000 and up)**
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- Cable Family Foundation
- Chemalloy Company, Inc.
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
When the single-engine plane he was piloting on an Angel Flight Central mission crashed near Defiance, Ohio, Mr. Harris was a member of the AWS BSG Subcommittee on Fabricators, and served on the Fabricator Certification Project Team.

Mr. Harris and his wife, Rebecca, jointly founded Lake Process Systems, Inc., a provider of sanitary piping, design, and installation, in Barrington, Ill., 31 years ago. When he wasn’t working at the company, he combined his love for flying and helping others by piloting 75 missions for Angel Flight, and helped establish the Great Lakes Wing. He is survived by his wife; a daughter, Melissa; a son, Paul Jr.; brothers David, George, and Marc; sisters Renee Ainlay and Judi Johnson; and four grandchildren.

Frank Robert Schneider Jr.

Mr. Schneider is survived by his wife, Evelyn; children Bob, Linda, Jim, and Robin; five grandchildren, and three great-grandchildren.

♦

Obituaries

Paul E. Harris Sr.

Paul E. Harris Sr., 57, died Sept. 26, 2010. A resident of Cincinnati, Ohio, he was a certified welding engineer who had been employed by the company since 1995.

Mr. Schneider received his degree in metallurgy from Newark College of Engineering. His 41-year career contributed numerous advancements in the field of aluminum welding, including procedures used to build the Apollo lunar orbiter modules for NASA and reactor vessel seal welding and pipe brazing for U.S. Navy nuclear submarines. He led the General Dynamics welding engineering team in the construction of superconducting magnet cases for DOE research programs, and cruise missile fabrication. He supervised the procedures used to construct the Space Shuttle cargo bay and the Atlas and Centaur launch vehicles. He served on the Edison Welding Institute Industrial Advisory Board (1985–1992), the Advisory Committee for the California Polytechnic State University School of Engineering Technology, and the Industrial Advisory Board for Welding Technology at Arizona State University (1985–1987). He also served on the San Diego Job Corps Center, Industrial Advisory Board for Welding Vocation Training (1994–2001). At ASM International, San Diego Chapter, he organized the 1997 spring seminar.

Mr. Schneider is survived by his wife, Evelyn; children Bob, Linda, Jim, and Robin; five grandchildren, and three great-grandchildren.

♦

McCall Named GAWDA VP

Jenny McCall, president of Wesco Gas & Welding Supply, Inc., Prichard, Ala., was elected first vice president of the Gases and Welding Distributors Association (GAWDA). McCall has served on the association’s board of directors for the past four years and is scheduled to serve as president in 2010.

American Weldquip Appoints District Managers

American Weldquip, Inc., Sharon Center, Ohio, has appointed Ray Trudell district sales manager for Ontario, Canada, and Todd Harris district sales manager for Kentucky, southern Indiana, southern Illinois, and Missouri. Trudell most recently served as a territory manager for Praxair Industrial and Specialty Gases and Welding Equipment. Lindley has 27 years of experience in the industrial gas distribution and the hard goods manufacturing sectors.

Victor® Appoints Marketing Manager

Victor®, St. Louis, Mo., has appointed Randy Niederer marketing manager for Americas gas equipment. Niederer most recently served as director of strategic marketing for LaserBand.

Kaliburn Hires Senior Account Manager

Kaliburn, Charleston, S.C., has named John Tutino senior account manager, responsible for plasma cutting systems. Most recently, Tutino served as national sales manager for Promotion Controls, Inc.

National Sales Manager Named at Rexarc

George P. Lindley has joined Rexarc International, Inc., West Alexandria, Ohio, as national sales manager for industrial and specialty gas distribution equipment. Lindley has 27 years of experience in the industrial gas distribution and the hard goods manufacturing sectors.

Frank Robert Schneider Jr.

Frank Robert (Bob) Schneider Jr., 74, died Oct. 31. An AWS Life Member, he was an AWS Counselor, District 21 director (1990–2002), and San Diego Section chairman 1993–1994. He served on the National Convention Liaison Committee (1997), and the National Higher Education Committee.

Mr. Schneider received his degree in metallurgy from Newark College of Engineering. His 41-year career contributed numerous advancements in the field of aluminum welding, including procedures used to build the Apollo lunar orbiter modules for NASA and reactor vessel seal welding and pipe brazing for U.S. Navy nuclear submarines. He led the General Dynamics welding engineering team in the construction of superconducting magnet cases for DOE research programs, and cruise missile fabrication. He supervised the procedures used to construct the Space Shuttle cargo bay and the Atlas and Centaur launch vehicles. He served on the Edison Welding Institute Industrial Advisory Board (1985–1992), the Advisory Committee for the California Polytechnic State University School of Engineering Technology, and the Industrial Advisory Board for Welding Technology at Arizona State University (1985–1987). He also served on the San Diego Job Corps Center, Industrial Advisory Board for Welding Vocation Training (1994–2001). At ASM International, San Diego Chapter, he organized the 1997 spring seminar.

Mr. Schneider is survived by his wife, Evelyn; children Bob, Linda, Jim, and Robin; five grandchildren, and three great-grandchildren.

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All papers published in the Welding Journal’s Welding Research Supplement undergo Peer Review before publication for: 1) originality of the contribution; 2) technical value to the welding community; 3) prior publication of the material being reviewed; 4) proper credit to others working in the same area; and 5) justification of the conclusions, based on the work performed. The following individuals serve on the AWS Peer Review Panel and are experts in specific technical areas. All are volunteers in the program.

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A New Approach to Quantitative Evaluation of a Design for Brazed Structures

A system of design criteria with assigned score values is proposed

BY A. E. SHAPIRO AND D. P. SEKULIC

ABSTRACT. Brazement design is a critically important characteristic of a brazed joint structure. The design is responsible for reliability and proper service behavior of brazed products. According to the state of the art, a good design provides not only required properties of the brazed structure, but also a very high technological suitability. The latter is necessary in order to fabricate a product using the most economical manufacturing processes. Therefore, a rigorous approach to the assessment of the design beyond intuitive tools of the brazing art is necessary. However, many design variables should be considered during the development of a brazing task to reach the correct design solution. This variety of factors significantly complicates quantitatively assessing design. This paper offers such a rigorous methodology for achieving this goal.

A system of quantitative characteristics inherent to a good design is proposed. Subsequently, a figure of merit called “design effectiveness” is defined to facilitate the related assessment procedure. This is accomplished by evaluating the final design solution in terms of design effectiveness. Subsequently, a comparison between multiple designs (the proposed vs. all the other options for similar brazed structures available in practice) should be performed. Almost 100 design criteria levels and corresponding weighing coefficients are included in the analysis and their impact is evaluated. Ultimately, the design figure of merit is defined. The result of such an analysis leads to a single value of the design effectiveness magnitude. This value ranges between 0 (worst design) and 1 (ideal design), with an actual value between 0 and 1 as a carrier of a very complex assessment effort.

The application of this approach is illustrated by two examples extracted from the engineering practice. The design evaluations were made for a brazed aircraft structure and a computer hardware component.

Introduction

An analysis that precedes design consideration of a new brazed structure must resolve three problems: 1) provide a solution for required physical, chemical, and mechanical properties of the joint, 2) offer the procedure to manufacture the brazed structure at the lowest production costs, and 3) lead to the product and manufacturing process with minimal negative environmental impact (a sustainable product/process). An optimal solution capable of satisfying all factors rarely can be achieved. Most of the time, one has to accept a compromise among quality, expenses, and product/process sustainability. Market, application specifics, and/or governmental regulations dictate priority of one of these factors in any specific case. For instance, mechanical and/or corrosion resistance value for an ideal design solution. Furthermore, the quantitative values for equally good designs for different products may be quite different, hence leading to possible misleading interpretations. Finally, an absence of formal generalization and scaling necessary for any figure of merit leads to an approach that would be difficult to use for an analysis of individual contributions to design quality and for comparison purposes. To mitigate these problems, a more rigorous definition of the design quality figure of merit is proposed in this paper.

The main idea behind the definition of a figure of merit for design evaluation is straightforward and can be expressed by stating that it must satisfy three requirements: 1) a figure of merit must be defined using objectively quantified design criteria, 2) a figure of merit must be a dimen-

KEYWORDS
Brazement
Brazing
Design Criteria
Score Values
Weighted Coefficients
WELDING RESEARCH

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A figure of merit has to have a fixed range of values — preferably between 0 (the worst scenario) and 1 (the best scenario). The first requirement reflects the need for having a figure of merit involving relevant quantifiers that reflect the trade-off between the influential factors and performance criteria. For example:

Table 1 — Brazing Design Criteria and Score Values

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Design Criteria Name</th>
<th>Scores</th>
<th>Weighing Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Brazeability of the base metal:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>A_1</td>
<td>good</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>A_2</td>
<td>satisfactory</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>A_3</td>
<td>limited</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>A_4</td>
<td>poor</td>
<td>-10</td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>Compatibility of the base and brazing filler metals:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B_1</td>
<td>good</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>B_2</td>
<td>satisfactory</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>B_3</td>
<td>poor</td>
<td>-10</td>
<td></td>
</tr>
<tr>
<td>C</td>
<td>Type of joint:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>C_1</td>
<td>lap joint or tubing joint</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>C_2</td>
<td>thread or seam joint</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>C_3</td>
<td>T-joint</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>C_4</td>
<td>butt joint or scarf joint</td>
<td>-4</td>
<td></td>
</tr>
<tr>
<td>C_5</td>
<td>stepped joint (C_1 + C_3)</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Joint clearance:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D_1</td>
<td>uniform capillary clearance</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>D_2</td>
<td>nonuniform capillary clearance</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>D_3</td>
<td>uniform noncapillary clearance</td>
<td>-5</td>
<td></td>
</tr>
<tr>
<td>D_4</td>
<td>nonuniform noncapillary clearance</td>
<td>-10</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Fixturing of parts and brazing filler metal during the brazing operation:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>E_1</td>
<td>self-fixturing or gravity location</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>E_2</td>
<td>knurling with pressing-fit</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>E_3</td>
<td>pressing-fit</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>E_4</td>
<td>tack welding</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>E_5</td>
<td>coiling of one part on the other part</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>E_6</td>
<td>one brazed part is expanded, riveted, swaged, crimped, stacked, etc.</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>E_7</td>
<td>use of compressing devices or fixtures</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>E_8</td>
<td>impossible fixturing of parts to be brazed</td>
<td>-5</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Thermal expansion coefficient (CTE) of base metals:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F_1</td>
<td>equal (matched joint)</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>F_2</td>
<td>different (unmatched joint)</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>F_3</td>
<td>compressive stresses appear in the joint during cooling after brazing</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>F_4</td>
<td>tensile stresses appear in the joint during cooling after brazing</td>
<td>-10</td>
<td></td>
</tr>
<tr>
<td>G</td>
<td>Forms of brazing filler metals:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G_1</td>
<td>preform made of foil, wire, transfer tape, or compacted powder</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>G_2</td>
<td>coating</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>G_3</td>
<td>brazing paste</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>G_4</td>
<td>manual feeding of brazing filler metal in wire form</td>
<td>-5</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>Design for preplacement of brazing filler metals:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H_1</td>
<td>space for placement performs, paste, or powder is available</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>H_2</td>
<td>preplacement of the brazing filler metal is impossible (no space for brazing filler metal)</td>
<td>-5</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>Ratio of thickness of brazed parts:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I_1</td>
<td>equal thicknesses</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>I_2</td>
<td>smooth transition from one part to another</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>I_3</td>
<td>sharp transition from one part to another (a step)</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>I_4</td>
<td>unequal thicknesses</td>
<td>7</td>
<td></td>
</tr>
<tr>
<td>I_5</td>
<td>smooth transition from a thin part to a thick part</td>
<td>-5</td>
<td></td>
</tr>
<tr>
<td>J</td>
<td>Stress concentration:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J_1</td>
<td>design removes stress concentration in the joint</td>
<td>10</td>
<td></td>
</tr>
</tbody>
</table>
example, this requirement may be interpreted as signifying the departure of a
given design from the one that would constitute the worst possible case or the de-
parture of the ideal design from the worst
case. The second requirement is a conse-
quence of establishing relative value of the
figure of merit by comparing the entities
of the same physical character, while the
third establishes the scale range easy to
identify with limiting cases of design. Such
figure of merit is defined later in this
paper.

As an illustration of the application of
the method, a demonstration of the use of

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<tbody>
<tr>
<td>J1</td>
<td>design distributes stress concentration in point</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>J2</td>
<td>brazed joint with stress concentration</td>
<td>-10</td>
<td></td>
</tr>
<tr>
<td>J3</td>
<td>availability of flanges, doubles, or sleeves for joints subjected to alternating or dynamic loads</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>J4</td>
<td>absence of flanges, doubles, or sleeves for joints subjected to alternating or dynamic loads</td>
<td>-5</td>
<td></td>
</tr>
<tr>
<td>J5</td>
<td>possibility to use highly productive equipment for brazing:</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>K1</td>
<td>conveyor-belt furnace</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>K2</td>
<td>multichamber automatic vacuum furnace</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>K3</td>
<td>one-chamber vacuum or argon-atmosphere furnace</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>K4</td>
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<tr>
<td>K5</td>
<td>automatic multitorch system</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>K6</td>
<td>electron beam or laser beam</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>K7</td>
<td>IR radiation</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>K8</td>
<td>dipping in a flux bath</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>K9</td>
<td>electric resistance heating</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>K10</td>
<td>manual brazing</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>L1</td>
<td>residual stresses in the joint after brazing: not possible</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>L2</td>
<td>possible but can be eliminated by heat treatment</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>L3</td>
<td>possible and cannot be eliminated by heat treatment</td>
<td>-10</td>
<td></td>
</tr>
<tr>
<td>M1</td>
<td>effect of brazing thermal cycle on mechanical properties of the base metal: no effect</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>M2</td>
<td>deterioration $\leq 20%$ but can be restored by heat treatment after the brazing</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>M3</td>
<td>deterioration $\geq 20%$, which cannot be restored by heat treatment after the brazing</td>
<td>-2</td>
<td></td>
</tr>
<tr>
<td>M4</td>
<td>possibility of uniform heating</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>O1</td>
<td>possibility of uniform heating all parts when brazing several parts simultaneously</td>
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<td>P1</td>
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<td>universal fixtures are needed</td>
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<td>specially made fixtures are needed</td>
<td>-5</td>
<td></td>
</tr>
<tr>
<td>Q1</td>
<td>possibility of straight brazed seams</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Q2</td>
<td>simple, symmetric shape (e.g., circle, square, etc.)</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Q3</td>
<td>combination of Q1, Q2, Q4</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Q4</td>
<td>complex curvilinear shapes of joint</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>R1</td>
<td>quality inspection of resulting brazed article: only observation is needed</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>R2</td>
<td>nondestructive testing is needed</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>R3</td>
<td>selective testing is needed</td>
<td>-5</td>
<td></td>
</tr>
<tr>
<td>S1</td>
<td>possibility of brazing all joints of the article simultaneously: possible</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>S2</td>
<td>impossible</td>
<td>3</td>
<td></td>
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</tbody>
</table>

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<tr>
<td>J2</td>
<td>brazed joint with stress concentration</td>
<td>-10</td>
<td></td>
</tr>
<tr>
<td>J3</td>
<td>availability of flanges, doubles, or sleeves for joints subjected to alternating or dynamic loads</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>J4</td>
<td>absence of flanges, doubles, or sleeves for joints subjected to alternating or dynamic loads</td>
<td>-5</td>
<td></td>
</tr>
<tr>
<td>J5</td>
<td>possibility to use highly productive equipment for brazing:</td>
<td>9</td>
<td></td>
</tr>
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<td>multichamber automatic vacuum furnace</td>
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<td>one-chamber vacuum or argon-atmosphere furnace</td>
<td>8</td>
<td></td>
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<tr>
<td>K4</td>
<td>high-frequency induction coil</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>K5</td>
<td>automatic multitorch system</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>K6</td>
<td>electron beam or laser beam</td>
<td>9</td>
<td></td>
</tr>
<tr>
<td>K7</td>
<td>IR radiation</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>K8</td>
<td>dipping in a flux bath</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>K9</td>
<td>electric resistance heating</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>K10</td>
<td>manual brazing</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>L1</td>
<td>residual stresses in the joint after brazing: not possible</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>L2</td>
<td>possible but can be eliminated by heat treatment</td>
<td>0</td>
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<td>effect of brazing thermal cycle on mechanical properties of the base metal: no effect</td>
<td>10</td>
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<td>M2</td>
<td>deterioration $\leq 20%$ but can be restored by heat treatment after the brazing</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>M3</td>
<td>deterioration $\geq 20%$, which cannot be restored by heat treatment after the brazing</td>
<td>-2</td>
<td></td>
</tr>
<tr>
<td>M4</td>
<td>possibility of uniform heating</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>O1</td>
<td>possibility of uniform heating all parts when brazing several parts simultaneously</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>O2</td>
<td>access of electron beam or laser beam scanning, or IR radiation to brazing zone is available</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>O3</td>
<td>design elements or places for using compressive fixtures are available</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>O4</td>
<td>design does not match to the brazing process</td>
<td>-10</td>
<td></td>
</tr>
<tr>
<td>P1</td>
<td>necessity of brazing fixtures: fixtures are not needed</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>P2</td>
<td>universal fixtures are needed</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>P3</td>
<td>specially made fixtures are needed</td>
<td>-5</td>
<td></td>
</tr>
<tr>
<td>Q1</td>
<td>possibility of straight brazed seams</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Q2</td>
<td>simple, symmetric shape (e.g., circle, square, etc.)</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Q3</td>
<td>combination of Q1, Q2, Q4</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Q4</td>
<td>complex curvilinear shapes of joint</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>R1</td>
<td>quality inspection of resulting brazed article: only observation is needed</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>R2</td>
<td>nondestructive testing is needed</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>R3</td>
<td>selective testing is needed</td>
<td>-5</td>
<td></td>
</tr>
<tr>
<td>S1</td>
<td>possibility of brazing all joints of the article simultaneously: possible</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>S2</td>
<td>impossible</td>
<td>3</td>
<td></td>
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</table>
Table 1 — Brazing Design Criteria and Score Values (continued)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Design Criteria Name</th>
<th>Scores</th>
<th>Weighing Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>T</td>
<td>Necessity of using special brazing equipment that is not available in the industry or commercially on the market:</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>T₁</td>
<td>• unusual equipment is not needed</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>T₂</td>
<td>• unusual equipment is needed</td>
<td>-10</td>
<td></td>
</tr>
<tr>
<td>U</td>
<td>Accessibility of brazed seams:</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>U₁</td>
<td>• accessible</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>U₂</td>
<td>• partially accessible</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>U₃</td>
<td>• inaccessible</td>
<td>-5</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>Unification of parts in the brazed article (n – total number of parts, n₁ – number of names of the parts):</td>
<td>4</td>
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</tr>
<tr>
<td>V₁</td>
<td>• n/n₁ = 1</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>V₂</td>
<td>• n/n₁ = 2</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>V₃</td>
<td>• n/n₁ = 3</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>V₄</td>
<td>• n/n₁ = 4</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>V₅</td>
<td>• n/n₁ ≥ 5</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>W</td>
<td>Possibility of rebrazing or repair:</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>W₁</td>
<td>• possible repeatedly</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>W₂</td>
<td>• only one time</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>W₃</td>
<td>• impossible</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>Other technological criteria of brazing design:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Y₁</td>
<td>• free gas (air) exit from the joint clearance and any closed space:</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Y₂</td>
<td>• from 2 to 5</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Y₃</td>
<td>• ≥ 5</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Y₄</td>
<td>• stress compensators in face or embracing joints of ceramics, glasses, or graphite:</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Y₅</td>
<td>• available (compensated joint)</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>Y₆</td>
<td>• mechanical treatment over brazing (machining, filing, or grinding to remove sags, make fillets smooth, surface polishing, etc.):</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>Y₇</td>
<td>• mechanical treatment is not needed</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Y₈</td>
<td>• mechanical treatment is needed</td>
<td>-5</td>
<td></td>
</tr>
</tbody>
</table>

This new figure of merit for design evaluations of two brazed structures will be presented. These structures represent two demanding brazing tasks related to aerospace and electronics applications: 1) a titanium impeller and 2) a copper cryogenic evaporator for electronics cooling.

**List of Design Criteria**

**General Considerations**

A thorough study of the influential factors that may hamper adequate brazed-joint formation during brazing and hence compromise the design solution of a brazed structure has uncovered that more than two dozen design criteria must be satisfied (Table 1). These criteria include at this stage only assessments of the joint technical aspects and implicitly manufacturing considerations, without an inclusion of engineering sustainability issues. The authors approach to the latter are addressed elsewhere.

The most important criteria for the brazed structure design are the following: • brazability of the base metal, • metallurgical compatibility of the base metal with the brazing filler metal, • type of joints, • the uniformity and size of joint clearance, • fixturing of parts to be brazed, • compatibility of thermal expansion if dissimilar base materials are joined, and • a form of the brazing filler metal and its method of placement in the brazing zone.

Mistakes in the implementation of these criteria cause serious problems both on the manufacturing plant floor and in the quality of brazed products.

The design criteria presented in Table 1 determine the technological suitability and service properties of the resulting brazed assemblies. The best approach to the evaluation of these criteria is to consider all of them before and during the design process. This is particularly important for mass production and for complex and critical products such as compressor vanes, nuclear reactor coolers, and fuel heat exchangers. But, adequately addressing all design criteria is useful even in custom production of simple brazed parts. Such an approach will provide high-quality products, including the development of an adequate brazing design procedure important for other similar designs.

Traditionally, the base metal and the brazing filler metals are selected first, based on the projected mechanical and service properties of the brazed structure. The selected combination of materials specifies a choice of the brazing method and possible equipment. For example, if a ceramic is the base material, one has to go with vacuum furnace brazing rather than torch brazing.

**Brazeability: Criterion A**

Generally, we evaluate the brazeability as good if the base material can be brazed easily using 1) any of the suitable methods, such as furnace brazing, induction brazing, or torch brazing; 2) a number of brazing filler metals over a wide range of temperatures; and 3) a brazing operation that does not impair the structural or mechanical properties of the base material, or does not change those properties significantly. Carbon steels, austenitic stainless steels, and wrought copper alloys are examples of base metals with good brazability.

The term *satisfactory brazeability* relates to base metals that also can be joined by many brazing methods and filler metals but require special attention or specific approach to brazing operations. An appropriate example of such base metals are titanium alloys. Brazing of titanium requires high-vacuum or high-purity inert gas and a temperature below or only slightly higher than the temperature of $\alpha + \beta$ transus. Additionally, the brazing thermal cycle should be adjusted to minimize the growth of an intermetallic layer at the interface of the base and braze met-
als. Another example is martensitic stainless steels that require compatibility of the brazing thermal cycle with specific heat treatment.

Magnesium alloys and most refractory alloys are base metals with limited brazability. These metals are characterized by difficult wetting and can be joined with a limited number of brazing filler metals. Surprisingly, some ordinary metals such as cast iron or cast bronzes also have limited brazability.

Finally, base materials that have poor wettability and require additional operations to be brazed are described as having poor brazability. Diamonds and ceramics such as silicon carbide and yttria-stabilized zirconia are typical examples of this class of base materials that require preliminary metalization or brazing using active filler metals in high vacuum.

Metallurgical Compatibility: Criterion B

Compatibility of brazing filler metal with the base metal is the first problem that the designer faces when he/she starts the project. This is not as simple a problem as it may appear at first glance. A number of factors should be evaluated and weighed such as 1) the effect of the brazing thermal cycle on possible changes in the microstructure and the properties of the base material, 2) metallurgical reactions between the base material and molten filler metal, 3) formation of intermetallics and phase composition of the joint metal, and 4) corrosion problems and cracking resistance.

We can speak about a good compatibility of the base and brazing filler metals if 1) easy wetting of the base metal and flow of the brazing filler metal (BFM) can be reached during brazing, 2) heating to the brazing temperature of the BFM will not result in phase or structural transformations that may impair physical and mechanical properties of the base metal, 3) microstructures of the joint, interface, diffusion zone, and base metal can be controlled by adjusting parameters of the brazing thermal cycle (or optionally, by additional heat treatment), and 4) the resulting brazed joint exhibits physical, chemical, and mechanical properties required by the blueprint (customer).

The satisfactory compatibility of the base materials and BFM means that the easy satisfaction to at least one of the above-listed points (1–4) is difficult. However, these problems can be resolved technologically, for example, by metalization of the base material, adjusting the heating or cooling rates, multistep brazing with two different BFM, deposition of protective coatings on the joint after brazing, etc.

An example of the compatibility of different brazing filler metals with titanium base metals is presented in Table 2. Titanium base metals with the temperature of α↔β transus above 900°C have good compatibility to the brazing filler metals of the Ti-Cu-Ni family, while base metals with the α↔β transus below 900°C have good compatibility with the brazing filler metals of the Ti-Zr-Cu-Ni system. Both silver-based or aluminum-based BFM have satisfactory compatibility to titanium alloys due to galvanic corrosion problems, low strength, and thick intermetallic layers at the interface. However, the growth of intermetallics can be partially suppressed by using a short brazing time and fast cooling, the strength of joints can be improved by using a mechanically secured joint design, and fillets of joints can be protected against corrosion by using polymer, phosphate, or other coatings.

Finally, poor compatibility means that the given combination of BFM and base material results in problems that cannot be ameliorated by any one of the following: wetting, structure transformation, reactive phase growing, corrosion, and loss of the strength. This case is very rare. A typical example of poor compatibility is the brazing of carbon steel by Cu-P filler metals that always is accompanied by uncontrollable growth of iron phosphide, which causes a brittleness of brazed joints.

Table 2 — Compatibility of Titanium Base Metals with Brazing Filler Metals

<table>
<thead>
<tr>
<th>Brazing filler metals</th>
<th>Ag-based</th>
<th>Al-based</th>
<th>Ti-Cu-Ni system</th>
<th>Ti-Zr-Cu-Ni system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Good wetting of base metals</td>
<td>&lt;β-transus</td>
<td>&lt;β-transus</td>
<td>near or &lt;β-transus</td>
<td></td>
</tr>
<tr>
<td>Formation of intermetallics in the brazed joint</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Working temperature</td>
<td>≤500°C</td>
<td>≤500°C</td>
<td>≤600°C</td>
<td></td>
</tr>
<tr>
<td>Tempering is possible</td>
<td>Heat treatment is not recommended</td>
<td></td>
<td>Aging, solution treatment, or tempering are possible after the brazing</td>
<td></td>
</tr>
<tr>
<td>Middle strength</td>
<td>Low strength</td>
<td>Low strength</td>
<td>High strength of brazed joints</td>
<td></td>
</tr>
<tr>
<td>Corrosion problems</td>
<td>Corrosion problems</td>
<td>Corrosion problems</td>
<td>High corrosion resistance</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 5 — Copper evaporator (brazed with the silver-free filler metal P81) mounted in the working position to cool a CPU.
Score Values

Classification of design brazing criteria and their score values are presented in Table 1. One of the most important issues related to a proper assessment of suggested brazing criteria is a clear definition of each criterion and a precise quantification of its importance. For example, the first two criteria, brazeability of the base metal and compatibility of the base and filler metals, must both have precise definitions to be quantified within a range that spans from poor to good. The level of subjectivity in such an evaluation ideally would not exist. However, there is no consensus on what such terms may mean for each particular case. What is important is that an assessment of each individual criterion must be a subject of a rigorous study. Each level of the assessment of a criterion has two quantitative values: 1) the score value, $A \in (-10,10)$, and 2) the weighing factor $g \in (0,1)$. The weighing factor assigns the relative value of the score value for a given criterion vs. the remaining set of criteria. So, the criteria listed as the most important would have the highest weighing coefficients.

Negative score values were used as well to make an adequate difference between superior and inferior designs, i.e., the negative scores are assigned to most other criteria as the maximum. Indeed, it is practically impossible to get a stable brazing process and a decent quality of the brazed article if the adverse effect of a noncapillary joint clearance is defined as one of the most important factors. This criterion’s importance was emphasized by a weighing coefficient value of 20 instead of 10 as assigned to most other criteria as the maximum. Indeed, it is practically impossible to get a stable brazing process and a decent quality of the brazed article if the
Definition of the Design Figure of Merit

Let us define the brazing design figure of merit as follows:

$$
\varepsilon = \frac{\sum_{i=1}^{n} A_{i} s_{i} - \sum_{i=1}^{n} A_{i,\min} s_{i}}{\sum_{i=1}^{n} A_{i,\max} s_{i} - \sum_{i=1}^{n} A_{i,\min} s_{i}}
$$

(1)

In Equation 1, the terms \(\sum_{i=1}^{n} A_{i} s_{i}\) represent the compounded value of the products of score values and weighing coefficients for selected, relevant design criteria for 1) an actual design, \(\sum_{i=1}^{n} A_{i,\min} s_{i}\) the fictitious, worst case scenario design determined assigning the lowest score values for the selected design criteria, \(\sum_{i=1}^{n} A_{i,\max} s_{i}\) and 3) the idealized, best case scenario design determined assigning the highest score values for the same selected design criteria, \(\sum_{i=1}^{n} A_{i,\min} s_{i}\), respectively. Note that, by definition, Equation 1 in any considered case always offers the value of the design figure of merit within the prescribed value range \(\varepsilon \in (0,1)\). The result is dimensionless, and represents the measure of the actual design departure from the best possible design scenario case. Hence, the figure of merit satisfies all the requirements imposed previously.

Examples of Competitive Designs

It is best to demonstrate effectiveness of the proposed evaluation system by evaluating selected competitive designs of real brazed products. Two examples were selected: 1) a titanium impeller (Fig. 1, Table 3) and a copper cryogenic evaporator used in high-speed computers (Fig. 5, Table 4). For each example, two design solutions were presented.

The first design of the titanium impeller is presented in Fig. 2. Base metal is the alloy Ti-3Al-2.5V. The filler metal is AWS BTi-1 (Ti-15Cu-15Ni), having the liquidus temperature of 950°C (1742°F) and brazing temperature range between 980°-1050°C (1800°-1920°F). This means that brazing should be performed at the temperature above the \(\beta\)-transus temperature of the base metal, which is 935°C (1715°F). In order to cut production costs, the designer made a decision not to make the shaped holes for blades in the top and bottom titanium plates, and this resulted in an appearance of T-joints of blades with plates. A need for delicate assembling of all blades with the plates requires an application of a special fixturing device; consequently, all blades must be fixed to plates by arc spot welding — Fig. 2.

The paste of the powered brazing filler metal is deposited in all joint areas. First, the paste containing a polymer binder is deposited on the top plate. After this portion of paste is polymerized, another portion is deposited on the other side of the article and around the shaft. After brazing, all the welds and excessive braze metal should be removed mechanically to get smooth fillets of brazed joints. This operation can be done only manually, which increases the labor cost. Additional drawbacks of this design are 1) the necessity of using fixtures to compress the plates to blades during the assembling and brazing, 2) a stress concentration in the brazed T-joints due to sharp transition from blades to plates, and 3) problems with repair should it be needed.

The compatibility of different brazing filler metals with the titanium alloy Ti-3Al-2.5V is presented in Table 2.

This table shows that the Ti-Zr-Cu-Ni system is preferred for the previously mentioned design of the titanium impeller because brazing can be done at a temperature above the \(\beta\)-transus temperature of the base metal, and its mechanical properties will not be reduced by the brazing thermal cycle.

Therefore, the brazing filler metal AWS BTi-4 (Ti-24Zr-16Cu-16Ni) should
be selected for the preferred design Figs. 1 and 3. Several other important changes would also be made in the joint design. Incorporating shaped holes for the blades in the titanium plates that resulted in an easier assembly procedure without using a compressive fixture. Spot welding should also be used to fix the blades and they can be made outside of the flow passages of the working channels. Also, there is no necessity to remove them after the brazing. In addition, brazing paste is deposited outside of the working channels too. This guarantees the formation of smooth fillets at the inner side of the blade-to-plate joints. Stress concentration is insignificant in this design because the brazed joints are mechanically secured, and any impact or fatigue stresses would be transferred to the base metal, while in the first design the brazed metal had to resist these stresses itself. The only drawback of this design is the complexity of the joint shape. The assessments of the design criteria scores and weighing factors from Table 1 are given in Table 3. Each design criterion taken into account is associated with the corresponding score level and weighing coefficient. Each design criterion score value is listed in bold and the not scored options are omitted for the sake of clarity.

Another example of the evaluation of competitive designs is presented in Figs. 4 and 5. The assembly to be brazed is a cryogenic evaporator for cooling electronics. All parts of the evaporator are made of copper. The selected brazing filler metal is BAg-24 in Design C, and the silver-free P14 (Cu-6Sn-6P-0.1Zr) or P81 (Cu-26Zn-6P-6Ni) filler metals in Design D.

The first design version (Fig. 4A, Design C) was made for manual torch brazing. According to Table 1, this design has a number of drawbacks that are characterized by the following criteria: C3, D2, E8, G4, H2, K10, N2, P2, S2, Y6, Y8, and Y12 (Table 4).

The second design version (Fig. 4B, Design D) is intended for furnace brazing or brazing using an automatic multitorch system. According to Table 4, this design does not have the drawbacks mentioned previously (except Y6 — a problem with removing flux residues from the inner space of the article after brazing). Further, the problem of flux residue removal can be resolved, for example, by using self-fluxing brazing filler metals such as BCuP-6, BCuP-7, or silver-free P14 (Cu-6P-4Sn-0.1Zr). After testing, they can operate at cryogenic temperatures.

A brazed evaporator in the working position as a CPU cooler is shown in Fig. 5. The microstructure presented in Fig. 6 demonstrates the high quality of brazed joints provided by Design D. The brazed joint is fully dense, with developed diffu-

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**Table 4 — Brazing Design Criteria and Their Scores for Examples C and D**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Design Criteria Name</th>
<th>Scores Design C</th>
<th>Scores Design D</th>
<th>Weighing Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Brazability of the base metal:</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>A1</td>
<td>good</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>B</td>
<td>Compatibility of the base and brazing filler metals:</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>B1</td>
<td>good</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>C</td>
<td>Type of joint:</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>C1</td>
<td>lap joint or tubing joint</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>C2</td>
<td>T-joint</td>
<td>4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>D</td>
<td>Joint clearance:</td>
<td>20</td>
<td></td>
<td></td>
</tr>
<tr>
<td>D1</td>
<td>uniform capillary clearance</td>
<td>10</td>
<td>10</td>
<td></td>
</tr>
<tr>
<td>D2</td>
<td>nonuniform capillary clearance</td>
<td>8</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>E</td>
<td>Fixturing of parts and brazing filler metal during the brazing operation:</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>E1</td>
<td>self-fixturing or gravity location</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>E2</td>
<td>impossible fixturing of parts to be brazed</td>
<td>-5</td>
<td>-5</td>
<td></td>
</tr>
<tr>
<td>F</td>
<td>Thermal expansion coefficient (CTE) of base metals:</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>F1</td>
<td>equal (matched joint)</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>G</td>
<td>Forms of brazing filler metals:</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>G1</td>
<td>preform made of foil, wire, transfer tape, or compacted powder</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>G2</td>
<td>manual feeding of brazing filler metal in wire form</td>
<td>-5</td>
<td>-5</td>
<td></td>
</tr>
<tr>
<td>H</td>
<td>Design for preplacement of brazing filler metals:</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>H1</td>
<td>space for placement performs, paste, or powder is available</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>H2</td>
<td>preplacement of the brazing filler metal is impossible (no space for brazing filler metal)</td>
<td>-5</td>
<td>-5</td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>Ratio of thicknesses of brazed parts:</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>I1</td>
<td>equal thicknesses</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>J</td>
<td>Stress concentration:</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>J1</td>
<td>design distributes stress concentration in the joint</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>J2</td>
<td>brazed joint with stress concentration</td>
<td>-10</td>
<td>-10</td>
<td></td>
</tr>
<tr>
<td>K</td>
<td>Possibility to use highly productive equipment for brazing:</td>
<td>9</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K1</td>
<td>one-chamber vacuum or argon furnace</td>
<td>8</td>
<td>8</td>
<td></td>
</tr>
<tr>
<td>K2</td>
<td>manual brazing</td>
<td>2</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>L</td>
<td>Residual stresses in the joint after brazing:</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L1</td>
<td>not available</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>M</td>
<td>Effect of brazing thermal cycle on mechanical properties of the base metal:</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>M1</td>
<td>deterioration ≤20%</td>
<td>4</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>N</td>
<td>Mechanically secured design for joints served under high-stress, creep, fatigue, and impact loads:</td>
<td>8</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N1</td>
<td>available</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>N2</td>
<td>not available</td>
<td>-5</td>
<td>-5</td>
<td></td>
</tr>
<tr>
<td>O</td>
<td>Matching joint design to brazing process:</td>
<td>7</td>
<td></td>
<td></td>
</tr>
<tr>
<td>O1</td>
<td>possibility of uniform heating of all parts when brazing several parts simultaneously</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>P</td>
<td>Necessity of brazing fixtures:</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P1</td>
<td>fixtures are not needed</td>
<td>10</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>P2</td>
<td>specially made fixtures are needed</td>
<td>-5</td>
<td>-5</td>
<td></td>
</tr>
</tbody>
</table>
Quantitative Evaluation of Brazement Design

Table 4 — Brazing Design Criteria and Their Scores for Examples C and D (continued)

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Design Criteria Name</th>
<th>Scores for Design C</th>
<th>Scores for Design D</th>
<th>Weighing Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>O</td>
<td>Complexity of joint shape: • simple, symmetric shape (e.g., circle, square, etc.)</td>
<td>10 10</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>R</td>
<td>Quality inspection of resulting brazed article: • only observation is needed</td>
<td>10 10</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>Possibility of brazing all joints of the article simultaneously: • possible</td>
<td>10 10</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>T</td>
<td>Necessity of using special brazing equipment that is not available in the industry or on market: • unusual equipment is not needed</td>
<td>-10 -10</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>U</td>
<td>Accessibility of brazed seams: • accessible</td>
<td>10 10</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>Unification of parts in the brazed article (n – total number of parts, n1 – number of names of the parts): • n/n1=2</td>
<td>4 4</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>W</td>
<td>Possibility of rebrazing or repair: • possible repeatedly</td>
<td>10 10</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Y</td>
<td>Other technological criteria of brazing design: • free gas (air) exit from the joint clearance and any closed space:</td>
<td>10 10</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Y1</td>
<td>• formation of smooth fillets:</td>
<td>10 10</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Y2</td>
<td>• possible</td>
<td>10 10</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Y3</td>
<td>• impossible</td>
<td>3 3</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Y4</td>
<td>• ratio of the overlap size to thickness of the brazed part (thin part if different thicknesses):</td>
<td>-10 -10</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Y5</td>
<td>• from 2 to 5</td>
<td>10 10</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Y6</td>
<td>• mechanical treatment after the brazing (machining, filing, or grinding to remove sags, make fillets smooth, surface polishing, etc.):</td>
<td>10</td>
<td>6</td>
<td></td>
</tr>
<tr>
<td>Y7</td>
<td>• mechanical treatment is not needed</td>
<td>-5 -5</td>
<td>5</td>
<td></td>
</tr>
<tr>
<td>Y8</td>
<td>• mechanical treatment is needed</td>
<td>10 10</td>
<td>4</td>
<td></td>
</tr>
</tbody>
</table>

From the comparison given by Equation 2, it is easy to establish the superiority of Design B.

Conclusions

A new figure of merit for quantifying the design of a brazed joint or assembly has been devised. The figure of merit is based on a rigorous set of requirements and involves a cumulative assessment of design criteria values based on the art and science of brazing. The system of design criteria
with their quantitative values is proposed to facilitate the designing procedure, to evaluate the final design solution, and to compare it with the design of other brazed structures available in the practice of brazing.

About 100 design criteria are dedicated not only for providing reliability and service properties of the resulting brazed structures, but also for manufacturing them by the most economical and ecological way.

Acknowledgments

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References


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WELDING RESEARCH

Consumable Double-Electrode GMAW — Part 1: The Process

Arc stability, bypass current, and metal transfer mode were studied to better understand the fundamental issues of the process.

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

ABSTRACT. Double-electrode gas metal arc welding (DE-GMAW) is a novel welding process recently developed to increase welding productivity while maintaining the base metal heat input at a desired low level. In this paper, the DE-GMAW process was improved by replacing its nonconsumable tungsten electrode with a consumable welding wire electrode resulting in a new process called consumable DE-GMAW. To understand this new process and its prospects as an effective manufacturing process, the authors have studied fundamental issues and proposed solutions to resolve the problems encountered. These fundamental issues include the stability of the process, the adjustability of the bypass current, the effects of the bypass arc on the total current and the melting rate, and the mode of metal transfer of the bypass welding wire. Novel processes are one key to maintaining the manufacturing industry’s competitiveness and technological leadership by increasing productivity or reducing cost. With this in mind, several new welding technologies have been developed. For example, laser welding can deliver very dense energy, thus the weld pool is small but the penetration is deep. The filler metal is reduced resulting in high productivity. The combination of laser welding and gas metal arc welding (GMAW) has created hybrid laser-arc processes (Refs. 1–8) to further improve productivity. As the most widely used process, GMAW has been modified to obtain faster deposition. Because the welding current $I$ in conventional GMAW is the same for the anode and cathode, increasing the welding current to improve the deposition rate will also cause an increase in the base metal heat input (Refs. 9–11). In addition, arc pressure is considered to be proportional to $I^2$ (Ref. 12). A large arc pressure blows metal away from the weld pool and generates undesired undercuts. In certain applications, the allowable base metal heat input and arc pressure are limited, therefore the allowable welding current is capped. Thus, to increase the deposition rate, conventional GMAW must be modified.

Two technologies have been developed to modify GMAW for faster deposition: tandem GMAW (Refs. 13, 14) and variable-polarity GMAW (GMAW-VP) (Refs. 15–19). In tandem GMAW, two welding guns have been integrated into one bigger gun, and two close parallel arcs are adjusted by two GMAW power supplies independently. In essence, tandem GMAW is still considered two parallel GMAW processes, but tandem GMAW can alternate the maximum welding current to each welding gun. In that way, the arc pressure remains unchanged, and the wire feed speed can be doubled. Hence, if arc pressure is the major concern, tandem GMAW can double the deposition rate. For GMAW-VP, liquid droplets are still detached during the wire positive period, but the welding wire can be melted faster during the wire negative period (Refs. 15, 20). It was found that to melt the welding wire at the same rate, the base metal heat input could be up to 47% less than the conventional pulsed GMAW (Ref. 20).

Thus, when the allowed base metal heat input is given, GMAW-VP may also double the deposition rate.

Recently, another novel modification to GMAW has been proposed and successfully implemented at the University of Kentucky (Refs. 21–25). This modification utilizes a nonconsumable tungsten electrode to bypass part of the melting current in a conventional GMAW process as illustrated in Fig. 1. It can be seen that the total melting current is decoupled into base metal current and bypass current:

$$ I = I_{bm} + I_{bp} $$

As a result, the melting current can be increased to improve the deposition rate while base metal current can still be controlled at the desired level. Hence, the DE-GMAW process increases the deposition rate using a mechanism totally different from existing technologies.

The DE-GMAW process shown in Fig. 1 uses nonconsumable tungsten as the bypass electrode, and is referred to as nonconsumable DE-GMAW. It offers an effective way to reduce the base metal heat input and distortion without compromising productivity. However, if the energy absorbed by the tungsten electrode can be used in wire melting, welding productivity can be further improved. Thus, another variant of the DE-GMAW process has been studied by replacing the nonconsumable tungsten electrode with a consumable welding wire provided with a separate GMAW gun. This new DE-GMAW is referred to as consumable DE-GMAW in order to distinguish it from the nonconsumable DE-GMAW.

Consumable DE-GMAW Principle and System

The proposed consumable DE-GMAW is illustrated in Fig. 2. It can be seen that there are two GMAW welding guns: one bypass and one main. The main welding gun is powered by a constant volt-

KEYWORDS

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Welding Productivity
Deposition Rate
Dual Wire Welding
Welding Controls
Heat Input

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The bypass welding gun is powered by a constant current (CC) welding machine whose current can be adjusted. The nonconsumable tungsten electrode has been replaced with a consumable welding wire. The two welding guns are connected to their corresponding GMAW wire feeders. Both welding guns are moved together from right to left by a motor. As demonstrated in Fig. 3, the total melting current consists of two parts: the bypass current \(I_2\) provided by the CC welding machine and the base metal current \(I_1\) provided by the CV welding machine. (Here, the base metal current is denoted as \(I_{bm}\), and the bypass current is denoted as \(I_{bp}\). These notations will also apply to other variables or parameters, such as arc voltage and wire feed speed: \(V_1\), \(V_2\), \(WFS_1\), and \(WFS_2\).) Thus, the decoupling principle in the nonconsumable DE-GMAW denoted in Equation 1 still holds.

The consumable DE-GMAW illustrated in Fig. 2 was established at the University of Kentucky. Two Hobart 8065 Excel-Arc CV/CC welding machines were utilized to provide the base metal and bypass currents, respectively. This model of welding power supply has an interface to control its output, either welding voltage or welding current. Current sensors and voltage sensors were added to monitor the currents (base metal current and bypass current) and voltages (main arc voltage and bypass arc voltage), respectively. A Pentium PC computer equipped with a 12-bit A/D D/A transformation board was used to collect the data sample and run the control program. Two controllable GMAW wire feeders (Miller R115 and Hobart UltraFeed 1000) were used to feed in the welding wires, which were 1.2-mm- (0.045-in.-) diameter low-carbon steel shielded with pure argon at a flow of 18.9 L/min (40 ft³/h). During experiments, the welding guns were moved by a motor while the workpiece remained stationary. The workpiece was 12.7 mm (0.5 in.) mild carbon steel, and the travel speed was set to 0.64 m/min (25 in/min). At the same time, an Olympus i-speed high-speed camera with a narrow-banded optical filter (central wavelength 940 nm, bandwidth 20 nm) was used to study the arc behavior and metal transfer.

**Welding Gun Configuration**

To establish a stable DE-GMAW process, both welding guns must be appropriately designed and originated. For the proposed consumable DE-GMAW, the bypass welding gun is aligned before the main welding gun, as illustrated in Fig. 3. Because the shielding gas is provided by the main welding gun, the nozzle of the bypass gun is not necessary. Hence, the bypass gun is used without a nozzle to allow for a relatively small angle between the main welding gun and the bypass gun. In addition, it does not require any shielding gas although a small flow of argon might be beneficial for preventing the welding gun from overheating. The contact tip of the bypass welding gun is arranged slightly

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**Fig. 1 — Nonconsumable DE-GMAW system**

**Fig. 2 — Proposed consumable DE-GMAW system.**

**Fig. 3 — Welding gun arrangement.**

**Fig. 4 — Welding gun arrangement parameters.**
above the nozzle of the main welding gun to further reduce the distance between the two wires. Because the nozzle is isolated from the contact tip in the welding gun, the contact tip of the bypass welding gun is electrically insulated from that of the main welding gun.

Preliminary experiments suggest that the following parameters in Fig. 4 can be used to arrange the welding guns: 1) less than 40 deg for the angle between the two welding guns, 2) approximately 5 mm for the distance from the tip of the bypass welding wire to the workpiece, 3) approximately 25 mm for the distance from the contact tip of the main welding gun to the workpiece, and 4) approximately 10 mm for the length of the main arc established between the tip of the main welding wire and the workpiece.

**Experiments and Analysis**

**Need for Two Power Supplies**

The nonconsumable DE-GMAW was successfully implemented using a single power supply, although the bypass current energy was not effectively used. However, the preliminary experiments with the consumable DE-GMAW showed that one power supply was not sufficient. In the preliminary experiments, a temporary consumable DE-GMAW system, illustrated in Fig. 5, was established with a single power supply. This system was derived from the nonconsumable DE-GMAW system simply by replacing the tungsten electrode with the bypass welding wire. In this temporary system, the bypass welding wire has the same electrical potential as the workpiece. Experiments showed that the current tended to flow through the workpiece first. This is because the workpiece and bypass welding wire are similar materials and thus have similar values for the electron work function [eV] (the minimum energy needed to remove an electron from a solid to a point immediately outside the solid surface), but the welding wire has a smaller size. Experiments also showed that the bypass current cannot be increased beyond a limited level with the preliminary system.

In the experiment demonstrated in Fig. 6, the main arc voltage and wire feed speed were 36 V and 11.4 m/min (450 in./min), respectively. Both welding wires were 1.2-mm- (0.045-in.-) diameter low-carbon steel. The bypass current was limited around 106 A (mean value) even though the bypass welding wire was fed at a speed as high as 8.9 m/min (350 in./min).
Fig. 9 — Experiment 2 with nominal constant welding parameters. The bypass current remained constant and was larger than the base metal current.

This wire feed speed was so high that the bypass welding wire contacted the workpiece, thus preventing higher bypass currents from being obtained. The bypass electrode in the nonconsumable DE-GMAW has an electron work function of 2.6 eV, which is much smaller than iron’s electron work function (4.7 eV). This difference creates a need to restrict the bypass current. In the consumable DE-GMAW, the welding wire has material similar to that of the workpiece so that the cathode size becomes the determining factor for the electron emission. As a result, more electrons are emitted from the weld pool, and fewer from the bypass welding wire. The bypass current in consumable DE-GMAW thus must be much smaller than the base metal current.

A similar experiment was repeated by increasing the main wire feed speed to 14 m/min (550 in./min). It can be seen in Fig. 7 that the bypass current (mean value) was also 106 A while the base metal current was increased to approximately 280 A. Thus, the bypass current was not controllable with the preliminary system, in which only one power supply was used. Hence, to obtain the desired bypass and base metal currents, the use of two power supplies to provide the two currents separately appears to be an effective solution.

The preliminary experiments (Figs. 6, 7) showed that the total melting current increased a little bit when the bypass welding wire was introduced. High-speed videos show that the wire extension of the main wire became shorter after the new current path was established. Thus, the resistive heat produced in the main welding wire was decreased. To maintain a constant arc voltage, the total current had to increase to compensate for the decrease in resistive heat.

Adjustability of Base Metal Current

The experiment in Fig. 8 was conducted using the proposed system shown in Fig. 2 with a set of carefully selected constant welding parameters. As can be seen, the bypass current remained constant during the experiment. This implies that the bypass arc was present during the
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Fig. 13 — Main arc length increased after the ignition of the bypass arc.

Fig. 14 — Arc behavior of an unstable bypass arc.

whole experiment period. Both the base metal current and bypass current waveforms were smooth indicating a stable process. Hence, a stable consumable DE-GMAW process may be obtained if the parameters are carefully selected. The total current varied slightly because of the changes in welding conditions.

Figures 9 and 10 illustrate similar experiments repeated with different welding parameters selected carefully to obtain a stable bypass arc. In Fig. 8, the bypass current was 100 A while the base metal current was higher than 250 A. When the bypass wire feed speed was increased to 10.2 m/min (400 in./min) in Fig. 9, the bypass current had to be increased to 165 A to maintain the balance between the wire melting speed and feeding speed. While the bypass current was increased, the base metal current was decreased to approximately 200 A. In that way, the total melting current, which is the sum of the bypass current and base metal current, was not changed. In Fig. 10, the bypass current was increased to 240 A and the base metal current was decreased to approximately 145 A. But the bypass wire feed speed had to increase up to 16.5 m/min (650 in./min), which is the maximum bypass wire feed speed available for the experimental system used, to maintain the balance between the wire melting speed and feeding speed.

The above experiments (Figs. 8–10) suggest that a stable consumable DE-GMAW process may be achieved for applications with different base metal currents.

Local Stability

In the experiment shown in Fig. 11, parameters \( V_1 \), \( WFS_1 \), and \( WFS_2 \) were set constant but \( I_2 \) increased gradually. As can be seen, when the bypass current was increasing, the base metal current was decreasing at the same speed, but the total current remained constant. It can also be observed that the bypass voltage \( V_2 \) increased linearly with a slope of 0.1271 V/A. As was verified by the high-speed video, the increase in the bypass arc voltage reflected a backward movement of the tip of the bypass welding wire because of the imbalance between the bypass melting speed and feeding speed.

In Fig. 11, the process was stable before time \( t = 52 \) s. After that, the bypass current frequently oscillated to zero. The bypass voltage oscillated to the open-circuit voltage, which was about 64 V. This implies that the bypass arc extinguished from time to time and the process became unstable. Apparently, the instability was because the high cathode heat melted the bypass welding wire at a speed higher than its feeding speed. Because of the continuous feeding of the bypass welding wire, the extinguished bypass arc was reignited when the bypass welding wire touched the main arc again.

In the experiment demonstrated in Fig. 12, parameters \( V_2 \), \( WFS_1 \), and \( I_2 \) were set at constant but \( WFS_2 \) decreased gradually. It can be seen from the waveforms that the bypass arc voltage \( V_2 \) was greater than the main arc voltage when the bypass wire feed speed became smaller. In this case, the bypass arc was in the outside region of the main arc and the CC power supply maintained the desired bypass current despite the increased voltage. If \( WFS_2 \) decreased further, the bypass arc voltage increased abruptly (\( t = 45 \) s) then the bypass arc became unstable and could be extinguished at any time.

Experiments in Figs. 11 and 12 suggest that a stable consumable DE-GMAW process can be achieved when welding parameters are carefully selected. Hence, the process possesses local stability. This makes it possible to perform consumable DE-GMAW without feedback control if the welding parameters are appropriately selected and do not change abruptly. It appears that this local stability is a result of the self-regulation of the bypass arc, considering the resistive heat from the wire extension or stickout (Ref. 10).

In consumable DE-GMAW, the bypass welding wire is primarily melted by the cathode heat and resistive heat (Ref. 26). The resistive heat \( Q \) for an extended welding wire with diameter \( d \) and extension \( l \) can be calculated as

\[
Q = I^2 R, \quad R = \rho(T) \frac{l}{0.25\pi d^2}
\]

where \( \rho(T) \) [ohm \( \times \) m] is the resistivity at temperature \( T \). At room temperature \( T = 20^\circ C \), iron has a resistivity of \( \rho(20^\circ C) = 9.71 \times 10^{-8} \) [ohm \( \times \) m], but when the welding wire temperature is near to its melting point, the resistivity will increase 16 times (Refs. 26, 27) so that the resistive heat becomes significant in the melting of the welding wire. If the welding conditions change slightly and the cathode heat associated with the given bypass current decreases, the extension of the bypass welding wire may increase until the decrease in the cathode heat is compensated for by the increased resistive heat. Hence, this self-regulation capability can allow a stable bypass arc be achieved if the welding parameters are carefully selected and do not change abruptly. However, self-regulation would not be sufficient to compensate for the change in the cathode heat to maintain a stable process. The stability due to self-regulation is thus local and not sufficient. To guarantee a stable process, feedback control is needed to adjust the welding parameters.

Effects on Total Current and Melting Rate

Another observation in Figs. 8–10 is that the total melting current with the bypass arc is larger than that without the bypass arc. For example, in Fig. 10, the total melting current without the bypass arc was 335 A, but after the bypass arc was ignited, the total melting current was increased to...
was approximately doubled. $(550/350) = 1.91$. Hence, the melting rate in./min. Their ratio is $(1200/400)/\text{in./min}$ (720/360) = 2. Hence, the consumable DE-GMAW, the total current increased to approximately 400 A but the arc voltage was not changed because of the CV power supply. With the same contact-tip-to-work distance (CTWD), the wire extension would decrease when the welding arc became longer. Thus, the decrease in resistive heat resulted in a need to increase the melting current to maintain the constant welding voltage. (Recall that the welding wire is melted by both the arc heat and resistive heat.) As a result, the total melting current was increased after the bypass arc was ignited. However, the decoupling principle denoted in Equation 1 still holds and can be used to develop an algorithm to control the base metal current by adjusting the bypass current. Once the process becomes stable, the total current will remain approximately constant.

It should also be noted that consumable DE-GMAW can use energy much more effectively than conventional GMAW even though there is a small increase in the total melting current. Thus, consumable DE-GMAW also has the advantage of achieving a higher melting rate (mass/current*time) because of the use of the cathode heat in melting the bypass welding wire. For example, in Fig. 10, the wire melting speed for the conventional GMAW was 14 m/min (550 in./min) when the current was approximately 350 A. For the consumable DE-GMAW, the total current increased to approximately 400 A but the melting speed increased to 1200 in./min ($WFS_1 = 550$ in./min, $WFS_2 = 650$ in./min). Their ratio is $(1200/400)/(550/350) = 1.91$. Hence, the melting rate was approximately doubled.

### Bypass Arc Behavior

High-speed videos were used to help understand the bypass arc behavior and metal transfer. They revealed that a stable bypass arc and smooth metal transfer are required to assure a stable consumable DE-GMAW. Here, a stable bypass arc means a continuous melting of the bypass welding wire without any extinguishment. When the bypass wire feed speed is too slow for the given bypass current, the melting-feeding balance will be broken, and the bypass arc will periodically start and then extinguish. Figures 14 and 15 show the arc behavior and data plots from an experiment with the following parameters: $WPS_1 = 14$ m/min (550 in./min), $V_1 = 36$ V, $WPS_2 = 5.1$ m/min (200 in./min), and $I_1 = 150$ A.

Figure 14 shows that the bypass arc is not always present if the bypass current is larger than what the given bypass wire feed speed needs. As a result, the bypass arc alternates its states between ignition and extinguishing. Pictures in Fig. 14 were selected from 439 frames of high-speed video to illustrate the arc behavior in a period of ignition and extinguishing, which was approximately 0.4 s, considering the capturing rate of 1000 fps (frames per second). In the beginning, there was no bypass arc, and the main arc was small because of the high wire feed speed. The bypass welding wire was fed in continuously thus the bypass arc was ignited. Then the main arc moved upward, and the bypass welding wire moved backward so that the tip of the bypass welding wire was out of the region of the main arc and the melted metal at the bypass welding wire was transferred in globular mode. Because the melting speed was greater than the feeding speed, once the bypass arc was present, the tip of the bypass welding wire would keep moving backward and increased the length of the bypass arc. If the bypass arc exceeded a specific length, the bypass arc would be extinguished. After that, the main arc became smaller again and the bypass welding wire extended toward the main arc to reignite the bypass arc.

The periodic ignition and reignition were also indicated in data plots shown in Fig. 15. The oscillation of the data also had a period of 0.4 s, which agrees with the observation from the high-speed video in Fig. 14.

### Metal Transfer of Bypass Droplets

For a consumable process, metal transfer must be controlled in order to be accepted as a practical manufacturing process. In consumable DE-GMAW, the bypass welding wire is the cathode of the bypass arc and this forms a DC electrode negative (DCEN) mode. The electromagnetic force, which is the dominant detaching force in conventional GMAW, now becomes a retaining force to prevent the droplets at the tip of the bypass welding wire from being detached. Unless other major detaching forces are introduced, gravity may become the primary detaching force. As a result, globular transfer, and its associated severe spatter, may occur as shown in Fig. 16.

In consumable DE-GMAW, if the bypass welding gun is close enough to the main welding gun and the angle between the two welding guns is small, the tip of the bypass welding wire may be covered by the main arc. And the pressure of the main arc can become a major detaching force to avoid globular transfer. High-speed videos confirmed that the corresponding bypass metal transfer was stable without producing spatter as can be seen in Figs. 17 and 18. But the bypass arc exhibited different behaviors when the bypass current was different. In Fig. 17, the bypass current was only 120 A, resulting in a smaller cathode spot. When the bypass current
was increased to 240 A (Fig. 18), the bypass arc was even brighter than the main arc. Also, the cathode spot was larger and covered a significant length of the bypass welding wire. Because of the higher melting speed and reduced main arc pressure, the molten metal was transferred in large particles without spatter.

The metal transfer of the main welding wire was in spray mode (Figs. 17, 18) because the total melting current was larger than the critical current. Thus, once the bypass arc is stable, both the bypass metal transfer and main metal transfer are smooth, and the resulting weld bead should be uniform. Figure 19 shows an example weld when the base metal current is 250 A.

Conclusions

A two-power-supply system has been developed to implement the proposed consumable double electrode gas metal arc welding (DE-GMAW) process. For this system, the following conclusions can be drawn:

1) A stable consumable DE-GMAW process can be achieved with the proposed welding gun configuration if the welding parameters are appropriately selected.

2) The consumable DE-GMAW can maintain its stability when the welding parameters vary within certain ranges and this stability is considered a local stability.

3) The consumable DE-GMAW can significantly increase the deposition rate by melting two welding wires.

4) Main arc pressure plays a critical role in successfully transferring the molten metal from the bypass welding wire (cathode) without spatters.

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References


Effects of Temporal Pulse Shaping on Cracking Susceptibility of 6061-T6 Aluminum Nd:YAG Laser Welds

Use of temporal pulse shaping may make it possible to laser weld 6061-T6 aluminum hermetic packages without the need for filler material

BY J. ZHANG, D. C. WECKMAN, AND Y. ZHOU

ABSTRACT: Pulsed laser beam welds of 6061-T6 aluminum alloy hermetic packages for encapsulation of sensitive electronic and optoelectronic components typically exhibit severe solidification cracking when a conventional rectangular or on/off laser pulse is employed. In this study, the effects of temporal pulse shaping on the solidification cracking susceptibility of Nd:YAG pulse laser welds made in 6061-T6 aluminum were investigated. The results showed that it was possible to eliminate solidification cracking in 6061-T6 pulse Nd:YAG laser seam welds by decreasing the ramp-down gradient of the laser pulse power after the main welding pulse sector. Crack-free welds were produced over a limited range of trailing ramp-down gradients; however, intermittent solidification cracking occurred when the gradient was further decreased. The solidification cracking susceptibility was also found to increase with increasing peak power density of the main welding sector. Use of a trailing ramp-down pulse shape was found to affect the solidification morphology of the welds. The width of the initial planar grain growth layer at the fusion boundaries and the dendrite and cell spacing increased with decreasing ramp-down gradient. EDS measurements of the overall chemical composition of the solidification crack surfaces of welds showed that microsegregation of Mg, Si, Fe, and Cu to the grain boundaries increased with decreasing ramp-down gradients. This was thought to be the reason for the return of intermittent cracking when low ramp-down gradients were used.

Introduction

Encapsulation of electronic and optoelectronic components or assemblies in hermetic enclosures or packages is performed to improve the reliability of these components by providing mechanical support, shielding from electromagnetic interference, better thermal management, and environmental protection of the environmentally sensitive components (Refs. 1, 2). Hermetically sealed electronic packages are widely used in the electronics, communications, automotive, computer, and medical industries. Figure 1 shows an example of an electronic package consisting of a box machined from 6061-T6 aluminum and a 4047 aluminum alloy sheet lid. Once the electronic circuits are assembled into the box, the package is placed in a glove-box environment with the desired enclosure gas and the lid is welded to the box. wrought aluminum alloys such as 6061-T6 are widely used for microwave amplifier and optoelectronic packages because they are lightweight, and have high corrosion resistance, good workability and machinability, and high thermal and electrical conductivity (Ref. 3).

The quality and durability of the hermetic seal in these packages must be high as failure of the seal can lead to corrosion of the package contents and premature failure of the device (Ref. 4). Pulsed Nd:YAG laser welding has become the method of choice for hermetic sealing of the most critical devices, because it has low and precise heat input that produces a small heat-affected zone, low distortion and residual stresses, is a noncontact process with an ability to weld a wide range of materials, has good process flexibility for automation, and is capable of making reproducible, high-quality welds (Refs. 4–7).

Many wrought aluminum alloys, especially 6xxx series aluminum alloys, are known to be susceptible to hot cracking during fusion welding due to their relatively high thermal expansion coefficient, large solidification shrinkage, and wide solidification temperature range (Refs. 8–16). There are generally two main categories of cracks generated during welding of such aluminum alloys; either solidification cracking within the weld fusion zone or liquation cracking in the partially melted zone (PMZ) adjacent to the fusion boundary (Refs. 8–19). Figure 2 shows an example of a pulsed Nd:YAG laser seam weld made in 6061-T6 aluminum using a series of overlapping on/off or rectangularly shaped laser pulses. This weld has severe solidification cracking (Fig. 2A, B) and also liquation cracking in the PMZ (Fig. 2B) and would, therefore, be unacceptable for electronic packaging or any other applications.

For solidification cracking to occur,
two conditions must exist at the solid-liquid interface of the solidifying alloy: one is related to the thermomechanical conditions present and the other is the solidification morphology. Solidification cracking will occur when tensile thermomechanical strains in the material due to thermal contraction of the recently solidified metal causes adjacent dendrites or cellular-dendrites to pull away from each other near the base of the dendrites (Refs. 9, 20, 21). If the distance between the tip and base of the dendrite is large and there is significant restriction to fluid flow down the relatively long narrow passage between the dendrites, then a void will form at the base of the dendrites. Continued solidification will cause growth of this void in the direction of solidification and the creation of a solidification crack similar to those shown in Fig. 2.

The susceptibility of alloys to solidification cracking is influenced by the weld metal composition, the welding process and weld process parameters used, and the restraint to thermal contraction due to weldment and joint design or clamping. For example, solidification cracking susceptibility is known to increase with alloy freezing range, which in turn is influenced directly by the alloy composition, the presence of impurities, and microsegregation due to nonequilibrium solidification effects (Refs. 8, 9, 18–21). A longer freezing range will promote the formation of long, thin dendritic morphology with poor fluid flow between the dendrites. Cracking susceptibility is also influenced by the solidification microstructure, the amount and distribution of liquid at the final stage of solidification, the primary solidification phase, the surface tension of the grain boundary liquid, the grain structure, and the ductility of the solidifying weld metal (Refs. 17–21). For a given alloy composition, the dendritic spacing, nonequilibrium freezing range, and the distance from start to finish of solidification are all affected by the local growth velocity and temperature gradient (Refs. 20, 21). All of these factors affect the resistance to fluid flow between the dendrites and, therefore, influence cracking susceptibility.

Several techniques have been reported to be effective in reducing or eliminating solidification cracking in laser welded aluminum alloys. The first approach involves use of a filler metal with a different composition and shorter freezing range. Normally, 4xxx and 5xxx series welding wires or Al-Si alloy foil can be used to move the weld metal composition and freezing range away from the crack-sensitive range (Refs. 8, 9, 14, 15, 22, 23). When fabricating hermetic packages by laser welding, this can be also be done by making the lid

<table>
<thead>
<tr>
<th>Mg</th>
<th>Si</th>
<th>Cr</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Zn</th>
<th>Ti</th>
<th>Al</th>
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</thead>
<tbody>
<tr>
<td>0.8–1.2</td>
<td>0.4–0.8</td>
<td>0.04–0.35</td>
<td>0.7</td>
<td>0.15–0.40</td>
<td>0.15</td>
<td>0.25</td>
<td>0.15</td>
<td>balance</td>
</tr>
</tbody>
</table>
out of the filler metal alloy as shown in Fig. 1 or by making a special insert for the joint out of the filler metal alloy. However, filler metal alloys are not always available in the desired shapes and the extra parts and manufacturing steps required are time consuming and costly. Laser welded aluminum alloy hermetic packages have also been made successfully by Ni plating one or both aluminum parts prior to welding (Refs. 24, 25). The weld metal can be changed to a zero freezing range Al-Ni eutectic and solidification cracking avoided by plating an optimized thickness of Ni on the aluminum part prior to laser welding; however, this also requires an additional manufacturing step that can introduce other problems such as hydrogen porosity from the plating operation.

Temporal pulse shaping has also been used to reduce or eliminate defects in welds made in various alloys using the pulsed Nd:YAG laser spot welding process (Refs. 26–30). A conventional pulsed laser welding beam pulse is simply on/off, i.e., it has a simple rectangular shape on a plot of laser beam power vs. time. However, temporal pulse shaping involves varying the laser beam power with time during the pulse in a predetermined manner. Temporal pulse shaping has been reported to be an effective method of modifying weld fusion area and penetration (Ref. 26) and reducing or eliminating a number of commonly observed defects in pulsed laser welds, such as porosity (Ref. 26) and solidification cracks (Refs. 28–30).

Matsunawa et al. (Refs. 28, 29) developed a laser pulse shape composed of two distinct pulses, the initial welding pulse followed by a second pulse a short time later. They found that using this pulse shape with a controlled decrease in beam power at the end of each pulse was beneficial in reducing cracking in A5083 aluminum and A7N01 stainless steel alloy welds. More recently, Michaud et al. (Ref. 27) developed an optimized ramp-down pulse shape that significantly reduced solidification cracking in individual spot welds in a pure binary Al-3.75 wt-% Cu alloy and produced crack-free seam welds. A thermal analysis of the optimized pulse shape on the pulsed laser welding conditions showed that solidification times and interface velocities were lower, and temperature gradients were higher during the solidification process (Ref. 31). Such conditions are known to have beneficial effects on the solidification microstructure and solidification cracking susceptibility (Refs. 9, 20, 21).

Temporal pulse shaping has the advantage over other methods of preventing various weld defects because it does not require the addition of a filler metal or use of extra manufacturing process steps such as plating. This simplifies the manufacturing process and makes it possible to fabricate the hermetic package using one single material, thereby improving the corrosion resistance of the package. However, most previous studies of the use of temporal pulse shaping during laser spot welding of aluminum alloys have been done using 2xxx and 5xxx series of aluminum alloys (Ref. 27). These alloys have lower solidification cracking indexes compared to 6061-T6 aluminum alloy (Refs. 8–13). The objective of the present study, therefore, was to study the effects of tem-

**Table 2 — Laser Welding Process Parameters Used in This Study**

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse frequency</td>
<td>5 Hz</td>
</tr>
<tr>
<td>Pulse width of main welding sector</td>
<td>4 ms</td>
</tr>
<tr>
<td>Peak power of main welding sector</td>
<td>1.26–2.21 kW</td>
</tr>
<tr>
<td>1/(ramp-down gradient)</td>
<td>0–19.7 ms/kW</td>
</tr>
<tr>
<td>Welding speed</td>
<td>0.3 mm/s</td>
</tr>
<tr>
<td>Focal position</td>
<td>0.0 mm</td>
</tr>
<tr>
<td>1/e² beam diameter</td>
<td>437 μm</td>
</tr>
<tr>
<td>Overlap rate</td>
<td>~87%</td>
</tr>
<tr>
<td>Argon shielding gas flow rate</td>
<td>0.24 L/s</td>
</tr>
</tbody>
</table>
poral pulse shaping on solidification cracking susceptibility of pulsed laser seam welds on 6061-T6 aluminum. In this work, the influences of both ramp-down gradients and the peak power density of the main welding sector on characteristics such as total solidification crack length, solidification morphologies, and severity of microsegregation were examined.

Experimental Materials
Apparatus and Methodology

The base metal used for this study was 6061-T6 aluminum with a nominal chemical composition as shown in Table 1 (Ref. 32). All samples were cut from 3.175-mm (0.125-in.) sheet into 50- × 50-mm coupons. Before welding, the as-received surface of each specimen was cleaned with acetone in an ultrasonic bath followed by a methanol rinse and air drying. The specimens were then clamped on the welding jig and laser seam welded.

All laser seam welds were made using a Lumonics JK702H pulsed Nd:YAG laser welding machine with a fiber-optic beam

<table>
<thead>
<tr>
<th>Location</th>
<th>Mg</th>
<th>Si</th>
<th>Cr</th>
<th>Fe</th>
<th>Cu</th>
<th>Al</th>
</tr>
</thead>
<tbody>
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<td>5.9</td>
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<td>0.0</td>
<td>4.0</td>
<td>2.3</td>
<td>79.5</td>
</tr>
<tr>
<td>3</td>
<td>0.4</td>
<td>4.2</td>
<td>0.8</td>
<td>4.9</td>
<td>2.2</td>
<td>87.5</td>
</tr>
<tr>
<td>4</td>
<td>1.4</td>
<td>10.3</td>
<td>0.7</td>
<td>6.8</td>
<td>2.6</td>
<td>78.2</td>
</tr>
<tr>
<td>5</td>
<td>1.3</td>
<td>9.9</td>
<td>0.5</td>
<td>4.2</td>
<td>2.5</td>
<td>81.6</td>
</tr>
<tr>
<td>6</td>
<td>1.2</td>
<td>7.5</td>
<td>0.6</td>
<td>3.8</td>
<td>4.4</td>
<td>82.7</td>
</tr>
<tr>
<td>Base Metal</td>
<td>0.5</td>
<td>0.6</td>
<td>0.5</td>
<td>0.8</td>
<td>0.3</td>
<td>97.4</td>
</tr>
</tbody>
</table>
delivery system. A schematic diagram of the laser welding head and specimen clamping fixture is shown in Fig. 3. As indicated, the laser beam delivery head was tilted 15 deg from the normal to avoid backreflection of the laser beam. The Nd:YAG pulsed laser welding machine was capable of up to 350 W mean power, 0.5 to 20 ms pulse widths, maximum peak pulse power of up to 5000 W, and energy up to 55 J/pulse. The laser beam delivery system consisted of a 600-μm fiber-optic cable feeding into a beam delivery head with a 200-mm focal length collimator lens and a 120-mm final process lens. The intensity distribution of the laser beam at the focal plane was measured using a rotating-wire-type laser beam analyzer (Ref. 33) and a LeCroy 9410 digital oscilloscope. The beam profile was found to be well described by a Gaussian distribution with the 1/e² beam diameter of 437 μm. The spot size of the pulsed laser beam was verified by the measurements of burn patterns produced in 25-μm-thick Kapton films using the technique developed by Wang et al. (Ref. 34). The internal laser energy meter was calibrated independently with an Ophir Optronics laser power/energy meter. Thus, the energy/pulse and peak power actually delivered to the surface of the material was well characterized. The nominal peak power density was calculated using the relation

\[ P_D = \frac{4P}{\pi w_0^2} \times 1000 \]  

(1)

where \( P_D \) is the peak power density (GW/m²), \( P \) is the peak power (W), and \( w_0 \) is the 1/e² beam diameter (μm).

The laser welding process parameters used in this study are listed in Table 2. All bead-on-plate seam welds were made with the laser beam focused on the surface of the specimen. The welding speed was kept at 0.3 mm/s and a pulse frequency of 5 Hz was used. This combination of welding speed and pulse frequency resulted in about 87% spot weld overlap rate, which is consistent with the normal requirement of 85–90% overlap to ensure the hermeticity of electronic packages (Ref. 35). A coaxial flow of argon shielding gas was supplied to the workpiece at a flow rate of 0.24 L/s through an 8-mm-diameter ceramic shielding gas nozzle set about 6 mm above the workpiece.

The temporal pulse shape technique used by Bransch et al. (Ref. 26) to change the pulse shape on the JK702H pulsed Nd:YAG laser welding machine when welding 304 stainless steel was used, i.e., each laser pulse was divided into sectors where the peak power and width of each sector were adjusted to obtain the desired temporal variation of power during a pulse. In the present study, an initial series of individual pulse sectors of stepwise decreasing peak powers. As indicated in Fig. 4B, pulse shapes were then developed that involved a controlled rate of decrease of beam power after the initial rectangularly shaped welding pulse. Figure 4A shows a schematic of the idealized waveform design used in the present study for the ramp-down temporal shaping experiments. The initial rectangular portion of the pulse can be considered the “welding portion” of the pulse while the trailing ramp-down portion was considered the “solidification control portion” of the pulse. Both the peak power of the main welding sector and the ramp-down rate of the solidification portion of the pulse were adjusted to evaluate the effect of ramp-down gradient, \( R_g \), and peak power density, \( P_D \), on solidification cracking susceptibility. Weckman et al. (Ref. 36) found that pulsed laser weld dimensions in 1100 aluminum increased rapidly for the first 2 ms of laser pulse and changed little thereafter; therefore, a 4-ms main welding sector pulse width was used in the present study.

Figure 4B is an example of a series of measured ramp-down pulse shapes. The spike in power at the leading edge of the welding sector is characteristic of many solid-state pulsed laser welding machines and has been shown by Weckman et al. (Ref. 36), Bransch et al. (Ref. 26), and Michaud (Ref. 27) to have no measurable effect on the final weld dimension or weld quality. Note that the actual ramp-down portion of the pulse is not linear, rather it consists of a series of individual pulse sectors of stepwise decreasing peak powers. As indicated in Table 2, laser seam welds were made using peak powers for the main welding sector ranging from 1.26 to 2.21 kW and \( 1/R_g \) values of 0 ms/kW (rectangular pulses) to 19.7 ms/kW (\( R_g = 50.8 \) kW/s).

Laser seam welds produced using a range of peak power densities of the main
welding sector and ramp-down gradients were transversely sectioned, as shown in Fig. 5. All sectioned samples were mounted, ground, and polished to a 0.06-μm colloidal silica finish. An optical metallographic microscope with image analysis system was employed to characterize the severity of cracking through measurements such as total crack length, number of cracks, and cracking area on polished, unetched specimens. The total crack length on transverse sections was found to have the least experimental scatter in data and most sensitivity to the effects of the various weld process parameters on cracking. Therefore, the total crack length on transverse sections was used to characterize the solidification cracking susceptibility of the laser welded 6061-T6 aluminum. Following crack length measurements, the specimens were etched using both Keller’s reagent (Ref. 37) (5 mL HNO₃, 3 mL HCl, 2 mL HF, and 190 mL H₂O) and Graff and Sargent reagent (Ref. 37) (31 mL HNO₃, 1 mL HF, 6 g CrO₃, and 168 mL H₂O) in a two-step etching process to reveal the weld microstructure. Finally, surfaces of solidification cracks in welds were examined using a JEOL JSM-6460 scanning electron microscope (SEM) and composition measurements were made using energy dispersive spectroscopy (EDS). All SEM images were taken at 20 keV and a 13-mm working distance. The EDS measurements were conducted at 20 keV and a 20-mm working distance.

**Results**

**Effect of Ramp-Down Gradients on Solidification Cracking Susceptibility**

Figures 6–9 show bead-on-plate pulsed laser seam welds made on 6061-T6 alloy with a peak power density of the main welding sector of 11.5 GW/m² and various ramp-down gradients. Figure 6 shows a seam weld produced with a conventional rectangular pulse where welding was performed from left to right. In Fig. 6A, B, the original oxide layer was vaporized from the middle of the weld bead where the power density of the Gaussian distributed laser beam was greatest. However, the original surface oxide was not removed but remained floating on the weld pool surface toward the outside edges of the weld pool where the power density was much lower. The actual fusion zone width was greater than the width of ripples shown due to the much lower melting point of the aluminum base metal (925 K) relative to that of the aluminum oxide, Al₂O₃ (2373 K) on the specimen surface.

In Fig. 6A, B, severe solidification cracking initiated in one pulse and continued into subsequent spot welds following the local direction of solidification. Cieslak and Fuerschbach (Ref. 12) observed the same pattern of solidification cracking in pulsed Nd:YAG laser welds made in this same alloy. Significant crater cracking was evident in the crater at the end of the welds — Fig. 6B. Examination of the transverse sections such as shown in Fig. 6C revealed that severe solidification cracking had occurred in the weld metal and liquation cracking had occurred in the HAZ. The semicircular bands evident from the bottom to the top of the weld zone in Fig. 6C are the fusion boundaries of the sequential overlapping spot welds that form the spot weld.

As shown in Fig. 7, there was a reduction in severity of cracking observed when ramp-down pulse sectors were added to the initial rectangular pulse sector. In Fig. 7A, the solidification cracking was reduced to a single centerline crack that occurred intermittently along the seam weld. Notable crater cracking still existed in the crater at the end of the weld — Fig. 7B. The transverse section shown in Fig. 7C exhibited both solidification cracking in the weld metal and liquation cracking in the HAZ, but only down the centerline of the weld. In addition, some evidence of grain boundary liquation toward the sides away from the centerline was observed in both the weld metal and the HAZ.

As shown in Fig. 8, crack-free seam welds were achieved with further decrease of the ramp-down gradient to 100 kW/s. As may be seen in Fig. 8A, B, there was no evidence of solidification cracking on the surface of the weld bead during steady welding or in the crater area. The crack-like patterns in the crater in Fig. 8B were breaks in the oxide layer only. As shown in Fig. 8C, there were no cracks in the transverse sections, but there was some evidence of grain boundary liquation. This was confirmed by examination of the as-polished, unetched specimens as well as examination of the specimens using the SEM. A higher magnification photomicrograph of the interface region of one of these welds is shown in Fig. 13C.

Figure 9 shows a weld made with further reduction of the ramp-down gradient to 36 kW/s. As may be seen, intermittent...
solidification cracking was evident again. The intermittent solidification cracking occurred along the centerline of the weld bead (Fig. 9A) and there was crater cracking in the weld crater (Fig. 9B). Meanwhile, there was both solidification and liquation cracking located close to the centerline of the seam weld. As shown in Fig. 9C, some evidence of grain boundary liquation existed in both the weld metal and the HAZ.

Effects of Ramp-Down Gradient and Peak Power Density of Main Welding Sector on Solidification Cracking Susceptibility

Figure 10 shows a plot of total crack length as a function of $1/R_g$ for welds made with a peak power density of 8.1 GW/m². Note that $1/R_g$ is used in these plots because the value of $R_g$ for a rectangular pulse approaches infinity whereas $1/R_g$ is 0. There are three identifiable regimes for solidification cracking susceptibility evident in this plot. In Regime I, severe solidification cracking to intermittent cracking was observed in welds produced using rectangular pulses and relatively high ramp-down gradients such as those shown in Figs. 6 and 7. In Regime II, crack-free welds were produced using intermediate $R_g$ values such as the weld shown in Fig. 8. Finally, in Regime III, intermittent cracking was exhibited again in welds produced using low $R_g$ values such as the weld shown in Fig. 9. Note that the first two data points in this regime are zero only because, by chance, the three transverse sections were made in uncracked or sound portions of the weld bead surfaces.

The results in the first regime in Fig. 10, which showed decreasing cracking tendency with decreasing $R_g$ (increasing $1/R_g$), are in good agreement with the results of the study by Michaud et al. (Ref. 27) on the use of temporal pulse shaping in laser welding of Al-Cu alloys and Matsunawa et al. (Refs. 28, 29) when working with 5083-O aluminum alloy and SUS 310S stainless steel. However, in Regime III, there was increasing solidification cracking susceptibility when $R_g$ was further decreased. This behavior has not been previously reported.

As shown in Fig. 11, when the peak power density of the main welding sector was increased from 8.1 to 11.5 GW/m², the same trends in cracking behavior shown in Fig. 10 were observed; however, there was a noticeable decrease in the range of $R_g$ values for the crack-free Regime II. Finally, crack-free welds could not be produced when the peak power density was further increased to 14.7 GW/m² and $1/R_g$ values from 0 to 18.0 ms/kW were used.

Figure 12 is a plot of the range of $R_g$ values that could be used to produce crack-free welds vs. peak power density of the main welding sector. There was a clear trend that the range of $R_g$ values that could be used to produce crack-free welds decreases with increasing peak power density of the main welding sector. These results indicated that the solidification cracking susceptibility was not only affected by $R_g$, but was also influenced by the peak power density of the main welding sector.

Metallographic Examination Results

Solidification cracking is known to be affected by alloy composition, solidification rate, and thermal gradient at the solid-liquid interface during weld metal solidification (Refs. 9, 20, 21). To help better understand the effect of $R_g$ on solidification cracking susceptibility, it is useful to examine the effects of $R_g$ on the solidification morphology and microsegregation of alloy elements within the weld metal. For example, Fig. 13A shows the microstructure at the fusion boundary of a weld produced with the conventional rectangular pulse shape. There are fusion boundaries from three subsequent spot welds also evident in this photomicro-
The solidification was initially planar over a narrow band at the fusion boundary adjacent to the base metal. This band was about 1.5 μm wide. Beyond this band of planar solidification, the interface broke down to a cellular-dendritic solidification structure that extended in a band that was about 5–8 μm wide — Fig. 13A. This transition of weld solidification microstructure can be explained in terms of the $G/V$ ratio, where $G$ is the temperature gradient in the liquid at the solid-liquid interface and $V$ is the local growth rate (Refs. 9, 20, 21). Since $V$ is expected to be initially small at the fusion boundary, $G/V$ is large and planar growth takes place. However, as the laser spot welds begin to cool, $V$ increases, $G$ decreases (Ref. 31), and the growth morphology changes from planar to cellular-dendritic (Refs. 9, 20, 21). Planar growth was evident only when the weld bordered unmelted base metal. At fusion boundaries of subsequent spot welds in previously solidified weld metal, a planar growth region was less evident, although a band was often present — Fig. 13A. The dendritic structure was not visible beyond this point, suggesting a transition to a very fine solidification microstructure that was beyond the resolution of the optical microscope. There was severe solidification cracking in the weld metal and intergranular liquation cracking in the HAZ adjacent to the fusion boundary. There was also evidence of grain boundary liquation in the HAZ.

Welds produced with ramp-down pulse shapes exhibited very different microstructures. Figure 13B shows the microstructure of a weld produced with a peak power density of the main welding sector of 11.5 GW/m² and $R_g$ of 420 kW/s ($1/R_g = 2.4$ ms/kW). The microstructure at the very beginning of weld metal solidification was similar to that in the weld made with a rectangular pulse. However, the band of planar solidification adjacent to the fusion boundary was wider at about 3.5 μm. Beyond this band, the solidification morphology was cellular-dendritic — Fig. 13B. As solidification proceeded, the primary dendrite arm spacing (DAS) became finer until the cellular-dendrites reached the boundary of a subsequent spot weld. The solidification microstructure was coarser with larger primary DAS in this weld compared with that in the welds made with a rectangular pulse shape — Fig. 13A, B. The solidification cracking exhibited was less severe and was reduced to a single centerline crack that propagated along the grain boundary in the direction of solidification. The observed reduction of solidification cracking may be the result of improved ability of liquid metal to flow back to cellular-dendrites or dendrite roots at the final stage of weld metal solidification with larger DAS. Finally, as shown in Fig. 13B, there was some evidence of grain boundary liquation in the HAZ and continued solute segregation along the grain boundaries in the weld metal.

As shown in Fig. 13C, when the ramp-down gradient was further decreased to
100 kW/s (1/Rg = 10 ms/kW), there was a notable increase of the width of the initial planar solidification band adjacent to the fusion boundary and the primary DAS in the weld metal. The width of the initial planar solidification band increased to about 5.5 μm. There was no solidification cracking or liquation cracking evident in this weld; however, there was noticeable evidence of grain boundary liquation in the HAZ and solute segregation along the weld metal grain boundaries.

As expected, the width of the initial planar solidification band increased when the ramp-down gradient was further decreased to 36 kW/s (1/Rg = 28 ms/kW) — Fig. 13D. The width of the band of planar solidification in this weld is about 8.0 μm. Both solidification cracking and liquation were evident again. In the photomicrographs shown in Fig. 13A–D, the width of the initial planar growth band at the fusion boundary increased and the primary dendrite arm spacing in the remaining weld metal increased with decreased ramp-down gradient. This is indicative that lower solidification rates and higher thermal gradients exist during solidification of laser spot welds produced using decreasing ramp-down gradients in the laser pulse (Refs. 9, 20, 21).

**SEM/EDS Investigation of Fracture Surface Compositions and Microsegregation**

SEM/EDS analysis of the fracture surfaces of cracked welds made using a peak power density of the main welding sector at 11.5 GW/m² and a series of ramp-down gradients was performed to evaluate the morphology of the fracture surfaces, to obtain a measure of the element segregation that had taken place near the cracks, and to identify the chemical composition of second-phase particles observed on these crack surfaces. In order to provide a basis for comparison for the EDS results, freshly polished and cleaned samples of base metal were also analyzed.

Typical crack surfaces in the weld metal and the HAZ are shown in Fig. 14. Figure 14A shows well-developed cellular dendrites of the primary α phase. As may be seen at ①, some second-phase particles formed on the primary dendrite surfaces. The dendritic morphology of the crack surfaces further suggests that these cracks are solidification cracks. Figure 14B shows a liquation crack surface in the partially melted zone (PMZ) in the HAZ adjacent to the fusion boundary. There is evidence of solidification of the liquated thin film in the lower half of the image. The second-phase particle at ② is on the intergranular solidification crack in the weld metal adjacent to the fusion boundary.

**Fig. 14 — SEM photographs of crack surfaces in welds made using a rectangular pulse shape with peak power density of 11.5 GW/m²: A — Solidification crack in the weld metal; B — liquation crack in the HAZ adjacent to the fusion boundary.**

**Fig. 15 — SEM photographs of crack surfaces in welds made using a ramp-down pulse shape with peak power density of the main welding sector of 11.5 GW/m² and ramp-down gradient of 3 kW/s: A — Overall crack surface; B — higher magnification for area of interest in ① in A.**
SEM images of a solidification crack surface in a weld made using a ramp-down pulse shape with a peak power density of the main welding sector of 11.5 GW/m² and the slowest ramp-down gradient of 36 kW/s is shown in Fig. 15. Liquid that was drawn out into spikes or thin sheets by thermal strains during the last stages of weld metal solidification was also observed on crack surfaces — Fig. 15A. In addition, there were significantly more second-phase particles on the crack surface — Fig. 15A, B. As shown in Table 3, EDS analysis of these second-phase particles at locations ○—○ in Fig. 15A showed that they were Mg, Si, Fe, and/or Cu-rich phases.

EDS measurements of the overall chemical composition of the crack surfaces of welds with hot cracking were done at 500× magnification. This lower magnification was chosen as it provided higher accuracy and less scatter of the EDS results. It must be recognized that these EDS measurements cannot be expected to be qualitatively accurate as their resolution is poor when element concentrations are less than 1% because the energy peak associated with that element is very small and close to the normal background noise of the detector. Also, the electron beam excites not only the surface elements but a small volume of metal below the surface. Thus, the EDS measurement is an average measure of the composition in the excitation volume. If the surface film on the surface of the crack is thinner than the excitation volume, then EDS measurement of composition will not be quantitatively accurate. These measurements should, however, be qualitatively accurate.

As shown in Fig. 16, the average Fe, Mg, and Si concentrations on the crack surfaces increase slightly with increasing 1/RG (decreasing ramp-down gradient) below the 1/RG values that produce crack-free welds, i.e., in Regimes I and II. However, in Regime III, there is a dramatic increase in these solute concentrations on the crack surface when 1/RG exceeds about 15 ms/kW. Most notably, the Fe concentration increased by about 4.5 times the nominal base metal composition, the Mg concentration increased by about 3 times the nominal base metal concentration, and the Si concentration increased by about 10 times the nominal base metal Si concentration when a pulse shape with a 1/RG value of 28 kW/s was used compared with a rectangular pulse with the same peak power density. These increased solute concentrations can be expected to significantly lower the melting temperature and increase the freezing range of the liquid in the intergranular regions during solidification, thereby dramatically increasing the propensity for solidification cracking.

**Discussion**

Changes of laser welding process parameters can significantly influence the cooling rate, solid/liquid interface velocity, V, temperature gradient in the liquid, G, and microsegregation during weld metal solidification. These changes will in turn result in different solidification times, dendrite arm spacing, mushy zone width, dendrite growth rate, strain rate, cell or cellular dendrite length, and solidification temperature range. All of these factors ultimately affect the propensity for solidification cracking in 6061-T6 aluminum during solidification of laser spot welds.

**Effects of Solidification Time**

Solidification cracking is caused in part by difficulties in feeding liquid from the molten weld pool to the cellular-dendrite or dendrite roots during the solidification process and by tensile strains transverse to the solidification direction due to thermal contraction as the weld metal solidifies and cools (Refs. 9, 20, 21). If liquid can flow back freely between the dendrites as they are pulled away from each other during cooling, then voids created by the accumulation of thermomechanical strain from thermal contraction can be healed, thereby preventing solidification cracking. The thermal conditions present during rectangular and ramp-down pulse shapes can have a significant influence on these factors. Based on the work by Michaud et al. (Ref. 27) on Al-3.75 wt-% Cu for both a rectangular and an optimized ramp-down pulse shape, the solidification time for the ramp-down pulse shape was much longer than that of the rectangular pulse. Solidification cracking was not observed in this alloy when using the ramp-down pulse shape. Similar results were obtained by Matsunawa et al. (Refs. 28, 29) for an
A5083-O aluminum alloy using a pulse with a trailing pulse in comparison with a rectangular pulse shape. The longer solidification time experienced in welds produced with the ramp-down pulse shapes would allow more time for liquid to flow back to the cellular-dendrites or dendrite roots thereby reducing the solidification cracking susceptibility as was observed in Regimes I and II in Figs. 10 and 11; however, this does not explain why intermittent cracking returned with further decrease of the ramp-down rate in Regime III.

**Effects of Interface Velocities during Solidification**

From solidification theory, it is known that the interface velocity and temperature gradient at the solid-liquid interface during solidification affect the resulting solidification microstructure (Refs. 20, 21). A planar interface morphology will be formed at extremely high solidification rates where there is no time for diffusion in the liquid ahead of the interface or when the thermal gradient is high and the solidification velocity is low. At intermediate solidification rates and temperature gradients, a cellular-dendritic or dendritic solidification morphology will be produced where the primary dendrite arm spacing, $\lambda_1$, can be calculated based on the equation proposed by Hunt (Ref. 38)

$$\lambda_1 = C(G^2 V)^{\frac{1}{4}}$$  \quad (2)

where $C$ is a material constant whose value is dependent on the alloy system, $G$ is the temperature gradient, and $V$ is the solid-liquid interface speed during solidification. For the ramp-down pulse shape, the interface velocities are lower than that for a rectangular pulse shape (Ref. 31), resulting in increased primary dendrite arm spacing and a coarser microstructure compared with the welds produced with a rectangular pulse shape. This is in qualitative agreement with the observed differences in weld metal microstructure of the welds produced using the rectangular and ramp-down pulse shapes shown in Fig. 13A–D. The coarser microstructure observed with the ramp-down pulse shape would lead to a larger cell or dendrite interstices and, thus, larger passages for the flow of liquid back to the cellular-dendrites or dendrite roots thereby resulting in reduced solidification cracking susceptibility. This is consistent with the observed decrease in crack length with decreasing ramp-down rates (increasing $1/R_g$) in Regimes I and II in Figs. 10 and 11; however, this also does not explain why intermittent cracking returned with further decrease of the ramp-down rate in Regime III.

**Effects of Temperature Gradient on Cell or Cellular Dendrite Length**

Based on a numerical thermal analysis by Michaud et al. (Ref. 31), the temperature gradients for ramped down pulse shapes are higher than those made by a rectangular pulse shape because heat is constantly being introduced into the surface of the weld pool during the ramp-down phase of the laser pulse and a higher thermal gradient is required to conduct this heat into the surrounding base metal. From solidification theory, the temperature gradient, $G$, directly influences the cell or cellular dendrite length, $\lambda_c$, in the mushy zone. This is given approximately by (Refs. 20, 21)

$$\lambda_c = \frac{G}{G_T} \left( T_s - T_p \right) \quad (3)$$

where $\Delta T'$ is the difference between the cell tip temperature, $T_s$, and the root temperature $T_p$, and $G$ is the temperature gradient. According to Equation 3, the increased thermal gradient at the interface with decreasing laser pulse ramp-down rate would result in shorter cells or cellular dendrites and therefore shorter feeding distance for liquid to flow back to the dendrite root. Consequently, cracks could be more easily healed by the liquid flowing back to the dendrite roots and the propensity for solidification cracking would be reduced. This reduced solidification cracking susceptibility with decreasing ramp-down gradient and higher thermal gradients during solidification is consistent with the results observed by Michaud et al. (Ref. 27) with a binary Al-3.75 wt-% Cu alloy and by Matsunawa et al. (Refs. 28, 29) with A5083-O aluminum and SUS 310S stainless steel. The data shown in Regions I and II in Figs. 10 and 11 are also consistent with these effects, that is, solidification cracking susceptibility in the 6061-T6 aluminum alloy decreased with decreasing ramp-down rate (increasing $1/R_g$). However, the reason for the increase in intermittent solidification cracking observed with further decrease of the ramp-down rate in Region III is not explained by Equation 3.

**Effects of Cooling and Strain Rate during Weld Metal Solidification**

The solidification rates and cooling rates of a spot weld produced using a rectangular laser pulse is greater than that of a ramp-down pulse shape (Ref. 31). This leads to higher deformation rates (strain rates) for welds produced using a rectangular pulse shape. According to a combination of Borland’s generalized theory (Ref. 39) and the critical strain rate theory (Refs. 9, 11, 40, 41), an alloy at high temperature and most notably within the solidification temperature range is affected by a low-ductility brittle temperature range (BTR) near the solidus. In the BTR, cracking can occur in the material in which continuous liquid films separate grains or in which some solid-solid bridges exist between grains when localized tensile strains in the materials exceed its resistance to cracking or when the material is subjected to tensile strain at a rate faster than the critical tensile strain rate. For a normal rectangular pulse shape, the higher cooling rate and higher interface velocity will lead to higher strain rates as the metal cools through the BTR. Alternatively, the lower cooling and strain rates present when using the ramp-down pulse shape will decrease the tendency for cracking as the material cools through the BTR. The experimental results in Regimes I and II in Figs. 10 and 11 are consistent with this theory for solidification cracking susceptibility; however, the reason for the return of intermittent cracking with further decrease of the ramp-down rate in Regime III remains unexplained.

**Microsegregation**

Hot cracking of aluminum alloy welds is influenced metallurgically by the freezing
temperature range of the dendrites during nonequilibrium solidification and the heat and amount of liquid available at the root of the dendrites during solidification. These are affected mainly by the weld metal composition and microsegregation that occurs during solidification (Refs. 17–19, 22, 41). Microsegregation, in turn, can be affected by the cooling rate during solidification. The cooling rate during solidification of a laser spot weld made using a ramp-down pulse shape is lower than one made with a rectangular pulse shape, so there is more time available for microsegregation to take place in the interdendritic and intergranular regions of the microstructure. In most cases, this will result in a solute-rich liquid film in the interdendritic and intergranular regions that has a much lower melting temperature and greater freezing range than the base material. This low-melting-point liquid film is unable to resist the thermomechanical contraction strains that take place during cooling, and voids and solidification cracking will occur. Low ramp-down gradients may also provide enough time for low-melting-point eutectics to form at cell or grain boundaries. Low-melting-point eutectics can be formed in 6xxx series AP-Mg-Si alloy systems such as Al-Mg3Si, Al-Si, Al-Mg-Si-Fe-Mg5Si, Al-Mg-Si (CrFe)5SiAl13Si, Al-CuAl2-Mg3Si, Al CuMg2Si, Al-CuAl2Si, Al-CuAl2Si, etc. The melting temperatures of these eutectics range from 787 to 868 K (Ref. 42), which are much lower than the liquidus temperature of 6061-T6 (925 K) (Ref. 32, 42). Hatch (Ref. 43) has reported that coarse MgSi was present in 6061 aluminum and a Al-Mg-Si eutectic could be formed with a eutectic temperature of 868 K in this alloy. Also, Huang and Kou (Ref. 44) observed Si-, Fe-, and Cr-rich particles in the base metal of 6061 aluminum and segregation of Si up to 20 wt-% and Mg up to 10 wt-% at the grain boundaries in the partially melted zone (PMZ) of gas tungsten arc welded 6061-T6 aluminum alloy in addition to Fe-, Si-, Cr-, and Mn-rich particles in the PMZ. The formation of such eutectics and solute-rich liquid films will increase the freezing range of the alloy and increase the susceptibility of this alloy to solidification cracking.

As shown in Fig. 16, the severity of Fe, Mg, and Si microsegregation on the solidification crack surface increased with a decrease of the ramp-down gradient especially in Regime III where the ramp-down gradient used was lowest (highest 1/R). In addition, solidification cracking susceptibility increased in Regime III as the ramp-down gradient was decreased (see Figs. 10 and 11). This suggests that reappearance of solidification cracking in Regime III may be caused by severe interdendritic and intergranular microsegregation and the formation of low-melting-point liquid films that occurred when the ramp-down gradients were reduced to low levels and solidification times were increased.

**Summary of the Effects of Temporal Pulse Shaping on Solidification Cracking Susceptibility**

Based on the previous results and discussions, it is clear that the effects of longer solidification time, larger dendrite arm spacing, narrower mushy zone, and smaller strain rate during welding metal solidification would benefit the reduction and elimination of solidification cracking when decreasing the ramp-down gradient. However, longer columns and more severe microsegregation would cause feeding problems for the remaining liquid metal to flow back to the dendrite roots and widen the solidification temperature range, resulting in increased solidification cracking tendency, when decreasing the ramp-down rate further. Figure 17 illustrates the combined effects of the above-mentioned factors as a function of the ramp-down gradient. The resultant solidification cracking susceptibility would follow the trends of decreasing to increasing cracking tendency when decreasing the ramp-down gradient (increasing 1/R2) as was observed in Figs. 10 and 11. As shown in Fig. 17, a crack-free or less severe cracking region may be reached when the cumulative influences of both effects are minimized.

**Conclusions**

In the present study, the effects of temporal pulse shaping, specifically the effects of ramp-down gradient and peak power density of the main welding sector, on solidification cracking susceptibility of pulsed Nd:YAG laser beam welds made in 6061-T6 aluminum alloy were examined. The results showed that it was possible to eliminate solidification cracking in 6061-T6 pulsed Nd:YAG laser beam welds using temporal pulse shaping. The solidification cracking susceptibility was found to decrease with decreasing ramp-down gradient. A limited, intermediate range of ramp-down gradients resulted in sound, crack-free welds, however, intermittent solidification cracking occurred again when the gradient was further decreased.

There were three identifiable regimes of solidification cracking susceptibility with decreasing ramp-down gradients for welds made with the peak power densities of the main welding sector less than 11.5 GW/m². Regime I showed decreasing cracking tendency with decreasing ramp-down gradients. This is in good agreement with previous studies of the use of temporal pulse shaping during pulsed laser welding in Al-Cu and Al-Mg alloys. It is thought that cracking in the laser spot welded 6061-T6 was reduced with decreasing ramp-down gradient in Regime I because of the beneficial effects of longer solidification time, larger dendrite arm spacing, narrower mushy zone, and smaller strain rate during weld metal solidification. Regime II was the crack-free region. However, intermittent solidification cracking was exhibited again in Regime III, in which the solidification cracking susceptibility increased with a further decrease of the ramp-down gradients. In this case, it was thought that longer cracks and more severe microsegregation caused feeding problems for the remaining liquid metal to flow back to the dendrite roots and widened the solidification temperature range, thus resulting in increased solidification cracking tendency in Regime III when the ramp-down rate is decreased further beyond that used in Regime II.

The crack-free range of ramp-down gradients that produced welds decreased when the peak power density of the main welding sector was increased. Crack-free welds could not be produced when the peak welding power density was greater than 11 GW/m². Thus, the solidification cracking susceptibility was not only affected by the ramp-down gradient, but was also influenced by the peak power density of the main welding sector.

The weld metal solidification structures for welds made using a ramp-down pulse shape were different from those made using a rectangular pulse. The width of the initial planar grain growth layer at the fusion boundaries and cell spacing increased with decreasing ramp-down gradient in the laser pulses. Following the initial planar solidification, there was a transition to cellular and then cellular-dendritic solidification. The typical solidification crack surfaces in the weld metal revealed well-developed cellular dendrites of the primary phase. Some Cu-, Fe-, Mg-, and/or Si-rich second phases formed on the primary dendrite surfaces. EDS measurements of the overall chemical composition of the solidification crack surfaces of welds showed a clear trend that Cu-, Fe-, Mg-, and Si microsegregation to the grain boundaries increased with decreasing ramp-down gradients. This increased microsegregation was thought to be the cause of the return of intermittent solidification cracking in Regime III when low ramp-down gradients were used.

In summary, temporal pulse shaping can be used to affect the solidification time, the dendrite arm spacing, the size of the mushy zone, the strain rate, and the severity of interdendritic and intergranular...
lar microsegregation of alloying elements during weld metal solidification. These in turn influence the resultant solidification cracking susceptibility. Crack-free pulsed laser seam welds could be made in 6061-T6 aluminum alloy by using a limited range of intermediate ramp-down gradients where both the positive and the detrimental effects of laser pulse ramp-down rate were at an optimum level.

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References

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