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**Waterjet Technology Helps BP Cap Gulf Oil Leak**

Jet Edge, Inc., and Chukar Waterjet, Inc., both of St. Michael, Minn., recently played a role in helping BP stop the oil leak in the Gulf of Mexico that started after a fire and explosion occurred April 20th onboard Transocean Ltd.’s semisubmersible drilling rig, *Deepwater Horizon*. The rig is located approximately 41 miles offshore of Louisiana. BP operates the licence on which Transocean’s rig was drilling an exploration well.

Jet Edge custom engineered a 36,000 lb/in.² waterjet intensifier pump that was dropped 5000 ft into the Gulf to power a robot-operated waterjetting lance. It blasted away the hydrate ice crystals that formed inside a containment cap at the spill site, clogging the containment system. The company utilized a filtration and ultrahigh pressure seal technology capable of withstanding the undersea environment. The system was designed to blast with seawater or liquid gas.

Chukar Waterjet provided onsite applications engineering services throughout the project, working with a subsea technology company, offshore logistics and supply company, offshore transportation company, BP, and an independent safety group.

Since July 15, the *Deepwater Horizon* well has been shut-in and no new oil has flowed into the Gulf of Mexico, but work continues to identify and collect oil on the sea’s surface as well as collect and clean up oil that has reached shore.

For more information on the matter and response efforts, visit the following links: www.bp.com/gulfofmexico and www.deepwaterhorizonresponse.com/go/site/2931.

**Lincoln Electric Automation to Host SteelDay 2010**

Lincoln Electric Automation, Cleveland, Ohio, will host a SteelDay event at the company’s Automation Center of Excellence on Sept. 24. The agenda will include presentations covering topics such as cost reduction through welded steel, historical bridge restoration, and welding safety; demonstrations including robotic submerged arc welding, robotic cutting and scribing, weld fume control, and the new VRTEX™ 360 virtual reality welding trainer; a facility tour; and lunch. In addition, guest Dr. Omer Blodgett will be available to sign books. Visit www.lincolnelectric.com/steelday for more details.

SteelDay 2010, sponsored by the American Institute of Steel Construction, is the second annual national event dedicated to providing accessibility to the latest developments in the structural steel industry. Many events will take place across the United States, at mills, fabrication shops, service centers, manufacturers, and galvanizers.

**New Rule Strengthens Railroad Bridge Safety Programs**

Federal Railroad Administrator (FRA) Joseph Szabo recently announced a final rule requiring railroad track owners to adopt and follow procedures to protect the safety of their bridges, and strengthen federal oversight of railroad bridge maintenance programs.

It requires track owners to implement bridge management programs that include at least annual inspections of railroad bridges; know the safe capacity load of bridges; and conduct special inspections if the weather or other conditions warrant these.

Also, it requires an inventory of all railroad bridges, the audit of the bridge management programs, and inspections by the FRA; requires railroads to maintain the design documents of each bridge; to document all repairs, modifications, and inspections of each bridge subject to administration review; and allows FRA to levy fines of up to $100,000. The final rule is available at the following link listed below: www.fra.dot.gov/downloads/safety/bridgesafetyrule2010.pdf.
THERMADYNE, a global cutting and welding leader, joins the American Welding Society in encouraging individuals to practice the art, craftsmanship and professions of welding, metalworking and fabrication. Victor, Thermal Dynamics, Thermal Arc, Arcair, Tweco, Stoody, Cigweld and TurboTorch are among the Thermadyne family of brands that you can count on for safety, reliability and quality.

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Committee Expands Awareness of Brazing and Soldering

On behalf of AWS, I’d like to take this moment to recognize the 60th anniversary of the American Welding Society’s C3 Committee on Brazing and Soldering. The achievements of this committee are truly amazing when one considers the relatively small contingent of experts on this subject matter within the larger AWS organization. The C3 committee is responsible for nearly a dozen specifications in the field of brazing technology that are used by engineers across the globe. Those documents also form the basis for many of the current ISO specifications. Foreseeing the need for similar documents within the structural soldering industry, the committee membership has now embarked on the development of specifications that address structural soldering processes.

A particular goal of the C3 committee has always been to disseminate brazing and soldering information to the joining industry. There are many examples to this effect. First and foremost, there is the Brazing Handbook. The fifth edition is available, and the committee has already begun to develop the format and supporting materials for the sixth edition. Also, there is the sister document to the Brazing Handbook, the third edition of the Soldering Handbook, which has entered its tenth year on the AWS bookshelf. A guideline for hand soldering is also in the works.

The committee has always appreciated the rapid pace at which brazing and soldering technologies are advancing. It became clear to the membership that there was a critical need to bring these technologies to engineering students in the university classroom. The result was the development of a one-semester course in brazing and soldering that was spearheaded at The Ohio State University. The course is taught by both university faculty and C3 committee members who volunteer their time and resources toward educating these young people in these technologies. Development of the course curriculum was described in an article in the December 2008 Welding Journal.

Of course, one cannot say enough about the extraordinary contributions the C3 committee has made to AWS conferences and shows. The committee’s flagship event is the International Brazing and Soldering Conference (IBSC). Every three years, this conference brings together leading scientists and engineers from around the world in the fields of brazing and soldering to discuss the latest advances in materials and processes. The conference itself is the product of a strong collaboration between the C3 committee, the AWS Conferences Department, and ASM International. The next IBSC is slated for Spring 2012.

Let me encourage everyone to warmly congratulate the members of the C3 committee on their 60 years of outstanding contributions to the American Welding Society, and to the joining industry as a whole. May the next 60 years bring similar achievements.

John C. Bruskotter
AWS President
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Brooklyn Bridge to Get Major Upgrade

New York City Mayor Michael R. Bloomberg recently joined Vice President Joe Biden to mark the start of work on rehabbing the Brooklyn Bridge, a $508 million project supported by $30 million in American Recovery and Reinvestment Act funds. The four-year project will replace bridge decks on the ramp and approach structures, expand the number of lanes on ramps, repaint all the bridge’s steel components, reconstruct the roadway surface over the bridge’s masonry arch blocks, install a waterproofing seal and new drainage system on the bridge, and rehabilitate and seismically retrofit steel support structures, including the Franklin Square Arch. The vehicle entrance ramp from the southbound FDR Drive and Brooklyn-side exit ramp to Cadman Plaza will also be expanded from one to two lanes. Repainting the bridge’s steel will prevent corrosion of bridge components and keep components from prematurely aging.

“Thanks to stimulus funding and a major investment by the city, we’re about to begin more than a half billion dollars worth of improvements to the city’s most famous bridge,” said Mayor Bloomberg. “The work will bring the bridge into a state of good repair, improve traffic flow, and create needed construction jobs. While too often we have seen a lack of investment in infrastructure, our administration has made it top priority, and that’s why we’ve invested more than $5 billion in city bridges, including the rehab of all East River bridges, since 2002.”

In addition to the reinvestment act funding, the project is being paid for using $286 million in city capital funds and $192 million in other federal funding. The contractor was given notice to proceed in January, and staging along with other preparatory work is currently underway, with pilings for the expanded ramps already being installed. Also in attendance at the event were U.S. Deputy Secretary of Transportation John D. Porcari, Congressman Jerrold Nadler, City Transportation Commissioner Janette Sadik-Khan, and Denise Richardson, managing director of the General Contractors Association of New York at a work site adjacent to the Brooklyn Bridge in Lower Manhattan. The entire project is expected to be completed in 2014. For additional information, visit www.nyc.gov.

Superior Industries and Its Westmor Division Join Forces for Welding Training

Superior Industries, a manufacturer of portable and stationary conveying equipment, recently started a welding school in cooperation with its Westmor division, a designer and manufacturer of petroleum and liquid handling equipment, both located in Morris, Minn. It fulfills the growing demand for welders in the area’s manufacturing sector.

Primarily, the target weld training program participants are Superior Industries employees looking to add a new technique that also pays a higher wage. It’s offered to new employees, too, if there are not enough staff members applying for welding positions available within the company. Most students are young, just out of high school, or experienced workforce looking to add a new skill.

The training facility houses a classroom, library, and lab with eight welding and two grinding booths. Gas metal arc, gas tungsten arc, flux cored arc, shielded metal arc, and submerged arc welding are taught along with oxyfuel and plasma cutting. In addition, welds undergo destructive, guided bend, Charpy V-notch testing.
impact, macroetch, radiographic, and ultrasonic tests. Instruction consists of 30% class time and 70% hands-on welding work. “Class size can vary from four to eight people at a time,” said Superior Industries welding instructor/consultant Dave Dybdal, an American Welding Society (AWS) member. “Class length can be from one week to two months; it all depends on the class and how they absorb all the material. On average, the class will be three to four weeks long. We then just focus on that one weld process over that time period. I tell all my students to stay engaged and have some fun with it.”

Upon completion, there’s an opportunity to earn certifications adhering to AWS D1.1, Structural Welding Code — Steel, as well as the American Society of Mechanical Engineers Boiler and Pressure Vessel Code.

Superior’s goal for this program is to continue improving its weld capability through learning new technology, providing quality products through continuous training, and meeting the growing welding needs as expansion occurs. Presently, the company has 584 staff members. The number of welders is also slightly higher at Superior divisions, but Westmor is quickly gaining. For more information, visit www.superior-ind.com.

**Terra-Gen Power Closes $1.2 Billion Financing to Launch Wind Farm**

Terra-Gen Power, LLC, New York, N.Y., has closed a $1.2 billion financing for four wind power projects with a total of 570-MW of capacity at its Alta Wind Energy Center in Kern County, Calif. Alta Projects II–V will use 190 V90-3.0 MW turbines manufactured by Vestas-American Wind Technology, Inc.

Along with the 150-MW Alta Project I utilizing GE turbines, which is anticipated to begin commercial operations in January 2011, this financing puts the company on its way to completing what is anticipated to be the nation’s largest wind energy farm.

The center is expected ultimately to provide up to 3000-MW of pollution-free electrical generating capacity, 1550 MW of which will fulfill a power purchase agreement with Southern California Edison in 2006. According to Jim Pagano, Terra-Gen’s CEO, the projects will create more than 1500 domestic manufacturing, construction, and operation and maintenance jobs.

Project construction is expected to begin right away, with commercial operation anticipated in the first and second quarters of 2011. Delivery and commissioning of the Vestas turbines will begin in October.

**AMT and NAM Partner to Promote Manufacturing Importance in U.S. Economy**

The Association for Manufacturing Technology (AMT), McLean, Va., is joining forces with the National Association of Manufacturers (NAM) to promote the importance of manufacturing and innovation in the U.S. economy. This will bring the organizations together in support of IMTS 2010, The International Manufacturing Technology Show, sponsored by AMT, will be held at Chicago’s McCormick Place Sept. 13–18.

NAM’s President and CEO John Engler will give a keynote address in the Emerging Technology Center on the show’s second day. He will highlight how investment in innovation, technology, and technical skills are critical to a strong U.S. manufacturing sector. Also, the former Michigan governor will provide insights on how the U.S. and its states can create an economic climate that encourages innovation.
SkillsUSA Welding Champions Honored

Winners of the annual SkillsUSA welding championships were recently announced at the organization’s National Leadership and Skills Conference award session. The conference took place June 21–25 at various locations in Kansas City, Mo.

In the welding high school category, Brendon Edwards of Douglas, Wyo., earned the gold medal; Aaron Hopf of Jasper, Ind., won the silver medal; and Sean Murray of Imlay City, Mich., received the bronze medal. Also, in the college/postsecondary division for welding, Alex Puzkowski of Saline, Mich., earned the gold medal; Dylan Olson of Helper, Utah, got the silver medal; and Blake Parks of Douglas, Wyo., took the bronze medal.

Welding competitors received contest drawings and a set of welding procedure specifications. All drawings, symbols, and terms conformed to the latest edition of the American Welding Society (AWS) standards. Contestants were tested on numerous aspects, including measuring weld replicas; laying out a plate and using oxyacetylene equipment; gas metal arc welding on steel making welds in various positions using pulse transfer; and using a combination machine for shielded metal arc and gas tungsten arc welding. They completed the steel project and welded a stainless steel project in various positions using many filler metals.

Judges were provided by the AWS Kansas City Section. Contestants were judged while assembling and welding the project. Certified Welding Inspectors judged the completed project. Inspection methods included visual and liquid penetrant techniques.

Also, winners were honored in the welding art sculpture category, where contestants designed and produced a sculpture of that design, and the welding fabrication team competition that required three students from each school to use their welding and fabrication skills to build a designed project from the given material. For more details on these events, visit www.skillsusa.org.

At the SkillsUSA National Leadership and Skills Conference award session, the winners of its welding championships were named. In the front row (from left) are Martica Ventura, AWS director of operations, educational services department, and national technical committee member; high school medalists Aaron Hopf (silver), Brendon Edwards (gold), and Sean Murray (bronze); and Steve Houston, national technical committee member. In the back row (from left) are Nicholas Peterson and Jason Schmidt, national technical committee members; college/postsecondary silver medalist Dylan Olson; Steve Theesen, national technical committee member; college/postsecondary gold winner Alex Pazkowski; John C. Bruskotter, AWS president and national technical committee member; college/postsecondary bronze winner Blake Parks; and Ed Norman, national technical committee member. (Photo courtesy of Clay Allen, SkillsUSA photographer.)

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Please note: discounts and items discounted are at the sole discretion of each distributor/branch. For discount amount, please contact the company/branch directly.

Check out all participating locations at www.aws.org/distdiscounts
Wisconsin High-Speed Rail Awarded $46.5 Million to Continue Work

U.S. Transportation Secretary Ray LaHood and Wisconsin Governor Jim Doyle signed an agreement providing $46.5 million in American Recovery and Reinvestment Act funds for work to continue on the state’s high-speed rail program. The funding is the latest installment from the $822 million President Obama announced for Wisconsin high-speed rail from the recovery act in January. Previously, Wisconsin received a $5.7 million recovery act grant that brings its high-speed rail total to $52.2 million.

Under the agreement, the Wisconsin Department of Transportation will complete preliminary engineering and final design work, conduct program management activities, and complete environmental management plans for the Milwaukee to Madison high-speed rail corridor that will operate up to 110 miles/h.

Instructional Mobile Welding Lab for Wyoming Inmates Opens

The Wyoming Department of Corrections (WDOC) recently completed a new instructional mobile welding lab that will be used for training inmates. “We know that 95% of Wyoming inmates leave prison at some time, and we’re always looking for job skills that will help them obtain jobs that will keep them out of prison, supporting their families, and being productive citizens,” said Betty Abbott, WDOC education programs manager.

In addition, Abbott said the 2008 Wyoming legislature approved a $194,000 one-time appropriation to fund the welding lab, training, and certification for inmates. By using the department’s staff and inmates to complete much of the lab’s construction, they were able to stay within budget. Abbott mentioned the original trailer was purchased from surplus a few years before the project began. It had been used to power a missile site for the military, so the generator was already on board.

The welding lab has stations for five students at a time. It will be used at the Wyoming Women’s Center, Wyoming State Penitentiary, and Wyoming Medium Correctional Institution on a rotating basis. The department has a stand-alone welding facility at the Wyoming Honor Conservation/Boot Camp as well. Eastern Wyoming College has approved welding certification for all inmates who complete programs at the Wyoming Women’s Center, Wyoming Medium Correctional Institution, and Wyoming Honor Conservation/Boot Camp. The department is working with Central Wyoming College to provide that same certification to inmates at the Wyoming State Penitentiary.


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Ford India Exports Engines to Thailand

Ford India recently began exporting 1.4- and 1.6-L high-compression gas engines being manufactured at its Maraimalai Nagar engine facility to the AutoAlliance Thailand plant. The company has been exporting diesel power trains to South Africa since 2008.

“The first shipment of 1000 petrol engines is a significant first step in our goal to become a major production and export hub of diesel and petrol engines,” said Michael Boneham, president and managing director, Ford India. “We are excited about the significant growth opportunities for our engine export program, and proud of Ford India’s contributions to the further development of the local auto industry and economy overall.”

The number of engines exported will increase to 2500 per month and will continue to build as projected export demand gradually increases through the end of this year and into 2011.

In addition to the AAT facility, Ford India will export engines to other Ford plants in the Asia Pacific region. Ford Motor Co. has invested $500 million at the Maraimalai Nagar site.

ThyssenKrupp Europe to Supply Steel for Hydroelectric Power Plant

Heavy steel plate for the Ingula hydroelectric power project is loaded at the port of Antwerp (©ThyssenKrupp Steel Europe AG).

ThyssenKrupp Steel Europe AG is supplying 17,000 metric tons of high-strength, quenched, and tempered plate to the Ingula pumped storage project of the South African power utility Eskom. The steel will be used to manufacture pipe up to 5.1 m in diameter.

In pumped storage facilities like Ingula, huge water reservoirs are used to store energy that can be quickly converted into electricity when required and fed into the supply grid. The power station, which is located in the Drakensberg mountains on the border of the Free State and KwaZulu Natal, features two reservoirs that each have a capacity of 22 million cubic meters. The are located about 6 km apart, with a height difference of 470 m. Between them is a powerhouse with four 333-MW turbines, which can be used both as generators to produce electricity and as pumps. During periods of peak electricity demand, water is released from the upper to the lower reservoir, driving turbines to generate electricity that can be fed into the grid. During off-peak periods, the water is pumped back up to the upper reservoir.

The 17,000 tons of quenched and tempered plate for the project is the largest single order since this product was introduced more than 40 years ago. The steel plates being supplied to Ingula are 32–60 mm thick and have a strength of 700 mPa. The material, known as NAXTRA M 700, can withstand temperatures down to -40 deg without becoming brittle.

Besides providing the material, ThyssenKrupp Steel Europe will also be providing technical advice for welding the high-strength steel plate. Because the heat treated plate is heated again during welding, close attention has to be paid to welding temperatures and cooling times to ensure the material maintains its good properties in the region of the weld.

Technip Awarded Two Contracts for Pipeline Production in UK North Sea

Talisman Energy (UK) Ltd. recently awarded two engineering procurement and installation contracts, worth more than $52 million, to Technip for the development of the Auk North and Burghley fields. The fields will be tied back to Talisman’s Fulmar A platform and the Premier Oil-operated Balmoral floating production vessel, respectively.

The Auk North contract covers fabrication and installation of a production pipeline, an umbilical, a power cable, and subsea equipment. The Burghley contract covers fabrication and installation of a production pipeline and a gas lift pipeline, as well as the installation of an umbilical and subsea structures.

The pipelines will be welded at Technip’s spoolbase in Evanton, Scotland. The company’s operating center in Aberdeen, Scotland, will execute the contracts.

Work Begins on Welding School in Bahamas

The BORCO Foundation board of directors recently acquired two fully equipped containerized mobile units for the training, testing, and certification of welders. Seated (from left) are Geneva Rutherford, Wille Moss, Ann Farkas, and Dr. Havard Cooper. Standing (from left) are Matthew Missick, Larry Russell, BORCO’s Chairman of the Board Pieter Bakker, Managing Director Raymond L. Jones, Simon Lewis, Rev. Wilbur Outten, and Fred Delancy.

Renovations have begun on two buildings that will become the home of the BORCO Foundation Technical School. The school will be located in the Old Hawksbill High School complex and is expected to begin operations this month. The Foundation’s board of directors recently signed a contract with a local construction company to perform the renovations.

The board also announced an agreement has been reached with a U.S.-based company for acquisition of two fully equipped containerized mobile units for the training, testing, and certification of welders.

The six-month program will be free of charge, and the application process and entry requirements will be announced soon.

BORCO International Ltd. provides storage of petroleum products for a number of international clients and has a capacity of 21.4 million barrels. The company also offers blending, transshipment, and bunkering services. Its terminal is located in Freeport, Grand Bahama, and is the largest storage terminal in the Caribbean. 
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For Info go to www.aws.org/ad-index
Q: We are to fabricate a rather complicated weldment of 304L stainless steel plates. We previously fabricated a similar weldment of carbon steel, and we used heavy restraint to reduce distortion and shrinkage. We understand that stainless steel has a greater tendency to distort during welding than does carbon steel. Our customer is invoking AWS D1.6/D1.6M: 2007, Structural Welding Code — Stainless Steel. We are concerned about how to restrain in view of Clause 5.3.4 of that Code, especially the last sentence of that clause.

A: Your understanding that stainless steel has greater tendency for distortion and shrinkage is only partly correct. The tendency for weld distortion and shrinkage is closely related to the magnitude of the coefficient of thermal expansion (CTE) of the metal. The larger the CTE, the greater is the tendency for weld distortion and shrinkage. Table 1 lists average CTE data over the temperature range of 0° to 538°C (32° to 1000°F) for carbon steel and various stainless steels, as presented in the soon-to-be-published Welding Handbook, Ninth Edition, Volume 4, Chapter 5, Table 5.2. Within this temperature range, the weld metals develop enough strength to produce most of the distortion and shrinkage a weldment experiences.

From these data, you can see that martensitic and ferritic stainless steels behave similarly to carbon steels with regard to tendency for distortion and shrinkage during welding. Duplex stainless steels are a little more severe in this regard than carbon steels. But it is easy to see that austenitic stainless steels like 304L have a much greater tendency for weld distortion and shrinkage than do carbon steels, and in fact, more than any other type of stainless steel.

Now turning to AWS D1.6/D1.6M: 2007, Clause 5.3.4 of the code reads as follows, “In assemblies, joints expected to have significant shrinkage should be welded before joints expected to have less shrinkage. They should also be welded with as little restraint as possible.” First, I would point out the word “should” that appears in both sentences of Clause 5.3.4. This is a nonmandatory word, which means that each sentence provides guidance, not requirements. This means that you have the opportunity to exercise engineering judgment in applying this guidance. I refer you to Clause 1.3.8.2 of D1.6/D1.6M:2007, which I quote as follows: “Should. The American Welding Society (AWS) understands that one size does not fit all. For that reason, we’ve created FOUR different levels of corporate membership, starting for as little as $150 per year, allowing you to select a program that best fits with the way your company operates. With an 88-year history in the welding industry, and 50,000+ members worldwide, AWS Corporate Membership offers your company the ability to INCREASE ITS EXPOSURE and IMPROVE ITS COMPETITIVE POSITION.
word “should” is used to recommend practices that are considered beneficial, but are not requirements.

Clause 5.3.4 in D1.6 was lifted, word-for-word, from AWS D1.1/D1.1M, Structural Welding Code — Steel. The year of the D1.1 code is not important because the clause hasn’t changed in some time. In D1.1/D1.1M:2008, this same clause appears as Clause 5.2.15. It is in D1.1 because many structural steels have limited ductility and can be susceptible to hydrogen-induced cracking. This same consideration would apply to martensitic stainless steels. It makes very good sense to use as little restraint as possible for welding martensitic stainless steels. But 304L is not a martensitic stainless steel, it is an austenitic stainless steel.

This clause is also sensible for welding fully austenitic stainless steels — those like 310, 320, 330, etc., in which weld metal ferrite is not possible. Such stainless steels, which solidify as 100% austenite, are susceptible to solidification cracking, and restraint makes solidification cracking more likely. This is not to say that such steels cannot be welded with high restraint, but welding such steels with high restraint is risky. Welding of these steels is best done with low heat input techniques that produce convex weld beads, and additional precautions should be taken.

However, austenitic stainless steels whose weld metals solidify as primary ferrite (304L, 316L, and the other austenitic stainless steels listed as prequalified for welding in Chapter 3 of AWS D1.6/D1.6M:2007) are highly ductile and highly resistant to solidification cracking. They also do not form hard weld heat-affected zones, even when rapidly cooled. They are essentially immune to hydrogen-induced cracking. Even very severe restraint is unlikely to cause any cracking problems when welding these steels. So adhering to this guidance about minimizing restraint is entirely unnecessary in welding such stainless steels.

The same consideration applies to welding the duplex stainless steels. These steels too are not hardenable, and they are not susceptible to hydrogen-induced cracking except when high filler metal hydrogen combines with high Ferrite Number (greater than 70 FN). Modern duplex stainless steels and duplex stainless filler metals comfortably avoid these conditions, and they are quite ductile. They are almost as resistant to solidification cracking as the austenitic stainless steels which solidify as primary ferrite. As with the austenitic stainless steels that solidify as primary ferrite, adhering to the D1.6 guidance about minimizing restraint during welding is entirely unnecessary with duplex stainless steels.

In conclusion, when welding austenitic stainless steels that are prequalified in Chapter 3 of AWS D1.6/D1.6M, or when welding duplex stainless steels, sound engineering judgment would allow you to weld these steels without adhering to the guidance to minimize restraint. Perhaps in the future, D1.6 will be modified to clarify the guidance suggesting minimizing restraint. I suggest you use very rigid restraint in welding your 304L to minimize distortion and shrinkage.

DAMIAN J. KOTECKI is president, Damian Kotecki Welding Consultants, Inc. He is a past president of the American Welding Society, currently treasurer and a past vice president of the International Institute of Welding, and a member of the AWS A5D 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-Base Alloys. E-mail your questions to Dr. Kotecki at damian@damiankotecki.com or to Damian Kotecki, c/o Welding Journal, 530 NW LeJeune Rd., Miami, FL 33126.
Q: My company is in the process of procuring resistance projection welding equipment. A question that has come up during the design phase of the project is that the tooling integrator has not been able to find projection welding schedules to assist in the sizing of the welding components. A review of the RWMA Welding Manual (Ref. 1) reveals weld schedules for stamped projections in sheet metal, but nothing that resembles the weld nut for our application. Further research turned up weld nut manufacturer-suggested schedules that contain parameter ranges that appear too broad to be useful for component sizing. Why aren’t projection welding schedules available like the weld schedules for spot welding?

A: This is an interesting question that is in line with feedback I have received from within the resistance welding community. I say this as it has been my privilege to participate in several resistance welding seminars and tutorials throughout my career, and inevitably the subject that generates the most questions and comments is projection welding. No matter what aspect of projection welding one wants to discuss — quality, processing, or welding — or how the material is presented, projection welding always tops attendees’ lists of concerns.

Resistance welding of forged or coined projection weld fasteners (fastener in this context indicates all manner of solid, formed projection weld parts, including weld studs, weld nuts, etc.) is similar to resistance spot welding of sheet metal in that it uses the heat generated by the passage of current through predetermined points to join metallic parts. In the case of spot welding, those points are determined by the electrode’s contact area with the sheet metal (Ref. 2). While projection welding utilizes large contact area electrodes to transfer the force and current to the fastener, the predetermined points are the actual projections created during the forming process. These projections allow for the local heating required to bring the material at the faying surface to a molten, or near-molten, condition. While still constrained by the electrodes that are providing the necessary forging pressure, the flow of current is stopped. This permits the parts to cool, thereby forming either a weld nugget, or more commonly, a solid-state bond between the weld nut and the base material.

Resistance spot welding of sheet metal is a mature process on which a great deal of research has been done. This research has resulted in the creation of well-documented welding schedules for various sheet metal and electrode configurations, schedules that have been proven over time. These spot welding schedules are beneficial to obtaining a consistent, quality weld but also have other uses. Primary among them is use as an aid in designing new resistance spot welding tooling.

**Tooling Design**

Proper design of resistance welding tooling relies on knowing the welding schedules that will be used to produce the welds on that particular tool. This critical knowledge permits the tooling designer to provide correctly sized welding components. A partial list of these welding components includes transformers, cylinders, and primary and secondary current conductors. If these components are sized too small, premature equipment failure may result and/or, in a worst-case scenario, a proper weld may never be achieved. Conversely, if the components are sized too large, the tool may become larger and more expensive than required for the intended job. If the transformer is oversized, current adjustment may become difficult due to the standard AC weld control’s limited ability to accurately manage current levels at the low end of its operating range.

The resistance welding community, which thrives on the standardization provided by the spot welding schedules at its disposal, is currently lacking a robust set of welding schedule guidelines for the resistance welding of forged or coined projection weld fasteners. There are several reasons for this. Key among them is the fact that available data are typically based on a particular welded fastener being welded to a specific base material.

The issue with part-specific data is that it is not readily accessible to the resistance welding community. As a result, individuals on the plant floor attempting to weld a forged projection fastener do not have the benefit of the good starting point that spot welding schedules afford. Also, as pointed out in your question, lack of an established set of welding schedule guidelines targeting forged or coined projection fasteners forces tooling designers to either make educated guesses as to the parameters required to weld a particular fastener and sheet metal combination or to incur the additional time and expense of developing a unique welding lobe curve. The result is that the tooling design may or may not be capable of making a quality, repeatable projection weld.

The primary reason for the difficulty in finding a solution for the lack of a standardized projection welding schedule is the large number of variables that must be accounted for. Items associated with the fastener that must be considered include the material and projection volume, geometry, and number. The base material must also be considered. Factors such as substrate thickness, strength, and coating all must be taken into account. As an ex-
ample of this complexity, I only needed to open my desk drawer to find several different types of weld nuts. My guess is that many others in the resistance welding community have a similar collection — Fig. 1. All of the above-mentioned items are known within the resistance welding community; however, a solution to this issue has so far been elusive, and I will not attempt to offer one here.

Selecting Weld Schedules

That all being said, the following guidelines should help you select a forged fastener projection welding schedule and perform any subsequent tooling component sizing.

The required welding time will be shorter than you think. While it is necessary for the required weld time in a spot weld to increase as a result of an increase in material gauge, the same does not hold true with the projection welding of forged fasteners. For applications up to a size M12–14, with three properly sized projections, any weld time in excess of five or six cycles should be viewed with suspicion, with only a cycle or two more required for the equivalently sized full-ring projection fastener. This value will be slightly lower with mid-frequency DC (MFDC). Fasteners designed with significantly larger projections for much thicker substrates will require more weld time, but those are very application specific.

The required weld force will be higher than you think. The high weld force associated with projection welding is required for several reasons. These include the proper contact of the projections to the substrate prior to the initiation of current flow (crucial, especially, if welding anything other than a three projection design), and the necessary forging pressure once the current has stopped. Those machines that have poor follow-up may require even more weld force to achieve a successful weld. The idea of the need for higher force values makes even more sense when you realize that the force applied must pass through each projection and an increase in their number drops the pressure that each one feels.

The required weld current will be much higher than you think. This is one area where you can encounter real issues. While it is usually not too hard to turn down the weld time, and it may be a bit harder to find additional weld force, tell someone their expensive and long lead time transformer and/or weld control is not sized properly, stand by for some very long faces. The reasons can be many: the primary bus does not have the capacity to support the turns ratio of their secondary circuit, the inverter does not provide enough primary capacity for their MFDC transformer, the list goes on.

To add insult to injury, when folks make a mistake in this area, it is often a large one. I have seen applications where testing revealed an excellent projection weld could be obtained with 40 kA, but the tooling was capable of only 20 kA. A difference that large often does not leave open the door for any kind of weld schedule compromise.

Despite the challenges I’ve mentioned, projection welding of forged or coined fasteners can be a robust and capable process if the basic rules are known and followed. That being said, due caution must be exercised, especially in the initial development of a new process, to ensure that capable equipment is procured lest you find yourself in a situation where you are forced into trying to achieve a weld under less than optimal conditions. To put it another way, it’s like trying to see how far your car will go when you put in only 6 gallons instead of the required 25. While this discussion has focused on the weld schedule portion of the projection welding process, rest assured the design of the weld nut plays an equally important role in obtaining a quality weld and will be the topic of a future column.

References


Acknowledgment

I would like to thank Chuck Padden, former AWS D8 and AWS Detroit Section chairman, for his invaluable perspective on projection welding.

Donald F. Maatz Jr. is laboratory manager, RoMan Engineering Services. He is a member of the AWS Detroit Section Executive Committee, serves on the D8 and DSD Automotive Welding committees, is vice chairman of the Certified Resistance Welding Technician working group and of the RWMA Technical committee, and a graduate of The Ohio State University with a BS in Welding Engineering. This article would not have been possible were it not for the assistance from members of the RoMan team. Send your comments/questions to Don at dmaatz@romaneng.com, or to Don Maatz, c/o Welding Journal, 550 NW LeJeune Rd., Miami, FL 33126.
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Railroads are vital to our infrastructure, and welding plays a key role in keeping them moving.

For most of us, exposure to railroads and railcars is probably limited to those few minutes when a train momentarily blocks our journey. As the train passes before us, we anxiously await the appearance of that last railcar — a sign that we will soon be able to cross the railroad tracks and move toward our destination. We probably don’t even think about how vital rail transportation is to our way of life.

Tank cars, freight cars, passenger cars, locomotives, box cars, and flat cars all play significant roles in the transportation of goods and people across this nation and the North American continent. Welding is a major part of both railcar construction and repair, and rail track installation and maintenance. The ultimate goal is to move commodities and passengers in the safest possible manner.

Tank Car Construction

Tank cars (Fig. 1) are probably the most stringently regulated form of rail transportation. The Federal Railroad Administration (FRA) and the Association of American Railroads (AAR) have strict rules governing the building, operation, and maintenance of tank cars. The commodities they transport vary widely from orange juice and vegetable oil to benzene, hydrochloric acid, and chlorine. Safe transport of these commodi-

Fig. 1 — The welding of this 34,000-gal tank car is critical to prevent leaks and ensure the safe transport of toxic materials.

MIKE UNTERMeyer (untermeyer@utlx.com) is manager, weld and materials engineering, UTLX Manufacturing, Inc., Chicago, Ill.
ties and the prevention of leaks is the ultimate objective.

For pressure tank cars (operating pressure usually over 100 lb/in.2), construction begins with normalized AAR TC128 Grade B steel. This proprietary steel (similar to ASTM A612) has a minimum tensile strength of 81 ksi and minimum yield strength of 62 ksi. The steel plate usually ranges in thickness from ½ to 1 in. The normalizing process refines the steel grain structure and improves toughness and ductility and the ability to absorb energy without fracturing. Normalized steel has been a requirement for pressure tank car construction since 1989. If a tank car is in a collision or derailment, the tank should absorb the energy of the impact without fracture.

The normalized tank shell and head plates must be joined by welding, so the notch-toughness properties of the weld metal and heat-affected zone (HAZ) are critical to tank car construction and safety. Average weld metal and HAZ notchtoughness values of 15 ft-lb at -30°F are required for standard pressure cars. For transport of certain low-temperature commodities, the Department of Transportation (DOT) requires average notchtoughness values of 15 ft-lb at -50°F for the base metal, HAZ, and weld metal.

Since most tank car builders use the high-heat-input submerged arc process (SAW) for welding tank cars, the required notchtoughness values are not always easy to achieve when welding procedures are qualified. Heat inputs on the order of 70–90 kJ/in. are common and most welding procedures use single pass per side welds, so the benefit of weld metal and HAZ grain refinement from multipass welding is usually limited. Most builders work with weld consumable suppliers to find optimum SAW wire/flux combinations for welding pressure tank cars.

For general-purpose tank cars (operating pressures below 100 lb/in.2), notchtoughness requirements are not usually imposed, but welding and weld procedure qualification are still critical to the tank car performance and safety. Most carbon steel general-purpose tanks are constructed from A516 Grade 70 pressure vessel steel. Just as with pressure tanks, high-deposition submerged arc welding is generally used for joining tank shell and head plate. ASTM A240 Type 304 or Type 316 austenitic stainless steel is used for tanks that transport very corrosive commodities or food-grade products that require high purity. If stainless steel tanks are used, the DOT requires that welding procedure qualifications include a corrosion test of base metal, weld metal, and HAZ per ASTM A262 specifications.

Tank weld joints and inserted nozzles and attachments must be examined with radiography and/or ultrasonic inspection. Additionally, all welds must be visually inspected per code requirements.

All carbon-steel tank car tanks (pressure and general purpose) and attachments welded directly thereto must receive a postweld heat treatment (PWHT) to relieve the residual stresses associated with welding. These residual stresses might otherwise cause stress corrosion cracking that could lead to tank fracture and loss of lading. Postweld heat treatment temperatures usually range from 1100° to 1200°F and unit PWHT in an enclosed furnace is normally done for new tank car tanks or existing tanks with major repairs.

**Tank Car and Freight Car Underframes**

The underframe is the support structure that connects the tank and freight car containment vessel to the truck assembly (wheels, axles, brakes, couplers, etc.). Welding procedure and performance qualification for railcar underframes are governed by AWS D15.1, *Railroad Welding Specification for Cars and Locomotives*. Most underframe welding is accomplished using submerged arc welding, gas metal arc welding, and flux cored arc welding. ASTM A572 Grade 50 and ASTM A516 Grade 70 steels are commonly used to construct railcar underframes.

The railcar underframe is usually welded to reinforcing pads which in turn are welded directly to the tank car or freight car body. These reinforcing pads are used to prevent the tearing away of the underframe directly from the railcar containment vessel in the event of a derailment. If the underframe was welded directly to the containment vessel, the containment itself would very likely be damaged or fractured in a derailment, thereby increasing the chances for a loss of lading.

Railcar underframes must be designed and built to withstand high impact and cyclic loading, and railcar builders along with the regulatory agencies (FRA, AAR) are constantly striving to make improvements in underframe design, welding, and inspection requirements. A single fully loaded railcar can weigh as much as 286,000 lb, so a typical string of loaded railcars can easily weigh several million pounds. A tremendous amount of force is needed to start and stop a massive freight train.

**Track Welding**

Welding of the railroad tracks is another key component of safe transportation by rail. If railroad tracks are not in proper condition, train derailments, containment damage, and subsequent loss of lading are very real possibilities. Track rails and rail components must be joined by welding and brazing. Guidelines for track welding are provided in AWS D15.2, *Recommended Practices for the Welding of Rails and Related Rail Components for Use by Rail Vehicles*.

Rail track materials are usually grouped as follows: carbon-steel rail (minimum hardness of 240 BHN), premium steel rail (alloyed or heat treated to achieve minimum hardness of 341 BHN), and austenitic manganese steel.

The following welding processes are commonly used for track welding: shielded metal arc welding (SMAW), flux cored arc welding (FCAW), thermite welding (TW), and flash welding (FW).

Because of the higher carbon/alloy content of carbon-steel rail and premium rail grades of steel, preheat and interpass temperatures on the order of 700° to 800°F are typically required for welding followed by a tempering PWHT operation. Rail welding procedures are qualified and weld joint integrity is verified with rolling load tests, slow bend tests, and hardness tests. These mechanical testing methods are designed to simulate actual load and stress conditions of a railroad operation.

Since rail steels are primarily designed for wear resistance and compressive loads, ductility is limited and standard side bend...
tests cannot be used for welding procedure qualification and welder performance qualification. Macroetch tests are used instead to verify weld integrity and welder proficiency.

**Thermite Welding**

Thermite welding is widely used for joining rail joints. Thermite is a mixture of finely divided aluminum and iron oxide. The extreme heat generated by the chemical reaction between aluminum and iron oxide melts and joins the rail ends. A mold is required to contain the chemical reaction and the liquid metal — Fig. 2. Since thermite welding is based on a chemical reaction and does not require the generation of an electric arc, it is very portable and ideally suited for rail welding in the field — Fig. 3.

**Flash Welding**

The flash welding process is also commonly used for joining rail ends. The rail ends are heated by electrical resistance and forged together under considerable force. The upset metal from the forge welding operation is subsequently sheared off. Postweld heat treatment (when required) is then performed followed by finish grinding of the rail weld joint to the proper contour.

**Austenitic Manganese Steel**

Austenitic manganese steel is an extremely tough, nonmagnetic alloy with properties uniquely different from those of most commonly used structural and wear-resistant steels. It is the preferred material for a number of rail components. It has high strength and durability and resists failure under impact and heavy loading. The surface of austenitic manganese steel work hardens under impact while the underlying body retains toughness and ductility.

Most rail-related welding of austenitic manganese steel is for the purpose of repair (weld buildup) and restoration of components to proper contour. Flux cored arc welding and SMAW are generally used for this purpose. Before repair/weld buildup is done, the work-hardened surface of the part should be removed by grinding or air-arc gouging. Preheat is generally not required for welding, and interpass temperature should be kept to a minimum.

**Summary**

Quality railcar and rail track welding performed in accordance with qualifying procedures by qualified welders is a vital part of the safe transportation of goods and passengers by rail. Railroads, railcar builders, and regulatory bodies are constantly striving to improve railroad transportation safety. The technology has come a long way since that famous railroad spike was driven at Promontory Point, Utah, back in 1869. You might want to think about this the next time you are sitting at a railroad crossing waiting for that last railcar to pass.

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Cold spray can produce high-quality, ultrathick metallic deposits of specially formulated metal powders with low oxide content and porosity.

BY JULIO VILLAFUERTE AND DAVID WRIGHT

In common thin-film deposition processes such as physical vapor deposition (PVD) or chemical vapor deposition (CVD), a solid target and a substrate are placed together in a high-vacuum environment. Sputtering is one of several techniques whereby atoms on the target surface are ejected into their gas phase by bombardment with energetic particles, such as argon ions in a plasma jet. The evaporated atoms from the solid target are not in their thermodynamic equilibrium state; therefore, they tend to deposit on all surfaces within the vacuum chamber, including the intended substrate. In CVD, the evaporated target material further reacts with a chemically active gas in the chamber and at the surface of the substrate, resulting in compounds chemically bonded to the substrate. Thin-film deposition is used in a vast range of industries including renewable energy, microelectronics, heated glass, architectural glass, packaging, automotive, aerospace, and many others. There are hundreds of target materials on demand for hundreds of applications including pure metals, alloys, oxides, borides, nitrides, selenides, fluorides, silicides, sulfides, carbides, and other nonmetals.

High-volume thin-film deposition is used during the fabrication of hundreds of familiar consumer products such as calculators, toys, food packages, CDs, DVDs, hard drives, eyeglasses, jewelry, cell phones, microchips, and many others. High-volume thin-film deposition utilizes large vacuum chambers along with large rotatable sputtering targets. These targets typically consist of large water-cooled steel, stainless steel, aluminum, or copper tubes. The target material is generally bonded to the surface of these tubes by brazing, casting, or thermal spraying. Thermal spraying is often selected because of its ability to lay down composite target materials, ability for reapplication and restoration of these targets, and be-
An Alternative Manufacturing Process

Cold spray is one of the many names for describing a solid-state coating process that uses a high-speed gas jet to accelerate powder particles toward a substrate where metal particles plastically deform and consolidate upon impact. The term “cold spray” refers to the relatively low temperature involved in the process, which is typically much lower than the melting point of the spray material. Although the concept of cold spraying metallic materials onto substrates goes back to the early 1900s, it was not until the 1980s that the applicability of this technology was demonstrated and patented by the Institute of Theoretical and Applied Mechanics of the Academy of Sciences in Novosibirsk (Ref. 1) (high-pressure cold spray) and then by the Obninsk Center for Powder Spraying (Ref. 2) (low-pressure cold spray) in the former Soviet Union.

In cold spray equipment, air, nitrogen, or helium at certain pressures and temperatures are injected into a converging-diverging (DeLaval) nozzle to convert gas enthalpy into kinetic energy and subsequently accelerate the gas jet to supersonic speeds. The spray material in the form of powder can be introduced upstream of the nozzle (high-pressure cold spray), or downstream into the diverging section of the nozzle (low-pressure cold spray) — Fig. 1. At a given impact temperature, every material requires a minimum level of kinetic energy above which acceptable bonding may occur. Generally, the higher the melting point and mechanical strength of the spray material, the more kinetic energy is required to produce acceptable bonding at a given impact temperature. In cold spray, the type of gas, gas pressure, and gas temperature determine the amount of kinetic energy available to accelerate particulate. High gas pressures (above 700 lb/in.$^2$) and gas temperatures (above 600°C) with helium gas provide high kinetic energy levels; however, with limitations in economics and portability. On the other hand, many common engineering materials can be successfully cold sprayed at lower pressures (less than 300 lb/in.$^2$), gas temperatures (below 600°C), and using lower-cost carrier gases (nitrogen, air).

Since adhesion of the metal powder to the substrate and deposited material is achieved in the solid state, the characteristics of cold spray deposits are unique,
making cold spray suitable for depositing a wide range of traditional and advanced materials on many types of substrates, especially in nontraditional applications that are sensitive to the temperature of the process. Some characteristics of cold spray include the ability to form dense deposits with extremely low oxygen content, free of residual tensile stresses, grain growth, recrystallization zones, phase changes, and ability to deposit ultrathick coatings — Fig. 2. These attributes make cold spray suitable for depositing a range of temperature-sensitive materials in temperature-sensitive situations.

**Utilizing Cold Spray for Sputtering Targets**

Cold spray technology is a natural candidate for the fabrication of sputtering targets as it allows the target material to retain its original properties, does not induce metallurgical transformations or oxidation, and is able to produce ultrathick and fully dense coatings. Therefore, applicators are utilizing commercially available low-pressure cold spray equipment (Fig. 3) to fabricate or refurbish rotatable sputtering targets for the military, aerospace, energy, and medical industries. Whether for repairing jet engine parts or fabricating sputtering targets, many standard as well as specially formulated target materials can be applied by prequalified cold spray procedures (Ref. 3) without worries about metallurgical compatibility or dilution with the substrate. As an example, during flame spraying (one of a number of thermal spray processes that are used), coatings undergo thermal reactions such as phase changes, oxidation, and porosity, which make sputtering less effective and less productive. The cold spray process allows the chemistry of the spray material to be maintained in the deposit with virtually no porosity.

One practical example is the manufacturing, refill, and repair of indium-copper-based targets for thin-film deposition in the solar and microelectronics industries. Many of these targets are used to create thin films for photovoltaic, heat, and low-voltage transfer. Other target materials, such as Ni and Al based, can be used during the manufacture of battery cells. After basic surface preparation, standard or specially formulated spray materials can be successfully deposited by a prequalified cold spray procedure — Fig. 4. The density and bond strength of the cold-sprayed deposit typically exceed the minimum specifications for a sputtering target, i.e., less than 1% porosity and better than 5000 lb/in.² bond strength.

**Summary**

Cold spray constitutes a family of emerging solid-state processes that expand the capabilities of traditional thermal spraying into unique applications that are either technically or economically prohibitive for traditional thermal spray. Cold spray can produce high-quality, ultrathick metallic deposits of specially formulated metal powders with low oxide content and porosity. Low-pressure cold spraying has become a reliable, accurate, and economical technique for the manufacturing or refurbishing of rotatable sputtering targets for high-volume thin-film deposition.

**References**

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Calculating Joint Clearance at Brazing Temperature

A simple analytical methodology is offered to evaluate and troubleshoot thermal expansion effects on brazing processes

BY D. G. STROPPA, T. HERMENEGILDO, J. UNFRIED S., N. OLIVEIRA, AND A. J. RAMIREZ

Many industrial fabrication procedures require joining dissimilar base materials, and brazing can be a suitable joining process for most of them. However, brazing process design for joining dissimilar materials requires some caution to prevent defective joints, as indicated — Fig. 1. The mismatch of thermal expansion coefficients between the base materials is commonly cited as the main source of residual stresses and dimensional distortions on the brazed joints (Ref. 1), and may even cause incomplete joint penetration due to an inadequate joint clearance at brazing temperature.

This article presents a simple analytical methodology to predict joint clearance at brazing temperature and indicates the most relevant parameters to be considered when designing a brazed joint with dissimilar base materials.

Joint Geometry Considerations

The joint clearance at brazing temperature can be evaluated with a simple model for thermal expansion of base materials. Due to the fundamental characteristic of thermal expansion, any joint configuration can be evaluated if the correct geometric relationships for the joint cross section are applied.

Intending to achieve the most comprehensive and applicable model, a joint constituted of two coaxial pipes with different diameters is considered, as sketched — Fig. 2A. The cross section of the joint is shown in Fig. 2B, where the joint clearance is highlighted.

As presented in Fig. 2B, the joint clearance for the selected geometry is given by the difference between the internal radius of external pipe $R_e$ and the external radius of internal pipe $R_i$ for a concentric assembly.

Thermal Expansion Model

The two-dimensional (2D) thermal expansion evaluation for a pipe ensemble cross section is similar to that applied to holed surfaces (Ref. 2), which is schematically presented in Fig. 3.

As shown in Fig. 3, the hole expands as the temperature increases in the same way as the base material. Thus, evaluation of thermal expansion can be applied to the joint cross section to calculate $R_e$ and $R_i$ dimensions at brazing temperature. Equation 1 presents the two-dimensional (2D) thermal expansion evaluation for a general joint cross section, which leads to Equation 2 for the circular area profile of a pipe ensemble.

1. Thermal expansion of surfaces:

$$A_j = A_0 \cdot (1 + 2 \cdot \alpha_n \cdot \Delta T) \quad (1)$$

where $A_j$ is the area at the state $j$, with 0 and 1 denoting the initial and final states, respectively; $\alpha_n$ is the linear thermal expansion coefficient of base material $n$, with $e$ and $i$ denoting the external and internal materials; and $\Delta T$ is the temperature change.

2. Thermal expansion for circular profiles:

$$R_i^2 = R_0^2 \cdot (1 + 2 \cdot \alpha_n \cdot \Delta T) \quad (2)$$

where $R_i$ is the radius at the state $j$ with 0 and 1 denoting the initial and final states, respectively.

The joint clearance ($L$) at brazing temperature can be evaluated as follows in Equations 3–5 by the calculation of $R_e$ and $R_i$ dimensions at brazing temperature.

3. Joint clearance at room temperature:

$$L_0 = R_{e0} - R_{i0} \quad (3)$$

4. Joint clearance at brazing temperature:
Combining with the results obtained on Equation 2:

\[ L_1 = (Re_0^2 - (1 + 2\alpha \cdot \Delta T))^{0.5} \]

where \( L_1 \) is the joint clearance at brazing temperature, and \( R_{n0} \) is the room temperature radius at the state \( n \), with \( i \) and \( e \) denoting internal and external radii, respectively.

Therefore, the joint clearance at brazing temperature can be easily calculated, and the capillary conditions for correct joint penetration can be evaluated prior to the process.

Verifying Brazeability of Specific Steel Joints

The applicability of a brazing filler material for a specific brazing configuration is defined by a number of factors, such as chemical compatibility with the base materials and overall costs. Among these factors, the joint clearance dimension at brazing temperature and its tolerance must be carefully considered due to its impact on the base material preparation costs and their adequacy to the designed brazing process.

Table 1 presents the recommended joint clearance for the most common brazing filler metals applied for stainless steels brazing according to specialized literature.

Notice that Table 1 refers to joint clearance at brazing temperature and its tolerance. The minimum and maximum joint clearances are provided for each filler metal, along with the brazing temperature range and brazing process type.

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clearance at the brazing temperature. Therefore, when designing a joint with dissimilar base materials, it is fundamental to consider the mismatch between the thermal expansion coefficients for calculating the actual joint clearance at the brazing temperature, which can be done by using Equation 5.

**Evaluating and Troubleshooting a Real Application**

A practical evaluation of the joint clearance at brazing temperature is presented by the proposed thermal expansion calculation for a dissimilar steel pipes ensemble, similar to the one presented schematically in Fig. 2.

The proposed example is an ensemble of an American Iron and Steel Institute (AISI) 304 stainless steel with 127-mm internal diameter \((R_{e0})\) external pipe and AISI 1020 carbon steel with 126.93-mm external diameter \((R_{i0})\) internal pipe. Therefore, this joint has a 35 \(\mu\)m clearance at room temperature. The AISI 304 stainless steel and AISI 1020 steel present mean thermal expansion coefficients of 18.7 \(\mu\)m/m°C \((\alpha_e)\) and 13.9 \(\mu\)m/m°C \((\alpha_i)\), respectively (Ref. 5). A feasible filler metal for this ensemble is BCu-1, which requires a brazing temperature of at least 1093°C. Table 2 summarizes the initial brazing setup.

The application of Equation 2 for the given parameters results in a joint clearance of 357.0 \(\mu\)m at brazing temperature, which indicates an inadequate brazing setup for the BCu-1 filler metal, according to Table 1. Therefore, the joint design accordingly must be changed to provide the ideal conditions for complete penetration of the joint. Figure 4 illustrates the main project aspects that can be changed to minimize the thermal expansion coefficient mismatch effect.

Some of the possible modifications that can be implemented to reduce the

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**Table 2 — Required Parameters for Thermal Expansion Evaluation at Brazing Temperature**

<table>
<thead>
<tr>
<th>Geometrical Properties</th>
<th>Base material properties</th>
<th>Filler Metal Properties</th>
</tr>
</thead>
<tbody>
<tr>
<td>(R_{e0} = 63.5) mm</td>
<td>(\alpha_e = 18.7) (\mu)m/m°C</td>
<td>(\Delta T = 1073°C)</td>
</tr>
<tr>
<td>(R_{i0} = 63.465) mm</td>
<td>(\alpha_i = 13.9) (\mu)m/m°C</td>
<td></td>
</tr>
</tbody>
</table>

**Table 3 — Adapations to Reduce Thermal Expansion Coefficient Mismatch Effect on Brazing**

<table>
<thead>
<tr>
<th>Project Feature</th>
<th>Properties</th>
<th>Possible Modification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base materials</td>
<td>(\alpha)</td>
<td>Substitute base material to reduce (\alpha) mismatch</td>
</tr>
<tr>
<td>Geometry</td>
<td>(R)</td>
<td>Modify base material dimensions and/or ensemble</td>
</tr>
<tr>
<td>Filler metal</td>
<td>(\Delta T)</td>
<td>Substitute filler metal to reduce brazing temperature</td>
</tr>
<tr>
<td>Filler metal</td>
<td>Clearance tolerance</td>
<td>Use a filler metal indicated to widen joint clearances</td>
</tr>
</tbody>
</table>
effect of thermal expansion coefficient mismatch for brazing processes on dissimilar base material are listed in Table 3.

### Thermal Expansion Coefficient Temperature Dependence

Linear thermal expansion coefficient $\alpha$ is a temperature-dependent property. However, a good approach can be obtained for most of the engineering materials using a constant value of $\alpha$ at room temperature for the joint clearance calculations. Any condition that demands higher accuracy or for brazing base materials with a thermal expansion coefficient that is highly dependent on temperature must be evaluated carefully. In these circumstances, a mean thermal expansion coefficient for most common engineering materials can be found in the literature (Ref. 5) for usual ranges of temperature. However, for specific materials or application, a better calculation can be attained by an integral analysis of $\alpha(T)$ function that can be obtained experimentally by using a dilatometer. For this case, Equation 3 may replace Equation 1.

6. Thermal expansion for coaxial profiles with temperature dependent $\alpha$:

$$R_f^2 = R_i^2 \cdot \left(1 + \frac{1}{T_f} \int_0^{T_f} \alpha(T) dT \right)$$

### Conclusion

This article highlights a simple analytical model to evaluate joint clearances at brazing temperatures and a simple procedure for evaluating and troubleshooting joint clearance incompatibility on brazing processes for dissimilar materials. An example of the proposed methodology application to an ordinary pipe ensemble showed that the mismatch in thermal expansion coefficient can be a determining factor on success or failure of a brazing setup.

### References


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Liquation of Brazing Filler Metals — Good or Bad?

When a brazing filler metal is melted during a brazing process, it is not uncommon for “liquation” to occur.

BY DAN KAY

Liquation in brazing is defined as the tendency of the lower-melting constituents of a brazing filler metal (BFM) to separate out and flow away (by capillary action) from the higher-melting constituents of the BFM during heating. Sometimes a nonmelted “skull” of alloy remains at the point where the BFM was applied. Liquation is usually apparent in BFMs having a wide melting range, i.e., having a large difference between the solidus and liquidus temperatures. It occurs when the BFM is heated slowly through that melting range (such as when furnace brazing). Liquation is not typically encountered when rapid brazing techniques — flame brazing or induction brazing — are used.

Liquation of a BFM is easily recognized on the outside of a brazed joint because of the separated “lumps” of apparently nonmelted BFM observed along the line of the braze-fillet at the edge of a brazed joint. Examples are shown in Figs. 1 and 2.

Melting and Solidification of Brazing Filler Metal

First of all, it's important to understand how the melting and solidification of an alloy affects liquation. Shown in Fig. 3 are three screen samples that have been furnace brazed. Each screen was placed on a flat steel plate. A quantity of silver-based BFM was placed on top of the screen at its center, and then each was brazed. The photos show the condition of each screen after brazing. Note that in Fig. 3A all the BAg-1 BFM has flowed by capillary action throughout the screen material. In Fig. 3B and C there is a significant amount of nonmelted BFM residue present in the center of each screen, even though much of the BAg-2 BFM has flowed out by capillary action.

Now, under laboratory conditions, it can easily be shown that the BAg-1 BFM has a narrow melting range of only about 20°F/11°C (solidus temp: 1125°F/607°C; liquidus temp: 1145°F/618°C) and is known as a “eutectic-type” alloy. Thus, when heated (either rapidly or slowly) during furnace brazing, the eutectic-type BFM will flow out completely, leaving virtually no nonmelted residue behind.

The BAg-2 BFM, by comparison, has a wide melting range of 170°F/95°C (solidus: 1125°F/607°C; liquidus: 1295°F/702°C). Notice in Fig. 3B and C that there is a “skull” of BFM left in the center of the two screens brazed with the BAg-2. Seeing this residue on a brazement might raise the question that since two screens were brazed at a temperature higher than the liquidus temperature of BAg-2, why is there a residue of BFM left at the center of the screen? Something must either be wrong with the BFM or the furnace never got up to brazing temperature. Both these conclusions are incorrect in this situation.

Let’s look more closely at what happens during BFM melting in order to understand how and why liquation can become a problem to a production brazer. Let’s start in the BFM manufacturer’s laboratory to see how it determines the solidus and liquidus temperatures of a BFM and then move to a brazing shop furnace using that BFM in production.

Determining Liquidus and Solidus

In determining the solidus/liquidus temperatures for a particular BFM in their laboratory, the manufacturer carefully blends a certain ratio of metallic constituents for that BFM in a laboratory crucible. It is then heated up while carefully monitoring the temperature of the mixture (using special thermocouples) until it starts to melt. When any metal starts to melt, a large amount of energy is absorbed to change it from solid to liquid, and this change is noticed in the temperature chart being recorded. Figure 4 shows some typical thermal-arrest curves for two different types of BFMs. This method of determining melting characteristics of metals is just one of a few that can be used for determining solidus/liquidus temperatures.

Each chart in Fig. 4 shows the rising temperature of the solid metal as it is heated. A break in each curve (change in its slope) will occur when the heat input is no longer being used merely to raise the temperature of the metal, but is now being absorbed by the metal as it changes from solid to liquid (Point S on each chart). After all the metal has changed to liquid (at point L) on each chart, all the added heat is once again used to raise the tem-
temperature of the liquid, and the slope of the curve changes again. In Fig. 4A, there is no temperature difference between points S and L, and this would represent the thermal-arrest curve for a eutectic BFM (it all melts at the same temperature). Figure 4B shows the curve for a typical wide-melt-range BFM because there is a large difference between the temperatures of S and L.

Please note that in the laboratory crucible being discussed, all the metal constituents are held inside the crucible and cannot escape. Thus, as melting continues, more and more liquid is formed and surrounds (bathes) any remaining solid materials, helping to dissolve them as they continue to be heated.

Once these thermal-arrest curves have been verified, they will be published by the BFM manufacturer as the true solidus and liquidus temperatures. Please understand, however, that these temperatures are strictly based on laboratory conditions using crucibles to keep all the BFM constituents together while they are being heated and melted.

Any brazing shop using a specific BFM will probably assume that when it is heated it in a furnace to a temperature higher than its published liquidus temperature, the BFM will completely melt and flow out by capillary action into the braze joint. This is, unfortunately, often not the case. Instead, when components are examined after brazing, there are sometimes a significant number of lumps of nonmelted BFM along the edge of the joint area (like those in Figs. 1 and 2). What has happened?

**Real-World Brazing**

The first thing to note is, unlike in the laboratory, the BFM in the brazing furnace is not sitting in a crucible. It has no constraints to keep all the liquid in one place as it melts. Therefore, the first liquid to form will flow away into the braze joint or start to climb out over the hot external surfaces of the part being brazed. Then, when the BFM becomes hot enough for the higher-melting constituents (HMCs) to melt, they may not do so at all since part of its ability to be completely melted (as in the lab) depended on these HMCs being immersed in, and dissolved by, the liquid BFM bath surrounding it. When left alone by itself in the brazing furnace heat with no "surrounding bath" of liquid BFM to help it dissolve, the HMCs may require temperatures far in excess of the published liquidus for that BFM in order for it to actually melt.

Thus, when there is a large temperature difference between the published solidus and liquidus temperatures for a BFM, it is not uncommon in furnace brazing for liquation to occur and be clearly in evidence along the edge of the resultant brazed joint if the BFM was applied at the outside edge of the joint. The important thing to remember when this occurs is that the problem does not lie with "bad BFM from the manufacturer" or with "the furnace failed to reach brazing temperature." Instead, it lies with the inherent melting characteristics of that particular brazing alloy (from any supplier) when it is heated in a brazing furnace.

Here is a quick review of some of the causes of liquation:
- Using a wide melting-range BFM.
- Slowly heating the BFM through the melt range.
- BFM placed outside the joint to be brazed.

Below are some ways to minimize liquation:
- Change BFM selection to one that is more eutectic-like (Fig. 3A).
- Heat more rapidly through the BFM melt range (Fig. 3C).
- Bury the BFM inside the joint.
- Shield any externally placed BFM so that it won't start to melt until the base metal has come up to brazing temperature.

**How Bad Is a Brazed Joint that Exhibits Liquation?**

One of the assumptions some people make about liquation is that since there are lumps of nonmelted BFM around the edge of a brazed joint, the BFM that
Brazing & Soldering Today

Fig. 3 — Samples of furnace brazed screen. A — No liqation of the eutectic-like BAg-1 brazing filler metal is seen; B — example of brazing filler metal liqation of BAg-2; C — same as B except heated more rapidly through the melt range.

Fig. 4 — Typical temperature charts for two different brazing filler metals. A — Thermal-arrest curve for eutectic material; B — thermal arrest curve for wide-melt-range brazing filler metal.

Fig. 5 — Binary phase diagram for silver-copper (Ag-Cu) alloy system.

Metallurgically speaking, we can now introduce a useful concept known as the lever law. Using this, at any given point vertically along the line (or any similar vertical line at any chemistry), we can determine the actual chemistry of the constituents that are solidifying and coming out of solution as well as the chemistry of the liquid that remains in the joint. The lever law can also be used to determine percentages of phases. As cooling continues down the line to point B, the actual chemistry of the phases that are coming out of solution and solidifying will be as shown at point B2 at the far right side of the horizontal line (lever-arm) drawn through point B (a vertical dotted line from point B2, intersecting the bottom axis, tells us what that chemistry is). At the left end of the horizontal lever-arm through point B, i.e., where it intersects the slope of the liquidus line (at point B1), is shown the chemistry of the liquid portion of point B that remains as a liquid in the capillary space in the joint being brazed. The same is true for points C and D as well.

Notice that as the cooling continues down the vertical line, the chemistry of the liquid remaining in the joint is continually changing and follows the slope of the liquidus line. Thus, the last chemistry to exist as a liquid in the joint just prior to complete solidification is the eutectic chemistry, and it is the last component to freeze upon cooling the BFM from brazing temperature.

Now let’s reverse our thinking and start from a solid BFM in a brazed joint to see what happens as we heat that alloy up to the brazing temperature. We will use the
The Basics

- The solidus temperature is the temperature at which a solid material will begin to melt when it is being heated. We often call it the melting point for that material. The liquidus temperature is the temperature at which a liquid metal will start to solidify when it is being cooled down from the molten state. Thus, it is the lowest temperature at which that BFM will be completely liquid. In brazing, the assumption is often made (incorrectly) that the liquidus temperature is reached when the BFM, upon heating, has finally become completely liquid. Such an assumption for “liquidus” can lead many people into erroneous conclusions about the flowing characteristics of BFMs.
- A eutectic BFM is an alloy of two or more metals that, when heated to its melting point (solidus temperature), will completely melt and turn to liquid at that same temperature (called the eutectic temperature or eutectic point). Thus, there is no melt range associated with eutectic alloys, and its solidus and liquidus temperatures are the same (it is isothermal).
- When the difference between the solidus and liquidus temperatures of a BFM is only 25°F/12°C or smaller, that BFM is known as a eutectic-type BFM since it will behave in much the way as a eutectic BFM.
- Liquid BFM likes to flow toward the heat, i.e., the “hot spots” in any brazing environment. Thus, it will often find the outside surfaces of components much more attractive than the cooler spaces inside the gap waiting to be brazed where the temperatures are somewhat lower than the outside surfaces of the parts.

When to Reject Brazed Assemblies Exhibiting Liquation

It is not uncommon for some people to scrap assemblies that exhibit liquation for the simple fact that liquation is present since such assemblies in their opinion can’t be any good. Such rejections can be very wasteful and could needlessly scrap parts that might perform perfectly well in service.

The question that should really be asked is: “What will any liquation residues do to the parts in service from a performance point of view?” If there will be no negative impact on the performance (such as strength, leak-tightness, etc.), then such parts should be put into service.

Liquation would need to be reworked to remove the surface lumpiness (by grinding, etc.) prior to being placed in service if
- Smooth flow of air across a brazed surface is affected (such as in airfoils).
- Turbulence is created in the flow of liquids across surfaces or through channels where such flow is supposed to be smooth.
- Germs are entrapped or fluids contaminated in the medical or food industries.
- Aesthetics of brazed components is another important aspect of liquation, such as in the jewelry business, where brazing is a common joining method. No person would be happy to receive a brazed piece of jewelry exhibiting poor brazing with lots of liquation on it. This is a time when perfect brazing is required by the end user, and liquation is not to be tolerated.

Conclusion

Remember, the acceptability or unacceptability of liquation should always be based on its impact on end-use service conditions, such as airflow, fluid flows, medical concerns, or aesthetics required by end user. It should never be based on the following false assumptions:
- Liquation will cause the parts to be weak — False.
- Liquation will cause the parts to leak — False.
- Liquation means the parts were brazed incorrectly — False.
- Liquation indicates that the BFM is of poor quality — False.

This article has explained what liquation is, what causes it, and how to minimize or eliminate it. Use this new understanding of liquation in your brazing environment.
To ensure durable, leak-free joints, proper soldering and brazing procedures must be in place when joining metal tubes and fittings on appliances, plumbing, and heating, ventilation, air-conditioning, and refrigeration (HVACR) systems — see lead photos.

Yet, too often, many of the critical care procedures are overlooked, leaving joints ineffective. A weak joint in a HVACR system, or hot and cold water pipes, can damage the entire structural backbone of a building. One pipe burst, or even a continual minor leak, can put an entire facility out of commission and be costly to repair.

Following a few simple tips and tricks of the trade can help any craftsman make a dependable connection for a stronger, more reliable joint.

**Recognizing Both Soldering and Brazing**

As defined by The American Welding Society, the difference between soldering and brazing is the temperature required to melt the filler metal. Soldering is a joining process that takes place at below 842°F/450°C, and brazing is a similar process that occurs above 842°F/450°C but below the melting point of the base metal.

Both soldering and brazing involve the same basic steps — measuring and cutting, reaming, cleaning, fluxing, assembly and support, heating, applying the filler metal, and cooling and cleaning.

The joining process is also the same for both connections in measuring and cutting, reaming, cleaning, fluxing, and assembly and support. Similarly, these procedures are basically the same for all diameters of tube. In contrast, the variables between the two applications are in the composition of the filler metal, type of flux used, and amount of time and heat necessary to melt the filler metal within an individual joint.

From start to finish, attention to detail in each technique contributes to the strength and overall success of each joint.

**Five Guidelines to Follow**

**1. Make Accurate Measurements**

When measuring the length of each tube, accuracy is the key. If the tube is too short, it will not reach all the way into the fitting, creating a weak link. If the tube is too long, it could cock in the fitting and put strain on the system. Both of these conditions could affect the life of the system. In either case, if the tube is not seated in the fitting cup to its full depth, then the integrity of the joint may be compromised.

**2. Cut Properly**

Once the tube is measured, it can be cut. The cut must be square with the run of the tube to ensure the best fitting. Regardless of the type of equipment used in the cutting procedure, respect for the material must be taken to avoid deformities in the structure of the tube. The tube must then be reamed to remove any burrs.

**3. Clean with Care**

Although one of the quickest and easiest steps, cleaning is often the most overlooked. Unremoved oxides, surface soils, and oils can inhibit proper flow of the filler metal into the joint causing failure. Cleaning the tube and fitting is critical for the filler metal to flow into the joint and form a strong connection.

When applying the flux, or chemical cleaning agent, it’s important to choose one that is not too corrosive and use only the minimum amount of flux needed to make a joint. Careless craftsmanship in applying a flux can be dangerous to the system long after installation.

Fluxes used for soldering are different from those used for brazing; plus, the two types cannot be used interchangeably. Also, the type of flux used can be a good indication of the required temperature of the application.

**4. Employ Skilled Assembly Practices**

After both the tube and fitting surfaces are fluxed, they should be assembled. A quick way to be sure of even flux application is to slightly twist the pipe within the fitting, making sure the tube is set against the base of the fitting. Furthermore, uniform space around the entire circumference of the joint will ensure a successful joint, while excessive space can cause the filler metal to crack under stress or vibration.

Good practice suggests that after a product has been cleaned, fluxed, and assembled, it should be soldered or brazed within the same period. If left to sit overnight, the joint will need to be disassembled, recleaned, and refluxed before continuing. Protecting the surface that has been cleaned and fluxed and completing the soldering or brazing operation in a timely manner ensures clean uncontami-

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**Tips for Producing Strong Soldered and Brazed Joints**

*By using five easy-to-understand steps, dependable connections for more reliable joints can be made*

**BY GREG MITCHELL**

GREG MITCHELL (Greg_Mitchell@thermadyne.com) is the central regional manager for TurboTorch®, a Thermadyne brand. For more information, visit www.thermadyne.com/turbotorch.
Soldering, pictured in use here, is a joining process that takes place at below 842°F/450°C. Brazing, shown above, generally involves air settling swirl or oxyfuel torches due to higher temperatures used to melt filler metals. 

It's recommended to preheat the tube, then preheat the fitting. Preheating with the flame ensures a uniform distribution of heat inside and out. When preheating, care should be taken not to overheat the joint. While similar to soldering, brazing generally involves air settling swirl or oxyfuel torches due to the higher temperatures required to melt the filler metals. First, preheat the tube, then the fitting. When the filler metal starts to flow, it will be drawn into the joint by capillary attraction ensuring a strong, dependable connection.

Similar to preheating, care must be taken not to overheat the joint. Also, cooling should be allowed naturally. Shock cooling with water may cause unnecessary stress on the joint. Because purging with nitrogen reduces the chance of oxidation at the joints, many HVACR professionals always carry a purging kit with materials such as a nitrogen regulator, charging hoses, blow pipe, and purging and cleaning tips. Lastly, clean off any flux residue with hot water and/or a wire brush to avoid future corrosion.

5. Work Smart and Safe

Because soldering and brazing require an open oxyfuel or air-fuel flame at high temperatures, care must be taken for the safety of the operator as well as the materials being used. Proper safety training is essential to avoid dangers such as burns, eye damage, fumes, and overexposure to ultraviolet light. With the use of new technologies and proper protection, the risk of injury associated with metalworking can be greatly reduced. It's important that the user always practice safe operating procedures and wear protective equipment. As an additional word of caution, make certain to read and follow all operation instructions before using any oxyfuel or air-fuel apparatus.

Close attention to detail and strict adherence to all steps will ensure any professional a strong, long-lasting connection for years to come.

New Advances in Soldering and Brazing

As the soldering and brazing industries continue to grow, improved equipment capabilities and efficiency are essential if the plumbing, heating, ventilation, air-conditioning, and refrigeration industries want to keep up with user demands. Additionally, manufacturers are responding to these needs. TurboTorch®, for example, a manufacturer of air-fuel and oxyfuel torches and accessories, recently expanded offerings with the Viper™ line of brazing alloys, solders, and fluxes. The new alloys, featuring compositions for a range of flow and fill characteristics, are useful for joining copper to copper and are self-fluxing in this application.

Other industry advancements include cadmium-free and lead-free solders that are approved for plumbing and building industries. As more products are engineered for field repair, once difficult tasks now produce quick and consistently durable results.

With manufacturers dedicated to designing and producing better, safer metalurgy equipment, and soldering and brazing professionals crossing new thresholds, today's joints are stronger than ever before.
Lead-Free Solder with Low Susceptibility to Copper Leaching

A lead-free solder, which is significantly less susceptible to copper leaching in a molten state, was developed and tested at Senju Metal Industry Co., Ltd., Tokyo, Japan (Ref. 1). Testing was carried out by dipping coil ends of the copper wire into the liquid solder at 400°C (752°F).

Exemplary compositions of the solder contain the following: 1) copper 8 wt-%, cobalt 1 wt-%, nickel 1 wt-%, and tin in the balance (melting range 228°–409°C, copper leaching rate is 1 μm/s); 2) copper 6 wt-%, cobalt 0.3 wt-%, nickel 0.3 wt-%, gallium 0.07 wt-%, phosphorus 0.02 wt-%, germanium 0.01 wt-%, and tin in the balance (melting range 227°–380°C, copper leaching rate is 1.5 μm/s); 3) copper 2 wt-%, silver 2 wt-%, cobalt 0.2 wt-%, nickel 0.2 wt-%, gallium 0.07 wt-%, phosphorus 0.01 wt-%, and tin in the balance (melting range 218°–281°C, copper leaching rate is 2.2 μm/s). For comparison, the standard Sn-3Ag-0.5 Cu solder exhibits a copper leaching rate of 5.3 μm/s.

Alloying solder with cobalt and nickel decreases the dissolution of copper into the solder melt. Adding P, Ge, and Ga in small amounts inhibits oxidation of the solder at high soldering temperatures.

Wetting of copper coupons with the new solder occurred for 1.5 s of the composition (a), 2.1 s of the composition (b), and 0.5 s of the composition (c), while wetting with the standard Sn-3Ag-0.5 Cu solder occurred in 0.5 s at 400°C.

The low leaching rate prevents a significant reduction of diameter of insulated copper wire or complete disappearance of the wire when the wire diameter is <100 μm.

Thermodynamic Properties of Lead-Free Solders with Ag-Cu-Sn, Ag-Ni-Sn, and Ag-Cu-Ni-Sn Systems

Detailed reference data were calculated and presented in the form of tables in papers (Refs. 2, 3) upon experimental study of solder alloys, as well as the study of phase diagrams made in the Institute of Inorganic Chemistry/Material Chemistry, University of Vienna, Austria.

Enthalpy of mixing of liquid alloys from Sn$_{99}$Ag$_{10}$Cu$_{5}$ (at.-%) to Sn$_{40}$Ag$_{10}$Cu$_{50}$ (at.-%) were measured experimentally as for starting alloys and with Ni additions of 0.05 to 0.3 at-% with the increment of 0.05%. Also, compositions of liquidus surface of the quaternary Ag-Cu-Ni-Sn system were determined.

Partial and integral enthalpies of mixing of liquid Ag-Cu-Ni-Sn alloys were determined at 1000°C by a drop calorimetric technique using a Calvet type microcalorimeter. They were obtained by adding Ni to the ternary Ag-Cu-Sn alloys with different compositions. The data were evaluated by an extended Redlich-Kister-Muggianu polynomial fit for substitutional solutions. The minimum and maximum in the quaternary system were also calculated. The maximal integral enthalpy of mixing (13310 J/mol at 41 at-% Ag) occurs in the binary Ag-Ni system while the minimum
integral enthalpy of mixing (~21390 J/mol at 61 at.-% Ni) occurs in the binary Ni-Sn system. Moreover, the experimental data were compared to values calculated by different extrapolation models based on binary data.

**Lead-Free Solder Resistant to Tin Whisker Formation and Thermal Shock**

The whisker-resistant solder alloy is proposed and tested by Iljin Copper Foil Co., Ltd., Iksan-city, Republic of Korea. The solder contains tin, 0.1–5 wt-% of copper, and 0.001–0.4 wt-% of beryllium (Ref. 4). Also, silver in amount of 1–3 wt-% and boron in amounts of 0.003–0.5 wt-% can be added. For example, the solder compositions are 1) Cu 0.496 wt-%, Be 0.02 wt-%, and Sn in the balance; 2) Cu 0.679 wt-%, Ag 1 wt-%, Be 0.021 wt-%, and Sn in the balance; 3) Cu 2.88 wt-%, Ag 3 wt-%, Be 0.12 wt-%, and Sn in the balance; and 4) Cu 1 wt-%, Be 0.5 wt-%, and Sn in the balance.

The average length of whisker generated on the surface of soldered specimens after thermal shock test was 3–3.4 microns and number of whiskers per unit area was from 3/mm² to 5/mm², while the standard lead-free solder Sn-3Ag-0.5Cu exhibited whiskers of 11.8–14.4 microns in length at 11/mm² to 14/mm² whiskers per unit area.

The Be-Cu master alloy is first manufactured when making this solder. Then, tin is melted in a melting pot, and silver with Be-Cu master alloy are added to the Sn melt. The melt is kept in the solder pot for a certain time at 600°-650°C (1112°-1202°F), and the ready solder Sn-Cu-Ag-Be is cast into bar-shaped ingots.

**Extruded Rods Comprise a Powder Mixture of Filler Metal and Flux for Brazing Aluminum**

A method for manufacturing brazing rods containing both the braze alloy and flux was developed by F.P. Soudage Co., Aubagne, France, for joining aluminum alloy parts in air (Ref. 5). This product comprises a solid, rigid, and compacted material consisting of a powder mixture of the flux 20–30 wt-% and Al-12Si (AWS BA1-4) in the balance. The flux is NOCOLOK® Cs supplied by Solvay, Belgium, that has a melting point of 566°C and contains potassium 29 wt-%, cesium 1.8 wt-%, aluminum 17 wt-%, and fluorine 51 wt-%. Particle size of the flux powder is 10–20 microns. Melting temperature of the brazing rod is 580°C.

Also, the composition may comprise the Zn-2Al solder melting at 440°C and the flux containing cesium 51 wt-%, aluminum 10 wt-%, and fluorine 32 wt-%. This flux is melted at 450°-460°C (842°-860°F).

The powder metal-flux mixture is granulated to 3-mm-diameter particles that are dried at 120°-150°C (248°-302°F), and then subjected to hot extrusion at 7000 bars and 450°C for Al-12Si brazing rods or 330°C (626°F) for Zn-2Al solder rods. The resulting product is suitable for manual torch brazing or soldering. The patent also describes schematically the devices for granulation and hot extrusion of the composite brazing rods.
New Method for Brazing Steel and Aluminum Sheets Using Spot Welding Equipment

A novel method designed for producing joints between a sheet steel component, in particular, a press-hardened high-strength steel and a sheet aluminum component, is disclosed by Volkswagen AG, Wolfsburg, Germany (Ref. 6). Firstly, a brazing filler metal or a solder deposit is fixed on the steel component by using arc or laser radiation in such a way to keep it secured during transportation. Then, the process applies an electric current and a compressive force using spot welding, pressing the sheet-metal components together, and local heating the region to form the weld or brazed joint between steel and aluminum. Deposition of the brazing filler metal also can be done by induction heating.

The brazing filler metal is selected from Al-, Ni-, or Cu-based alloys or Zn-Al solder. Applications of the solder or copper- or nickel-based braze alloys are preferable because the Al-Si brazing filler metal forms a brittle intermetallic layer at the steel interface. Parameters of the process were not disclosed.

Joining Alumina and Steel by a Laser-Supported Brazing Process

A laser-supported method of joining alumina ceramic with metals was studied by the team of Forschungszentrum Karlsruhe GmbH and Institute of Metallforschung, Eggenstein, Germany (Ref. 7). Pure alumina ceramic and zirconia-toughened alumina (ZTA) (SN80, Ceramtec) were brazed to steels 100Cr6 and Ck45 using a CO2 laser and the active brazing filler metal CB4 (BrazeTec) in the form of 50 microns foil that contains Ag 70.5 wt-%, Cu 26.5 wt-%, and Ti 3 wt-%. The argon purged with a flow about 300 L/h to prevent oxidation of steel and the braze foil. The laser power was ramped up to 300-360 W. The joining procedure is highly flexible and can be easily adapted to complex component geometries.

Processing time was several minutes, which is significantly less than that of vacuum furnace brazing. The wetting behavior of the brazing alloy was also evaluated, and the contact angle on ceramic was about 30 deg, which exhibits good adhesion to the ceramic. Titanium-rich zones were observed close to ceramic and steel interfaces on scanning electron microscope images, as well as a (Ti, C, Fe) reaction layer at the steel Ck45 interface and a (Ti, Cu, Al, O) reaction layer at the ZTA ceramic interface. Mechanical tests of brazed joints showed that the failure occurred within the ceramic close to the interface between the braze alloy and ceramic part. Thermally induced stresses may lead to cracks in the ceramic, which result in the failure under mechanical loading. The typical bending strength varies between 40 MPa (5.8 ksi) and 80 MPa (11.6 ksi) with a Weibull modulus ranging from 4.3 to 6.1 that is lower than that of the original ceramic. Therefore, the laser process has to be optimized with the focus on reduction of residual thermal stresses in the ceramic.
Neutron Diffraction Measurement of Residual Stresses in Carbon-Fiber Composite with Copper Alloys for Nuclear Fusion Applications

A high heat flux plasma facing component proposed for the divertor of ITER nuclear fusion reactor is formed by an armor carbon-fiber composite (CFC) NB31 and a heat-sink material (CuCrZr alloy). Residual stresses and strains were experimentally measured in bar specimens of CFC brazed to CuCrZr alloy, as it must withstand cyclic thermal, mechanical, and neutron loads to provide the design lifetime and reliability. The main problem related to CFC-Cu alloy joints is the large thermal expansion mismatch between the two base materials, which generates big residual stresses at the interface during the joining process. A very ductile pure copper layer between the CFC and CuCrZr alloy is aimed to partially relax these residual stresses in the joint.

Residual stresses and strains were measured in the joints using neutron diffraction by the team of Universita Politecnica delle Marche and Politecnico di Torino, Italy (Ref. 8). Firstly, the CFC surface was modified by depositing a chromium carbide layer, which provided wetting of the CFC composite by brazing filler metal. Neutron diffraction experiments were performed at the E3 diffractometer of HMI-BENSC, Berlin, having a fixed neutron wavelength 1.37 angstroms. Thermal fatigue cycling was carried out by heating to 450°C followed by fast cooling to room temperature in air using water quenching. The cycles were repeated 50 times for each specimen.

The results for the as-brazed specimens showed expected stress states (tensile in the CFC and compressive in the CuCrZr alloy). The effect of thermal fatigue cycling was a general relaxation of residual stresses, probably due to the formation of microcracks at the CFC-Cu joint during the cycling.

Brazing SiC Ceramic to Graphite Using Ni-51Cr Powder Mixture as a Filler Metal

Recrystallized SiC ceramic was brazed in vacuum to high-strength graphite at 1380°C (2516°F) for 5 min using the brazing filler metal composed of Ni and 51 wt-% Cr powders. The mechanical properties of the brazed joints were investigated in Beijing University of Aeronautics and Astronautics, P. R. China (Ref. 9). The maximum three-point bending strength of the brazed joints was 32.3 MPa (4.7 ksi), which is equal to 81% of the graphite strength.

Microstructure and phase analyses reveal that interdiffusion and chemical reactions took place at the interfaces between base materials and braze alloy, as well as in contacts with the nickel and chromium powders. The braze alloy powder mixture was melted completely. A reaction layer 60-100 microns thick was formed at the SiC surface, and an interlayer 200 microns thick was found between the reaction layer and graphite surface. The reaction layer is mainly composed of Ni2Si, while the interlayer is mainly composed of Cr23C6 and Ni2Si phases. At the same time, Si and C diffused into the nickel and chromium powders, forming Ni2Si and NiCr2 phases.
Low-Cost Joining of Silicon Carbide with a Molten Glass in Air

A method for brazing SiC at 1300°-1600°C in air using calcium aluminosilicate glasses as filler materials was developed in CEA Grenoble, France (Ref. 10), for joining parts of the largest reflector in the world (3.5 m diameter) for the Herschel telescope. This technology has a low cost due to no shielding atmosphere and facilitates repairing damaged ceramic components. Many glass-ceramics were studied earlier to join SiC and SiC/SiC composites in vacuum, but only a few of them exhibited wetting and interfacial reactions with ceramic. The SiC substrate used in these tests comprised 2 wt-% of B4C as a sintering aid. Wetting of calcium aluminosilicate glass on SiC was studied using the sessile drop technique in air in the temperature range 1100°-1590°C. Good wetting was observed at the temperature above...
1300°C, as well as good filling of the joint gap by the glass containing 23CaO-15Al₂O₃-62SiO₂ (wt%).

Lowest contact angle of the glass on the SiC substrate was found as little as ~20 deg at 1400-1500°C and holding time more than 3 min. Average shear strength of SiC joints at RT was 42 MPa. These results clearly showed that SiC/(23CaO-15Al₂O₃-62SiO₂) is a reactive system, despite no reaction layer was observed at the interface. Reactivity is enhanced by oxygen from air that forms bubbles in the liquid glass. The wetting of SiC ceramic occurs by dissolution of the silica layer in the molten glass at the liquid-solid-vapor phase equilibrium. Further work is planned to study the formation of crystals at the edge of the joint.

Testing of New Filler Metals for Reactive Air Brazing Ceramic-to-Ceramic for Fuel Cell Applications

Reactive air brazing (RAB) is a promising method to join metals to ceramics in air using brazing filler metal modified with copper or silver oxides. A number of new compositions of oxide-modified filler metals were studied and characterized in Aachen University (Ref. 11) and Fraunhofer Institute fuer Keramische Technologien und Systems, Dresden, Germany (Ref. 12).

The following brazing filler metals were tested for joining alumina in air at 970°, 1050°, 1150°, and 1350°C for 20 min: Ag8Cu, Ag8Cu0.5Ti, Ag8Ni, Ag0.5Al, Ag4Cu4Mn, and Ag4Cu4Ni. The contact angle of all these brazes on alumina was in the range of 30–40 deg at all the above mentioned brazing temperatures except the Ag8Ni alloy at 1350°C that is about 90 deg. The tensile strength of brazed joints depends on the brazing temperature — the brazing filler metal Ag8Cu showed strength more than 100 MPa after brazing at 1050°C, while only about 60 MPa after brazing at 1150°C, and 40 MPa after brazing at 970°C. The filler metal Ag8Cu0.5Ti provided tensile strength of brazed joints more than 80 MPa after brazing at 1150°C, while only about 60 MPa after brazing at 1050°C, and only 30 MPa after brazing at 970°C. The brazing filler metal Ag4Cu4Ni showed the best result more than 60 MPa after brazing at 1350°C. All other filler metals had lower strength of brazed joints of alumina.

Thermal analysis clearly provided evidences of metal-oxide reactions during brazing resulted in the formation CuO and NiO oxides and their interaction with alumina. Formation of interfacial layers — controlled by thermal treatment — between RAB braze metal and the base metal Crofer 22AP (Fe-22.7Cr-0.4Mn) was investigated at different amounts of CuO (from 0 to 10.5 mol-%) added to silver (Ref. 12). Thermal treatment was changed by using induction or furnace heating for brazing at 1000°C followed by annealing at 850°C for 200, 500, and 800 h. The induction brazing process led to the formation of thin interfacial layers both at the interface with the ceramic 3YSZ and the base metal. Ceramic samples brazed with Mn-containing base metal had thicker oxide layers at the metal interface than at the ceramic interface, independently on the CuO content in silver paste. The growth of the layers is controlled by diffusion of minor elements originating from the steel Crofer 22AP. Tailoring of the braze composition by varying the content of CuO does not have a significant effect on the microstructure of the interfacial layers.

Joining of Vanadium-Modified Diamond to (Kovar) Fe-42Ni Alloy Using the Zn-5Al Solder

A low-temperature process for joining ornamental diamonds to metal polishing jigs was developed and investigated in Tokai University, Tokyo, Japan (Ref. 13). The process includes brief metallization at 1080 K without compromising the diamond clarity. Reactive vanadium hydride powder was used for low-temperature vacuum metallization of the diamond surface that was covered by doi-like islands of vanadium. The metallization process was performed using Ag-Cu eutectic powder and vanadium hydride powder at the weight ratio of 14.5. After the formation V₃C₃ at 1080 K for 240 s, silver dots were deposited also by maintaining temperature to melt the Ag-Cu eutectic. Soldering with the Zn-5Al filler metal was carried out in air using ultrasonic vibration. Thermodgravimetric and differential thermal analysis of the vanadium hydride-
diamond system were performed in argon to find out what vanadium carbide phases are formed in the contact. The formation of vanadium carbides on the diamond surface is a continuous exothermic reaction. The DTA test showed three reactions at 608, 710, and 780 K. The diamond weight began decreasing with the formation of $V_2C$ phase and continued decreasing during the formation of $V_3C$. As the result $V_2C_{5.67}$, $V_3C_y$, and $V_4C_y$ carbides were found.

The average strength of the joints was 20 MPa. Joint strength does not depend on the number of the surface modification cycles, whereas the wetting behavior of the solder was improved. It was also found that the $Al_4C_3$ reaction product was formed during the ultrasound soldering process at 770 K.

Low-Oxygen, Controlled Atmosphere Oxynon® Furnace for Brazing Stainless Steel Heat Exchangers and Metal-Ceramic Joints

The drawback of continuous furnaces for controlled atmosphere brazing (CAB) is the application of explosive gases such as hydrogen. A nonoxidizing continuous furnace using only inert gas atmosphere was newly developed by Kanto Yakin Kogyo Co., Kanagawa, Japan, for brazing stainless steel heat exchangers at 1443 K with BNi-5 filler metal (Ref. 14). The furnace has a carbon/carbon composite conveyor belt that can be used up to 2873 K. The Oxynon® furnace employs a principle that is completely different from hydrogen and carbon monoxide reduction. The partial oxygen pressure is low in the furnace atmosphere (less than 10$^{-5}$ Pa) due to the formation of CO by reacting of carbon-based components in the contact. The formation of CO in the contact is a continuous exothermic reaction. The DTA test showed three reactions at 608, 710, and 780 K. The diamond weight began decreasing with the formation of $V_2C$ phase and continued decreasing during the formation of $V_3C$. As the result $V_2C_{5.67}$, $V_3C_y$, and $V_4C_y$ carbides were found.

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References

10. Refs. 10–14 are abstracted from the 9th International Brazing & Soldering Conference held in Aachen, Germany, June 2010, DVS-Berichte.
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For info go to www.aws.org/ad-index

Preparation and Exam for AWS Certified Welding Inspector/ Educator. Two-week-long courses beginning Sept. 20, Nov. 1, Nov. 29 in Troy, Ohio. Call Hobart Institute of Welding Technology (800) 332-9448; hiwt@welding.org; or visit www.welding.org.

Preparation and Exam for AWS Certified Welding Supervisor. One-week-long course begins Oct. 18 in Troy, Ohio. Call Hobart Institute of Welding Technology (800) 332-9448; hiwt@welding.org; or visit www.welding.org.


Welding Inspection Course Level 1. A nine-day course presented in Canada beginning Sept. 13 and Oct. 18, Edmonton, AB; Sept. 27, Langley, BC. Call The Canadian Welding Bureau, (800) 844-6790, or visit www.cwbgroup.org.


Welding Supervisor Seminar — Steel. A five-day course presented in Canada beginning Sept. 13, Langley, BC; Sept. 20, Milton, ON; Sept. 27, Edmonton, AB. Call The Canadian Welding Bureau, (800) 844-6790, or visit www.cwbgroup.org.

ASM Int'l Courses. Numerous classes on welding, corrosion, failure analysis, metallography, heat treating, etc., presented in Materials Park, Ohio, online, webinars, on-site, videos and DVDs. Visit www.asminternational.org search for “courses.”


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. Troy, Ohio. This is a two-week preparation and exam program. For schedule, call Hobart Institute of Welding Technology (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. Call Welder Training & Testing Institute (800) 223-9884, 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. Call Real Educational Services, Inc. (800) 489-2890, info@realeducational.com.

Consumables: Care and Optimization. Free online e-courses presenting the basics of plasma consumables, designed for plasma operators, distributor sales and service personnel, etc. Visit www.hyperthermcuttinginstitute.com.

Crane and Hoist Training. Safety courses and operator training for users of overhead cranes and hoists. For schedules, contact Konecranes Training Institute, Springfield, Ohio; (262) 821-4001; or visit www.konecranesamericas.com.

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

Environmental Online Webinars. Free, online, real-time seminars conducted by industry experts. For topics and schedule, visit www.augustinack.com.

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

GULLCO INTERNATIONAL INC. • U.S.A
21568 Alexander Road • Cleveland • Ohio • 44146
Tel: 440-439-8333 Fax: 440-439-3634 e-mail: ussales@gullco.com
For info go to www.aws.org/ad-index
### 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 Dates</th>
<th>Exam Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corpus Christi, TX</td>
<td>EXAM ONLY</td>
<td>Sept. 4</td>
</tr>
<tr>
<td>Pittsburgh, PA</td>
<td>Sept. 12-17</td>
<td>Sept. 18</td>
</tr>
<tr>
<td>Houston, TX</td>
<td>Sept. 12-17</td>
<td>Sept. 18</td>
</tr>
<tr>
<td>Minneapolis, MN</td>
<td>Sept. 12-17</td>
<td>Sept. 18</td>
</tr>
<tr>
<td>St. Louis, MO</td>
<td>Sept. 19-24</td>
<td>Sept. 25</td>
</tr>
<tr>
<td>Miami, FL</td>
<td>Sept. 19-24</td>
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<tr>
<td>New Orleans, LA</td>
<td>Sept. 19-24</td>
<td>Sept. 25</td>
</tr>
<tr>
<td>Anchorage, AK</td>
<td>EXAM ONLY</td>
<td>Sept. 25</td>
</tr>
<tr>
<td>Nashville, TN</td>
<td>Oct. 3-8</td>
<td>Oct. 9</td>
</tr>
<tr>
<td>Tulsa, OK</td>
<td>Oct. 3-8</td>
<td>Oct. 9</td>
</tr>
<tr>
<td>Long Beach, CA</td>
<td>Oct. 3-8</td>
<td>Oct. 9</td>
</tr>
<tr>
<td>Newark, NJ</td>
<td>Oct. 3-8</td>
<td>Oct. 9</td>
</tr>
<tr>
<td>Portland, OR</td>
<td>Oct. 17-22</td>
<td>Oct. 23</td>
</tr>
<tr>
<td>Roanoke, VA</td>
<td>Oct. 17-22</td>
<td>Oct. 23</td>
</tr>
<tr>
<td>Cleveland, OH</td>
<td>Oct. 17-22</td>
<td>Oct. 23</td>
</tr>
<tr>
<td>Miami, FL</td>
<td>EXAM ONLY</td>
<td>Oct. 28</td>
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<tr>
<td>Corpus Christi, TX</td>
<td>EXAM ONLY</td>
<td>Oct. 30</td>
</tr>
<tr>
<td>Atlanta, GA</td>
<td>Nov. 14-19</td>
<td>Nov. 20</td>
</tr>
<tr>
<td>Dallas, TX</td>
<td>Nov. 14-19</td>
<td>Nov. 20</td>
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<tr>
<td>Sacramento, CA</td>
<td>Nov. 14-19</td>
<td>Nov. 20</td>
</tr>
<tr>
<td>Spokane, WA</td>
<td>Nov. 14-19</td>
<td>Nov. 20</td>
</tr>
<tr>
<td>St. Louis, MO</td>
<td>EXAM ONLY</td>
<td>Dec. 4</td>
</tr>
<tr>
<td>Los Angeles, CA</td>
<td>Dec. 5-10</td>
<td>Dec. 11</td>
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<tr>
<td>Houston, TX</td>
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<tr>
<td>Syracuse, NY</td>
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<tr>
<td>Reno, NV</td>
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<td>Dec. 11</td>
</tr>
<tr>
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<td>Dec. 11</td>
</tr>
<tr>
<td>Corpus Christi, TX</td>
<td>EXAM ONLY</td>
<td>Dec. 18</td>
</tr>
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</table>

#### Certified Radiographic Interpreter (CRI)

<table>
<thead>
<tr>
<th>Location</th>
<th>Seminar Dates</th>
<th>Exam Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miami, FL</td>
<td>Oct. 18-22</td>
<td>Oct. 23</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 Sales Representative (CWSR)

<table>
<thead>
<tr>
<th>Location</th>
<th>Seminar Dates</th>
<th>Exam Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indianapolis, IN</td>
<td>Sept. 22-24</td>
<td>Sept. 24</td>
</tr>
<tr>
<td>Atlanta, GA</td>
<td>Nov. 2-4</td>
<td>Nov. 4</td>
</tr>
</tbody>
</table>

CWSR exams will also be given at CWI exam sites.

#### 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 Robotic Arc Welding (CRAW)

<table>
<thead>
<tr>
<th>Location</th>
<th>Week of</th>
<th>Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Genesis-Systems, Davenport, IA</td>
<td>Sept. 13</td>
<td>(563) 445-5688</td>
</tr>
<tr>
<td>Wolf Robotics, Ft. Collins, CO</td>
<td>Sept. 13</td>
<td>(970) 225-7736</td>
</tr>
<tr>
<td>Genesis-Systems, Davenport, IA</td>
<td>Sept. 20</td>
<td>(563) 445-5688</td>
</tr>
<tr>
<td>Genesis-Systems, Davenport, IA</td>
<td>Sept. 27</td>
<td>(563) 445-5688</td>
</tr>
<tr>
<td>Genesis-Systems, Davenport, IA</td>
<td>Oct. 4</td>
<td>(563) 445-5688</td>
</tr>
<tr>
<td>Genesis-Systems, Davenport, IA</td>
<td>Oct. 11</td>
<td>(563) 445-5688</td>
</tr>
<tr>
<td>Genesis-Systems, Davenport, IA</td>
<td>Oct. 17</td>
<td>(563) 445-5688</td>
</tr>
<tr>
<td>Lincoln Electric, Cleveland, OH</td>
<td>Oct. 25</td>
<td>(216) 383-8542</td>
</tr>
<tr>
<td>ABB, Inc., Auburn Hills, MI</td>
<td>Nov. 1</td>
<td>(248) 391-8421</td>
</tr>
<tr>
<td>Genesis-Systems, Davenport, IA</td>
<td>Nov. 1</td>
<td>(563) 445-5688</td>
</tr>
<tr>
<td>Genesis-Systems, Davenport, IA</td>
<td>Nov. 8</td>
<td>(563) 445-5688</td>
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<tr>
<td>Genesis-Systems, Davenport, IA</td>
<td>Nov. 15</td>
<td>(563) 445-5688</td>
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<tr>
<td>Genesis-Systems, Davenport, IA</td>
<td>Nov. 29</td>
<td>(563) 445-5688</td>
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<tr>
<td>ABB, Inc., Auburn Hills, MI</td>
<td>Dec. 6</td>
<td>(248) 391-8421</td>
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<td>Genesis-Systems, Davenport, IA</td>
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<td>(563) 445-5688</td>
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<tr>
<td>Genesis-Systems, Davenport, IA</td>
<td>Dec. 13</td>
<td>(563) 445-5688</td>
</tr>
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</table>

#### Certified Welding Supervisor (CWS)

<table>
<thead>
<tr>
<th>Location</th>
<th>Exam Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miami, FL</td>
<td>Sept. 13-17</td>
</tr>
<tr>
<td>Norfolk, VA</td>
<td>Oct. 4-8</td>
</tr>
</tbody>
</table>

CWS exams are also given at all CWI exam sites.

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Important: This schedule is subject to change without notice. Please verify your event dates with the Certification Dept. and confirm your course status before making your travel plans. For information on AWS seminars and certification programs, visit [www.aws.org/certification](http://www.aws.org/certification), or call (800/305) 443-9353, ext. 273, for Certification; or ext. 455 for Seminars. Apply early to avoid paying the Fast Track fee.
The 12th annual AWS Leadership Symposium was held July 19–21 at AWS headquarters in Miami, Fla. Section members representing all 22 AWS Districts participated this year. The purpose of the seminar is to develop leadership and communication skills to enhance each Section’s value to its members. Listed here are the District number, attendee’s name, and Section. 1) Robert Lavoie, Boston; 2) Thomas J. Garland, Long Island; 3) Stephen Hill, Cumberland Valley; 4) Jenord Alston, Tidewater; 5) David Ennis, Atlanta; 6) Curtis Warren, North Central Florida; 7) Todd E. Parker, Wheeling; 8) Erven Perrigan, Northeast Mississippi; 9) Anthony Blackeney, Baton Rouge; 10) DeLayne Jacobs, Northwest Pennsylvania; 11) Mike Palko, Detroit; Nate Vanderhoof, Northern Michigan; 12) Randall Counselman, Fox Valley; 13) Mike Spangler, J.A.K.; 14) James Matta, Lexington; 15) Jay Gerdin, Northwest; 16) Dennis Wright, Kansas City; Rick Guffey, Iowa; Chris Beaty, Nebraska; 17) Cary Reeves, Oklahoma; Pete Goad, Tulsa; 18) Steve Sigler, San Antonio; 19) Sheri Acheson, Alberta; 20) John P. H. Steele, Colorado; 21) Samuel J. Lindsey, San Diego; and 22) Ken Morris Sr., Sacramento Valley; Tom Smeltzer, San Francisco.

The Leadership Symposium is conducted each year by Ron Gilbert, senior partner and principal management consultant for GEMS of Florida (Gilbert Education & Management Systems), www.gilbertems.com, and a professor of management in the Chapman Graduate School of Business at Florida International University. Assisting Dr. Gilbert again this year was Lee Kvidahl, an AWS past president, and manager of welding/manufacturing engineering at Northrop Grumman Ship Systems Ingalls Operations in Pascagoula, Miss. Participating AWS staff members included Rhenda Kenny, director, Member Services Dept.; and Alfred Nieves, senior coordinator, Member Services.
D3B Subcommittee on Underwater Welding Meets in Louisiana

Shown, from left, are Mike Pett, Shawn Henderson, Tom West, Jim O’Sullivan, D3B Chair Rodger Holdsworth, Rob Murray, Peter Szlegalowski, Fon Stonum, Michael Cameron, Brad Walden, and Uwe Aschemeyer.


Both standards are expected to be published later this year.

If you are interested in learning more about the standards-writing process or joining this Subcommittee, contact Committee Secretary Brian McGrath, (800/305) 443-9353, ext. 311.

Two Interpretations: C3.7M/C3.7:2005, Specification for Aluminum Brazing

Subject: Furnaces
Code Provision: C3.7: Page 5, Subclause 5.4.2. (Vacuum Furnaces)

Inquiry: Presently, the leak rate test for the vacuum furnaces we possess is performed once a half year in accordance with the in-house regulation. On the other hand, subclause 5.4.2 requires that the leak test shall be performed at least once a week.

The requirement of the in-house regulation is as follows: A cold and previously outgassed furnace shall have a total of no more than 0.07 Pa per hour when the vacuum chamber is isolated from the pumping system after being evacuated to less than 0.01 Pa. The leak rate test for the vacuum furnaces that we possess is performed with a stricter requirement than subclause 5.4.2, so we believe that it is impossible for the furnaces to have a total leakage of more than 2.6 Pa.

Our interpretation is: When the leak rate test is successfully performed once a half year in accordance with the in-house regulation, it does not need to be performed once a week because subclause 5.4.2 states, “Such a leak rate test shall be performed at least once a week or whenever there is reason to suspect an unacceptable leak rate exists.”

Response: The brazing operator may impose a lower leak rate criteria but that does not override the requirement for weekly testing.

Subject: Furnaces
Code Provision: C3.7: Page 4, Subclause 5.3.2.1 (Aluminum Brazing Furnaces)

Inquiry: The vacuum furnaces we possess for brazing are controlled and operated in accordance with SAE/AMS 2750, Pyrometry, and the furnace class is “2.” So, we perform TUS (Temperature Uniformity Survey) to verify that the temperature uniformity is within the range of ±11°F (±5.5°C) with nine thermocouples. On the other hand, subclause 5.3.2.1 requires temperature uniformity as below:

1) Within the range of ±20°F (±11°C) before thermal equilibrium has been reached.
2) Within the range of ±5°F (±3°C) after thermal equilibrium has been reached.

If we braze in accordance with AWS C3.7M/C3.7:2005, Specification for Aluminum Brazing, do the vacuum furnaces we possess need to be performed TUS to verify the above two requirements?

Our interpretation is: The vacuum furnaces that we possess do not need to be applied the requirement of subclause 5.3.2.1 because subclause 5.3.2 states that “the requirements of 5.3.2 are considered met if the requirement is controlled and operated in accordance with SAE/AMS 2750.”

Response: The requirements of subclause 5.3.2.1 do not need to be met if the furnace is controlled and operated in accordance with SAE/AMS 2750, Pyrometry, Class 1. Furnace Class 2 does not comply with AWS C3.7M/C3.7.
Standards for Public Review
(These public reviews expired 8/30/2010.)
B2.1-1/8-227:200X, Standard Welding Procedure Specification (WPS) for Gas Tungsten Arc Welding of Carbon Steel (M-1/P-1/S-1, Groups 1 or 2) to Austenitic Stainless Steel (M-8/P-8/S-8, Group 1), 3/8 through 1/2 Inch Thick, ER309(L), As-Welded Condition, Primarily Pipe Applications. Amendment Standard — $25.
B2.1-1/8-229:200X, Standard Welding Procedure Specification (WPS) for Gas Tungsten Arc Welding followed by Shielded Metal Arc Welding of Carbon Steel (M-1/P-1/S-1, Groups 1 or 2) to Austenitic Stainless Steel (M-8/P-8/S-8, Group 1), 3/8 through 1/2 Inch Thick, ER309(L) and E309(L)-15, -16, or -17, As-Welded Condition, Primarily Pipe Applications. Amendment Standard — $25.
B2.1-1/8-230:200X, Standard Welding Procedure Specification (WPS) for Gas Tungsten Arc Welding, with Consumable Insert Root of Carbon Steel (M-1/P-1/S-1, Groups 1 or 2) to Austenitic Stainless Steel (M-8/P-8/S-8, Group 1), 3/8 through 1/2 Inch Thick, IN309 and ER309(L), As-Welded Condition, Primarily Pipe Applications. Amendment Standard — $25.

ISO Draft Standard for Public Review
ISO/DIS 10225.2 — Gas welding equipment — Marking for equipment used for gas welding, cutting, and allied processes
Copies of the above draft international standard are available for review and comment through your national standards body, which in the United States is ANSI, 25 W. 43rd St., Fourth Fl., New York, NY, 10036; (212) 642-4900. Send comments regarding ISO documents to your national standards body, in the United States, if you wish to participate in the development of International Standards for welding, contact Andrew Davis, adavis@aws.org; (800/305) 445-9535, ext. 451, to obtain draft copies.

Revised Standards Approved by ANSI
B2.1-22-015:2011, Standard Welding Procedure Specification (SWPS) for Gas Tungsten Arc Welding of Aluminum (M/P-22 to M/P-22), 18 through 10 Gauge, ER4043 or R4043, in the As-Welded Condition, with or without Backing. Approved 7/7/10.

Technical Committee Meetings
Sept. 21–24, D1 Committee on Structural Welding, Chicago, Ill. Contact: Selvis Morales, ext. 313.
Oct. 6–8, A2 Committee on Definitions and Symbols, Troy, Ohio. Contact: Annette Alonso, ext. 299.
Oct. 12–14, B2 Committee on Procedures and Performance Qualifications, Columbus, Ohio. Contact: Selvis Morales, ext. 313.

All AWS technical committee meetings are open to the public. To attend a meeting, call (800/305) 445-9535, and the extension of the contact staff member.

Contribute Your Expertise to These Documents

Marine Construction

Surfaceing Industrial Mill Rolls

Robotic and Automatic Welding

Thermal Spraying

Labeling and Safe Practices

Magnesium Alloy Filler Metals
A5L Subcommittee on Magnesium Alloy Filler Metals to assist in the updating of AWS A5.19-92 (R2006), Specification for Magnesium Alloy Welding Electrodes and Rods. Contact R. Gupta, gupta@aws.org, ext. 301.

Nominations Sought for M.I.T. Masubuchi Award
November 2, 2010, is the deadline for submitting nominations for the 2011 Prof. Koichi Masubuchi Award, sponsored by the Dept. of Ocean Engineering at Massachusetts Institute of Technology (M.I.T.). This award, including an honorarium of $5000, is presented each year to one person, 40 years old or younger, who has made significant contributions to the advancement of materials joining through research and development.

The nomination package should include the candidate’s background, experience, publications, honors, and awards, plus at least three letters of recommendation from fellow researchers. The award was established to recognize Prof. 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.

Send your nominations to Prof. John DuPont at jnd1@lehigh.edu.
New AWS Supporters

**New Sustaining Companies**

**Eleet Cryogenics, Inc.**
11132 Industrial Pkwy. NW
Bolivar, OH 44612
Representative: Douglas Morton
www.electcryogenics.com

Eleet Cryogenics offers complete cryogenic bulk tank rehab services, installation, and on-site field services, and is a supplier of industrial and medical gas-control manifolds and vaporizers. The company also offers cryogenic delivery vehicles for sale or rent.

**Matheson**
166 Keystone Dr.
Montgomeryville, PA 18936
Representative: Beth Sullivan
www.mathesongas.com

Matheson (the brand name was formerly Matheson Tri-Gas) provides industrial welding and safety supplies, medical, specialty, and electronics gases, gas-handling equipment, and high-performance purification systems. It also offers engineering and gas-management services, and on-site gas-generation systems.

**Quality Technical Training Institute**
4490 Broadway, Depew, NY 14043
Representative: Paul Swatland
pswagenland@qtti.com

The Institute provides basic and advanced welder training for students in the western New York state region. Its state-licensed instructors are AWS Certified Welding Inspectors (CWIs) and Certified Welding Educators. Additional educational opportunities include weld procedure writing, procedure and welder qualifications, and CWI course training.

**Supporting Companies**

**ENGlobal Systems, Inc.**
225 Portwall St., Ste. 200
Houston, TX 77029

**NATCO Al Rushaid Middle East, Ltd.**
Murjan Village Unit A17-7
Jubail 31961, Saudi Arabia

**TYCO Fire Suppression and Building Products**
2700 Ind. Pkwy. South City
Marinette, WI 54143

**Educational Institutions**

**Cincinnati Job Corps Academy**
1409 Western Ave.
Cincinnati, OH 45214

**Corrigan – Camden ISD**
504 S. Home St.
Corrigan, TX 75939

**Dickinson High School**
3800 Baker Dr.
Dickinson, TX 77539

**Goodheart – Wilcox Publisher**
18604 W. Creek Dr.
Tinley Park, IL 60477

**Institute of International Recognised Qualifications (IIRQ)**
Technology Innovation Centre, Ste. 10
237 Oldhope Rd.
Kingston 6, Jamaica

**North Central Career Center**
1401 Daily Rd., PO Box 445
Bethany, MO 64424

**Socoro IS.D. Americas High School**
12101 Pellicano
El Paso, TX 79936

**Affiliate Companies**

**Circle M Contracting**
1400 London Blvd.
Portsmouth, VA 23704

**Contracting Engineering Consultants**
400 Fort Martin Rd., Ind. Park
Maidsville, WV 26541

**Ebersole Structural Engineers, Ltd.**
10275 Brecksville Rd.
Brecksville, OH 44141

**Engel Welding, Inc.**
PO Box 307, St.
Albans, WV 25177

**Frontier Tank Center, Inc.**
3800 Congress Pkwy.
Richfield, OH 44286

**Helium Leak Testing, Inc.**
19348 Londelius St.
Northridge, CA 91324

**Isnad Engineering Industries**
2nd Fl. Bldg., 12 Ste., Nassir Ben Jameel
Shmesani Amman, Jordan

**Lambo Erecting, Inc.**
261 Ampere Pkwy.
Bloomfield, NJ 07003

**Maritime International, Inc.**
1186 Petroleum Pkwy.
Broussard, LA 70518

**Maxum Industrial, LLC**
18 Navajo Way
Rockaway, NJ 07866

**Precision EB, LLC**
7 Thompson Rd.
East Windsor, CT 06088

AWS Member Counts
August 1, 2010

**Grades**

Sustaining.......................... 521
Supporting............................ 307
Educational............................ 540
Affiliate............................... 474
Welding Distributor.................. 45
Total Corporate Members......... 1,887
Individual Members................. 53,366
Student + Transitional Members... 9,734
Total Members....................... 63,100

Nominations Sought for National Officers

AWS members who wish to nominate candidates for President, Vice President, and Director-at-Large on the AWS Board of Directors for the term starting Jan. 1, 2012, may

1. Send their nominations by Sept. 22, 2010, to Gricelda Manalich, gricelda@aws.org, c/o Victor Y. Matthews, chairman, National Nominating Committee or
2. Present their nominations in person at the open session of the National Nominating Committee meeting scheduled for 2:00 to 3:00 PM, Tuesday, Nov. 2, 2010, at the Georgia World Congress Center, Atlanta, Ga., during the FABTECH show.

Nominations must be accompanied by biographical material on the candidate, including a written statement by the candidate as to his or her willingness and ability to serve if nominated and elected, letters of support, plus a 5 x 7-in. color portrait.

Note: Persons who present their nominations at the show must provide 20 copies of the biographical materials and written statement.
AWS Meets with Its International Agents in China and India

Cassie Burrell, AWS deputy executive director; and Priti Jain, director, international business and certification programs, visited AWS International Agents in China and India in June. The meetings were planned to review performance for the first half of 2010, and to discuss opportunities into 2011. They visited Moody International Headquarters in Shanghai, China, June 15th, where they met with Sun Aimin, regional director for the Asia-Pacific region, and Shi Kaifeng, deputy general manager.

On June 16th, Burrell and Jain met with officials of the Shanghai Welding Society (SWS), an AWS agent since 2009.

Burrell and Jain visited Chennai, India, June 17 and 18 to meet with Industrial Quality Concepts (an agent since 1994), Moody International — India (an agent since 2007), BETZ Engineering (an agent since 2008), and DASH Inspectorate (an agent since 2008).

To date, AWS certification programs have been held in 17 cities throughout India. Burrell said, “Certification supports the globalization of welding. Internationally recognized certifications, like the AWS CWI designation, have fueled the growth of welding worldwide. An increased emphasis on the quality of welds has contributed to the increased demand in AWS Certification programs. Currently, 10,580 or 33% of the Society’s certified personnel live outside the United States and that number is growing. Nearly 30 AWS International Agents are now authorized to administer AWS certification programming overseas.”
### Section Meritorious

<table>
<thead>
<tr>
<th>Dist.</th>
<th>Awardee</th>
<th>Section</th>
</tr>
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<tbody>
<tr>
<td>14</td>
<td>Gary Tucker</td>
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### Section CWI of the Year

- 6 Bill Davis, Syracuse, Syracuse
- 6 Bob Davis, Syracuse
- 8 David Hamilton, Chattanooga
- 8 Joey Foster, Greater Huntsville
- 8 Steve McGill, NE Tennessee
- 8 David Carwyle, NE Mississippi
- 8 Bobby O’Neal, Nashville
- 9 Barry Bernard, Acadia
- 9 Mary Howell, Baton Rouge
- 9 Perry Theriot, Baton Rouge
- 9 Barry Latham, Birmingham
- 9 Glen McDaniel, Birmingham
- 9 Jackie Morris, Mobile
- 9 Chris Fernandez, New Orleans
- 9 William Harris, Pascagoula
- 9 Dale Box, Pascagoula
- 10 Kenneth Kasnyik, Cleveland
- 10 Ward Kiser, Drake Well
- 10 Mike Sampson, Mahoning Valley
- 13 Ron Ashelford, Blackhawk
- 13 George Bane, Blackhawk
- 14 John Vaughn, St. Louis
- 14 Brian Butera, St. Louis
- 14 Tony Brosio, Indiana
- 14 Luke Bland, Indiana
- 14 Gary Dugger, Indiana
- 14 Bennie Flynn, Indiana
- 16 Scott Blankman, Nebraska
- 17 Ray Wildorf, Tulsa
- 17 John Trotter, Oklahoma City
- 17 Jimmy Brewer, Central Arkansas
- 17 Matt Siddles, Central Texas
- 17 Dan Bricker, E. Texas
- 18 Elyre Francisco, Corpus Christi
- 18 Barney Burks Jr., Houston
- 18 J. D. Garcia, Rio Grande Valley
- 18 Albert Hungerford, Lake Charles
- 18 Alton Wolfe, Sabine
- 20 Dean Mitchell, Colorado
- 20 Anthony Vidick, Wyoming
- 20 Russell Gurney, Utah
- 20 Stephen Chase Kryger, Utah

### District CWI of the Year Award

- 1 Andrea Burke, Boston
- 2 Winston Sturge, New Jersey
- 4 Greg Pike, Tidewater

### District Private Sector Instructor

- 4 Jennifer Alston, Tidewater
- 5 J. T. Mahoney, N. Central Florida
- 6 Bob Davis, Syracuse
- 6 Dusty Jones, Chattanooga
- 12 Joseph Campbell, Milwaukee
- 13 Norman King, Blackhawk
- 14 Jack Laudig, Indiana
- 14 Carl Schmitz, St. Louis
- 14 Tony Brosio, Indiana
- 15 Scott Blankman, Nebraska
- 17 Jim Bridwell, Ozark
- 18 David Savoy, Lake Charles
- 18 Richard Marslander, Corpus Christi
- 18 Howard Thomas, San Antonio
- 18 Morris Weeks, Sabine
- 20 Adam Johnson, Utah
- 20 Jesse Grantham, Colorado
- 21 Richard Samanich, Nevada

### Section Private Sector Instructor

- 4 Paul Miller, Tidewater
- 4 Bob Poirier, Tidewater
- 4 Rob Egloff, Tidewater
- 4 Brian Burroughs, Tidewater
- 4 Gary McCrickard, Tidewater
- 4 Wallace Hathaway, Tidewater
- 4 David King, Tidewater
- 4 Henry Price, Tidewater
- 4 Mark Gresek, Tidewater
- 4 Joe Strickland, Tidewater
- 4 Garrett Sonnenberg, Tidewater
- 8 Steve Peterson, Nashville
- 9 Darryl Bryant, Mobile
- 9 Anthony DiMarco, New Orleans
- 9 Darren Haas, Pascagoula
- 13 Kim Hamilton, Peoria
- 13 Jodi Lan caster, Peoria
- 13 Jeff Jones, Peoria
- 14 Justin Roy, St. Louis
- 14 Gary Tucker, Indianapolis
- 14 Bennie Flynn, Indianapolis
- 14 Tony Brosio, Indianapolis
- 16 Dave Elsloo, Iowa
- 17 Mike Schneider, Ozark
- 17 Donnie Williams, N. Texas
- 17 Robert Warke, E. Texas
- 18 David R. Berridge, Houston
- 18 Rick Ford, Corpus Christi
- 18 Brian McCoy, Corpus Christi
- 18 Janie Solano, Rio Grande Valley
- 18 Clay Savoy, Lake Charles
- 20 Alan Barber, Colorado
- 20 Jim Corbin, Colorado
- 20 Hassan Bilah, Albuquerque
- 20 William Casias, Albuquerque
- 22 Lilly Judkins, San Francisco
- 22 J. W. Rails, Corpus Christi
- 22 Bob Burger, Sacramento
- 22 Brian McCoy, San Francisco

### District Director Awards

This award provides a means for District Directors to recognize members who have contributed their time and effort to the affairs of their Section and/or District. District 1 Director Tom Ferris has nominated the following members:

- Russ Norris, Maine
- Jesse Crosby, Maine
- Walter Chojnacki, Connecticut
- Albert Moore Jr., Connecticut

District 9 Director George Fairbanks has nominated:

- James Cooley, Birmingham
AWS Participates in ISO/TC 44/SC3 Meeting in Istanbul

Shown are (from left) Kübra Kahraman, Leo van Nassau, Lennart Wittung, H. Didem Gençkan, Dave Fink, Beate Rickes (chairman), Tim Hofmann, Andrew Davis (secretary), Alice Lau, M. Hosseinioun, Damian Kotecki, Naoki Suzuki, and Michael Vellmer, members of ISO/TC 44/SC3, Welding Consumables. The committee met at GEDIK Welding in Istanbul, Turkey, concurrent with the 63rd Annual Assembly of the International Institute of Welding that was held July 11–17.

Amongst other documents, the committee worked on draft standards for SMAW electrodes for arc welding of stainless and heat-resisting steels; tubular cored electrodes for arc welding of nickel and nickel alloys; fluxes for submerged arc and electroslag welding; and SMAW electrodes for arc welding of high-strength steels.

The United States participants were David Fink, The Lincoln Electric Co.; Damian Kotecki, IIW treasurer and a past AWS president; and Andrew Davis, managing director, AWS Technical Services.

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AWS Life Members should register now to receive the entire Professional Program ($325 value) free plus free admission to FABTECH, scheduled for Nov. 2–4 at the Georgia World Congress Center, in Atlanta.

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To obtain your free registration, mark “AWS Life Member: Free Registration” at the top of your Registration Form. Then FAX both sides of the form to (305) 443-5647, Attn: Rhenda Kenny, membership director; or mail the form to Rhenda Kenny, AWS, 550 NW LeJeune Rd., Miami, FL 33126.

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64 SEPTEMBER 2010
Win Great Prizes in the 2010-2011 AWS Member-Get-A-Member Campaign* 

**GREAT PRIZES. GREAT CAMPAIGN. START SPONSORING MEMBERS TODAY!**

**ABOUT:** AWS is looking for individuals to become part of an exclusive group of AWS Members who get involved and win. Give back to your profession, strengthen AWS and win great limited-edition prizes by participating in the 2010-2011 Member-Get-A-Member Campaign. By recruiting new members to AWS, you’re adding to the resources necessary to expand your benefits as an AWS Member. Year round, you’ll have the opportunity to recruit new members and be eligible to win special contests and prizes. Referrals are our most successful member recruitment tool. Our Members know first-hand how useful AWS Membership is, and with your help, AWS will continue to be the leading organization in the materials joining industry.

To recruit new Members, use the application on the reverse, or visit www.aws.org/mgm

### PRIZE CATEGORIES

**President's Honor Roll:** Recruit 1-2 new Individual Members and receive an AWS Sportpack bag.

**President's Club:** Recruit 3-8 new Individual Members and receive an AWS hat and an AWS Sportpack bag.

**President’s Roundtable:** Recruit 9-19 new Individual Members and receive an AWS polo or denim shirt, hat and an AWS Sportpack bag.

**President's Guild:** Recruit 20 or more new Individual Members and receive an AWS Messenger Bag, an AWS polo or denim shirt, a one-year free AWS Membership, the "Shelton Ritter Member Proposer Award" Certificate and membership in the Winner's Circle.

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

### SPECIAL PRIZES

Participants will also be eligible to win prizes in specialized categories. Prizes will be awarded at the close of the campaign (June 2011).

**President of the Year:** The individual who sponsors the greatest number of new Individual Members during the campaign will receive a plaque, a trip to the 2011 FABTECH Show, and recognition at the AWS Awards Luncheon at the Show.

**Student Sponsor Prize:** AWS Members who sponsor two or more Student Members will receive an AWS Sportpack bag.

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

### LUCK OF THE DRAW

For every new member you sponsor, your name is entered into a quarterly drawing. The more new members you sponsor, the greater your chances of winning. Prizes will be awarded in November 2010, as well as in February and June 2011.

**Prizes Include:**
* Complimentary AWS Membership renewal
* AWS t-shirt
* AWS hat

### SUPER SECTION CHALLENGE

The AWS Section in each District that achieves the highest net percentage increase in new Individual Members before the June 2011 deadline will receive special recognition in the Welding Journal.

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

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*The 2010-2011 MGM Campaign runs from June 1, 2010 to May 31, 2011. Prizes are awarded at the close of the campaign.*
AWS MEMBERSHIP APPLICATION

4 Easy Ways to Join or Renew:

☑ Mail this form, along with your payment, to AWS
☑ Call the Membership Department at (800) 443-9353, ext. 480
☑ Fax this completed form to (305) 443-5647
☑ Join or renew on our website <www.aws.org/membership>

☑ Mr. ☐ Ms. ☐ Mrs. ☐ Dr. Please print & Duplicate this page as needed

Last Name
First Name
Middle Initial
Title

Were you ever an AWS Member? ☐ YES ☐ NO If “YES,” give year and Member # ____________________________

Primary Phone ( ) Secondary Phone ( )

FAX ( ) E-Mail

Did you learn of the Society through an AWS Member? ☐ YES ☐ NO

If “YES,” Member’s name: ___________________________________ Member’s # (if known): ____________________________

From time to time, AWS sends out informational emails about programs we offer, new Member benefits, savings opportunities and changes to our website. If you would prefer not to receive these emails, please check here ☐

ADDRESS

NOTE: This address will be used for all Society mail.

Company (if applicable)
Address
Address Cont’d.

City ____________________________ State/Province ____________________________ Zip/Postal Code ____________________________ Country ____________________________

PROFILE DATA

NOTE: This data will be used to develop programs and services to serve you better.

☒ Who pays your dues?: ☐ Company ☐ Self-paid ☐ Sex: ☐ Male ☐ Female

Education level: ☐ High school diploma ☐ Associate’s ☐ Bachelor’s ☐ Master’s ☐ Doctoral

PAYMENT INFORMATION (Required)

ONE-YEAR AWS INDIVIDUAL MEMBERSHIP ........................................ $80

TWO-YEAR AWS INDIVIDUAL MEMBERSHIP ................................. $160 $135 (New Members Only)

New Member? ☐ Yes ☐ No If yes, one-time initiation fee of $12... ☐

International Members add $90 for optional hard copy of Welding Journal (note: digital delivery of J is standard)........................................... $50 (Optional)

Domestic Members add $25 for book selection ($92 value), and save up to 87%... $50 (Optional)

International Members add $75 for book selection (note: $50 is for international shipping) +... $50 (Optional)

(Note: Book Selection applies to new Individual Members only - Book selections on upper-right corner)

TOTAL PAYMENT .............................................................................. $...

AWS STUDENT MEMBERSHIP ++

☒ Domestic (Canada & Mexico incl.)................................. $15

☒ International............................................................................ $50

TOTAL PAYMENT ...................................................................... $...

NOTE: Dues include $18.70 for Welding Journal subscription and $4.00 for the AWS Foundation.

BOOK/CD-ROM SELECTION

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

NOTE: Only New Individual Members are eligible for this selection. Be sure to add $25 to your total payment.

ONLY ONE SELECTION PLEASE:

☒ Jefferson’s Welding Encyclopedia (CD-ROM only)

☒ Design and Planning Manual for Cost-Effective Welding

☒ Welding Metallurgy

☒ Welding Handbook (9th Ed., Vol. 3)

☒ Welding Handbook (9th Ed., Vol. 2)

☒ Welding Handbook (9th Ed., Vol. 1)

For more book choices visit www.aws.org/membership

Learn more about each publication at www.awspubs.com

☐ New Member

A free local Section Membership is included with all AWS Memberships.

Section Affiliation Preference (if known):

Type of Business (Check ONE only)

☐ Contract construction

☐ Chemicals & allied products

☐ Petroleum & coal industries

☐ Primary metal industries

☐ Fabricated metal products

☐ Machinery except elect. (incl. gas welding)

☐ Electrical equip., supplies, electrodes

☐ Transportation equip. – air, aerospace

☐ Transportation equip. – automotive

☐ Transportation equip. – boats, ships

☐ Transportation equip. – railroad

☐ Utilities

☐ Welding distributors & retail trade

☐ Misc. repair services (incl. welding shops)

☐ Educational Services (univ., libraries, schools)

☐ Engineering & architectural services (incl. assns.)

☐ Misc. business services (incl. commercial labs)

☐ Government (federal, state, local)

☐ Other

Job Classification (Check ONE only)

☐ President, owner, partner, officer

☐ Manager, director, superintendent (or assistant)

☐ Sales

☐ Purchasing

☐ Engineer – welding

☐ Engineer – design

☐ Engineer – manufacturing

☐ Engineer – other

☐ Architect

☐ Architect designer

☐ Metallurgist

☐ Research & development

☐ Quality control

☐ Inspector, tester

☐ Supervisor, foreman

☐ Technician

☐ Welder, welding or cutting operator

☐ Consultant

☐ Educator

☐ Librarian

☐ Student

☐ Customer Service

☐ Other

Technical Interests (Check all that apply)

☐ Ferrous metals

☐ Nonferrous metals except aluminum

☐ Advanced materials/internormals

☐ Ceramics

☐ High energy beam processes

☐ Arc welding

☐ Brazing and soldering

☐ Resistance welding

☐ Thermal spray

☐ Cutting

☐ NDT

☐ Safety and health

☐ Bending and shearing

☐ Roll forming

☐ Stamping and punching

☐ Aerospace

☐ Automotive

☐ Machinery

☐ Marine

☐ Piping and tubing

☐ Pressure vessels and tanks

☐ Sheet metal

☐ Structures

☐ Other

☐ Automation

☐ Robotics

☐ Computerization of Welding

American Welding Society

P.O. Box 440367
Miami, FL 33144-0367
Telephone (800) 443-9353
FAX (305) 443-5647

Visit our website: www.aws.org

Member Services Revised 12/12/08
BOSTON
June 21
Activity: The Section hosted its 58th annual outing at Ridder Farm Country Club in East Bridgewater, Mass. Events included a shotgun scramble golf tournament in the morning followed by a New England-style dinner of chowder, steamed clams, and lobster. The top golf winners were Paul Kimbar, John Matarese, Fred Baglioni, and Tom Ferri, District 1 director.

District 2
Kenneth R. Stockton, director
(908) 412-7099
kenneth.stockton@pseg.com

District 3
Michael Wiswesser, director
(610) 820-9551
mike@welderinstitute.com

District 3 Conference
June 11
Activity: The District 3 conference was held at Heritage Hills Conference Center in York, Pa., chaired by Mike Wiswesser, District 3 director.

READING
April 23
Activity: The Section hosted a welding tournament at Reading-Muhlenberg Career and Technology Center in Reading, Pa. The third-level contestants, Jeremy Martin, Lebanon County CTC; Ben Dehoff, York County School of Technology; Alex Ferrara, Berks CTC West; and James Norman, Lancaster County CTC, received certificates and are ready to enter the work force. The top scorers were Wesley Hess, Lancaster County CTC; Cory Stuebner, Berks CTC; and James Norman; in levels one, two, and three, respectively. Welding instructor Daniel Milan accepted welding equipment donated by ESAB for use in his classes at Reading-Muhlenberg CTC.
Top scorers in the Reading Section welding tournament were (from left) Cory Stuebner, Wesley Hess, and James Norman.

Daniel Milan, a welding instructor at Reading-Muhlenberg CTC facilitated the Reading Section welding competition event.

May 20
Activity: The Reading Section held an awards-presentation program to recognize the outstanding students in several local welding programs. Honored were Jason Wallace, Reading-Muhlenberg Career & Technology Center (CTC); Jeremy Martin, Lebanon County CTC; Alex Ferrara, Berks CTC West; George E. Eby, Lancaster County CTC; and Casey Kelly, Lancaster Mennonite School.

District 4
Roy C. Lanier, director
(252) 321-4285
rlanier@email.pittcc.edu

CAROLINA
May 27
Speaker: David Schaefer, senior account manager
Affiliation: Panasonic Factory Solutions
Topic: Robotic GTA welding
Activity: The program was held at Guilford Technical Community College in Jamestown, N.C. Following the talk, the attendees toured the school’s welding shop.

July 8
Activity: The Carolina Section executive committee held a board meeting at Bonefish Grill in Greensboro, N.C. Attending were District 4 Director Roy Lanier, Chris Coble, Mike Hartman, Bill Shore, Sam Glass, David Schaefer, Nancy Cusmano, and Chair Randy Owens.

Shown at the Carolina Section May program are Sam Glass (white shirt) and back row (from left) speaker David Schaefer, Chris Coble, Walter Sperko, and Chair Randy Owens.

Third-level contestants in the Reading Section welding competition are (from left) Jeremy Martin, Ben Dehoff, Alex Ferrara, and James Norman.
Shown at the Carolina Section board meeting in July are (from left) Chris Coble, Mike Hartman, District 4 Director Roy Lanier, Bill Shore, Sam Glass, David Schaefer, Nancy Cusmano, and Randy Owens, chair.

District 5
Steve Mattson, director
(904) 260-6040
steve.mattson@yahoo.com

District 6
Kenneth Phy, director
(315) 218-5297
KAPhylnc@gmail.com

District 7
Don Howard, director
(814) 269-2895
howard@ctc.com

District 8
Joe Livesay, director
(931) 484-7502, ext. 143
joe.livesay@ttcc.edu

NORTHEAST MISSISSIPPI
JUNE Activity: Sam W. Gray, outgoing Section chair, received a certificate of appreciation for his leadership from Treasurer Gary Gammill.

District 9
George D. Fairbanks Jr., director
(225) 473-6362
fits@bellsouth.net

District 10
Richard A. Harris, director
(440) 338-5921
richaharris@windstream.net

District 11
Efthios Siradakis, director
(989) 894-4101
ft.siradakis@alr gas.com

DETROIT
May 11–14
Activity: The Section hosted the Detroit Sheet Metal Welding Conference XIV at the Schoolcraft College in Livonia, Mich. Don Maatz and Mark Rotary were among the numerous speakers at the event.

District 12
Sean P. Moran, director
(920) 954-3828
sean.moran@hobartbrothers.com

Gary Gammill (left) is shown with Sam Gray, outgoing Northeast Mississippi Section chair.

Mark Rotary (left) passes the chairman’s gavel to John Bohr, incoming Detroit Section chairman, at the June meeting.

JUNE 12
Activity: The Detroit Section held its past chairmen’s night program at Karl’s Cabin in Plymouth, Mich. Outgoing Chair Mark Rotary passed the gavel to John Bohr, incoming chair. Past chairs attending included Mike Karagoulis, Amos Winsand, Marty Keasal, Mark Rotary, Carl Hildebrand, Jim Goode, Bernie Bastian, Dick DuCharme, John McKenzie, Jim Dolfi, Bob Wilcox, Tom Spurschu, Dave Beneteau, and Chuck Padden.
The Detroit Section celebrated its past chairmen in June. Shown (from left) are Mike Karagoulis, Amos Winsand, Marty Keasal, Mark Rotary, Carl Hildebrand, Jim Goode, Bernie Bastian, Dick DuCharme, John McKenzie, Jim Dolfi, Bob Wilcox, Tom Sparschiu, David Beneteau, and Chuck Padden.

District 13
W. Richard Polanin, director
(309) 694-5404
rpolanin@icc.edu

CHICAGO
JUNE 23
Activity: The Section held a board meeting at Papa Passero’s Restaurant in Westmont, Ill., led by Chair Chuck Hubbard.

PEORIA
JUNE 4
Activity: Section members who served as delegates to the District 13 conference included Chair Phil England, Curt Rippey, Jeff Joos, and Treasurer Eric Ockerhausen, advisor for the Illinois Central College Student Chapter.

District 14
Tulliy C. Parker, director
(618) 667-7795
tullyparker@charter.net

ST. LOUIS
JUNE 7
Activity: The Section held its annual golf outing and scholarship fund-raising event at Fox Creek Golf Club in Edwardsville, Ill. The first-place winners were (A Flight) Larry Miller, Walter Ford, Bob Garner, and Allen Thomas; (B Flight) Chris Corrigan, Ryan Dunn, Heath Wells, and Kevin Corrigan; (C Flight) Tony Johns, Jerry Kehlenbrin, Rudy Santacruz, and Ray Connolly. Chairman Vick Shorkey received recognition for his services from Dave Beers and Jerry Simpson.
Shown (from left) are Lincoln College Technology Student Chapter members Susan Delong, Timothy Walker, David Flores, Nicholas Mahon, Kody Kimmell, Adebanjo Ipinlay, and Christopher Willmon.

District 15
Mace V. Harris, director
(612) 861-3870
macevh@aol.com

NORTHWEST
JUNE 14
Activity: The Section held its 31st annual golf outing at Sundance Golf in Dayton, Minn. Mike Hanson was the event committee chair. Event sponsors included District 15 Director Mace Harris, Dwight Affeldt, Todd Bridigum, Mike Hanson, Dan Johnson, Bob Sands, Advantage Marketing, Chart Industries, H&F Mfg., Integration PLUS, Matheson Tri-Gas, Miller Electric, Minneapolis Oxygen, Northland Fastening Systems, Oxygen Service, Ridgewater College, St. Paul College Welding Dept., and Weld Safe. Recognized were outgoing Section Chair Todd Bridigum and incoming Chair Jay Gerdin. The event raised $3000 for the Section’s scholarship fund. Production Engineering Corp. donated $1000 for the 11th year in a row.

District 16
David Landon, director
(641) 621-7476
dlandon@vermeermfg.com

District 17
J. Jones, director
(940) 368-3130
jjones@thermadyne.com

Lincoln College of Technology Student Chapter
JUNE 21
Activity: The Student Chapter members, guided by Advisor Donnie Williams, designed, welded, and installed shopping cart racks for the Christian Community Action outlet store as a community service project. Chapter members who contributed to the work include Susan Delong, Timothy Walker, David Flores, Nicholas Mahon, Kody Kimmell, Adebanjo Ipinlay, and Christopher Willmon.

District 18
John Bray, director
(281) 997-7273
sales@affiliatedmachinery.com

District 18 Conference
MAY 15
Activity: The District 18 conference was held in San Antonio, Tex.

District 19
Neil Shannon, director
(503) 419-4546
neilshnn@msn.com

District 20
William A. Komlos, director
(801) 560-2353
bkoz@arctechllc.com
District 21
Nanette Samanich, director
(702) 429-5017
Nan07@aol.com

District 22
Dale Flood, director
(916) 288-6100, ext. 172
flashflood@email.com

District 22 Conference
JUNE 19
Activity: The District 22 conference for northern California and Nevada was held June 19 at Zephyr Point Conference Center in South Lake Tahoe, Nev. Entertainment events included dinner and entertainment the night before. Also featured was dinner and dancing during a paddle boat cruise on Emerald Bay to visit Vikingsholm Castle. Delegates included District Director 22 Dale Flood, Matt Wysocki, Don Robinson, Jerry Wentland, Randy Naylor, Tom Erichsen, Chazz Bookout, District 22 Director Dale Flood, Ken Morris, Scott Holcomb, Steve Hedrick, Liisa Pine, Elizabeth Moore, and Tom Smeltzer. The AWS staff representative was Steve Hedrick, manager, safety and health.
Member-Get-A-Member Campaign

Listed are the members participating in the 2010–2011 Member-Get-A-Member (MGM) campaign. For campaign rules and the prize list, see page 65 in this Welding Journal or visit the AWS campaign Web site www.aws.org/mgm.

Call the AWS Membership Dept. (800/305) 443-9353, ext. 480, for information on your member-proposer point status.

Winner’s Circle
Sponsored 20+ new members per year since 6/1/99. The superscript indicates the number of years the member has achieved this status.

J. Compton, San Fernando Valley
E. Ezell, Mobile
J. Merzthal, Pero
G. Taylor, Pascagoula
L. Taylor, Pascagoula
B. Chin, Auburn-Opelika
S. Esders, Detroit
M. Haggard, Inland Empire
M. Karagoulis, Detroit
S. McGill, NE Tennessee
B. Mikieska, Houston

W. Shreve, Fox Valley
T. Weaver, Johnstown-Altoona
G. Woomer, Johnstown-Altoona
R. Wray, Nebraska

President's Club
Sponsored 3–8 new members

C. Crampton, Florida W. Coast
W. Sartin, Long Bch./Orange City
W. Sturge, New York

President's Honor Roll
Sponsored 1 or 2 new members

M. Allen, Charlotte
E. Ezell, Mobile

Student Member Sponsors
Sponsored 2 or more new student members

V. Facchiano, Lehigh Valley
E. Norman, Ozark
D. Schnalzer, Lehigh Valley
G. Seese, Johnstown-Altoona
M. Haggard, Spokane
G. Kirk, Pittsburgh
T. Buchana, Mid-Ohio Valley
C. Warren, N. Central Florida
J. Gerdin, Northwest
S. Robeson, Cumberland Valley
J. Sullivan, Mobile

Honorary Meritorious Awards

The Honorary Meritorious Awards Committee makes recommendations for the nominees presented to receive the Honorary Membership, National Meritorious Certificate, William Irrgang Memorial, and the George E. Willis Awards. These honors are presented during FABTECH each fall. The deadline for submissions is December 31 prior to the year of the 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 these awards follow.

William Irrgang Memorial Award
Sponsored by The Lincoln Electric Co. in honor of William Irrgang, the award, administered by AWS, is given each year to the individual who has done the most over the past five years to enhance the Society’s goal of advancing the science and technology of welding. It includes a $2500 honorarium and a certificate.

National Meritorious Certificate Award
This certificate award recognizes the recipient’s counsel, loyalty, and dedication to AWS affairs, assistance in promoting cordial relations with industry and other organizations, and for contributions of time and effort on behalf of the Society.

George E. Willis Award
Sponsored by The Lincoln Electric Co. in honor of George E. Willis, the award, administered by AWS, is given each year to an individual who promoted the advancement of welding internationally by fostering cooperative participation in technology transfer, standards rationalization, and promotion of industrial goodwill. It includes a $2500 honorarium and a certificate.

Honorary Membership Award
The honor is presented to a person of acknowledged eminence in the welding profession, or to one who is credited with exceptional accomplishments in the development of the welding art, upon whom the Society deems fit to confer an honorary distinction. Honorary Members have full rights of membership.

International Meritorious Certificate Award
This honor recognizes recipients’ significant contributions to the welding industry for service to the international welding community in the broadest terms. The awardee is not required to be an AWS member. Multiple awards may be given. The award consists of a certificate and a one-year AWS membership.

Nominees for National Office

Only Sustaining Members, Members, Honorary Members, Life Members, and 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 (NNC) to nominate candidates for national office. The committee shall hold an open meeting, preferably at the Annual Meeting, at which members may discuss the eligibility of all candidates.

The next NNC meeting is scheduled for 2 PM, Tuesday, Nov. 2, 2010, during FABTECH at the Georgia World Congress Center in Atlanta. The terms of office for candidates nominated at this meeting will commence Jan. 1, 2012.

To be considered a candidate for national office 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; chairman or vice chairman of a standing, technical, or special committee of the Society; or District director.

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

E-mail the letter to Gricelda Manalich, gricelda@aws.org, c/o Victor Y. Matthews, chair, National Nominating Committee.
Our world class manufacturing plant in Florence, Kentucky is a showplace for producing the highest quality welding materials in North America.

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7950 Dixie Highway Florence KY 41042 USA
General Office Phone: 859.371.0070 Fax: 859.371.5210 Email: kiswel@kiswelusa.com

For Info go to www.aws.org/ad-index
A new four-page brochure details the company’s line of all-position, nickel-based gas shielded flux cored wires for welding stainless steel components used in gas desulfurization units for reducing sulfur dioxide in flue gases. Charts display typical applications for the various base materials and matching flux cored wires and overmatching flux cored wires. Other charts display typical welding parameters with constant voltage and deposition rates. Another chart displays typical wire compositions and mechanical properties referenced to the AWS standards. The brochure may be downloaded from the Web site, or call to receive a hard copy.

Stoody® Co.
www.stoody.com
(800) 426-1888

New Text Details Friction Stir Welding in Industry

The recently released text Friction Stir Welding presents a comprehensive review of the process’ use with aluminum and its alloys, particularly in the shipbuilding, aerospace, mass transportation, and automotive industries. Topics covered include process basics, equipment, modeling, inspection, quality control, and applications. Part one covers general issues of the friction stir welding process including material deformation and joint formation. Part two focuses on defects in friction stir welds, modeling thermal properties, residual stresses, metallurgy, and weld performance. The authors are Daniela Lohwasser with AIRBUS, Germany, and Zhan W. Chen, professor, Auckland University of Technology, New Zealand. The book may be ordered from the company’s Web site.

Research and Markets
www.researchandmarkets.com/reports/1207048
U.S.A. FAX (646) 964-6609

Welding and Cutting Guide for Leading Brands

The July 2010 Welding & Cutting Equipment Guide, formerly known as the Condensed Catalog, displays welding and metal fabricating products from many vendors. Included are oxyfuel welding and cutting torches, regulators, plasma arc cutting and welding systems, arc welding power supplies, hardfacing and welding alloys, a wide array of manual and semiautomatic arc welding torches, tips, and accessories, and high-pressure gas-control products. The brands featured include Victor®, Tweco®, TurboTorch®, Arcair®, Thermal Dynamics®, Thermal Arc®, and Stoody®. The 68-page Guide No. 67-2836 can be downloaded from the Web site or by contacting your local distributor.

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(800) 426-1888

— continued on page 78
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Ph. 847.550.0033 Fx. 847.550.0444
cmindustries.com EMAIL: sales@cmindustries.com

For Info go to www.aws.org/ad-index
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**Video Details Hardfacing**

A ten-minute video describes the company’s capabilities in a wide range of manufacturing processes, products, services, and industrial applications. The video covers the atomization process, hardfacing products and services, Nicrobraz® high-temperature brazing products, castings, the industries served, and a brief history of the company. The video can be viewed at the Web site listed.

Wall Colmonoy Corp.
(248) 585-6400

**Metal Fabrication Products Catalog Updated**

Released in June, the *CGW-Camel Grinding Wheels Catalog* includes more than 1200 new products for the metal fabrication market. The 128-page catalog illustrates and describes the Quickie Cut™ Extreme cut-off wheels and improved ¾-in.-thick reinforced cut-off wheels, and the economical abrasive Z-PCE flap discs, and Fast Cut 12-16-in., high-speed cut-off wheels. Also pictured are abrasive belts, carbide burrs, and wire brushes, Z3 trimable flap discs, finish wheels, and porous surface grinding wheels.

CGW-Camel Grinding Wheels
www.cgwheels.com
(800) 447-4248

**Clean Air Weld Station Detailed in Brochure**

The Clean Air Weldstation™ brochure illustrates solutions in air filtration using downflow technology. Originally designed for use in schools, colleges, and union training facilities to control smoke, dust, mist, and odors, the units are now used for manufacturing facilities for 24/7 operation. The Clean Air Smart Control™ panel operates multiple systems from a single location with daily and weekly data-logging summaries to document maintenance filter status servicing. Pictured is a cutaway view of the equipment to show its construction, LED lighting, no venting to the outside, automatic start and shutdown feature, and optional motors and variable-frequency drive.

Clean Air America, Inc.™
www.clean-air.com
(866) 665-1829 (toll-free)

**Practical Metal Fabrication Guide Updated**

The third edition of *Metal Fabrication – A Practical Guide* serves as the basis for a comprehensive training curriculum in
Switch from weld to grind in a matter of seconds.

You can’t afford downtime and lost productivity when workers switch between welding and grinding jobs. So we developed our *Fibre-Metal QuickSwitch System* to go from one job to the other in just a few seconds. This system delivers high-performance head, face, and eye protection, along with all-day comfort – no matter how often workers switch between tasks. Let the *Fibre-Metal QuickSwitch System* help make your business safer and more productive. For a free demo, contact one of our safety experts today at **888-422-3798**.

**Take the QuickSwitch Speed Challenge!**

How fast can you switch? Find out at our booth at FABTECH in Atlanta, November 2–4, 2010. Winners of fastest time each hour will receive valuable *Fibre-Metal* head, face and eye protection equipment, plus a chance to win an Apple iPad!

Only *Fibre-Metal QuickSwitch System* offers two mounting designs to match your work requirements: Speedy™ Mounting Loop and Quick-Lok™ – plus industry-preferred SuperEight™ SwingStrap™ caps.
TRUMPF Appoints Two Product Managers

TRUMPF, Inc., Farmington, Conn., has appointed Tracey Ryba product manager — lasers; and Frank Geyer product manager — laser systems, for the company's Laser Technology Center in Plymouth, Mich. Ryba joins the company with 21 years of laser experience ranging from applications to product management. Geyer previously worked in the automotive industry with experience in engineering, manufacturing, and advanced material processing.

HIWT Taps Board Member

Hobart Institute of Welding Technology (HIWT), Troy, Ohio, has named Richard L. Cultice to its board of directors. Cultice has served as auditor for the city of Troy since 2004, and serves on the board of Dollars for Scholars, and is a member and past president of the Kiwanis Club of Troy. Prior to his position as auditor, Cultice was employed for 35 years with Hobart Brothers Co. in various accounting and finance positions, including corporate treasurer.

AK Steel Researcher Elected ASM Fellow

Jerry L. Arnold, a principal research engineer at AK Steel Research Center, Middletown, Ohio, has been elected a Fellow of ASM International. Dr. Arnold is recognized for his “distinguished contributions in the field of materials science and engineering.” The award will be conferred Oct. 19 in Houston, Tex., during the society’s awards-presentation dinner. AK Steel is a producer of flat-rolled carbon, stainless, and electrical steels.

Bishop-Wisecarver Names VP Sales

Bishop-Wisecarver, Pittsburg, Calif., a manufacturer of guided motion technology, has promoted Michael McVeigh to vice president of sales, responsible for both domestic and international sales. Since joining the company in 2006, McVeigh has served the company as national sales manager.

Mexico Regional Manager Named at Wheelabrator

Wheelabrator Group, LaGrange, Ga., a provider of surface-preparation and finishing solutions, has named Humberto Juarez regional manager for Mexico. Juarez previously served as an industrial and IT engineer for Pace Industries, concerned with industrial operations, sales, service, manufacturing, and the supply chain.

EPRI Awards TVA Employees

Six Tennessee Valley Authority (TVA) employees have been presented Technology Transfer Awards from the Electric Power Research Institute (EPRI), an independent, nonprofit, research organization. Cited were Suzanne Fisher, Ralph McKosky, Mark Goff, Lisa Beard, Ritchie Carroll, and Michael Turnbow. Also rec-
**Member Milestones**

I IW Cites Elmer, Fink, Kotecki, Lundin, Shook, and Weber

John W. Elmer, David A. Fink, Damian J. Kotecki, Carl D. Lundin, Ray Shook, and Jeff Weber were recognized at the 63rd Annual Assembly and International Conference of the International Institute of Welding (IIW) in Istanbul, Turkey, in early July.

John W. Elmer, of Lawrence Livermore National Laboratory, was presented the Yoshiaki Arata Award. The award is presented annually for extraordinary achievements in fundamental research in welding science and technology and allied areas.

David A. Fink, The Lincoln Electric Co., received the AWS-sponsored Thomas Medal. This award is presented annually to an individual for their active participation in IIW/ISO international standards-preparing activities.

Damian J. Kotecki, an AWS past president, is serving as IIW treasurer.

Carl D. Lundin, a professor at the University of Tennessee, received the Evgeny Paton Prize in recognition of his significant contributions to science and technology through his lifetime dedication to applied research and development in the fields of advanced technologies, and materials and equipment for welding and allied processes.

Ray Shook, AWS executive director, was elected vice president of the IIW. For the past three years, Shook has served as an IIW board member.

Jeff Weber, AWS senior associate executive director, accepted the Andre Leroy Prize for a video detailing resistance welding processes that was produced by the Resistance Welding Manufacturers Alliance (RWMA), an AWS standing committee. Awarded by the French delegation, the prize is awarded for a multimedia piece intended for use in education and training in any aspect of welding or an allied process. This is the first time an American delegate has received this award.

**Rexarc Hires NE Sales Manager**

Rexarc International, West Alexandria, Ohio, a supplier of industrial gas control systems for the welding and specialty gas industries, has named Luke Leslie regional sales manager — Northeast. Prior to joining the company, Leslie served for three years as national accounts sales manager at ThermoDyne.

**Obituary**

Richard Allen Lake

Richard Allen Lake, 71, died July 3 in Pinehurst, N.C. He served as president and CEO of National Welders (now Airgas National Welders™) prior to his retirement in 2004. Until 2008, he was a member of the AWS Triangle Section. A graduate of Marshall University, he worked 14 years in engineering sales with Westinghouse Electric. In 1971, Lake started his career in the industrial gas and welding supply business as a regional sales manager at National Welding in Charlotte, N.C. He left the company in 1973 for brief stints with Selox in Atlanta and Carolina Welding in Raleigh. He returned to National Welding in 1979 as a cryogenic sales engineer. He progressed to cryogenic and bulk gas sales manager, then became vice president of sales and distribution where he served until becoming president and CEO in 1998. Lake is survived by Sheila, his wife of 53 years, a son, a daughter, a brother, four grandchildren, and two step-grandchildren.

**WELDING JOURNAL**
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Pointers for Choosing a Plasma Cutting Machine

A little advanced planning can ensure you purchase the plasma cutting model that offers the flexibility needed.

There are a number of factors to consider when purchasing a plasma cutting tool. They include cut capacity, cut quality, reliability, duty cycle, ease of use, and operating costs.

The first step is to determine whether you will be cutting by hand, automated on a table, or both — Fig. 1. Some plasma cutting tools are capable of doing both, easily switching from hand-held to mechanized cutting and back again. A few systems include a computer numeric control (CNC) interface and an internal voltage divider to provide greater options for mechanized applications.

Some Factors to Consider

Once you have determined the types of plasma cutting you expect to do, then consider the thicknesses of the materials you plan to cut. The general rule is to choose a system with a recommended cut capacity that matches the material thickness you plan to cut 80% of the time. For example, if you mainly plan to cut ¼-in.-thick metal, and only occasionally cut metal that’s a little thicker (say ½ in.), then it’s recommended to choose a ½-in. system.

Cut quality is another important consideration. Not only does it impact the quality of your finished piece, it saves time in later stages of production. Ideally, you want a clean, smooth edge so you don’t spend a lot of time on secondary work. Narrow kerf (cut width) translates to more precise, cleaner cuts, and less wasted metal.

The more reliable plasma cutting systems are engineered with fewer parts, use software instead of hardware where possible, are manufactured to exacting ISO standards, and are thoroughly tested.

Centralized fan cooling is a feature that brings cool air in through the center of the system where the most heat-sensitive components are located, thus offering more efficient cooling and a higher duty cycle for industrial applications.

Simple operation permits experienced operators to perform jobs faster and more efficiently, and helps the less-experienced workers to get acceptable results.

Portability will be important should you plan to move the cutting equipment around a lot or do some of your work away from the shop — Fig. 2. Lightweight systems are available that perform well without sacrificing power and performance.

Operating costs are important, but...
they should be weighed against the benefits of productivity and work quality, and plasma consumable life, which can vary significantly from one brand of plasma cutting system to another. The better brands utilize technology to extend plasma consumable life, while also delivering high-quality cuts.

More Facts about Plasma Cutting

Plasma cutting, in use for more than 50 years, has evolved into a versatile, productivity enhancing tool.

Compared to other cutting systems, plasma generally offers faster cutting speeds without any preheating of the workplace, and higher-quality cuts, which result in fewer finishing operations.

Most hand-held plasma systems use compressed air that eliminates the need for the gas cylinder rentals and delivery charges incurred with oxyfuel.

While the initial cost of plasma systems is higher, they can be cost effective factoring in the savings in gases and labor-intensive finishing operations.

Plasma also offers some advantages for cutting thin materials, including a narrower heat-affected zone and less warping compared with oxyfuel cutting. Advances in plasma torches, consumables, and power supply designs have produced systems that can cut metals as thick as 1.75 in. (44 mm).

Oxyfuel is still the choice for very thick metals, but plasma is faster and gives better cuts for many jobs.

Plasma’s ability to cut stainless steel and aluminum is one of its primary advantages over oxyfuel, which is not effective for cutting these materials. Plasma is also more effective cutting painted, dirty, or rusted steel, which makes it an indispensable tool for heavy-equipment repair, automotive restoration, farm equipment maintenance, and many other tasks. Plasma is effective for cutting any electrically conductive metal and is one of the most popular methods for cutting mild steel, as well as cut, pierce, gouge, and bevel electrically conductive metals of all types, shapes, and sizes. Plasma systems can also be used on x-y cutting tables, on robotic arms, with a track burner for effective long, straight cuts; or with pipe cutting and beveling tools. As a gouging tool, plasma emits less smoke and noise while backgouging for weld preparation or removing worn and cracked parts for repair or replacement.

Getting started with plasma is easy. Systems like the Hypertherm Powermax45 include power supply, torch, consumable parts for cutting and gouging, and step-by-step operating instructions in both print and DVD format. The operator needs to supply only the power; clean, dry compressed-air or nitrogen; and protective hand and eyewear.
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Ways to Limit Spatter

Reducing spatter will help you increase productivity, reduce expenses, and stay safer

BY AUGUST F. MANZ

Welding spatter causes many problems with gas metal arc welding (GMAW) guns, as well as welding problems. It can also cause fires and burns. The advice in this article will help you reduce costs, improve weld quality, and keep safer.

Spatter Sources

Spatter can originate from exploding gas bubbles in the weld pool or from expanding gases inside the metal drops that transfer from the end of the electrode — Fig. 1. Expanding gases can cause drops to explode like an overinflated balloon. Spatter can come from the splash of drops as they hit the weld pool, just like the splash of raindrops — Fig. 2. It can come from electromagnetic motor forces that cause molten drops to rotate and whip around on the end of the welding wire — Fig. 3. And, spatter can come from the explosive fuse action that helps metal transfer from the tip of the welding wire as it is melted by the action of the welding arc — Fig. 4. Usually it is the explosive fuse action that creates the most spatter. Frequently, careful adjustment of the welding conditions (voltage, amperage, shielding gas, etc.) and tuning in the power source can reduce spatter. With correct settings of the welding equipment, spatter can be reduced to manageable levels.

Gas Shielding Problems

Spatter tends to cling to the inside surface and edge of gas shielding cups of GMAW guns. The spatter can build up until it interferes with the gas shielding flow. Sometimes the buildup can completely block the gas cup opening. Operators must be careful when they clean away the spatter buildup; however, this is not always done. Cleaning away spatter buildup is especially troublesome with robotic welding systems. On occasion, a hunk of spatter buildup falls out of the end of the gas cup, in the form of a ring of spatter. If the spatter ring falls out while you are welding, it can land in the weld pool and ruin the weld properties.

It is more difficult for spatter to stick to clean, smooth surfaces. When a molten ball of spatter strikes a surface, it can instantly cool off and solidify. As it solidifies, the molten material molds itself around scratches and microscopic grooves in the surface. It literally grabs onto the surface and won’t let go. Then it is easy for more spatter to stick to the spatter already there.

When you use a sharp tool, like the end of a screwdriver, to remove spatter buildup, it can scratch the inside surface of a gas cup. That makes it easier for the spatter to stick to the cup the next time you start to weld. Some operators bang their GMAW guns against the floor or some other hard surface to knock the spatter loose. That isn’t a good idea because it can damage the gun. Other operators set the gas cup against a hard surface and whack it with a hammer to try to knock the spatter loose. That, too, is a no-no because it can damage the gun. If
Some tips are threaded into the GMAW gun. As a consequence, some operators use pliers to grip the tip and turn it tighter. The gripping jaws of the pliers leave marks and grooves on the tip. Spatter will stick to contact tips that are scratched and marked for the same reason: it sticks to gas cups. Once spatter begins to stick to the end of the contact tip it can build up to where it begins to close off the wire feed hole. As the hole in the tip begins to close, wire feed forces are increased by the wire feeding system. Sooner or later, the increased wire feed force causes the wire to jam inside the conduit leading from the wire feeding control to the GMAW gun, unless, of course, the spatter is removed.

Sometimes, while welding, an operator can see a hunk of spatter pulled off of the contact tip by the welding wire as it is fed from the tip. These little hunks of spatter can cause a blip in the arc and may cause a small defect in the weld. You can slow the buildup of spatter on a contact tip by keeping it smooth and clean, and by coating it with one of the commercial antispatter sprays.

Buildup and release of spatter from the contact tip causes fluctuations in the wire feed speed, and consequently, the welding current. Whenever you become aware of fluctuations in the arc you should suspect the trouble is from a spatter-clogged contact tip. Keep the tip clean and smooth to reduce the chance of wire feeding problems.

**Spatter Bridges**

Gas metal arc welding guns are designed to electrically isolate metal gas cups from the current-carrying parts of the gun. That prevents accidental arcs between the edge of a gas cup and the workpiece while you are welding. Such accidental arcs could result in defects in the weld zone.

However, when spatter builds up to the point where it completely bridges the space between the inside wall of the metal gas cup and the contact tip, the gas cup becomes electrically hot. Current for an accidental arc-over between the edge of the gas cup and the workpiece can flow from the contact tip, through the spatter bridge, into the gas cup. Such arc-overs can ruin weld and cause accidents due to the reflex action of the operator. Spatter bridges should be avoided at all costs.

**Spatter Removal Tools**

Some companies market tools for removing spatter from the inside of gas cups. Those tools should be used with care and only as directed by the manufacturer of the tools. Incorrect usage can create scratches and marks inside the gas cup. Instead of correcting the problem, it may make it worse.

**Gas Composition**

In some cases, the amount and size of spatter can be reduced by changing the shielding gas composition. Whenever it is possible to use any one of several different gases for making the weld, choose the one that gives the least amount of spatter. You may have to run an experiment to find the best shielding gas for use with the material you are welding, but the time will be well spent.

**A Safety Reminder**

As you know, spatter is hot. It can cause burns and start fires. But did you know a hunk of spatter can bounce and roll like a rubber ball? As it flies through the air, surface tension causes the bits of molten spatter to become ball shaped. While a ball of spatter is falling, it cools off a bit. A thin skin forms on the ball surface, like the skin on an apple. When the ball of spatter hits the ground, it can bounce, roll, and ricochet. It can roll and bounce as much as 35 ft, fall through cracks where it can ignite a fire, etc. So you should protect the welding area for 35 ft in all directions from the hazards of hot welding spatter.

The following are a few good safety references:

- ANSI Z49.1, Safety in Welding, Cutting and Allied Processes (available at www.aws.org)

Also, be sure to read and follow the instruction literature the suppliers of your equipment and materials provide.

**The Bottom Line**

Follow the teachings of this article. Spatter reduction will increase productivity, reduce expenses, and keep you safer.
Teaching Human Development Skills to Welders

Instructors and students in all disciplines will learn a lot from this veteran welding professor’s advice

BY JACK D. COMPTON

In today’s educational climate, as it was 20 years ago, vocational preparation is more important than ever and more neglected. This type of instruction has to be much more than hands-on training in a specific skill.

The single word “education” is seldom uttered. It is invariably preceded by the phrase “crisis in.” Despite high dropout and failure rates in urban school systems, the fact is that most American youth are attending school.

According to the Census Bureau, more than 90% of young people aged 16 to 17 are enrolled in school. This figure has not changed in the last 20 years. The real question, of course, is what are they doing there? Also, what will their schooling prepare them to do in the future?

The Problem Has Not Changed over the Years

United States workers are competing on an international level, and that competition is getting stiffer every day. Computer-integrated manufacturing has changed the industrial context. Simultaneous engineering advances are forcing the need for effective teamwork among groups of production workers.

This could leave the skilled factory worker, a welder for instance, out in the cold — unless that worker can communicate clearly, understand ideas put forth both verbally and mathematically, process those ideas, and adjust his or her performances to meet the daily requirements of competing in a global arena.

From where we stood 20 years ago and where we stand today, that’s a tall order. At the outset, forget about blame. It’s a waste of energy. Each one of us is responsible for educating the children of this country to be productive citizens.

Welding education is important to the American Welding Society (AWS). Here’s a look at what can be done.

A Workable Solution for Welding Training

A well-run welding class should be a microcosm of an efficiently operated business. In addition, welding students should have the opportunity to meet challenges that will prepare them for the real world. Only by modeling instructional environments on the actual demands of the real world, can they consistently produce welders capable of making a contribution to industry, and by extension, the larger society.

For those with a copy of Modern Welding by Althouse, Turnquist, Bowditch, and Bowditch, use Chapter 33 on “Getting and Holding a Job in the Welding Industry.” Move it up to be included with Chapter 1 on safety, because it outlines the conduct expected from students from the first day of class, and not just what is going to be expected from their employer after leaving class.

When a student demonstrates inappropriate conduct or behavior, don’t tell them they are going to get a bad grade, tell them they are “fired.” Of course, they cannot be let go or dropped from
Seven Point Plan for Effective Welding Instruction

1. Comprehension of welding procedures and the importance of adhering to necessary codes must be consistently stressed. In my book, Guide to Certified Welder Examinations, I stress that in addition to the hands-on physical test required by AWS, the 50-question written test required by the city of Los Angeles to become a certified welder was critical because it “is an outstanding representation of what an experienced welder should know and understand before taking on the responsibilities of making welds upon which life and property will likely depend.”

2. Reading, writing, and verbal communication skills of every type must be practiced every day. My students were required to document, if only to check off their progress daily and verbally describe their accomplishment to me, before I would give them credit. For example, saying the following would suffice: “This is a lap joint welded with the shielded metal arc welding process in the horizontal position with E7018.”

3. The importance of perfect attendance, a cooperative attitude, and evidence of personal ambition must be reinforced with effective systems of reward. A basic element of these is just to compliment your students on their achievements in front of their colleagues. A high-five works, too. Most jobs require employees to “clock in.” Try installing a clock with time cards. This will also help with roll taking and tracking hours of your students.

4. Establishing and meeting both short-term and long-term goals must become a part of each student’s daily experience. In your syllabus, on the first day of class, outline what your expectations are. Set the bar high. Your students will rise to your level of expectations. Ask much and you will be given much. Post inspirational and motivational quotes in your classroom and shop.

5. Students must be encouraged to develop the desire to find a better way. A good weld is like a work of art, and each artist painting a masterpiece uses a different brush stroke. Encourage your students to develop their own.

6. A safe workplace is an orderly workplace; students must be required to keep the shop neat and clean. Students must be required to keep the shop neat and clean while maintaining the highest industrial safety standards. I would require students to sweep the shop meticulously and mop at the end of every class. It surprised me how many of them didn’t know how to do this, but rest assured, they learned.

7. In today’s world, computer literacy is the logical extension of traditional communications skills. It should be incorporated as part of the standard vocational curricula. Encourage students to do their weekly homework on a computer and e-mail their completed tasks rather than printing them out. The library research assignment mentioned in the article is required to be produced on a computer and printed out, bound, and delivered in a proficient manner.

Build Character Skills

Traditionally, vocational instruction has been heavily oriented toward the development of technical competence. Too often, however, the opportunity has been missed for students to develop the following living skills that will bolster technical excellence: responsibility, self-discipline, individual initiative, dress for success, personal hygiene, clear communications, teamwork, and analytical/critical thinking. With these, the welding course graduate will have unlimited potential as a human being and as an employee; without them, even superb welding skills will not count for much.

Look up Michael Josephson’s organization, Character Counts (character-counts.org), and encourage students to do likewise.

If the most technically qualified welder doesn’t show up for work regularly, what good are those excellent welding abilities to the contractor who has to deliver a job on time? If the best welder cannot communicate with coworkers and supervisors, how much can that individual’s skills contribute to the project as a whole? If the talents of creative thinking, analytical ability, and cooperative effort — possessed by everyone to one degree or another — remain undeveloped in our skilled workers, how can they be expected to remain competitive in global markets?

Albert Schweitzer said, “Example is not the main thing in influencing people. It is the only thing.” All of us know that some vocational instructors do a better job than others, but has it been examined why? Can it honestly be said that we are responsible enough to be on the job every day, spending our class time in the welding booth with the students? Encourage and reward 100% attendance. For example, maybe give your students with perfect attendance AWS Student Memberships.

Challenge Students with Contests to Spark Enthusiasm

Students have radar that detects hypocrisy. If teachers feel free to take personal days as often as their contracts permit, why should students feel that their own class attendance is important? If teachers busy themselves with paper-
work at their desks, while students struggle in the welding booth without adequate hands-on instruction, what does that say about dedication to the task at hand? Teachers can never expect students to perform diligently until they make a commitment to do the same. Are we self-disciplined enough to keep good records, tracking the progress of every student?

Are we creative enough to devise rewards that will motivate each of our students to achieve? Have in-shop competitions to see who can make the best weld. One project is to see who can properly finish a vertical 1-in., V-groove certification in the shortest time. Fewer than 30 min is a goal. Another idea is to have a race rolling empty oxygen cylinders 100 ft around a trash can and back.

Light the spark of enthusiasm for underachievers by giving them tasks that will ensure success. Almost no one will keep trying in the face of unremitting failure. Make it your business to develop tasks appropriate to each student’s ability. Are there a couple of stand-out students in the classroom? Motivate them with projects that will exercise their talents. For instance, encourage participation in various awards programs and community service projects.

**Employ Synergy**

From the first day, teach and encourage them to know and use synergy. Not often in their careers will they have to make or build anything alone. Little of what’s taught has value unless it is put into action. Nothing will give you greater satisfaction than seeing a student showing or teaching one of their classmates something you just showed them.

When a class has synergy, the instructor’s efforts are magnified, and the students will all benefit. Challenge them to move some heavy object that cannot be moved by one person or even all pushing together in opposite directions. Then, have them all push together in the same direction, and applaud their success. I have found a 2000-lb, 5 × 5-ft platen table is useful for this demonstration.

**Offer Credit**

Are we communicative enough to impart the value of good work habits as well as essential technical information?

Give credit for good work habits. Not extra credit but basic credit that is a fundamental part of each student’s grade. Some students will grasp new technical information better than others. However, every student can learn to attend class regularly, be on time, maintain an orderly work area, cooperate with others, dress for success, have good personal hygiene, and work steadily toward a clearly communicated goal. If this could be said for every American worker, the country would be in a more competitive position right now.

**Provide Practical Help**

Are we analytical enough to develop a personal plan for productivity that will maximize valuable training time?

As educators, it is important to look at ourselves first, see where our performance is strong, and what areas need some work. Are we spending enough time in a welding booth? Is each student receiving a fair share of our attention? Do we ever rob our students of precious class time by closeting ourselves with administrative details? If every student knows that the instructor is going to stick his or her head into welding booths, ask if help is needed, and guide progress, they are more likely to stick with it knowing you care and will be there for them. Plus, they are less likely to disappear when they know you will notice their absence.

**Use Educators and Technical Libraries as Resources**

Are we cooperative enough to work with other instructors and administrators, ensuring that the vocational and academic curriculum reinforce and support each other?

One way to foster cooperation among educators is to ask for help. Invite the chemistry or physics instructors to bring their classes over to see these subjects at work and let students participate in the demonstrations. Give assignments that require students to prepare written reports on their welding projects. Then, suggest they consult their English teachers for guidance in the preparation of those reports. Encourage students to give talks on welding in their speech classes. When they need to make mathematical calculations in connection with a project, encourage colleagues in the math department to assist them.

Another idea is the creation of a technical library serving the vocational education department. Assemble and maintain an up-to-date collection of texts and reference books. Have the school become an AWS Sustaining Company Member to get the Society’s Technical Standards Library. When students ask questions, encourage them to look up the answers. This not only bolsters literacy skills, it fosters self-sufficiency. The student who learns to use a library is learning to learn, and that’s a lifetime skill.

**The Commitment Ahead**

If a welding student cannot read a power source operating manual, does it matter whose fault it is? Finding fault will never rectify the sad fact that the individual’s potential is severely compromised. In the course of a normal work day, most welders are called upon to meet the stringent requirements of codes and specifications. This requires the ability to comprehend and follow directions, which is a direct function of self-discipline. When a student is shown the directions written on a welding power source or under the easy lift cover of a machine that gives setting details, it becomes an empowering experience.

Responsibility, self-discipline, and literacy are fundamentally the most precious skills anyone can possess. They develop our ability to be flexible, adapt to change, see what needs to be done in a given situation, and then do it. If we do not strive to develop these basic skills in our students, who will? Change is essential because welding proficiency involves trial and error. If we or our students keep doing something wrong, something must be changed to get it right.

Albert Einstein said, “The definition of insanity is doing something over and over again and expecting different results.” He also said, “Anyone who has never made a mistake has never tried anything new.” If a weld is made over and over again, and it is ugly, a person will just get better at making ugly welds.

In teaching welding, it should be imagined that we are running a business of our own: Which of our students would we hire? What do our other students need to learn in order to emulate, and eventually become, the best job candidates?

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**Acknowledgment**

I thank Richard S. Sabo for his inspiration for this Plummer Lecture and my efforts to be a better teacher.
The Welding and Cutting of Pipe and Tubing Conference

November 4, 2010 / FABTECH Atlanta

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For the latest conference information, visit our website at www.aws.org/conferences or call 800-443-9353, ext. 264.
Understanding Various Weld Types

An upset weld results from a resistance welding process producing a weld over the entire area of faying surfaces or progressively along a butt joint — Fig. 1A.

A flash weld results from a resistance welding process producing a weld at the faying surfaces of butting members by the rapid upsetting of the workpieces after a controlled period of flashing action — Fig. 1B.

A surfacing weld is applied to a surface, as opposed to making a joint, to obtain desired properties or dimensions — Fig. 1C.

A slot weld is made in an elongated hole in one member of a joint fusing that member to another member — Fig. 1D. The hole may be open at one end. A fillet-welded slot is not to be construed as conforming to this definition.

A plug weld is made in a circular hole in one member of a joint fusing that member to another member — Fig. 1E. A fillet-welded hole is not to be construed as conforming to this definition.

A fillet weld is a weld of approximately triangular cross section joining two surfaces approximately at right angles to each other in a lap joint, T-joint, or corner joint — Fig. 1F.

Fig. 1 — Various weld types.

Excerpted from AWS A3.0M/A3.0:2010, Standard Welding Terms and Definitions.
Extensively revised and updated from the eighth edition, this comprehensive volume had more than 50 experts in materials and materials applications assure its accuracy and the currency of its content. It is a great reference source for engineers, educators, welding supervisors, and welders. Covers carbon and low-alloy steels; high-alloy steels; coated steels; tool and die steels; stainless and heat-resisting steels; clad and dissimilar metals; surfacing; cast irons; maintenance and repair welding; and underwater welding and cutting. Includes more than 500 tables, charts, and photos.
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Monroe County Community College Offers Accelerated Welder Training Program

New AWS-based programs offer fast tracks for students to study entry- and advanced-level welding

BY HOWARD M. WOODWARD

The 210-acre main campus of Monroe County Community College (MCCC) has been serving the community since 1967. It is a two-year institution located near the city of Monroe, Mich., with convenient access to Detroit and Toledo, Ohio. The college’s Whitman Center, in Temperance, Mich., near the Michigan-Ohio border, was established in 1991. Completed in 2004, the La-Z Boy Center is the newest building on campus. This 52,000-sq-ft building combines facilities equipped for education and training with a performing arts venue, the 575-seat Meyer Theater.

The college offers an accelerated welding technology program, a two-year associate of applied science degree with specialization in welding technology, and basic and advanced welding certificate programs. MCCC is accredited by the Higher Learning Commission and is a member of the North Central Association. Currently, the college serves approximately 8500 credit and noncredit students each year. The college recently received a grant from the Department of Labor under the Community Based Job Training Grant category for about $1.8 million to train welders to American Welding Society (AWS) specifications.

The Welding Staff

The accelerated welding technology program staff (Fig. 1) includes Joseph Czapiewski, welding grant coordinator; Cameron Albring, welding grant program assistant; Justin Schmidt, assistant professor of welding technology; Ken Matson, welding lab technician; Joe Czapiewski, welding grant coordinator; and Cameron Albring, welding grant program assistant.

Camp training receive National Career Readiness Certification.

The college offers a general education program for students seeking careers in a vocational field and for those who plan to transfer to a four-year university. School officials have noted a growth in industrial manufacturing that has resulted in a relatively steady demand for skilled, qualified welders in the area who are able to advance with the industry.

For this reason, the college implemented the accelerated welding technology programs in September 2009. The programs are designed to train future welders using the latest technologies and safety standards they will need to succeed in industry in a ten-week 250-hour format. The accelerated welding technology program offers both beginning and advanced tracks.

The beginning welder track is an accelerated hybrid of the college’s traditional program that culminates in students completing the requirements specified in the AWS document QC-10, Specification for Qualification and Registration of Level I — Entry Welders, certification examination.

The advanced welder track prepares students to fulfill the requirements of QC-11, Specification for Qualification and Certification for Level II — Advanced Welders.

In both tracks, students learn how to set up welding machines and make various weldments on a wide variety of metals. The welding procedures presented include gas metal arc welding (GMAW), gas tungsten arc welding (GTAW), shielded metal arc welding (SMAW), flux cored arc welding (FCAW), and oxyfuel cutting (OFC).

After completing the QC-10 and QC-11 certifications, the graduates qualify for entry into advanced-level employment, self-employment, and local welding labor
unions. The examinations for both programs are offered at the college.

The lead instructor for the welding program is Assistant Professor Schmidt — Fig. 3. Schmidt holds a bachelor’s degree in welding engineering technology from Ferris State University and several certifications in the welding field, including robotics. He has five years of experience as a welding and robotics engineer at L&W Engineering based in Blissfield, Mich. Schmidt’s goal is to help his students earn their QC-10 and QC-11 certificates.

This training includes welding safety and orientation; welding symbols and weldment design; SMAW in all positions on carbon steel plate; GMAW in all positions on carbon steel pipe; FCAW in all positions on carbon steel plate; GTAW on carbon steel, stainless steel, and aluminum plate; manual oxyfuel gas cutting operations, including welding techniques; and manual plasma arc cutting operations.

Upon successful completion, students earn 12 credit hours and the AWS QC-10 certification. To earn the AWS QC-11 certification, the students are required to study industrial awareness; SMAW in all positions on carbon steel pipe; GTAW in all positions on carbon steel tube and stainless steel tube; and GTAW in all positions on aluminum tube. Upon completion, students earn 12 credit hours and the AWS QC-11 certification.

**Equipment**

Grant funds were used to purchase equipment to establish a state-of-the-art, cross-categorical welding lab outfitted with a range of welding processes available to each student at each welding booth to help maximize the overall lab experience. The new equipment includes a CNC plasma/oxyfuel cutting system, Ironworker shear machine, 21 welding machines, and a guided bend tester. The CNC plasma/oxyfuel cutting system and Ironworker shear are used by the students to produce desired shapes from bulk steel, aluminum, or other metals that are then used to complete their welding assignment.

Additionally, a comprehensive electrical renovation of the welding lab was completed to enable the equipment to perform various combinations of welding processes on a variety of metals with just the flip of a switch.

**Academic and Career Pathways**

Successful completers of the WELD-115 program earn QC-10 Entry-Level certification, 12 credit hours, and are prepared for employment. At this point, students have the option to continue their studies in the WELD-215 program to earn the AWS QC-11 Advanced-Level Certification, 12 credits, and continue further to earn the associate degree in welding technology.

Joe Czapiewski stated, “We also wanted to make our welding grant students aware of the career pathway and the many options available to them at MCC. After you complete your associate’s degree, you can then transfer to a four-year college. We have a 2+2 agreement with Eastern Michigan and Ferris State University to earn a bachelor’s degree.”

The courses MCCC offers toward the associate degree in welding are:

- WELD 100, Introduction to Welding Processes
- WELD 101A, Introduction to GMAW
- WELD 101B, Basic SMAW
- WELD 101C, Arc Applications
- WELD 102, Advanced SMAW
- WELD 102A, Multipass Arc Welding
- WELD 102B, Code Welding Techniques
- WELD 102C, Multipass Pipe Fillet Welding
- WELD 103, Weldment Evaluation and Testing
- WELD 104A, Introduction to GTAW
- WELD 104B, Introduction to GMAW
- WELD 104C, GTAW-Stainless Steel
- WELD 104D, GTAW — Aluminum
- WELD 105, Welding Metallurgy
- WELD 106, Basic Pipe Welding
- WELD 106A, Pre-Pipe Welding Skills
- WELD 106B, SMAW Pipe Welding — Uphill
- WELD 106C, SMAW Pipe Welding — Downhill
- WELD 110, Welding Symbols and Blueprint Reading
- WELD 114, GMAW and GTAW Applications
- WELD 216, Basic Pipefitter
- WELD 240, AWS Qualification/Certification — Entry Level
- WELD 250, AWS Qualification, Certification — Advanced Level

With the increasing number of welders in training at MCCC who are in the grant-funded program and also working toward their associate of applied science degree with specialization in welding technology, the Industrial Technology Division has implemented a new course, TECH 296, Special Topics — Art Welding. This course is designed for amateur welding and blacksmith enthusiasts. Students learn to fabricate decorative iron and metal constructions that can be both practical and ornamental.

Another important feature of the MCCC program is the individual progress, audio-tutorial approach to mastering welding skills. Students may come in and, within certain parameters, progress at their own rate of speed. This allows students to complete course requirements based on their own ability rather than being locked into a set rate of progress for a given class.

**What’s New**

The college’s welding lab is approximately 1940 sq ft with 21 welding booths; the college is in the process of searching for a facility to increase its ability to train more welders. Also new at the college is a construction management technology certificate program with specialization in heavy and industrial construction. This program is designed for experienced construction personnel who wish to upgrade their skills to gain management positions with large industrial employers. The goal of the 31 credit-hour course is to standardize and enhance the skills and knowledge students need to succeed in industrial careers. The courses include Construction Blueprint Reading, Safety, Planning and Scheduling, Construction Estimating, Statics and Strength of Mate-
such as accounting, administrative, professional, and computer information systems, while the CCS Division offers customized training programs in a variety of technical and management areas. Gregory Adanin, CEO and president of Ventower, noted, “We are looking to continually develop and strengthen our relationship with Monroe County Community College in order to create an industry-specific arena and pipeline through which students can be trained, retrained, certified, and subsequently employed by our company.”

Ventower is a full-service fabricator and supplier of industrial scale, wind turbine towers. Focused on original equipment manufacturers, the company will provide wind towers to customers throughout the Great Lakes region by using readily accessible waterborne, rail, and truck transportation options. Earlier this year, Ventower was awarded an Advanced Energy Manufacturing Tax Credit for clean energy manufacturing projects across the United States under the American Recovery and Reinvestment Act of 2009.

David E. Nixon, MCCC president, said, “Ventower represents the green energy jobs of the future. This is Monroe County’s first major venture into clean energy, and MCCC is honored to be a training partner.”

Career Opportunities

More than 20 recent graduates of MCCC’s new Welding Center of Expertise program have secured full- or part-time employment upon completion of their ten-week entry-level and advanced-level welder training programs. Various local companies in Michigan have added MCCC students to their workforces, including Advanta Industries; Bar Processing; Fed-Ex; Faurecia; Mac Steel; Ort Tool & Die; and Great Lakes Ariel Tower.

Through a combined effort from the Welding Grant Staff and the Office of Workforce Development at MCCC, students were able to build résumés, learn interview-preparation skills, and the fine art of job hunting.

Derek Slominski, an MCCC welding student said, “I heard about the welding grant accelerated classes through the MIWORKS! [www.miworks.org] office, and I wanted to improve my welding career and job availability. The AWS certification learning process is what is motivating me and the fact that I never want to stop learning. I’m learning better welding techniques as well as a better understanding of the quality of weld. And Justin Schmidt is a good teacher. He is teaching us what AWS requires by assigning us chapters each night. I needed the Boot Camp. Boot Camp was a refresher for me. It was good to refresh my study skills. I have been out of school for 23 years so it helped me out a lot to get ready for the Weld 115 class.”

Job Placement Support

The Office of Workforce Development at the college offers students, alumni, and Monroe County residents free assistance in locating employment opportunities in the area. The office provides information regarding available part- and full-time, permanent, and temporary positions in a wide variety of occupations. Also available are student assistant positions. All job seekers can register for this service using the college’s online candidate registration form. Upon registration with the Workforce Development Office, job seekers can obtain job information referrals, request mailing of credentials packets to potential employers, and have access to a variety of job-seeking skills seminars and reference materials. The service also permits area employers free access to post their jobs and to contact qualified candidates registered with the office, and they can advertise their job openings by using the Job Posting Form.

Unique Tuition Base

Because the accelerated welding technology program is grant-funded, tuition assistance is available to those who are accepted. The college’s tuition is not based on credit hours; it is based on contact hours as determined by the amount of time the student spends in direct contact with an instructor, laboratory equipment, or other instructional setting. The current rates per contact hour are $78 for Monroe County residents, $130 for out of county students, and $144 for out of state students. These rates include a $6 technology fee. The college notes that charging by billable contact hours more fairly distributes the cost of instruction so those students who receive extra instruction will pay for the extra hours.

There are a variety of ways MCCC students receive help in paying tuition, including grants, work-study, scholarships, payment plans, and loans. To find out more about these options, call the Financial Aid Office at (734) 384-4135.

Prospective students can download application materials for the program at www.mcccweldcoe.org/application.htm.
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Ron Theiss Appreciates New Lease on Life

After not feeling well for quite some time, a new heart has brought the 30-year AWS member back up to speed

BY KRISTIN CAMPBELL

Ron Theiss, a long-time professor and American Welding Society (AWS) member from Cypress, Tex., sure has lots of things to smile about and look forward to nowadays. He’s healthy again due to the new heart he received last February 9th.

“I feel like I did twenty years ago,” Theiss said. He likes to think of the heart transplant as a transfer and is incredibly grateful to have another chance at life.

Not that long ago, Theiss wanted to create a unique piece of art honoring his donor, which became a reality with some assistance.

Working to Create the Artistic Heart

After getting released from the hospital, Theiss located former student Charles Strack. “I heard that he was doing some interesting things with metal. I broke the doctor’s orders and drove out to his shop,” Theiss said. “We went to lunch that day and talked about what I wanted to do. I was on light duty, so I was unable to construct what I wanted by myself.”

Theiss showed Strack a heart drawing he wanted to incorporate into a sculpture that could spin, turn, or rotate. “We went through different design aspects,” Theiss said. After two weeks, they decided on creating a heart center from rusted steel and four ribbons out of stainless steel to serve as support pieces circling its frame.

Strack did the physical work, includ-

ing lifting the metal; performing shield-
ed metal arc and gas metal arc welding; cutting with a plasma torch; and using a buffer wheel to achieve a swirl finish on the stainless steel. When complete, the figure was coated with clear urethane.

Special Celebration for Revealing the Sculpture

September 19, 2009, represents a significant day to Theiss as the unveiling of the Heart Art sculpture took place —

Fig. 1 — At the unveiling ceremony, Tammy Renfro gets ready to cut the ribbon and show off the Heart Art sculpture as Ron Theiss looks on. Theiss was the recipient of her son’s heart last year.

Figs. 1 and 2A, B. “It was a moving experience for everyone,” he said. The sculpture stands 9 ft tall and features a 5 x 5 ft heart-shaped center with circling ribbons secured to a bearing assembly, allowing it to twirl.

Eighty people were present for the dedication in Theiss’s back yard, including Tammy Renfro from Childress, Tex. “Her son, Joshuah Ackerman, is whose heart I have,” Theiss said.

The sculpture pays tribute to Josh, who passed away at the age of 19 after an automobile accident. He was studying to be a nurse and had hopes of becoming a doctor. His sister, Sarah Votaw, brought the stethoscope she gave him for school to the event so she and her mother could hear Josh’s heart — Fig. 3.

“After they listened, they were both happy that his heart was doing well and is giving me a new lease on life,” Theiss said. He’s fortunate to be close and stay
VanArsdale, who died in 2008; acknowledged his wedding anniversary with wife, Julie; and had cake, as he considers having two birthdays now after the transfer.

“I don’t think the words exist that I can use to really explain how that day makes me feel,” Theiss said.

**Teaching the Craft of Welding**

Theiss got hooked on welding after taking a class while in an apprenticeship program. He likes the concept of fusing two metal pieces together and finds the science, metallurgy, and technology interesting — Fig. 4. “There’s more to the occupation than meets the eye,” he said.

In 1981, Theiss received an associate’s degree in welding technology from North Harris College, Houston, Tex. In 1984, he earned a bachelor’s degree in applied technology from Sam Houston State University, Huntsville, Tex.

For 30 years, Theiss was a professor at North Harris College. He enjoyed passing on his skills; developing curriculums for welding and weld inspection; and judging SkillsUSA competitions on district, state, and national levels.

Theiss taught gas tungsten, gas metal, shielded metal, flux cored, submerged, and plasma arc welding; plasma arc cutting; blueprint reading; layout and fabrication; visual inspection; nondestructive examination; metallurgy; process materials; manufacturing; and specifications for different codes and standards.

“It means an awful lot,” he said of hearing from former students and how welding has changed their lives.

**Devotion to AWS**

Theiss joined AWS December 1, 1979. He has held all officer positions in the Houston Section and is honored the Section sponsors a scholarship fund in his name.

Being an AWS member is important. “It’s an extensive avenue for networking with people in the field,” Theiss said. Plus, he has attended many AWS welding shows over the years and found them to be valuable for meeting headquarters staff, members from other AWS Sections, and welding professionals.

In 1990, Theiss became an AWS Certified Welding Inspector (CWI), and earned the Senior Certified Welding inspector title in 1997. Additionally, he served as a member of the AWS board of directors as District 18 director from 1996 to 1999, and was part of the beta exam for the AWS radiographic interpreter certification in 2004.

During his career, Theiss has received the following recognitions: Houston Section Educator Award, District Educator Award, and Dalton E. Hamilton Memorial CWI of the Year Awards at Section and District levels.

**Enjoying the Present Day**

Currently, Theiss is glad to be back at work. “It feels better than great. It really makes me feel like a productive human being,” he said.

Theiss stays busy serving as an AWS contract instructor for the CWI program and other certification seminars. Also, he works with AWS as an adjunct faculty member teaching welding inspection technology, code clinic, visual inspection, radiographic interpretation, and weld processes courses.

Lately, he has been enjoying the company of his children and grandchildren, doing woodworking projects, and raising funds for Justin Gordy, treasurer of the AWS Houston Section, who recently suffered a spinal cord injury.

In the future, Theiss would like to volunteer his time and energy to help heart patients as well as donor families.

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November 3, 2010 / FABTECH Atlanta

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Laser-Enhanced GMAW

An innovative method to detach droplets at given arc variables is proposed

BY Y. HUANG AND Y. M. ZHANG

ABSTRACT

A novel modification to conventional GMAW is introduced by applying a low-power laser to droplets to generate an auxiliary detaching force. The electromagnetic force needed to detach droplets, thus the current that determines this force, is reduced. The undesired dependence of the metal transfer on the current is decoupled such that the current may be freely chosen to control the weld penetration and weld pool without restrictions as in conventional GMAW due to the need for metal transfer. The resultant process is referred to as laser-enhanced gas metal arc welding. To prove the feasibility of this idea, a constant-power laser was applied to droplets from a 0.8-mm-diameter steel wire in GMAW. A number of experimental conditions that typically would result in short-circuiting transfer in conventional continuous waveform GMAW were designed to conduct laser-enhanced GMAW experiments. It was found that the metal transfer changed from short-circuiting to spray in all these experimental conditions as can be seen from high-speed video images. The principles and fundamentals were analyzed to better understand the results and the process.

Introduction

Gas metal arc welding (GMAW) is currently one of the most widely used welding methods. It is operated as a semiautomatic or automatic arc process for joining metals. It is the most widely used process for robotic welding, in which a robot carries a welding gun along the weld joint or applies electrodes to join sheets (Refs. 1, 2).

In the GMAW process, as illustrated in Fig. 1, a welding wire is fed to the contact tube, which is typically connected to the positive terminal of the power supply. When the wire touches the negatively charged workpiece, an arc is ignited and the tip of the wire is rapidly melted forming a gap between the wire and the workpiece. The melted metal forms a droplet at the tip of the wire. After the droplet is detached, another droplet starts to form and a new cycle starts. This metal transfer process is subject to periodic changes in the arc voltage conditions and plays the most critical role in determining controlling the weld quality in GMAW. To produce high-quality welds similar to gas tungsten arc welding (GTAW) where the arc voltage conditions are stationary, the metal transfer needs to be appropriately controlled.

The American Welding Society classifies metal transfer into three major types: short-circuiting transfer, globular transfer, and spray transfer (Ref. 3). When a continuous waveform current is used and the current is small, the droplet may not be detached until the droplet contacts the weld pool. In this case, the droplet is transferred into the weld pool by the surface tension at a short-circuiting condition and the transfer mode is short-circuiting. As a result of the low current, the heat input is relatively small and relatively thin materials can be welded with relatively low heat input, distortion, and residual stress. However, the process needs to be appropriately controlled to minimize spatter that otherwise may be severe. If the current increases, but not large enough to generate a sufficiently large electromagnetic force (Ref. 4) to detach the formed droplet, then the droplet may surpass the diameter of the electrode wire and be detached mainly by gravity. This transfer mode is globular metal transfer. If the current further increases such that the detaching electromagnetic force becomes sufficiently large, the transfer mode may change to projected spray transfer in which discrete droplets detached at diameters similar to that of the wire; or even streaming or rotating spray transfer resulting in a stream of small continuous droplets. With spray transfer, high productivity is obtained due to the high current but may be at the expenses of high heat input, distortion, and residual stress.

The metal transfer mode under a continuous waveform current without control is mainly determined by the amperage of the current as can be seen above. For short-circuiting or globular mode, spatter typically would be expected. The surface tension transfer (STT) that adjusts the current waveform reactively based on the particular stage during the short-circuiting transfer process can reduce spatter to a minimum but is not suitable for other transfer modes where higher heat inputs may be needed (Refs. 5–7). Spray is a transfer mode associated with a stable arc and is often preferred. For continuous waveform current, an amperage higher than the transition current (Ref. 3) is needed to produce a spray transfer. However, if a pulsed current is used, the desired spray transfer may be produced at a wide range of average amperage (thus heat input and distortion).

While pulsed GMAW has been widely adopted in industry, it does have certain limitations. The fundamental cause of these limitations is that a peak current higher than the transition current (Ref. 3) must be used in order to detach the droplet to complete the metal transfer. Vaporization occurs with high amperage and results in fumes. More critically, the arc pressure is proportional to the square of the amperage (Ref. 8). The high arc pressure may blow liquid metal away from the weld pool. For a complete joint-penetration application where the workpiece has to be fully penetrated through the entire thickness, the high arc pressure

KEYWORDS

GMAW Laser Metal Transfer Recoil Pressure
may easily cause melt-through. This is the major reason why the less productive GTAW process, the amperage for which can be set at whatever level needed, has to be used for the root pass in complete-penetration applications.

It is apparent that the major role of the high peak current in pulsed GMAW is to generate the electromagnetic force to detach the droplets. However, the high peak current produces undesirable side effects that affect GMAW’s capability to be used in complete-penetration applications and to be a “clean” process to compete with the less-productive GTAW. In this paper, the authors propose an alternative way to apply a needed force to detach the droplets without producing undesirable side effects. The ultimate goal is to apply a pulsed laser of low power to the droplet to detach it whenever needed such that the droplet be detached at whatever amperage that best suits for the control of the weld pool. The resultant process is referred to as laser-enhanced GMAW. This study aimed to prove the concept and the feasibility of a laser-enhanced GMAW system, but it is subject to redesign and optimization in order to be developed into an industrial system.

**Table 1 — Experimental Conditions and Welding Currents**

<table>
<thead>
<tr>
<th>Experimental Condition Number</th>
<th>Voltage (V)</th>
<th>Wire Feeding Speed (in./min)</th>
<th>Welding Current Measured in Conventional GMAW (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>29</td>
<td>200</td>
<td>82.6 ± 21.0</td>
</tr>
<tr>
<td>2</td>
<td>30</td>
<td>250</td>
<td>98.8 ± 13.0</td>
</tr>
<tr>
<td>3</td>
<td>30</td>
<td>300</td>
<td>115.0 ± 8.1</td>
</tr>
<tr>
<td>4</td>
<td>30</td>
<td>350</td>
<td>125.0 ± 11.1</td>
</tr>
<tr>
<td>5</td>
<td>30.5</td>
<td>400</td>
<td>131.6 ± 9.6</td>
</tr>
</tbody>
</table>

**Figure 2** shows the principle of the proposed laser-enhanced GMAW. A laser beam aims at the droplet. The intention is to detach the droplet using the laser recoil pressure as an auxiliary detaching force to compensate for the lack of the electromagnetic force associated with a relatively small amperage that is needed for a particular application, rather than to provide additional heat to speed the melting of the wire. The associated additional heat from the laser should be insignificant in comparison with that of the arc used.

It should be mentioned, although the laser-enhanced GMAW system applies a laser beam into the GMAW process, it is different from the laser-GMAW hybrid process (Refs. 9–16) where a laser of significant power enhances the results of the arc in the weld pool. To this end, the laser in the hybrid process interacts with the GMAW process and is applied either at the arc or in the weld pool as shown in Fig. 3. Hence, the proposed laser-enhanced GMAW is different from the hybrid laser-GMAW process in both operation principle and objective.
To better understand the principle of the proposed method, the forces affecting metal transfer are briefly reviewed and analyzed first. It is well known that in conventional GMAW, the major forces acting on the droplet include the gravitational force, electromagnetic force (Lorentz force), aerodynamic drag force, surface tension, and momentum force (Refs. 18–20). In laser-enhanced GMAW, a laser is applied and an additional force is introduced as shown in Fig. 4. To be simple, the dynamic-force balance theory (DFBM) (Ref. 21) is used in this paper to conduct preliminary analysis of the forces for laser-enhanced GMAW.

The force due to gravity can be expressed as

$$F_g = m_g g = \frac{4}{3} \pi r_d^3 \rho g$$

(1)

where $m_g$ is the mass of the droplet, $r_d$ is the droplet radius, $\rho$ is the droplet density, and $g$ is the acceleration of the gravity.

The surface tension is given as

$$F_s = 2\pi R \sigma$$

(2)

where $R$ is the electrode radius, while $\sigma$ is the surface tension coefficient.

The aerodynamic drag force can be expressed as

$$F_d = \frac{1}{2} C_d A_d \rho v_p^2$$

(3)

where $C_d$ is the aerodynamic drag coefficient, $A_d$ is the area of the drop seen from above, $\rho_p$ and $v_p$ are the density and fluid velocity of the plasma.

The momentum force can be expressed as

$$F_m = \nu_e \dot{m}_d$$

(4)

where $\nu_e$ is the wire feed speed, $\dot{m}_d$ is the change of the droplet mass.

The electromagnetic force, $F_{em}$, is given by

$$F_{em} = \mu_0 I \left( \frac{1}{2} + \ln \frac{r_u}{r_e} \right)$$

(5)

where $\mu_0$ is the magnetic permittivity, $I$ is the welding current, $r_u$ is the exit radius of the current path, and $r_e$ is the entry radius of the current path. $r_u$ and $r_e$ are related to the process of the droplet status. Before the droplet starts to be detached, $r_u$ is the same as the radius of the wire and is thus a constant. However, once the droplet is being detached, $r_u$ reduces. The increase of $F_{em}$ thus accelerates and the detachment is completed rapidly. In the conventional GMAW process, the droplet is not detached when the retaining force $F_0$ is still sufficient to balance the detaching force $F_T$.

$$F_T = F_g + F_d + F_m + F_{em}$$

(6)

During the metal transfer process, the major variables that change or can be changed to affect the detaching force are the droplet mass and the current as can be seen from Equations 1–5. Because the surface tension is the major retaining force and is fixed for the given wire, the droplet can only be detached by 1) waiting for the droplet to grow into a larger size such that the gravitational force is sufficient to break the balance, 2) waiting for the droplet to touch the weld pool such that an additional detaching force — surface tension between the droplet and weld pool — be added, or 3) increasing the current to increase the electromagnetic force. Since none of these is ideal, a laser was introduced in this project to increase the detachment force to a sufficient level. Because this laser force is controllable through laser intensity/power, droplets may be detached at a desired diameter at a desired amperage.

**Experimental Setup and Conditions**

**System Setup Parameters**

Figure 5 shows the important parameters needed to realize the laser-enhanced GMAW system developed in this project to prove the concept of detaching droplets. To conduct the laser-enhanced
GMAW process as expected, parameters need to be set appropriately. In this research, the GMAW gun and the laser head did not move. The workpiece moved at a constant speed. The direction of this movement was perpendicular to the plane shown in Fig. 5A. The camera was also placed in this direction with a distance about 1.2 m from the gun.

Contact tube-to-workpiece distance. In conventional GMAW, this distance plays a role in determining the stability of the process. In laser-enhanced GMAW, a too small distance would make it difficult to install other components. Experimental results suggest that the distance should be set around 20 mm.

Angle between laser beam and GMAW gun. This determines the orientation of the laser recoil force as a vector in relation to other forces and its component/projection as the effective detaching force. It also affects the compactness and realizability of possible future system for industry use. While a large angle would reduce the effective detaching force along the wire axis and affect the compactness of the system, a small angle would require the gas nozzle to be modified such that the laser can reach the droplet. In this feasibility study, the nozzle is not modified and the angle is selected to be around 60 deg for easy installation at the expense of reducing system compactness.

Another important parameter is the distance from the point where the laser intersects the wire axis and is denoted as \(d_i\) in Fig. 5. As the laser beam must be applied onto the droplet to detach, a high-speed camera was first used to record the conventional GMAW process and then the recorded video was analyzed. Figure 6 shows the high-speed camera used that is capable of recording the metal transfer at 33,000 frames per second. Analysis of videos showed that this distance should be set in the range from 3 to 7 mm.

Choice of laser. As the laser is supposed to point to the droplet rather than the weld pool, the focal zone of the laser should be not much larger than the diameter of the wire. In this study, the diameter of the wire was 0.8 mm and the diameter of the droplet was slightly greater. The laser should thus be selected accordingly. However, because this is a preliminary study that aims at proving the feasibility of the idea proposed, a laser with a much larger focal zone may also be used. The University of Kentucky Welding Research Laboratory possesses a Nuvoxy Diode laser ISL-1000L whose focal beam dimensions are 1 x 14 mm and 808 nm wavelength. When this laser is used, only less than \(\frac{1}{3}\) of the laser beam can be applied onto the droplet to generate the recoil force to detach the droplet. However, for the preliminary study for idea verification presented in this paper, the efficiency of the laser is not a primary concern and the use of a laser of larger power and large focal zone should not affect the effectiveness of the experimental results.

Figure 7 shows the arrangement of the laser in relation with the welding gun. In this experimental setup, the laser beam is aligned with the wire. In order to protect the end of the laser from possible contamination from fumes, a shielding board (not shown in Fig. 7) was added between the laser and welding gun, and the...
laser was projected through a hole on the shielding board to the wire.

**Experimental Conditions**

A CV (constant voltage) continuous waveform power supply was used to conduct experiments. The wire used was ER70S-6 of 0.8 mm (0.03 in.) diameter. Pure argon was used as the shield gas and the flow rate was 12 L/min (25.42 ft/min). The workpiece was mild steel and experiments were done as bead-on-plate at a travel speed 10 mm/s (24 in./min). In the experiments, the power of the laser was set at 862 W and applied to the wire continuously. For the wire diameter and material, the transition current for the spray transfer is approximately 150 A (see Table 4.1 in Ref. 3). Table 1 shows a number of experimental conditions designed to conduct laser-enhanced GMAW and comparative conventional GMAW whenever needed. The current shown in the table is the actual measurements from the conventional GMAW experiments. It is apparent that in all experiments, the currents were lower than the transition current that is approximately 150 A (Ref. 3), and a short-circuiting mode. This was because the intensity of the laser is smaller than the maximum retaining force that can be provided by the laser beam. This is because the droplet is detached from the wire before it touched the weld pool. In particular, a direct comparison can be made between Fig. 10 and Fig. 8, which were both conducted using experimental conditions No. 2 in Table 1. The droplet detachment is approximately 150 A (Ref. 3), and a short-circuiting mode.

**Metal Transfer**

In the designed experiments shown in Table 1, the voltage was set approximately the same and the wire feed speed was altered. When conventional GMAW experiments were conducted without the application of the laser, short-circuiting mode and spatter were observed for all conditions in Table 1.

A band-pass filter centered at the laser wavelength 808 nm was used to observe the process and record the images. All images presented in this study were recorded using the high-speed camera shown in Fig. 6 with this band-pass filter. Figure 8 is an image series, at 3000 frames/s, that demonstrates the metal transfer process under experimental condition No. 2 without the laser. In this series, Fig. 8C clearly shows that the droplet does touch the weld pool. From Fig. 8D, spatter is seen clearly. Hence, the metal transfer is in the short-circuiting mode. This is because the droplet is smaller than the transition current is the cause.

Figures 9–13 show the metal transfer processes when the laser-enhanced GMAW process was performed using the experimental conditions given in Table 1. In all images, the weld pool surface illuminated by the laser beam was clearly shown as a bright line. As can be seen, the metal transfer in all experimental conditions changed to the spray transfer and the droplet detached from the wire before it touched the weld pool. In particular, a direct comparison can be made between Fig. 10 and Fig. 8, which were both conducted using experimental conditions No. 2 in Table 1. Because of use of the laser, the metal transfer changed from short-circuiting transfer in Fig. 8 to spray transfer in Fig. 10.

Each image series in Figs. 9–13 represents a complete transfer cycle under the respective conditions. Each first image represents the beginning of a metal transfer cycle. As the droplet grows, the gravitational force increases. The cross section of the laser beam intercepted by the droplet increases as the droplet thus grows. Because the intensity of the laser on the cross section is independent from the droplet, the recoil pressure of the laser acting on the droplet increases. As a result, the auxiliary force applied by the laser on the droplet and the gravitational force both increase. On the other hand, the surface tension as can be seen in Equation 2 is approximately constant when the droplet grows. Hence, as the droplet grows, the detaching force increases but the retaining force remains approximately constant. As a result, once the sum of the detaching force becomes larger than the sum of the retaining force, the droplet is detached. Because the droplet is detached in all conditions listed in Table 1 before it may touch the weld pool, the auxiliary detaching force introduced by the laser is sufficient to implement the laser-enhanced GMAW for the conditions listed in Table 1. Because the laser is applied continuously, the detachment of the droplet appears to be the natural result of the balance of the forces. Because of possible variation in other forces, the diameter of the droplet being detached is not accurately controlled. To control the droplet diameter, the laser can be pulsed and applied when the droplet needs to be detached. The control of the droplet diameter exceeds the scope of this present work.

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Fig. 12 — Metal transfer in laser-enhanced GMAW at experimental condition No. 4. Consecutive images in the figure were acquired at 3000 frames/s.

Fig. 13 — Metal transfer in laser-enhanced GMAW at experimental condition No. 5. Consecutive images in the figure were acquired at 3000 frames/s.
Current Waveforms

Figure 14 is the measured current waveforms for laser-enhanced GMAW experiments conducted using the conditions in Table 1. Observation of these current waveforms shows that the current waveforms become less fluctuating when the wire feed speed or the current increases. This can also be seen from the right column in Table 1. As analyzed above, the detachment of the droplet under a continuous laser application is a natural result of the balance of the force. When the current increases, the electromagnetic force increases at least quadratically with the current as initially suggested by Equation 5.

\[ F_{e_m} = \frac{\mu_0 I^3}{4\pi} \left( \frac{1}{2} + \ln \frac{r_e}{r_v} \right) \]

Further, the exit radius of the current path, i.e., \( r_e \) also increases as the current increases as the arc climbs toward the neck of the droplet. Hence, the electromagnetic force increases rapidly as the current increases. On the other hand, the surface tension does not change and the vapor jet force at most increases proportionally. Hence, the detaching force increases much faster than the retaining force as the current increases. The gravitational force needed to break the balance reduces. Hence, the droplet is detached at smaller diameters when the current increases in
Effect of wire feed speed on current and droplet transfer time in laser-enhanced GMAW.

As the wire feed speed is the major parameter to determine the current and thus the electromagnetic force, it plays a critical role in determining the laser power/intensity needed to ensure spray transfer. When the laser power/intensity and other welding parameters, including the wire diameter/material and arc voltage setting, are given, the droplet diameter and transfer frequency in the continuous laser-enhanced GMAW are primarily determined by the wire feed speed. As shown in Fig. 16, when increasing the wire feed speed from 200 to 400 in./min, the welding current increases approximately linearly from 82.6 to 131.6 A. However, because the electromagnetic force as a detaching force increases faster than a quadratic speed as the current increases, the increase in the detaching force would be significant. The increased gravitational force and electromagnetic detaching force would reduce the transition current. For experimental condition No. 4 in Table 1, if the voltage is changed to 34 V, the metal transfer will become spray mode without the application of a laser. Similarly, for the laser-enhanced GMAW process, the voltage setting would also affect the metal transfer in a similar way. For the same laser, when the voltage is reduced, the transfer could be changed from short-circuiting to spray short circuiting. However, in principle, it may typically be possible for laser-enhanced GMAW to ensure a spray transfer by increasing laser power. A pulsed laser of relatively high peak power is thus appropriate for laser-enhanced GMAW.

Because the wire feed speed is the major parameter to determine the current and thus the electromagnetic force, it plays a critical role in determining the laser power/intensity needed to ensure spray transfer. When the laser power/intensity and other welding parameters, including the wire diameter/material and arc voltage setting, are given, the droplet diameter and transfer frequency in the continuous laser-enhanced GMAW are primarily determined by the wire feed speed. As shown in Fig. 16, when increasing the wire feed speed from 200 to 400 in./min, the welding current increases approximately linearly from 82.6 to 131.6 A. However, because the electromagnetic force as a detaching force increases faster than a quadratic speed, the needed gravitational force to break the force balance decreases rapidly. As a result, the time needed in each cycle to detach the droplet (i.e., the metal transfer time) decreases rapidly.

There is another important change when wire feed speed increases. When the wire feed speed is 350 or 400 in./min, as shown in Figs. 12 and 13, the pinch effect could be observed between the droplet and the solid wire. This pinch effect is also demonstrated in Fig. 17. However, as can be observed from Figs. 9–11, when the wire feed speed is lower than 300 in./min, the pinch effect was not obvious.

Analysis of Laser Effect

The first question that needs to be answered through analysis is how the laser affects the metal transfer. To this end, the actual laser power applied on the droplet was estimated first. Because the laser beam dimension is 1 x 14 mm and the diameter of the droplet can be assumed to be no greater than 1.2 mm, the actual incident power of the laser applied on the droplet should be less than 70 W. Then taking experimental condition No. 4 in the Table 1 as an example, one may extend an analysis as follows:

When the voltage was set at 30 V, the metal transfer without an application of the laser was short circuiting and the current was 125 A approximately. When the laser was applied, the current was still 125 A approximately, but the metal transfer changed to spray mode. Because the heat applied onto the droplet by the laser is insignificant in comparison with that of the arc, the change of the metal transfer must be primarily due to the force rather than the heat generated by the laser spot. In fact, in comparison with the anode arc power that melts the wire, the laser power is approximately 4.6% (70 W over 125 A of current multiplied by 12 V of estimated anode voltage). Due to the specular reflection of the droplet surface, no more than 50% of the incident laser power should be absorbed. That is, the application of the laser should only increase the...
heat by 2.3%. Unfortunately, even when the current (thus anode heat) increases 15% from 120 to 138 A, the metal transfer would still not be spray transfer. Hence, it is the force rather than the heat that effectively changed the metal transfer from short circuiting to spray during laser-enhanced GMAW.

Secondly, how the laser force is produced needs to be understood. Basically, the pressure imposed by the laser on the droplet can be considered to have two major components: radiation pressure and recoil pressure. For the laser radiation pressure, previous studies have obtained clear results/conclusions. The radiation pressure \( P \) of a normally incident continuous wave (cw) light imposed on a macro-object with a plane surface can be expressed as (Ref. 22)

\[
P = \frac{I(1+R)c}{2}
\]

(7)

where \( c \) is the speed of the light, \( R \) is the reflectivity of the illuminated surface, and \( I \) is the intensity of the light. However, the radiation pressure on the object (droplet in our case) is very insignificant in comparison with the recoil pressure. For example, for a 100-W laser with 1-mm spot and \( R = 0.8 \), the radiation force calculated from Equation 7 is in the order of \( 10^7 \) N, while the surface tension needed to be overcome to detach the droplet is in the order of \( 4 \times 10^{-3} \) N (Ref. 23).

For the recoil pressure acting on a substrate during intense laser evaporation, Ref. 24 gave

\[
P_r = AB_0 T_s^{-3/2} \exp(-U/T_s)
\]

(8)

where \( A \) is a numerical coefficient, \( B_0 \) is a vaporization constant, \( T_s \) is the surface temperature, and \( U = M_p L_v/(N_0 k_b) \). Here \( M_p \) is the atomic mass, \( L_v \) is the latent heat of evaporation, \( N_0 \) is Avogadro’s number, and \( k_b \) is the Boltzmann’s constant. This equation is relatively complicated and Ref. 25 gave a simpler expression

\[
P_r = \frac{(P/A)\rho}{4}
\]

(9)

where \( P/A \) is the power density of the laser, \( \rho \) is density of the vapor, and \( E \) is the energy needed to evaporate 1 kg of metal. As its authors indicated (Ref. 25), when the laser intensity is about \( 3 \times 10^{12} \) W/cm², the recoil pressure will be about \( 10^7 \) Pa.

In the laser-enhanced GMAW process, as \( F_T = F_g + F_d + F_m + F_{em} + F_{recoil force} \), a higher \( F_T \) could be produced by adding a laser beam. The power intensity of the laser used is about \( 6.17 \times 10^7 \) W/cm² (864 W over the laser dimension 1 × 14 mm), the recoil pressure is at least on the order of \( 10^6 \) Pa. The surface of the droplet intercepting the laser beam could be estimated on the order of \( 10^{-6} \) m². In this case, the force generated by laser recoil pressure will be on the order of \( 10^4 \) N. It is at the same order of magnitude to detach a droplet as aforementioned.

**Conclusion and Future Work**

• An experimental system has been established and the feasibility of the novel laser-enhanced GMAW process was experimentally demonstrated.

• The laser aiming at the droplet in laser-enhanced GMAW can apply an auxiliary detaching force without significant additional heat.

• Spray transfer was successfully produced at continuous currents in the range from 80 to 130 A for 0.8-mm-diameter steel wire that would produce short-circuiting transfers in conventional GMAW.

• Phenomena observed in laser-enhanced GMAW were satisfactorily analyzed by applying established theories and fundamentals.

• The fundamental research will focus on larger-diameter wires and the application of a pulse laser to detach the droplet at desired diameter and amperage with continuous waveform current.

**Acknowledgment**

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**References**

**Characteristics Temperature Curves for Aluminum Alloys during Friction Stir Welding**

An empirically derived relationship between temperature and weld energy is used to predict maximum friction stir welding temperatures in aluminum alloys

**BY C. HAMILTON, S. DYMEK, AND A. SOMMERS**

**ABSTRACT**

Review of published friction stir welding (FSW) data across numerous aluminum alloys demonstrates that a characteristic relationship between the temperature ratio (the maximum welding temperature divided by the solidus temperature of the alloy) and the energy per unit length of weld exists. When the temperature ratio is plotted as a function of the energy per unit length of weld, a linear relationship whose slope is dependent on the thermal diffusivity of the alloy is revealed. Utilizing these characteristic curves, the maximum welding temperatures were estimated for Zn-modified Al-Zn-Mg-Cu alloy extrusions joined at 225 and 300 rev/min (all other weld parameters held constant). The characteristic curves successfully predict the maximum welding temperatures at the lower energy conditions, i.e., 225 and 250 rev/min, but for the high-energy welds, 300 and 400 rev/min, the curves overpredict the maximum welding temperatures. Despite this discrepancy, the characteristic curves demonstrate that it is feasible to predict the maximum FSW temperature in an alloy if the thermal diffusivity, welding parameters, and tool geometry are known.

**KEYWORDS**

Friction Stir Welding  
Peak Temperature  
Aluminum Alloys  
Specific Energy  
Thermal Modeling

C. HAMILTON (hamiltbc@muohio.edu) and A. SOMMERS are with Miami University, Department of Mechanical and Manufacturing Engineering, Oxford, Ohio. S. DYMEK is with AGH University of Science and Technology, Faculty of Metals Engineering and Industrial Computer Science, Kraków, Poland.

**Introduction**

Friction stir welding (FSW) is a novel solid-state joining process that is gaining popularity in the manufacturing sector and, in particular, the aerospace industry (Ref. 1, 2). Because no melting occurs during FSW, the process is performed at much lower temperatures than conventional welding techniques and circumvents many of the environmental and safety issues associated with these welding methods. The plastic deformation and temperature profile during FSW produce a microstructure characterized by a central weld nugget surrounded by a thermomechanically affected zone (TMAZ) and heat-affected zone (HAZ). The welded joint is fundamentally defect free and displays excellent mechanical properties when compared to conventional fusion welds (Ref. 3, 4). Since its introduction, numerous investigations have sought to characterize the principles of FSW and to model the microstructural evolution and temperature behavior. The current status of FSW research has been well summarized by Mishra and Ma (Ref. 5).

Researchers have found success in modeling the heat transfer characteristics of FSW. For example, Frigaard et al. (Ref. 6) developed a finite difference thermal model for a moving heat source and correlated the predicted temperature profile with the measured temperature profile for friction stir welded 6082-T6 and 7106-T79 extrusions. Utilizing a visco-plastic model, Ulysse (Ref. 7) studied the impact of varying weld parameters on the temperature distribution in 7050-T7451 plate. Also, Khandkar et al. (Refs. 8, 9) introduced a heat input model based on the torque of the FSW tool and successfully applied the model to friction stir welded aluminum 6061-T651 plate.

A commonality to each of these approaches, however, is the need to develop a computer simulation to satisfactorily solve the heat transfer equation for the alloy and welding conditions of interest, and to calculate the thermal profile and maximum welding temperature. To circumvent this sometimes work-intensive process, Roy et al. (Ref. 10) utilized the Buckingham Π-Theorem and proposed a dimensionless parameter based on material properties and process parameters to predict the maximum weld temperature during friction stir welding. Colegrove et al. (Ref. 11) also pursued a technique that would predict the heat generation in aluminum alloys during FSW based solely on material properties, in particular the solidus temperature of the alloy and flow stress. Defining the “contact radius” between the tool and workpiece as a measure of heat transfer efficiency between them, their work showed good agreement between predicted and experimental temperatures when applied to 7449-T73, 2024-T3, and 6013-T6 sheets.

Through similar motivation to derive a more direct approach to predict friction stir welding temperatures in aluminum alloys, the current investigation utilizes Khandkar’s torque-based heat input model to develop a relationship between the maximum welding temperature, solidus temperature, and energy per unit length of weld. This empirically derived relationship generates temperature curves characteristic to specific thermal diffusivities that correlate the temperature ratio (the ratio of the maximum welding temperature to the solidus temperature)
with the weld energy. From these curves, the maximum welding temperature may be estimated for a given aluminum alloy if the tool geometry, welding parameters, solidus temperature, and thermal diffusivity are known.

Experimental Procedure

For this investigation, Sc-modified Al-Zn-Mg-Cu billets (SSA038) were produced by UES, Inc., through direct chill casting and then extruded as 50.4 x 6.35-mm bars. The chemical compositions of SSA038 is summarized in Table 1 along with that of aluminum 7075 for reference and comparison (Ref. 12). Following extrusion, the bars were heat treated to a-T6 temper through the following schedule: 1) solution heat treat at 460°C for one hour followed by an additional hour at 480°C, 2) rapid quench in water to room temperature, and 3) age at 120°C for 19 h. The density of SSA038 is 2820 kg/m³, and the solidus temperature is 528°C.

After heat treatment, the bars were cut into eight, 305-mm lengths and sent to the Edison Welding Institute (EWI, Columbus, Ohio) to produce four friction stir welds in the configuration represented — Fig. 1. As shown in the diagram, FSW occurred along the L direction of the extrusions with a clockwise tool rotation. The diameter of the FSW tool shoulder was 17.8 mm, the pin diameter tapered linearly from 10.3 mm at the tool shoulder to 7.7 mm at the tip, and the pin depth was 6.1 mm. More specific details of the tool design are proprietary to EWI, but Mishra and Ma (Ref. 5) have reviewed many of the common FSW tool designs that are indicative of that utilized in this investigation. With a constant weld velocity of 2.1 mm/s and an applied force of 22 kN, unique welds were produced at the following tool rotation speeds: 225, 250, 300, and 400 rev/min. Even though the applied force during FSW was set to 22 kN, real-time data from the welding trials revealed that the load oscillated as the machine continuously corrected the load toward the set point. Consequently, the average load during welding deviated from the desired set point; therefore, the average load was determined from the recorded data for each weld condition and was utilized in the analysis of that condition. These average load values are 21.4, 20.1, 22.8, and 20.1 kN for 225, 250, 300, and 400 rev/min, respectively. The recorded data verified that the weld velocity remained constant at 2.1 mm/s for all welding trials.

By utilizing a Mikron M7815 thermal imaging camera during welding, the temperature profile across the weld was experimentally recorded for each condition. The thermal emissivity for the infrared section length heated to 400°C and adjusting the emissivity value until the recorded temperature of the camera matched the reference temperature. The appropriate thermal emissivity value was determined to be 0.285. The experimental temperature data were used to verify the efficacy of the characteristic curves proposed from this investigation.

Discussion

Energy per Unit Length of Weld

Because the weld velocity (v_w), tool rotation speed (ω), and applied force (F) all influence the total energy imparted to the workpieces, the total heat input more appropriately indicates the welding conditions than any individual welding parameter. The energy per unit length of weld was derived by Khandkar (Ref. 8) from a torque-based model for which the total torque, T_{total}, is expressed as the sum of torque contributions from the tool shoulder against the workpiece, bottom of the tool pin against thickness material, and pin surface against thickness material. For the FSW representation in Fig. 1, where r_0 is the radius of the tool shoulder, r_p is the radius of the pin at the tool shoulder, r_p is the radius of the pin at the pin bottom, h is the pin height, r is the shear stress during welding, and F is the applied force, the total torque then becomes

\[ T_{total} = \int_{r_0}^{r_p} (2\pi r) dr +\int_{r_p}^{r_b} (2\pi r) dr + \int_{r_b}^{h} (2\pi r) dr + \int_{r_p}^{r_b} (2\pi r) dr \]

(2)

The coefficient of sliding friction between aluminum and steel depends on the temperatures produced by the welding conditions. Frigaard et al. (Ref. 6) reasoned that the coefficient of friction between alu-

Table 1 — Chemical Compositions of SSA038 with 7075 as Reference

<table>
<thead>
<tr>
<th>Element</th>
<th>SSA038 Wt-%</th>
<th>7075 Wt-%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zn</td>
<td>7.11</td>
<td>5.60</td>
</tr>
<tr>
<td>Mg</td>
<td>2.14</td>
<td>2.50</td>
</tr>
<tr>
<td>Cu</td>
<td>1.56</td>
<td>1.60</td>
</tr>
<tr>
<td>Mn</td>
<td>0.25</td>
<td>0.30</td>
</tr>
<tr>
<td>Zr</td>
<td>0.17</td>
<td>&lt; 0.05</td>
</tr>
<tr>
<td>Sc</td>
<td>0.38</td>
<td>—</td>
</tr>
<tr>
<td>Cr</td>
<td>&lt; 0.05</td>
<td>0.23</td>
</tr>
<tr>
<td>Ti</td>
<td>&lt; 0.05</td>
<td>0.20</td>
</tr>
<tr>
<td>other, each</td>
<td>0.35</td>
<td>1.03</td>
</tr>
<tr>
<td>Al</td>
<td>Balance</td>
<td></td>
</tr>
</tbody>
</table>
Table 2 — Energy per Unit Length of Weld and Measured Maximum Temperature

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Tool Geometry</th>
<th>Welding Parameters</th>
<th>Measured Max. T (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>v_w (mm/s)</td>
<td>F (kN)</td>
</tr>
<tr>
<td>AA7108-T79 (Ref. 6)</td>
<td>7.5</td>
<td>2.5</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AA6061-T6 (Ref. 11)</td>
<td>12.0</td>
<td>9.5</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AA6061-T651 (Ref. 8)</td>
<td>12.7</td>
<td>5.0</td>
<td>8.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AA6082-T6 (Ref. 6)</td>
<td>7.5</td>
<td>2.5</td>
<td>6.0</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AA7050-T7451 (Ref. 15)</td>
<td>10.2</td>
<td>3.6</td>
<td>6.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>AA7050-T7451 (Ref. 7)</td>
<td>9.5</td>
<td>3.2</td>
<td>6.4</td>
</tr>
</tbody>
</table>

<minimum and mild steel should be set as the average value between 0.5 for sticky friction and 0.25 for dry sliding, while Soundararajan et al. (Ref. 13) allowed μ to vary between 0.5 and 0.4 depending on the welding conditions. For this investigation, initial calculations of the energy used a coefficient of friction of 0.5; however, if energy levels exceeded 2000 J/mm, i.e., “hot” welding conditions, the coefficient of friction was reduced to 0.45, and if the energies levels exceeded 3000 J/mm, the coefficient of friction was further reduced to 0.4. The energies were then recalculated according to the reassigned value of μ. The energy per unit length of weld, \( E_i \), is found by dividing the average power, \( P_{avg} \), by the weld velocity to yield the expression in Equation 3.

\[
E_i = \frac{P_{avg}}{v_w} = T_{total} \frac{\alpha}{v_w}
\]

Survey of Data from the Literature

A survey of the friction stir welding literature on thermal modeling of aluminum alloys produced the information presented in Tables 2 and 3. These specific investigations were selected because the researchers experimentally measured the
Temperature ratio as a function of effective energy per weld length; B — with linear regression curves added.

**Fig. 4** — Experimental and predicted temperature ratio as a function of effective energy per weld length for SSA038-T6.

Temperature profile to verify their thermal model and included the welding parameters and tool geometry, such that energy per unit length calculations could be made for their particular weld conditions (Table 2). Force values taken from Ref. 7 are numerical predictions, not experimental observations, for the weld velocity and tool rotation speed combinations.

Table 3 displays the properties for the investigated alloys at room temperature, where \( \rho \) is the density, \( c_p \) is the heat capacity, \( k \) is the thermal conductivity, and \( \alpha \) is the thermal diffusivity of the alloy \( (\alpha = \frac{k}{c_p \rho}) \). Though the heat capacity and thermal conductivity are temperature-dependent properties, a goal of this work is to predict friction stir welding temperatures utilizing these material properties at room temperature. Also listed in Table 3 are the maximum temperatures recorded by each researcher during welding. Though the thermocouple locations from each study are not identical, these temperatures are assumed to be the true maximum temperatures, i.e., temperatures under the tool shoulder, as each investigator did attempt to record the temperature near the weld centerline.

**Fig. 2A** plots the experimentally measured maximum temperature, \( T_{\text{max}} \), as a function of the energy per length of weld, \( E_i \), for the data in Table 2. The correlation between the two parameters from each data set is self-evident because the energy per length of weld must also reflect the maximum achievable temperature, i.e., as the welding energy increases, so must the welding temperature. As seen in the figure, the data tend to group based on alloy type and product thickness. Thus, the maximum temperatures for the 6061 and 6082 alloys with similar thicknesses (6.0, 6.4, and 8.13 mm), show the same linear relationship with \( E_i \), while the two 7050 data sets with different product thicknesses (6.4 and 19.1 mm) display unique relationships between temperature and energy.

Because 6061 and 6082 share a similar chemistry and thickness, the common relationship between temperature and energy is expected. Despite the 7050 having a distinct chemistry from the 6XXX alloys, its thermal diffusivity \( (6.5 \times 10^{-5} \text{ m}^2/\text{s}) \) is comparable to both 6061 and 6082 \( (6.9 \) and \( 7.1 \times 10^{-5} \text{ m}^2/\text{s} \), respectively); therefore, for the same thickness, the 7050 data from Reynolds’s (Ref. 15) investigation would be expected to show a similar temperature/energy trend as that of 6061 and 6082. Though showing a similar slope to that of 6061 and 6082, the 7050 relationship in Fig. 2A is shifted to the right, indicating that lower maximum temperatures are produced in 7050 at the same energy levels.

Consider, however, that as the welding temperature approaches the solidus temperature, \( T_s \), of an alloy, the material will soften, slip will occur, and less energy will be transferred into the workpiece. The solidus temperatures of 6061 and 6082 are greater than that of 7050; therefore, under the same welding conditions, the transfer of energy between the tool and the workpiece is more efficient in the 6XXX alloys than in 7050. Hence, the maximum temperature for a given energy level will increase with increasing solidus temperature. Figure 2B demonstrates that when the temperature ratio, \( \frac{T_{\text{max}}}{T_s} \), is plotted as a function of \( E_i \), the data group according to thermal diffusivity and product thickness. The data sets from 6061, 6082, and Reynolds’s 7050 display a relationship distinct from 7108, which has a lower thermal diffusivity, and from Ulysse’s 7050, which has a greater product thickness.

Consider a welding condition for which the initial material thickness approaches the length of the tool pin. As the workpiece thickness increases relative to the pin length, material below the pin conducts more heat away from the process zone. As the material thickness continues to increase, additional heat conduction will diminish until a threshold thickness is reached beyond which greater and greater workpiece thicknesses will effectively conduct the same amount of heat away from
the process zone. Below this threshold thickness and for a given alloy and FSW tool, the maximum welding temperature at a specific energy level will decrease as the material thickness increases. To account for the influence of material thickness below the threshold value, a scaling parameter, $e_i$, is defined as the ratio of the pin length, $l$, to the product thickness, $t$. The effective energy per weld length, $(E_i)_{eff}$, then becomes the energy per weld length multiplied by the scaling factor, such that

$$(E_i)_{eff} = \beta E_i$$

Assuming that the FSW data in Tables 2 and 3 are within the range that the scaling factor would be applicable, Fig. 3A plots $T_{max}/T_s$ as a function of $(E_i)_{eff}$ and Ulysse's 7050 data now reveal the same temperature ratio/energy relationship as the 6061, 6082, and Reynolds's 7050 data. The distinction between this relationship and that of 7108 lies in the difference between the thermal diffusivities of the data sets. The thermal diffusivity of 7108 is $5.2 \times 10^{-5} \text{m}^2/\text{s}$, while that of the 6XXX and 7050 data set is approximately $6.75 \times 10^{-5} \text{m}^2/\text{s}$ (though specific diffusivities are either slightly higher or lower than this value).

The temperature ratio of the 7108 data set shows greater sensitivity to $(E_i)_{eff}$, i.e., for equivalent increases in energy level, the maximum temperature increases more quickly for 7108 than for 6XXX and 7050. As thermal diffusivity decreases, the ability of an alloy to conduct energy away from a heat source also decreases. If the maximum temperature during FSW occurs under the tool shoulder, which is also the principal source of heat, then for a fixed tool material and energy level, the maximum temperature at this location must increase in alloys with lower thermal diffusivities if all other boundary conditions remain constant. Higher temperature ratios, therefore, are produced in 7108 at equivalent $(E_i)_{eff}$ than those produced in 6XXX or 7050.

Figure 3B displays the temperature ratio/energy level data with linear regressions added to each data set. Both regressions converge near the same $T_{max}/T_s$ ratio for an energy level of zero, the 7108 data set intercepting the axis at 0.58 and the 6XXX and 7050 data set intercepting the axis at 0.54. Though each regression converges at approximately the same intercept, it is difficult to rationalize any physical significance to this point, i.e., the temperature ratio at zero weld energy, other than as a convenient mathematical construct. The relationship between the temperature ratio and energy, however, does hold over the region of practical welding conditions. If the intercept value is taken as 0.56, then an empirical relationship between the temperature ratio and effective energy level is developed that is applicable to each of the aluminum alloys

$$T_{max}/T_s = m_\alpha (E_i)_{eff} + 0.56$$

where $m_\alpha$ is the slope of the linear relationship, and the $\alpha$ subscript indicates a dependence on the thermal diffusivity of the alloy. If the relationship between the slope and $\alpha$ is interpolated with the given experimental data, then Equation 5 may be rewritten as

$$T_{max}/T_s = (0.0013 - 16.5\alpha) (E_i)_{eff} + 0.56$$

Equation 6 describes a relationship between the welding energy and maximum welding temperature that is characteristic across numerous aluminum alloys. If the thermal properties and solidus temperature for a given aluminum alloy are known, then the maximum welding temperature during FSW may be estimated from the welding parameters, workpiece thickness, and tool geometry utilizing Equation 6.

### Application to SSA038-T6 Data

Utilizing the empirical relationship in Equation 6, the maximum temperature for each SSA038-T6 weld condition can be predicted. Table 4 summarizes these predicted temperatures and the experimental temperatures recorded for each weld trial. At 225 rev/min, the characteristic curve predicts a maximum temperature of 363°C, a 5% error with respect to the experimental value. A similar success is seen at 250 rev/min for which the characteristic curve predicts a maximum temperature of 371°C, only a 6% error. The accuracy of these lower energy results compare favorably with the accuracy of the models proposed by Roy et al. (Ref. 10) and Colegrove et al. (Ref. 11). The dimensionless parameter approach by Roy predicted temperatures within 10–15% of the experimental temperatures, while the model of Colegrove predicted temperatures easily within 10% of the actual welding temperature, but often were as accurate as ±5°C of the experimental values.

For the higher energy welds, however, the efficacy of this model decreases. At 300 and 400 rev/min, the error in the predicted temperature is 19 and 26%, respectively. Figure 4 plots the temperature ratio as a function of the effective energy for the

### Table 3 — Room Temperature Alloy Data from Survey of Literature

<table>
<thead>
<tr>
<th>Alloy</th>
<th>Thick (mm)</th>
<th>$\rho$ (kg/m³)</th>
<th>$c_p$ (J/kg-K)</th>
<th>$k$ (W/m-K)</th>
<th>$\alpha \times 10^5$ (m²/s)</th>
<th>Solidus Temp. (K)</th>
<th>Ref.</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA7108-T79</td>
<td>6.0</td>
<td>2780</td>
<td>960</td>
<td>140</td>
<td>5.2</td>
<td>748</td>
<td>Frigaard (Ref. 6)</td>
</tr>
<tr>
<td>AA6061-T6</td>
<td>6.4</td>
<td>2700</td>
<td>896</td>
<td>167</td>
<td>6.9</td>
<td>855</td>
<td>Soundararajan (Ref. 13)</td>
</tr>
<tr>
<td>AA6061-T651</td>
<td>8.13</td>
<td>2700</td>
<td>896</td>
<td>170</td>
<td>6.9</td>
<td>855</td>
<td>Khandkar (Ref. 8)</td>
</tr>
<tr>
<td>AA6082-T5</td>
<td>6.0</td>
<td>2700</td>
<td>889</td>
<td>170</td>
<td>7.1</td>
<td>879</td>
<td>Frigaard (Ref. 6)</td>
</tr>
<tr>
<td>AA7050-T7451</td>
<td>6.4</td>
<td>2830</td>
<td>860</td>
<td>157</td>
<td>6.5</td>
<td>761</td>
<td>Reynolds (Ref. 15)</td>
</tr>
<tr>
<td>AA7050-T7411</td>
<td>19.1</td>
<td>2830</td>
<td>860</td>
<td>157</td>
<td>6.5</td>
<td>761</td>
<td>Ulysse (Ref. 7)</td>
</tr>
</tbody>
</table>

### Table 4 — Effective Total Energies and Maximum Weld Temperatures for Each Weld Condition

<table>
<thead>
<tr>
<th>Rev/Min</th>
<th>$(E_i)_{eff}$ (J/kg-ft)</th>
<th>Maximum Welding Temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>225</td>
<td>938</td>
<td>346</td>
</tr>
<tr>
<td>250</td>
<td>977</td>
<td>350</td>
</tr>
<tr>
<td>300</td>
<td>1331</td>
<td>372</td>
</tr>
<tr>
<td>400</td>
<td>1567</td>
<td>390</td>
</tr>
</tbody>
</table>
experimental temperature data and predicted temperature data and reveals the discrepancy between the two relationships as the welding energy increases. Clearly, Equation 6 assumes a slope that is steeper than that of the actual relationship. As such, the predicted and experimental temperatures show relatively good agreement below 1100 J/mm, but diverge as the effective energy increases. The inability of Equation 6 to adequately capture the temperatures at higher weld energies lies in the interpolation of \( m_a \) from Equation 5. As previously discussed, \( m_a \) represents the thermal diffusivity-dependent slope of the temperature ratio/effective energy relationship. The expression for \( m_a \) introduced into Equation 6 models the data for both 7108, a "low" thermal diffusivity alloy, and from 6XXX and 7050, "high" diffusivity alloys. Thus, when Equation 6 is applied, it will underestimate the slope for alloys with thermal diffusivities similar to 7108, but overestimate the slope for alloys with thermal diffusivities similar to 6XXX and 7050. Because SSA038 shares a similar chemistry to 7050, the thermal diffusivities would be expected to be similar, and Equation 6 will overestimate the slope of the characteristic curve for SSA038.

**Conclusions**

Based on the torque during friction stir welding, the energy per unit length of weld was calculated for numerous investigations on various aluminum alloys. The data revealed a characteristic linear relationship between the temperature ratio, maximum welding temperature divided by the solidus temperature of the alloy, and effective energy per length of weld. The thermal diffusivity of the alloy determined the slope, and from this relationship, an empirical formula was proposed that can be used to estimate the maximum welding temperature from the tool geometry, welding parameters, solidus temperature, and thermal diffusivity for any given aluminum alloy. Using this empirical relationship, the maximum welding temperatures were estimated for SSA038-T6 (a Sc-modified Al-Zn-Mg-Cu aluminum alloy) extrusions joined at four different rotation speeds. For welding energies less than 1100 J/mm, the predicted temperatures from the characteristic curves showed good agreement with the experimental data; however, above this energy level, the predicted temperatures diverged from the experimental values.

The discrepancy between the two relationships rests in the interpolation of the slope of the characteristic curve as it relates to the thermal diffusivity. For thermal diffusivities similar to AA7108 (the lower limit of this investigation), the model will underestimate the slope of the characteristic curve, but for thermal diffusivities on the order of 6XXX or 7050 (the upper limit of this investigation), the model overestimates the slope of this relationship. Despite the discrepancy, the characteristic curves demonstrate the possibility of predicting the maximum FSW temperature from the thermal diffusivity, welding parameters, and tool geometry.

**Acknowledgments**

The authors acknowledge the Polish Ministry of Science and Higher Education (Grant No. NS07 446 337), UES, Inc., and the Materials and Manufacturing Directorate at Wright-Patterson AFB for their support of this research.

**References**


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Using Infrared Thermography in Low-Cycle Fatigue Studies of Welded Joints

The tests proved useful in predicting fatigue life of components and welded details made from the same steel and subjected to random service loading

BY V. CRUPI, G. CHIOFALO, AND E. GUGLIELMINO

ABSTRACT

This paper presents an analysis of the low-cycle fatigue (LCF) process during fatigue testing of welded steel joints by thermographic investigations. Infrared thermography has been applied in the past to investigate high-cycle fatigue (HCF) of metals and welded joints, and it has been found that the thermal pattern of the specimen surface during HCF testing is characterized by three phases with a stabilized temperature. A similar thermal pattern was observed in the LCF tests. The thermal increments during the LCF life were related to the hysteresis loops derived from the traditional procedure and the experimental results confirm that there is a correlation between the stable hysteresis loops and the stabilized temperature. Moreover, the LCF behavior of welded joints was compared to that of the base material.

Introduction

Welds sometimes represent a weak point, due to the presence of possible crack-like defects along with high stress concentration effects and tensile residual stresses caused by the thermal welding process itself.

Thus, several approaches have been proposed in literature (Refs. 1–3) for high-cycle fatigue (HCF) assessment of welded joints. However, some fatigue cracks have been detected in the structures within a few years of their service life, and this type of fatigue cannot be adequately explained by the HCF approaches based on the S-N curve. Under critical loading conditions, cyclic stress, which exceeds the material yield stress, can occur at some critical locations such as the welds. The fatigue cracks, which result from the presence of high stress concentrations, are related to low-cycle fatigue (LCF), but existing design codes do not properly consider LCF problems.

The approaches to predicting the LCF life of welded joints, subjected to a given stress-time history, are based on the local strain approach (Neuber’s rule or Molski-Glinka method) and finite element analysis. They require, apart from knowledge of LCF curves, also the knowledge of cyclic material properties derived from hysteresis loops at half fatigue life.

A review of experimental studies for a LCF test of a welded joint specimen has been presented by Madi et al. (Ref. 4). Borowski (Ref. 5) evaluated the cyclic material distribution in laser welded joints under LCF tests; the local strains in the weld metal, base metal, and heat-affected zone were measured using a laser grating extensometer (LES).

The assessment of the steel strength in the LCF regime is very important for a correct design of pressure vessels and offshore structures.

The fatigue assessment became very important after the Pressure Equipment Directive, which is the European Community Directive for pressure vessels, has been accepted. In this directive, fatigue assessment is included among the Essential Safety Requirements (ESR).

Failure due to LCF can occur in some pressure vessels because they can be subjected to high oscillations of the pressure or the temperature during their service life.

Some cracks related to LCF have been detected in offshore structures operating in the North Sea (Refs. 6, 7). Most offshore structures consist of plate details connected by welded circumferential and longitudinal joints, which are the sites of high stress concentrations and are subject to severe environmental loading from wind and wave action, which induces significant fatigue loads leading to cyclic stresses that exceed the yield stress locally. Moreover, hydrogen-induced cracking (HIC), resulting from cathodic protection in offshore structures and from the presence of H2S in aqueous phase (“wet H2S”) for pressure vessels can cause catastrophic failures. An experimental program (Ref. 6) was performed to assess the hydrogen-assisted cracking sensitivity of high-strength steels used for jack-up platforms. Comparative tests were carried out on normalized 50D (E355) and ASTM A516 Grade 70 steels, which are widely used for pressure vessels and offshore structures (Ref. 6).

The aim of this scientific work is the analysis of the LCF process in carbon steel welded joints. Strain-controlled fatigue tests were performed on ASTM A 516 Grade 70 steel and welded joints made of the same steel. The experimental results allowed the comparison of LCF behavior of the welded joints to that of the base metal.

The tests were carried out applying axial cyclic loads at different strain amplitudes with a strain rate of 1·10–3 s−1 and a strain ratio R = −1. An infrared scanner detected the temperature increment AT of the specimen surface during the tests. Analysis of the thermographic images has allowed measurement of temperature patterns during the fatigue tests and to correlate it to the hysteresis loops.

Infrared thermography has been applied in the past in the HCF regime to assess the

V. CRUPI (vcrupi@ingegneria.unime.it), G. CHIOFALO, and E. GUGLIELMINO are with University of Messina, Faculty of Engineering, Department of Industrial Chemistry and Materials Engineering, Messina, Italy.

KEYWORDS

Low-Cycle Fatigue (LCF)
Infrared Thermography
Welded Joints
Pressure Vessels
Offshore Structures
fatigue strength of aluminium (Refs. 1, 2) and steel (Ref. 8) welded details, used in shipbuilding, to estimate the thermoelastic effect (Ref. 9) and also to find the relationship between temperature increment in a metal specimen, which is cyclically loaded, and its specific damping (Ref. 10).

In this paper, an application of infrared thermography for the analysis of the LCF process in steel welded joints is presented.

**Materials and Methods**

The base material of the analyzed welded joints is an ASTM A 516 Grade 70 (UNI EN 10028 P355NH) steel.

The chemical composition and the mechanical properties of the steel are shown in Tables 1 and 2, respectively.

Hydrogen-induced cracking tests, according to NACE TM 0284, were conducted on welded joints and specimens made of the same steel (Ref. 11), and the toughness was evaluated by means of crack tip opening displacement (CTOD) tests (Ref. 11). Table 3 reports the CTOD values, obtained for both the base metal and welded joint in the standard condition and at increasing exposure time in a charging hydrogen environment, a NACE test solution A: 5.0 wt-% NaCl and 0.5 wt-% CH$_3$COOH, saturated with H$_2$S gas at ambient temperature and pressure.

In order to perform LCF tests, some specimens were machined from a welded plate with the length direction perpendicular to the rolling direction and that were subjected to a stress relief heat treatment before the tests.

Welding of the joints was performed with shielded metal arc welding (SMAW) with E7018 filler metal. The specimens underwent the following heat treatment: heating rate of 200°C/h up to 610°C, 3 h at 610°C, cooling rate (inside furnace) of 200°C/h.

After welding, the joints were checked by radiographic tests for 100% of their length. No cracks were detected.

The welded joints were machined flat, entirely removing the weld reinforcements. Figure 1 shows the geometry of the welded joints with a dog-bone shape, similar to that of the base metal specimens.

Tests were performed using an MTS 810 System servohydraulic load machine with a 250-kN capacity. The tests were undertaken in strain control with a constant strain rate of 1×10$^{-2}$ s$^{-1}$ and a strain ratio $R = -0.1$. Different strain ranges $\delta$ were applied: between 0.4 and 0.8% for base material specimens and between 0.2 and 0.7% for welded joints. The longitudinal strain was continuously measured throughout the test by means of a longitudinal extensometer with a 25-mm gauge length, clamped to the specimen. Fatigue testing was continued until the specimen failed.

The surfaces of all the specimens were painted with a uniform, thin black coating in order to avoid reflections from the environment and to get a greater thermal contrast. The thermographic images were acquired every 5 s by means of an infrared scanner.

**Table 1 — Chemical Composition of the Steel (wt-%)**

<table>
<thead>
<tr>
<th>Element</th>
<th>C</th>
<th>Mn</th>
<th>P</th>
<th>S</th>
<th>Si</th>
<th>Cu</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>Al</th>
<th>Nb</th>
<th>V</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>0.20</td>
<td>1.12</td>
<td>0.010</td>
<td>0.003</td>
<td>0.31</td>
<td>0.026</td>
<td>0.04</td>
<td>0.21</td>
<td>0.005</td>
<td>0.034</td>
<td>0.018</td>
<td>0.008</td>
<td>0.002</td>
</tr>
</tbody>
</table>
(Flyr System A40M with a thermal resolution lower than 0.08°C) located 0.3 m in front of the specimen — Fig. 2. ThermaCAM Researcher software was used to analyze the thermographic images. The digitized images contained 320 × 240 pixels.

During the tests, in order to consider only the effect due to the cyclic stresses, both the temperatures of the specimen surface and of the environment were simultaneously measured with the thermocamera scanner. The correct temperature increase of the specimen was then determined subtracting the environmental temperature variation.

Results and Discussion

The following results for each steel type have been obtained by the experimental tests:

- stable hysteresis loops
- LCF constants ($K'$, $n'$)
- $\varepsilon$-$N$ curve,
- cyclic $\sigma$-$\varepsilon$ curve,
- $\Delta T$-$N$ curves,
- asymptotic temperature increments $\Delta T_{AS}$.

Stable Hysteresis Loop

The tests were undertaken with ASTM E606 standard (Ref. 12), keeping constant the average strain rate $\dot{\varepsilon}$ throughout each test at the value $1 \cdot 10^{-2}$ s$^{-1}$ in order to avoid any influence of the strain rate on the hysteresis loop shape. The testing frequency was then calculated by the following

<table>
<thead>
<tr>
<th>Table 2 — Monotonic Mechanical Properties of the Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>$E$ (GPa)</td>
</tr>
<tr>
<td>210</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 3 — CTOD Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exposition Time (h)</td>
</tr>
<tr>
<td>Standard condition</td>
</tr>
<tr>
<td>30 h</td>
</tr>
<tr>
<td>72 h</td>
</tr>
<tr>
<td>96 h</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Table 4 — Low Cycle Fatigue Parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>$K'$ (MPa)</td>
</tr>
<tr>
<td>Steel Type</td>
</tr>
<tr>
<td>Base Metal</td>
</tr>
<tr>
<td>Welded Joint</td>
</tr>
</tbody>
</table>
The cyclic stress-strain curves were determined using the method of one specimen for each imposed strain level and defining the stable hysteresis cycle at approximately the half fatigue life $N_f/2$ according to ASTM E606 standard (Ref. 12). The tests were carried out with imposed strain ranges between 0.4 and 0.8% for base material specimens and between 0.2 and 0.7% for welded joints.

The LCF parameters ($K'$, $n'$) were obtained through analyzing the stable hysteresis loops that have a symmetric shape about the origin of the stress-strain axes — Fig. 3.

The plastic strain-range $\Delta \varepsilon_p$ was evaluated as the width along the abscissa of the stable hysteresis loop at half life $N_f/2$ (Fig. 3) and the stress amplitude $\Delta \sigma$ was calculated from the elastic portion of the total strain $\Delta \varepsilon$ ($\Delta \varepsilon = \Delta \varepsilon_e - \Delta \varepsilon_p$) as

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

where the Young’s modulus $E$ was evaluated equal to 190 GPa for the welded joint and 210 GPa for the base metal.

The plastic strain range $\Delta \varepsilon_p$ can be related to the stress amplitude $\Delta \sigma$ using the following empirically derived power equation similar to the monotonic plastic strain-stress relationship in a tensile test:

$$\frac{\Delta \varepsilon_p}{2} = \left( \frac{\Delta \sigma}{2 \cdot K'} \right)^{\frac{1}{n'}}$$  \hspace{1cm} (2)

The values of the strain-hardening exponent $n'$ and strength coefficient $K'$, reported in Table 3, were determined by the application of the linear regression method to the pairs of results, derived from the stable hysteresis loops, of the plastic strain range $\Delta \varepsilon_p$ and the stress amplitude $\Delta \sigma$ (Fig. 4) according to the following equation:

$$\Delta \sigma = k_n \cdot \Delta \varepsilon_p$$  \hspace{1cm} (3)

$$\Delta \varepsilon_p = \left( \frac{\Delta \sigma}{k_n} \right)^{\frac{1}{n'}}$$  \hspace{1cm} (4)

The LCF behavior of the welded joints is different with respect to that of the base material. The welded joints consist of three main zones: the base metal, heat-affected zone (HAZ), and welded zone. A strong material properties mismatching occurs in the three weld joint zones, so they are subjected to different strain distributions during fatigue tests and the local strain measurement is not easy. The local strength have been investigated by means of strain measurement, using image analysis techniques (Ref. 13) and hardness tests (Ref. 5, 14).

It is well known that the weld metal has lower fatigue strength than the base metal, and the HAZ has still lower fatigue strength. In the low-cycle fatigue regime, cracks generally initiate at the HAZ in the early stage of loading cycles and propagate until the complete failure as reported in

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Test</th>
<th>$\Delta \varepsilon$</th>
<th>$f$ (Hz)</th>
<th>$N_f$</th>
<th>$\Delta \sigma (N_f/2)$</th>
<th>$\Delta W (N_f/2)$</th>
<th>$\Delta W_T$</th>
<th>$\Delta T_{AS}$</th>
</tr>
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<tbody>
<tr>
<td>Base Metal</td>
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<tr>
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<td>649</td>
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<tr>
<td>Welded Joint</td>
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<td>0.769</td>
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<td>1.381</td>
<td>1.568</td>
<td>18.0</td>
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<td></td>
<td>10</td>
<td>0.00700</td>
<td>0.714</td>
<td>1633</td>
<td>717</td>
<td>1.716</td>
<td>1.850</td>
<td>23.5</td>
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</table>
the literature (Refs. 13, 14). With respect to the base metal, the presence of a welded area produced a decrease in the plastic strain and an increase in the stress. This behavior results also from analysis of the stable hysteresis loops.

Figure 5 shows the stable hysteresis loops, obtained for base and welded joint at the applied strain range $\Delta e$ equal to 0.4%.

The $e-N$ curves were assessed according to the ASTM E739 standard (Ref. 15). In plotting $e-N$ curves in a bilogarithmic scale, the independent variable $e$ is plotted along the ordinate, with the fatigue life $N_f$ (the dependent variable) plotted along the abscissa.

The analysis of the $e-N$ curves, shown in Fig. 6, demonstrated that the welded joints have a lower LCF strength with respect to the base material.

**Cyclic $\sigma-e$ Curve**

The cyclic stress-strain equation is expressed by a Ramberg-Osgood type relationship:

$$\frac{\Delta e}{2} = \frac{\Delta \sigma}{E} \left( \frac{\Delta \sigma}{2 \cdot K'} \right)^{1/n}$$  \hspace{1cm} (5)

The diagram in Fig. 7 shows, for welded joint and base metal, the cyclic stress-strain curves, obtained applying Equation 5.

The cyclic yield strength $S_y'$ is defined at 0.2% strain offset, which corresponds to a plastic strain amplitude of 0.002 on the cyclic stress-strain curve. The values of cyclic yield strength $S_y'$, reported in Table 4, were estimated by substituting $\Delta \sigma/2 = 0.002$ in Equation 5.

Although Equation 5 represents the relationship between stress and strain stable amplitudes, it cannot, generally, be applied to describe the hysteresis loop branches. A material is said to exhibit “Masing-type” behavior when the branches of its hysteresis loops can be described by magnifying the cyclic stress-strain curve equation (Equation 5) by a factor of two. This type of behavior is common for many metals.

Thus, the equation that represents the stabilized hysteresis loop curve of metals

$$\frac{\Delta e}{2} = \frac{\Delta \sigma}{E} + 2 \left( \frac{\Delta \sigma}{2 \cdot K'} \right)^{1/n}$$  \hspace{1cm} (6)

The areas $\Delta W'$, obtained by integration of the experimental stable hysteresis loops at half life, are reported in Table 5 and the areas $\Delta W'$ of the theoretical hysteresis loops, evaluated applying Equation 6, are also shown in the same table for comparison.

**Infrared Investigations**

Within the LCF regime, the failure mechanism is governed by the plastic damage. The plastic work can be obtained by integrating the area within the hysteresis loop of the material. Since plastic deformations always dissipate heat, the temperature increases in the regions undergoing plastic strain, which are visible in the infrared images. The fatigue damage phenomenon is an energy dissipation process that can be detected by the thermographic technique. From these assertions, it is intuitive to conclude that temperature increment and hysteresis loop of the material must be closely correlated.

From all the HCF tests conducted in the past (Refs. 2, 8, 10), it has been found that, if the specimen temperature is detected by means of an infrared camera during fatigue testing, three phases are observed in the $\Delta T-N$ curve.

When a specimen is cyclically loaded above its fatigue limit, the temperature of the specimen surface usually rises quickly in the initial phase (phase 1), then reaches a stabilized asymptotic value $\Delta T_{AS}$ (phase 2), and eventually this asymptote is left with a very high further temperature increment, leading soon to failure after few cycles (phase 3).

The temperature of the hottest area of the specimen surface can be detected during the load application by means of a thermocamera and the increment $\Delta T$ with respect to the initial temperature of the unloaded specimen can be evaluated. This temperature increase is directly related to the mechanical energy dissipated into heat.

In Figs. 8 and 9, the $\Delta T-N$ curves, corresponding to the welded joints and steel specimens subjected to different strain range levels, are plotted and the above mentioned three phases are observed also in these curves relative to LCF tests. Figures 10 and 11 show, for welded joint and base metal, the thermographic images at different fatigue cycles, corresponding to the three phases of the $\Delta T-N$ curves. The values of the asymptotic temperature increment $\Delta T_{AS}$ detected for each LCF test, are reported in Table 5.

From the analysis of the $\Delta T-N$ curves, it results that the stabilized asymptotic temperature $\Delta T_{AS}$ is reached after few cycles and is maintained until a few cycles before the failure.

At strain amplitude values lower than 0.004, the welded joints exhibit a plateau saturation almost similar to that observed in base metal, as shown in the $\Delta T-N$ curves reported in Fig. 9. At higher values of strain amplitude, the fatigue behavior, characterized by a more pronounced initial softening, is more influ-
Hysteresis loops of the base metal at different cycles ($\Delta e = 0.4\%$). Fig. 13 — Hysteresis loops of the welded joint at different cycles ($\Delta e = 0.4\%$).

Compared to the HCF tests, the LCF tests were performed on a steel specimen and on a welded joint at the same strain range $\Delta e = 0.4\%$, as shown in Figs. 12 and 13, respectively. The stabilized hysteresis loop $\Delta W$ is reached after few cycles as happened for the asymptotic temperature increment $\Delta T_{AS}$.

This behavior can be explained by the fact that the cycled metal exhibits steady-state behavior: Stress and strain reach their saturated values after few fatigue cycles, and there are no further changes in the hysteresis loop shape and area until the last cycles before the failure.

It means that there is a correlation between the asymptotic temperature increment $\Delta T_{AS}$ and the stable hysteresis loop.

**Conclusions**

1. Fatigue constants ($K', n'$) and LCF curves for welded joints and carbon steel specimens were determined from the strain-controlled fatigue tests. They are useful parameters in predicting fatigue life of components and welded details made from the same steel and subjected to any random service loading.

2. The thermal pattern of the HCF tests, characterized by three phases with a stabilized temperature, was observed also in the LCF tests.

3. The temperature increment and hysteresis loop of the materials are closely correlated because they are both a manifestation of the energy dissipation process in metals under fatigue loading during plastic deformation.

Further experiments are planned to investigate the failure surface and crack initiation and propagation through optical microscope evaluation of the specimen at cycle intervals and in order to correlate the detected temperature increment $\Delta T$ to crack initiation and propagation during low-cycle fatigue tests. Furthermore, the different mechanical strengths of the weld metal, HAZ, and base metal will be investigated through application of a technique, based on the digital image correlation that allows assessment of the displacement field on all specimen surfaces and the localized strain concentration.

**References**


**Nomenclature**

- $g$ frequency (Hz)
- $K'$ cyclic strength coefficient (MPa)
- $n'$ cyclic strain hardening exponent
- $E$ Young's modulus (MPa)
- $HCF$ high cycle fatigue
- $LCF$ low cycle fatigue
- $\Delta N$ number of cycles
- $\Delta N_f$ number of cycles to failure
- $2N_f$ reversals to failure
- $\Delta e$ strain ratio
- $S_y$ cyclic yield strength (MPa)
- $\Delta e_{sa}$ strain amplitude
- $\sigma_{pa}$ elastic strain amplitude
- $\sigma_{pa}$ plastic strain amplitude
- $\sigma_{ap}$ stress amplitude (MPa)
- $\Delta T$ temperature increment at the hot-spot area ($^\circ$C)
- $\Delta T_{AS}$ asymptotic temperature increment ($^\circ$C)
- $\Delta W$ area of the hysteresis loop at half life (MJ/m$^3$)
- $\Delta W(N)$ area of the hysteresis loop at a fixed number of cycles (MJ/m$^3$)
- $\Delta W_T$ area of the theoretical hysteresis loop at half life (MJ/m$^3$)
- $\Delta e$ strain range
- $\Delta \varepsilon_e$ elastic strain range
- $\Delta \varepsilon_p$ plastic strain range
- $\Delta \varepsilon_p$ stress range (MPa)
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