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AWS Energizes the World

This has been a great year to serve as your president. Many projects that were in the making were achieved by the American Welding Society in 2010. Following are just some of this year’s accomplishments.

- The first-ever combination conference for the Resistance Welding Manufacturers Alliance (RWMA) and Welding Equipment Manufacturers Committee (WEMCO) was held in March and was well attended.
- AWS secured a management relationship with the Gases and Welding Distributors Association (GAWDA). In October, AWS staff members executed their first GAWDA conference, which was attended by nearly 800 people. Many favorable comments were received regarding the outstanding venue.
- The Board of Directors approved the purchase of a new AWS headquarters building, which is located in close proximity to our current headquarters. Architectural planning and permitting are under way and office preparation will follow. The new facility will provide much-needed space for parking, functions, staffing, and future growth. We expect to move into the building during the first quarter of 2012. The building was purchased without burdening our resources because we are in the finest financial position in our history.
- My domestic travels were extensive and I was thrilled by the many invitations to address students, faculty, and administrators at welding schools, technical colleges, and universities. My thanks go to those board members who “chauffeured” me around their districts. The recession we’ve suffered through was an incentive for people to improve their career skills. No learning institution suffered from lack of students. Communities across the country are investing heavily in facilities and programs to enrich the knowledge of students.
- Our membership is at an all-time high and continues to grow. It was an honor to attend the many committee meetings. Volunteerism is the backbone of our Society and it is alive and well. Your combined efforts amaze other associations and the international community is paying attention.
- I was proud to represent AWS at the annual IIW Conference, which this year was held in Istanbul, Turkey. More than 700 members from 54 countries participated.
- During my travels, the international welding community expressed their opinions regarding the value of AWS standards, education and certification programs, publications, and committees, and I can assure you that your efforts are held in high esteem around the world. I met with the directors and staff of several different Bureaus of Standards. Your work is impressive, and your colleagues around the world are amazed that it is done by volunteers.

Special thanks go to my wife Donna for her dedication to getting me to the right place and on time. This year would not have been so pleasurable without her help and guidance. She was a fantastic emissary for the American Welding Society.

The Board of Directors and Executive Committee have great depth in technical and business experience and will do a responsible job of representing the AWS for years to come.

And, finally, I want to thank you, our members, for your support.

John C. Bruskotter
AWS President
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New Job Skills Initiative Established

The White House has announced the launch of a new initiative, Skills for America's Future, which is intended to improve industry partnerships with community colleges and build a nationwide network to maximize workforce development strategies, job training programs, and job placement. Housed at the Department of Labor and implemented in cooperation with the Department of Education, the initiative will seek to build career pathways with businesses, advance the teaching of basic skills, establish education partnerships with other institutions, and support new online, open-source courses so that community colleges across the country can offer more classes.

Further information is available at www.skillsforamerica.org.

OSHA Identifies Most Frequently Cited Standards

The Occupational Safety and Health Administration (OSHA) has announced the top ten most frequently cited standards for fiscal year 2010. OSHA publishes this list annually as a means of informing employers. Among the standards on the list are those addressing scaffolding, hazard communication, respiratory protection, ladders, and lockout/tagout. The list is available at www.osha.gov/top-ten-standards.html.

Report: U.S. Competitive Position Has Further Declined in Past Five Years

The outlook for America’s ability to compete for quality jobs in the global economy has continued to deteriorate in the last five years, and the nation needs a sustained investment in education and basic research to keep from slipping further, according to a new report issued by the National Academies. “Rising Above the Gathering Storm, Revisited: Rapidly Approaching Category 5” is a follow-up to a 2005 report, “Rising Above the Gathering Storm,” which called for strengthening K–12 education in the United States and doubling the federal government’s basic research budget.

Among the many indications that the United States’ competitive capacity is slipping, according to the report, is almost one-third of U.S. manufacturing companies responding to a recent survey say they are suffering from some level of skills shortage.

Small Business Legislation Signed into Law

The Small Business Jobs Act of 2010 includes several provisions designed to benefit small businesses, particularly with respect to access to loans. Small Business Administration section 7(a) loan limits are increased from $2 million to $5 million, 504 loans from $1.5 million to $5.5 million, and microloans from $35,000 to $50,000. The law also provides banks, with assets under $10 billion, with $30 billion in new capital to increase lending to small firms.

In addition, this new law provides a number of targeted tax breaks, including a five-year carryback of general business credits and reduced penalties for certain tax reporting errors.

Small Business Administration Quantifies the Cost of Federal Regulations

The annual cost of federal regulations increased to more than $1.75 trillion in 2008 (the most recent year for which data are available), according to the Small Business Administration. This translates into $8086 per employee for U.S. businesses, generally, and $10,585 per employee for small businesses, defined as firms employing fewer than 20 employees. The disparity in costs between small and large companies is greatest with respect to environmental regulations, by a factor of four.

Tax Reporting Requirement Still Unresolved

Congress and the business community continue to work together to try to devise a way of mollifying the impact of a federal law that, beginning in 2012, will require the IRS Form 1099 to be issued by companies to all vendors to which they pay $600 or more during the year for goods and services. The 1099 requirement currently applies only to payments made to unincorporated service providers. This new requirement is expected to significantly increase the administrative and paperwork burden of businesses, and there have been bipartisan efforts to address the issue. The challenge is that the new law also is expected to raise an additional $18 billion in tax revenue for the federal government, and replacing that revenue is the key challenge.

China Intellectual Property Violations Debated

Witnesses testifying at hearings before the Congressional-Executive Commission on China painted a disturbing picture of continuing tolerance in China of infringement and theft of intellectual property. According to Rep. Sander Levin (D-Mich.), commission cochairman, “The Chinese government has failed to comply with the commitments to protect intellectual property rights that it made as a member of the World Trade Organization, and it continues to undermine protections for intellectual property contained in its own laws and regulations.”

The Congressional-Executive Commission on China was created by Congress to monitor the rule of law in China. It consists of 12 Congress members and five senior administration officials appointed by the president.

OSHA Plans to Reinterpret Noise Standard

The Occupational Safety and Health Administration (OSHA) has announced its intention to change a 27-year-old policy regarding noise exposure in the workplace. Since 1983, except in extreme cases, OSHA has approved the use of personnel protective equipment and hearing conservation programs as means of complying with noise rules. However, OSHA has announced it plans to change that policy and begin requiring engineering and administrative controls to reduce or eliminate exposure in order to comply with 29 CFR 1910.95(b)(1) and 1926.52(b).
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**Stainless Steel Production Starts at ThyssenKrupp’s Alabama Facility**

The new stainless steel mill at ThyssenKrupp’s Alabama plant has gone into operation with production of cold rolling mill. Cold-rolled capacity is initially 100,000 metric tons a year and will increase to a maximum 140,000 tons a year. The material now being produced is 64 in. wide. Various units have been commissioned and further work is planned to integrate the cold-rolled strip as well as finishing equipment.

“The start of production marks a key milestone. I am proud of our team, who has mastered this complex project so successfully in a difficult economic environment,” said Dr. Ulrich Albrecht-Früh, CEO of ThyssenKrupp Stainless USA.

Work to build the new site began in 2007 in partnership with ThyssenKrupp Steel USA. The capital investment for the integrated stainless mill in Calvert is around $1.4 billion. ThyssenKrupp Nirosta shipped the first white coils in preparation for the hot commissioning of the stainless equipment. Following startup, production on the cold rolling mill is now being ramped up using material supplied from the company’s Europe stainless mills. Construction of the other units is planned or in progress.

**GAWDA Names Executive Director**

The Gases and Welding Distributors Association (GAWDA), Miami, Fla., recently named John C. Ospina as the organization’s executive director. Ospina will oversee the day-to-day administration of the association, its programs, and serve as the main liaison to sister associations. Also, he will provide input to the GAWDA board of directors on issues that may affect the association’s mission, programs, or future direction. His new post becomes official on December 1.

“John has a solid background in a variety of areas important to GAWDA’s mission and growth. His experience includes operations, events, contract negotiations, financial analysis, and marketing, and he is experienced in working with volunteer leadership, from board level to grass roots. He is a natural fit for the position of executive director of GAWDA,” said Lloyd Robinson, GAWDA president.

Prior to accepting the position, Ospina served the American Welding Society (AWS) for nearly 20 years in a variety of management positions. Most recently, he was the director of Conventions & Event Services for the association. AWS presently provides association management services for GAWDA.

Ospina is a graduate of La Guardia College in New York and currently resides in Hollywood, Fla., with his wife and two children.

**Miller Electric Expands Welding Automation Offering**

Miller Electric Mfg. Co., Appleton, Wis., entered into a strategic partnership with Panasonic Welding Systems Co., Ltd., a division of Panasonic Corp., to make Miller Welding Automation, a new business unit, the distribution route for Panasonic robotic welding arms in North America. These arms will be combined with the company’s products and delivered as part of a complete automated welding system.

In addition, Miller has purchased assets of the Panasonic Factory Solutions Co. of America (PFSA) welding automation business, and to augment this, Miller Welding Automation has been created to deliver and support the new system. The affected PFSA robotic welding employees will join the new business and continue to support welding automation needs in North America.

Miller Welding Automation will offer preintegrated systems and standalone automated welding components in cooperation with its distributor partners. For more complex requirements, it will support application-specific systems to qualified integrators. Also, it will establish a new dedicated welding automation facility in Carol Stream, Ill. The business will include a support office in Mississauga, Ont., Canada. John Winck will serve as the general manager of this new business.
Congratulations to John Mendoza

Incoming 2011 AWS President
From your District 18 Members

Incoming President
John Mendoza

Corpus Christi Section, El Paso Section,
Houston Section, Lake Charles Section,
Mexico Section, Rio Grande Valley Section,
Sabine Section, San Antonio Section
Vestas Towers America Celebrates Grand Opening of Wind Towers Factory

Vestas Towers America, Inc., recently opened what it states is the world's largest wind tower manufacturing plant. The new facility in Pueblo, Colo., features nearly 13 million sq ft of space and eight miles of on-site railway tracks for the transport of materials and finished tower components. This allows the company to address growing needs among North American wind power plants for reliable, high-performance wind turbines.

U.S. Secretary of the Interior Ken Salazar joined regional and local Colorado dignitaries, as well as Vestas Towers A/S President Knud Bjarne Hansen and Vestas Americas President Martha Wyrsch, in making the announcement during a ribbon-cutting ceremony. “The steel industry has and will continue to play a large role in Pueblo’s identity, but as seen here today, the renewable energy industry is carving its own path into the city and state’s history,” said Salazar.

In addition, participants at the event recognized a factory that currently employs more than 400 workers; is capable, at peak production, of producing 1090 towers per year; and has the ability to process more than 200,000 tons of steel per year.

In the past few months, Vestas Towers America has been recruiting and hiring people who are skilled in jobs ranging from engineering to human resources and from welding to painting.

“We’ve hired people in a number of functions related to tower building, including steel fabricators, finishers, welders, assemblers, and maintenance personnel,” said Anthony J. Knopp, vice president, Vestas Towers America. “It’s amazing how many traditional manufacturing job skills are directly transferable to Vestas.”

The Vestas Towers America factory in Pueblo, Colo., has officially opened for business. According to the company, it’s the world’s largest wind tower manufacturing plant. An overhead view of the facility is shown above. (Photo courtesy of Jesper Balleby.)

An employee welds tower sections at the new Vestas tower factory. (Photo courtesy of Vestas Wind Systems.)

The Need for Materials Joining in North America: Making a Compelling Case

Industry and markets often transform themselves as they come out of major economic disruptions such as the recent recession, remarled Henry Cialone, president and CEO of EWI, during the opening of the Future of Materials Joining in North America Conference. “The innovators that lead the change often prosper,” he said. “For example, the personal computing business grew rapidly following the deep recession of the early 1980s and the World Wide Web business took off after the recession of the early 1990s.”

The conference brought together speakers and attendees from manufacturers, universities, national laboratories, government, and nonprofit manufacturing-related organizations to explore collaborative approaches to advancing North America’s competitive position in regard to materials joining. The by-invitation-only event took place in Ohio in early August and was cosponsored by EWI and the American Welding Society. Attendees participated in breakout sessions to determine what materials joining challenges and opportunities should have highest priority, what collaborative approaches could be most beneficial for developing and implementing materials joining technologies to advance North American competitiveness, and what funding sources and collaborative arrangements are required to establish effective approaches. As a follow up to the conference, EWI staff is preparing a report to make a compelling case for materials joining technology for industry and government.

Cialone outlined a variety of challenges besides the effects of the recession that industry faces, including the following:

• Global competition
• Changing sources of energy
• Increased cost of energy and materials
• Environmental concerns that are leading to new regulations
• An aging workforce
• Increased importance of technical skills.

W. R. Timken Jr., former head of The Timken Co., a global bearing manufacturer, served as ambassador to Germany 2005–2008 and now chairs Strategic Public Partners Group, Columbus, Ohio, a public affairs and lobbyist organization.

“An objective analysis shows manufacturing offers three times the value of the service sector,” Timken said. “Every dollar of man-
Manufacturing activity results in $3 of something else in the economy. “To increase our standard of living, we need more highly productive manufacturing jobs,” he said. To encourage development of those jobs, Timken said the U.S. government needs to do the following:
• Produce better students with more math and science knowledge
• Build a better infrastructure
• Invest in basic research
• Reduce regulatory burdens
• Lower taxes.

“What government should not do is follow policies that increase the cost of energy,” he said, adding that readily available, low-cost energy has been a major benefit to U.S. industry over the years.

In her keynote address, Emily Stover DeRocco, president of The Manufacturing Institute, bemoaned “the air of inevitability and resignation about the loss of U.S. manufacturing.” Manufacturing is important for two primary reasons. The first is national security: “The people of any country must produce the tools to protect themselves.” The second is economic security. “Successful economies have the ability to turn raw materials into something of greater value” — Mary Ruth Johnsen, Editor.

Artistic Talents of Autoworkers Stand Out at UAW-Chrysler Exhibit

A welded sculpture symbolizing the plight of innocent civilians victimized by a civil war in Africa captured top honors as Chrysler Group LLC and the United Auto Workers (UAW) unveiled an art show that reveals autoworkers’ creative side.

The jointly sponsored 2010-2011 Artists at Work Exhibition features 85 pieces of art, ranging from sculpture and painting to blown glass and photography, by 39 UAW-represented and non-

Dennis Sabatowich’s Darfur metal sculpture, which is 48 x 12 x 12 in., earned first place in the 2010-2011 Artists at Work Exhibition sponsored by Chrysler Group LLC and the United Auto Workers. (Photo courtesy of R. H. Hensleigh.)
bargaining unit Chrysler employees.

The employee-artists were recognized at a reception at the UAW-Chrysler Technology Training Center in Warren, Mich. Three judges from the professional art community chose pieces for this exhibition, the eighth coordinated by the UAW-Chrysler National Training Center since 1999.

Judges awarded best-of-show prizes to three employees and singled out eight employees for honorable mention recognition. For the first time, Chrysler Group employees also shared the Artists at Work spotlight with children from a Detroit youth center that seeks to meet the needs of disadvantaged kids.

This year’s first-place winner, Dennis Sabatowich, is a weld inspector at Warren Truck Assembly. The UAW Local 140 member impressed the judges with his thought-provoking metal sculpture that raises awareness of the humanitarian crisis caused by the ongoing civil war in the Darfur region of western Sudan.

“I was trying to picture what an individual would look like after weeks of wandering in a desert, looking for help,” said Sabatowich. “Your village was burned to the ground, village people are killed, and the lucky ones flee into the desert with just the clothes on their backs.”

Loel Gnadt, an electrician at Warren Stamping and member of Local 869, earned second place for demonstrating his skills at wood turning. His entry consisted of a vase, candy dish, and rounded vessel. He said this process yields “great joy and satisfaction when the more complicated pieces come out just as I envisioned them.”

Richard Weber, an assembler at Belvidere (Ill.) Assembly and Local 1268 member, won third place with a photograph that provides a panoramic view of downtown Belvidere.

Eight employees also received honorable mentions for 2010-2011, including Michael Cattane, James Donnellon, Stanford J. Giles, Phillip H. Hill Sr., Michael M. Lynch, Catherine Stoey, Tamnie Wilson, and Ghevarghese Yohannan.

The artistic talents of five children from the Woodbridge Community Youth Center’s after-school program were recognized as well in the new Youth in Focus section of the display.

The Artists at Work Exhibition will travel to the Chrysler Technology Center where it may be viewed by employees and visitors at the headquarters complex for about six weeks. The UAW-Chrysler National Training Center and the UAW-Chrysler Technology Training Center will host the artwork for a year upon its return from corporate headquarters. The exhibit may be viewed at www.uaw-chrysler.com but is not open to the public.

**Porsche Reveals I-CAR Training Requirements for Technicians**

The Inter-Industry Conference on Auto Collision Repair (I-CAR), Hoffman Estates, Ill., recently announced Porsche now requires its classroom training, the I-CAR Steel GMA Welding Qualification Series and the I-CAR Structural Parts Steel Welding Qualification Series, as components of the “Porsche Approved Collision Center Program.”

“With a strong background in some of today’s most commonly used materials and procedures, as well as completion of two of I-CAR’s Welding Qualifications Series, technicians will be well-equipped to complete Porsche training and perform quality repairs on Porsche vehicles,” said Mike Kukavica, Collision Repair technology instructor.

Individuals will receive training on some of today’s most common collision repair procedures, as well as comprehensive welding instructions that includes theory, hands-on practice, and the
The I-CAR Steel GMA Welding Qualification Series requires students to make four different welds on galvanized steel coupons in the vertical and overhead welding positions. (Photo courtesy of I-CAR.)

Industry Notes

- Hobart Welding Products recently appeared on a SPEED Channel episode of Two Guys Garage. Host Bryan Fuller taught a group of disabled war vets from Operation Comfort the basic skills of gas metal arc welding. For scheduled times, check local listings.

- The welding technology program at Williston State College, N.Dak., has returned to the school after many years. Bruce “Buck” Dannar, an American Welding Society Certified Welding Inspector and Certified Welding Educator, is the instructor.

- Steel Dynamics, Inc., recently announced standard strength rail produced at its Columbia City, Ind., mill has been tested and approved by four U.S.-based Class I railroads and Amtrak.

- Starting in January, Austin Polytech’s Manufacturing Technology Center will open for adult education courses. Trainees will learn to operate computer numerical controlled (CNC) machines to earn the CNC Operator and CNC Set-up, Program, and Operator certificates from the National Institute for Metalworking Skills. For more details, go to www.austinpolytech.org.

- More than 200 people attended the grand opening/ribbon-cutting ceremony for the Skilled Trades Center at Terra Community College, Fremont, Ohio, which offers welding. The 23,225-sq-ft building was built at a cost of about $3.5 million.

— continued on page 84
Q: We have taken on a brazing application in our shop that requires silver brazing. Our brazing experience is in copper brazing of low-carbon steel in a furnace, but we are looking for new work and we successfully bid on this job.

The assemblies are 304 stainless steel and we are using induction heating with two, small, high-frequency units given to us by the customer. We use a BAg-24 brazing alloy and a black flux. One component is machined and the other is a tube. The brazing alloy is a ring placed on the outside of the joint with the brazed joint made by the alloy flowing into the joint.

The production volume is much lower than in our furnace brazing area, but we need an operator full time to run this process. We need to be careful about where we heat the parts in the induction coil or we run into problems with the brazing alloy running onto surfaces that it shouldn’t. The parts become heavily oxidized and need to be cleaned after brazing. It seems it would be much more cost effective to run these parts through our furnace using copper. What do we need to do to achieve this?

A: While both of the processes, one using copper and the other silver, are considered brazing, they have process and design characteristics that differ from one another. While it is possible that you could transfer assemblies from one process to another, the results may not be optimum and may require quite a bit of change to achieve.

Copper brazing is done extensively in industry segments such as automotive where large volumes of low-carbon-steel assemblies in a wide variety of irregular configurations can be run through a furnace. The parts are typically self-fixtured or can be tack welded together. Joint clearances are a press fit that is ideal for molten copper to flow through. The atmospheres have high dew points, as high as 20°F (−6.7°C). The assemblies exit the furnace clean, eliminating the need for postbrazing cleaning. In many cases copper brazing paste can be used, eliminating the need for a large inventory of complex preform shapes. Copper is acceptable from a corrosion point of view for the low-carbon steel that is being joined. In many cases the finished assemblies are painted or coated in some fashion. You do this in your core business so you are probably familiar with these characteristics.

In looking at your application, first consider the joint clearance. Unlike copper brazing, which uses press fits, when using silver brazing filler metals you need a clearance in the joint for the alloy to flow. Depending on the specific filler metal and heating conditions, the joint clearance would need to be somewhere between 0.001 and 0.005 in. (0.025 and 0.127 mm). I am sure your assemblies as currently designed fall in this range. You mentioned that you are using BAg-24 filler metal. This is considered to be one of the best general-purpose, low-temperature silver filler metals for brazing stainless steel with flux in air. To use copper, your assemblies would need to be redesigned to a press fit.

The BAg-24 filler metal is commonly recommended for brazing stainless steel. Its nickel content gives it good wetting and corrosion protection. It has a low melting range of 1220°–1305°F (660°–707°C) so there are minimal heat effects on the base metals. Copper, however, has a very high melting point. Copper melts at 1981°F (1083°C) so the heat effect on the assemblies is significantly greater.

Changing braze filler metals is a decision for the customer’s design staff. While the joint clearance change may be acceptable, the change in heat effect and corrosion protection may not. From a joint strength perspective, there should be no issue if, in both cases, the joints are properly designed.

Perhaps the most practical thing to consider is the furnace requirement. A furnace typically used for copper brazing of low-carbon steel parts is unsuitable for stainless steel. Stainless steels normally require a reducing atmosphere with a dew point of −60°F (−50°C) or drier. Your customer may have chosen induction heating as an alternative to furnace brazing because of the low production volume and the capital expenditure of a new furnace. It is also a work flow issue. If the volumes are low enough, one operator running two induction units may be able to keep up with it.

You also mention that the parts need to be heated in such a way as to keep the brazing filler metal from flowing in a detrimental manner. You mention that one part is machined and one is a tube. Generally, this implies differential masses with the machined part being more massive and the tube having a thin wall. These assemblies always present a challenge to heat.

A rule of thumb is to apply heat preferentially to the more massive component if possible. Induction heating is very local and precise, tied to the coil type and how closely the parts are placed in proximity to the coil. Many times it is difficult to place components in the coil so that they heat consistently from part to part due to part inconsistency, fixture design, or coil fabrication quality. It is common with round parts to rotate them in the heat to offset this heating nonuniformity. It is possible, however, to control brazing filler metal flow through coil design, power settings, and location of the parts in the coil.

This type of control would be difficult in a furnace. The entire assembly is brought up to brazing temperature and controlling flow is much different. You may need to redesign the joint to achieve the desired result. For example, with your assembly, the brazing ring is placed on the outside of the joint and, by controlling the induction heating, you pull it in to the joint. For furnace heating, you may need to place the ring inside the joint in some fashion and have the brazing filler metal flow outward to make the joint.

If volumes increase, there may be justifiable to look at the benefits of controlled-atmosphere furnace brazing. For now, with joint redesign and a possible capital expenditure needed, the application seems to fit well with what you are doing.

This column is written alternately by TIM P. HIRTHE and ALEXANDER E. SHAPIRO. Both are members of the C3 Committee on Brazing and Soldering and several of its subcommittees, ASH Sub-committee on Filler Metals and Fluxes for Brazing, and the Brazing and Soldering Manufacturers Committee (BSMC). They are coauthors of the 5th edition of AWS Brazing Handbook. Hirthe (tim.hirthe@aol.com) currently serves as BSMC vice chair and owns his own consulting business. Shapiro (ashapiro@titanium-brazing.com) is brazing products manager at Titanium Brazing, Inc., Columbus, Ohio.

Readers are requested to post their questions for use in this column on the Brazing Forum section of the BSMC Web site www.brazingandsoldering.com.

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Q&A

I recently attended the 2010 American Welding Society (AWS)/Aluminum Association (AA) Annual Aluminum Conference in Seattle, Wash. I feel fortunate to have participated in this event with many renowned authorities in aluminum welding technology.

During the conference, speakers addressed such diverse subjects as the aluminum designation system; metal preparation for welding aluminum; filler metal selection for aluminum alloys; gas metal arc welding (GMAW); gas tungsten arc welding (GTAW); weld discontinuities; AWS D1.2, Structural Welding Code — Aluminum; robotic applications; friction stir welding of aluminum; thermal cutting processes used for aluminum; and explosion bonding of aluminum to other materials.

The conference was well attended with individuals from as far as Japan and China. Considering today’s economic environment, I found the attendance impressive and surely an indication of aluminum’s continued advancement within the welding fabrication industry.

As an overview of some of the issues surrounding the welding of aluminum, I would like to address, in brief, some of the questions that were asked of me at the conference.

Q: Why am I having porosity problems in my aluminum welds?

A: Porosity arises from gas (dissolved in the molten weld metal) becoming trapped as the weld solidifies and forming bubbles in the solidified weld — Fig. 1. Determining the root cause of porosity in aluminum welds is similar to a detective solving a crime. We need to evaluate the evidence and eliminate the innocent to identify the culprit. In order to conduct such an investigation, it is essential that you understand the adversary. In order to conduct such an investigation, it is essential that you understand the adversary. In order to conduct such an investigation, it is essential that you understand the adversary.

Using the Plunger-Type Guided Bend Jig Rather than the Wraparound Guided Bend Jig

The AWS D1.2 code is very clear in stating that the wraparound bend jig is the preferred method of bend testing aluminum weldments and even provides an explanation in the commentary as to why. The plunger-type test jig may prove suitable for some of the low-strength base materials. However, it is my opinion that the wraparound should be used for all aluminum alloys — why take a chance?

Incorrect Preparation of the Bend Test Samples

This may be as simple as not applying the required radius to the edges of the test specimen or producing specimens of an incorrect size. However, it is most often associated with not applying the alloy-specific special bending conditions contained within the code.

In AWS D1.2, the footnote below Fig. 3.13 (see 3.8.1.7) is extremely important. This paragraph is titled — Special Bending Conditions — M23, M24, M27 Base Metal, and F23 Filler Metal. If the instructions contained within the special bending requirements paragraph are not followed, you may experience major problems during bend testing. Because of very different as-welded mechanical properties within the different groups of materials (aluminum alloys), dissimilar alloy groups must be tested in very different ways. Some of the variations that are alloy group specific are as follows: reducing the specimen thickness to ¾ in. prior to bend-

— continued on page 18
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What Does a 'Code' Shop Actually Represent?

A long-time American Welding Society member, who has been a Certified Welding Inspector (CWI) for 13 years, gives his thoughts on the matter.

All the time, I run into the issue of shops that constantly claim to be "code" shops but fall miles short of even coming close to being one. After speaking to a friend about this, it dawned on me that it's very possible there might be an honest misunderstanding about what a code shop really is. I haven't seen a definition in a long time, so here's my view on the subject.

What's involved in a code program? The uniform performance to an acceptable standard or code that will put all welding operations on the same level of the playing field, giving the customer a known level of expectations.

What's the purpose of being a code shop? To work to a set of rules with the sole intention of establishing a meaningful quality reputation.

To say you are a code shop and perform as a code shop are two different things. Integrity is just another word for being responsible or respectable. You can't put a price tag on that. One welder or 100, the application is the same.

Let's define three important words:
- Code — a body of rules for construction or fabrication of a product.
- Standard — a document or object used as a basis for comparison.
- Specification — describes the requirements for a particular object, material or service, and describes a specific part or material.

It all boils down to two things — product liability and giving the customer a certain comfort level in what their expectations of you are — both of which are extremely important to the existence and growth of the manufacturing and service industries, not to mention peace of mind. Determine what code best suits your operation; get qualified and competent quality control inspectors; work on, develop, and maintain that program; and stay current.

Is being a code shop worth it? Ask yourself what level of quality you expect from your vendors (their reputation). You have to pursue quality (your reputation). It's not free, as it requires a modest investment, but it's priceless.

Phil Evans
AWS CWI
Pulaski, Tenn.
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Fabricating Railcars with Resistance Welding

An overview is provided on the history, base materials, equipment, and standards regarding the use of resistance welding in creating stainless steel passenger railcars.

BY WŁADYSŁAW JAXA-ROŻEN

The application of resistance welding in the production of transportation vehicles has traditionally been associated with automobiles. However, there is a lesser known area where the process has been used with success and to its full potential since the 1930s — fabrication of stainless steel passenger railcars.

History

The use of resistance welding for stainless steel railcar fabrication was a fascinating feat of engineering linked to the creativity and vision of Edward Gowan Budd (1870–1946), founder of the Edward G. Budd Manufacturing Co., Philadelphia, Pa. — Fig. 1. His company was the first to produce all-steel automobile bodies and also one of the first to use resistance spot welding.

During his visit to Europe in 1930, Edward Budd became fascinated with stainless steel. At the same time, Ralph Budd (no relation), president of Burlington Railway, had the idea of applying stainless steel in railway car design and fabrication. Two important developments followed: the mastery of producing 18-8 cold-worked, high-strength austenitic stainless steel by the Allegheny Steel Co., and the growing experience and competence of the Budd Co. regarding formability of the material and spot welding technology.

Stainless steel used by the Budd Co. had tensile strengths up to 160 ksi (1100 MPa) and yield strength of 120 ksi (830 MPa). Its weldability with both fusion and resistance processes was impaired by a relatively high carbon content that caused chromium carbide precipitation in the heat-affected zone (HAZ). Budd’s chief engineer, Col. Earl J. W. Ragsdale, found the remedy. His ‘shotweld’ spot welding process featured a welding time that was shorter than the dwell time causing the development of chromium carbidies.

The Creation of Zephyr Trains

As a result, a new kind of passenger rail vehicle was manufactured and put into service in 1934. This was the birth of the Burlington Zephyr trains — Fig. 2. The conjunction of stainless steel, resistance welding, creative minds, and bold management brought a major paradigm shift. Compared with existing railcars, the stainless steel train was much lighter, which in turn made the first application of a diesel-electric propulsion unit practical.

In a display of its speed, the first Zephyr made a 1015-mile nonstop run from Denver to Chicago at the record average of 77 miles/h. Soon after, the first disc brakes were introduced. The sleek sil...
very train was a forerunner in streamlined industrial design.

The Zephyrs changed railway travel, due to their speed, comfort, and amenities such as attractive interior design, air conditioning, and an audio system broadcasting radio, public addresses, and music from wire recorders. A popular feature was the domed observation lounge.

**Progress**

Budd’s example was followed by the St. Louis Car Co. and Pullman-Standard in the United States. Together they produced thousands of stainless steel passenger railcars.

The next important development occurred in Japan, where stainless steel passenger railcars, mostly for subway and commuter trains, have been mass produced since the end of the 1950s. In Asia, stainless steel railcars are also produced in India and South Korea.

In North America, Bombardier Transportation entered the rail transit industry in the mid-1970s and has grown to be a global producer of subway, commuter, and intercity railcars. Its La Pocatière, Québec facility in Canada has specialized in stainless steel since the beginning of the 1980s. This plant also produced carshells of the Eurotunnel shuttle cars, the largest stainless steel cars ever made — see lead photo. In Europe, for reasons associated with a traditional requirement for car bodies to be entirely painted, stainless steel cars gained only limited popularity. This is not the case in Australia, where stainless steel cars are produced and used.

**Materials Used for Railcars Construction**

**Chemistry**

The first stainless steel railcars were made from an austenitic alloy produced by Allegheny and classified by Budd as 18-8 steel consisting of 18% chromium and 8% nickel. Relatively high carbon content made this steel susceptible to chromium carbide precipitation in the HAZ of welds and to subsequent intergranular corrosion. The need to limit dwell time in the critical temperature range inspired the motivation for Budd’s experts to invent the short-time spot welding process (‘shotweld’).

In the 1950s, 201 and 202 steels were also applied. In their chemistries, a substantial part of the nickel is replaced with manganese. Later, 17-7 Type 301 steel was introduced. In the 1980s, the advent of argon-oxygen decarburization allowed the fabrication of low-carbon stainless steels containing less than 0.03% C. This carbon level prevents sensitization of stainless steels caused by welding, either with resistance or fusion processes. Because of recent increases in the price of nickel, the 200 series of stainless steels is currently (2008–2010) regaining interest.

The chemical compositions of selected austenitic stainless steels are presented in Table 1.

With regard to other groups of stainless steels, duplex steels have the potential for application, especially because of their high strength in larger thicknesses. However, they probably will not become popular in the production of railcars. They are more expensive than austenitic steels, and in lower thicknesses (up to about 5 mm), cold-worked austenitics are stronger than duplex steels. Where larger thicknesses are required, high-strength, low-alloy (HSLA) steels with yield strengths up to 700 MPa are commonly used. The use of martensitic and ferritic steels is limited to nonstructural applications.

In the remaining part of this article, only austenitic steels are considered.

**Mechanical Properties**

In typical descriptions of austenitic stainless steels, their mechanical properties are those in the annealed condition. However, the strength of these materials may be significantly increased by cold deformation, such as thickness reduction in cold rolling, forming, or bending.

Deformation strengthening of austenitic steels results from partial transformation of austenite into martensite. Strength levels of cold-worked stainless steels are covered by ASTM International’s A666, Standard Specification for Annealed or Cold-Worked Austenitic Stainless Steel Sheet, Strip, Plate, and Flat Bar, and British Standard EN 10088-2, Stainless Steels: Technical Delivery Conditions for Sheet/Plate and Strip of Corrosion Resisting Steels for General Purposes.

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<tr>
<th>Element</th>
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<td>C</td>
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<td>Cu</td>
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Contents: wt.-%, maximum values unless otherwise specified.

**Table 1 — Chemical Composition of Selected Austenitic Stainless Steels**

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**Fig. 1** — Edward Gowan Budd. (Photo courtesy of the Hagley Museum and Library.)

**Fig. 2** — The Burlington Zephyr train came into service in 1934. It was a forerunner in streamlined industrial design.

**Fig. 3** — Only 20 of the RB-1 Conestoga cargo planes were produced. (Photo courtesy of Wikipedia.)

**Fig. 4** — A spot weld in a thick assembly, totaling 15.6 mm, is shown. (Photo courtesy of Bombardier.)
The strengthening efficiency of cold rolling depends on the material thicknesses. As an example, in thicknesses up to 1 mm, tensile strength close to 1300 MPa and yield strength (0.2% proof) close to 1000 MPa may be achieved. For 5-mm-thick materials, the achievable values are 1000 and 750 MPa, respectively. The high strength-to-weight ratio allows for considering cold-worked stainless steel as lightweight material.

The first stainless steel moving object manufactured by Budd was the Pioneer amphibious plane launched in 1931. It was followed 12 years later by the RB-1 Conestoga cargo plane, 20 of which were built — Fig. 3.

An important characteristic of cold-worked austenitic steels is the absence of yield point in tensile deformation. In design, 0.2% proof stress is typically used as the reference value.

**Technological Properties**

Austenitic stainless steels can be bent with ease. Even in the cold-worked condition, material may be safely bent with a radius equal to twice its thickness.

Formability of austenitic steels is strongly dependent on the initial condition of the material. Annealed material can be formed without difficulty, while the forming potential of cold-worked materials is limited. If material is to be formed, its final properties resulting from deformation may be considered for design.

**Physical Properties**

Three properties of austenitic steels are important for resistance welding — electrical resistivity, thermal conductivity, and coefficient of thermal expansion. In comparison with the properties for carbon steels, austenitic steels have a resistivity five times higher, thermal conductivity three times lower, and coefficient of thermal expansion one-third higher.

**Weldability**

Austenitic stainless steels do not undergo the γ-α transformation, which ensures their good metallurgical weldability. A limited recrystallization occurs in the HAZ, leading to some softening. However, this has practically no consequence on the strength of resistance welds. The HAZ remains ductile in all cases. In either a peel or chisel test of spot welds, a well-defined button is always obtained.

High resistivity of austenitic steels allows for rapid obtaining and growth of the weld nugget. This is further enhanced by the low thermal conductivity, which lim-
its heat sinking into surrounding material. As a result, relatively low amperages are required, and spot welding multiple part combinations of a large total thickness is possible — Fig. 4.

The high coefficient of thermal expansion results in a tendency to produce nugget shrinkage discontinuities as well as high residual stresses in welds and distortion of assemblies. To prevent both occurrences, high forging forces are applied.

Design

A typical car body is of monocoque design — Fig. 5. The sides and roof consist of cold-formed member frames to which skin is attached. The floor structure is composed of crossbeams, which are fixed to side sills. A center sill is rarely used. The design strength of spot welds is defined in standards such as the AWS Cl.1, Recommended Practices for Resistance Welding, and AWS D17.2, Specification for Resistance Welding for Aerospace Applications. Minimum distance between spot welds is limited by shunting current. The typical maximum center-to-center distance in North American practice is 50 mm + 2d, where d represents the nugget diameter. These design principles have ensured structural integrity of the cars through the decades. In addition, the strength of seam welds is comparable to that of base metal and is not a design consideration.

Fabrication

The external surfaces of stainless steel car bodies should be scratch free and flat. No thermal straightening, such as that used in the fabrication of carbon-steel cars, is possible, and restoration of the original finish is difficult. Also, spot weld indentations should be shallow and defect free, and no discoloration on visible surfaces is permitted. The answer to these challenges is the use of protective plastic foil, which is removed just before welding; appropriate welding schedules and sequences; and the use of shielding gas. Contact surfaces of electrodes should be maintained in a perfect state, and the schedules of electrode dressing and replacement should be rigorously respected.

Equipment

General Requirements

Resistance welding equipment should have the following characteristics:
- Large length and width coverage
- High forces up to 20 kN (4500 lbf)
- Moderate amperages with an order maximum of 15 kA for spot welds and 30 kA for seam welds
- High reliability

A description of the particular equipment elements follows.

Stationary Machines and Mobile Guns

Stationary machines and C-type mobile welding guns should have rigid structures — Fig. 6. Rectilinear movement of electrodes is preferable to rotational movement. For gun structures, nonmagnetic stainless steel is the material of choice.

Cylinders

Cylinders should ensure rapid advance movement, high forces, and soft contact with welded assembly. They should also have a limited size. Hydraulic and pneumatic cylinders only partially meet these requirements. An optimal solution is represented by a cylinder using both media with an internal intensifier. The device makes a quick “soft touch” approach using compressed air. Upon the contact between electrodes and the assembly, the air pressure is converted into a high hydraulic force — Fig. 7. Electric servo-guns represent an interesting application potential, especially when their squeezing force reaches the required level.

Electrodes

Resistance Welding Manufacturing Alliance (RWMA) Class 3 electrodes are used. This class primarily includes UNS C17510 beryllium copper and UNS C18000 nickel-silicon copper, the latter commonly referred to as beryllium-free Class 3. Beryllium copper provides remarkable performance; however, use of this alloy for electrodes has become complicated because of restrictions related to beryllium toxicity. As a result, C18000 is now the preferred alloy for electrodes. A spherical contact surface of a 75 mm (3 in.) radius, recommended by the AWS Cl.1 standard, represents an optimal shape. Large electrode diameters around 20 mm (0.750 or 0.875 in.) are preferred.

Gun Positioning

Guns for welding large structures are displaced by gantry systems, the level of mechanization of which varies from manual to fully automatic. In manual mode, spot welds are positioned with the help of templates.

The opposite side of the spectrum is represented by robotic gantry systems, which are typically used for welding side and roof frames. For better flexibility, the welding head is equipped with a gun exchanger.

Welding the roof and side skins to their structures represents a special challenge.
Up to a certain width, mobile C-type guns may be used. In some cases, guns may be introduced through window and door openings. However, this solution is laborious, and not always possible. In the case of roofs, the situation is further complicated by their curvature. A possible solution consists of using specialized gantry machines with separate but synchronized mechanical systems for top and bottom electrodes — Fig. 8.

**Power Sources**

All kinds of systems may be used to provide welding current. For large spot welding machines, direct current is the preferred logical choice. As in the whole resistance welding industry, medium frequency inverters have made their entrance.

**Seam Welding Machines**

Seam welding is used to assemble the roof and sometimes the side skin panels. The considerable size of both assemblies requires large installations. Fixed-machine stations have a length that is twice that of a railcar. This is not the case of stations using mobile machines. However, while sparing a lot of floor surface, this solution represents considerable challenges, not least of which is the accurate movement of heavy cantilevered equipment. Weld discoloration is prevented or limited by water jets from the top and bottom sides. The current used is direct with polarity changing from one pulsation to another.

**Resistance Welding Controls**

Because of the required quality of the welds, as well as of the multitude and complexity of schedules, the most advanced resistance welding controls are sought. Monitoring capability of the controls is used for a signature verification of each weld.

**Quality**

**General Requirements**

The requirements for weld integrity and appearance necessitate stringent weld quality criteria. There can be no nugget expulsion. Indentation must be shallow and uniform. Discoloration at surfaces exposed to users is not permitted. There are precise limits of nugget strength, diameter, penetration, and discontinuities.

**Standards**

The two basic standards used in North America are AWS D17.2, Specification for Resistance Welding for Aerospace Applications, which replaced the military specification MIL-W-6858D, Welding, Resistance: Spot and Seam, and AWS C1.1, Recommended Practices for Resistance Welding. AWS C1.1 covers a larger range of thicknesses, while AWS D17.2 has requirements for multiple thicknesses.

In Canada, the Canadian Standards Association’s W55.3, Certification of Companies for Resistance Welding of Steel and Aluminum, is also used. This standard defines conditions regarding personnel, equipment, and quality systems, which must be met by a company to be certified by the Canadian Welding Bureau.

The European Committee for Standardization and International Organization for Standardization have published numerous standards for resistance welding. Typically, they are short documents linked through cross references, describing test procedures, rather than specifying precise acceptance criteria.


**Welding Procedure Specification Establishment and Qualification**

Fabricating car bodies requires a large number of spot welded thickness combinations. Combinations may include three, four, and even five thicknesses of varying gauges. In large stations, dozens of different combinations must be welded, and their number is by far larger than that of available schedules. This represents a challenge for resistance welding technicians. Another difficulty is a need to verify the shear strength qualification assemblies totalling up to four faying surfaces.

**Production Control**

Every weld is important to the structural integrity of the car. Consequently, rigorous quality control is necessary during fabrication. Monitoring parameters combined with application of threshold values for essential variables allows for real-time verification of the process. On automatic equipment, position and signature records for each weld are used for traceability. Also, frequent testing is performed on samples, namely chisel tests and periodic verification of weld characteristics, which were determined in procedure qualification. The equipment operators’ involvement and constant vigilance represent equally important factors in ensuring quality of production welds.

**Conclusion**

In the fabrication of stainless steel rail cars, resistance welding ensures high-productivity, structural integrity, and aesthetic quality, while taking advantage of the characteristics for austenitic steels.

More than 75 years after introducing resistance welding in passenger railcar fabrication, the legacy of Edward G. Budd and his companions is still alive and well.♦

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It is important to minimize overwelding in order to reduce costs, distortion, and assembly problems.

Understanding welding economics and the variables that affect those economics are critical. This knowledge can provide you with the information necessary to make the best decisions to positively affect quality and productivity.

Overwelding can have a significant effect on costs because it increases filler metal consumption and your welders' total arc-on time. The following information should help you avoid overwelding.

Factors that Affect Welding Decisions

When deciding which type of weld joint to use, the choice becomes a trade-off between the cost of the weld preparation time for a groove weld vs. the additional deposited weld metal needed to make a fillet weld of equal strength. For sheet metal and light plate thicknesses, the comparison usually favors the use of fillet welds. In heavier plate, the advantage in productivity shifts to groove welds. The transition point usually occurs with fillet welds of less than ½ in. to ⅛ in. leg size. In some cases it can occur before, depending on an individual company's cost of weld groove preparation.

Once a groove weld has been selected over a fillet weld, then the decision whether to use a single-sided weld joint (single bevel or single-V groove) or a double-sided weld joint (double bevel or double-V groove) must be made. As the plate thickness increases, the amount of extra deposited weld metal needed to make a single-sided groove weld will exceed the cost of double-sided joint preparation. Where this changeover point occurs will in part be affected by the company's cost of making weld joint preparations, but in most cases this point occurs in groove welds when the thickness of the metal exceeds ⅛ in.

Another factor that can affect the requirement to use the least amount of filler metal is the need to control distortion in the welded plates. When welding is done from one side only, the amount of weld metal deposited about the neutral axis of the plate being welded is unbalanced, which can lead to distortion of the material about that axis. In most cases, depositing the same amount of filler metal on each side of the neutral axis will result in the least amount of distortion.

When backgouging is not required (e.g., for a partial-joint-penetration weld), this is achieved by equal groove preparations on both sides. When backgouging is required (e.g., for a complete-joint-penetration weld), this is accomplished by making the first side of welding deeper than the second side. When the backgouging operation is performed from the second side into the root of the first side, the resulting groove on each side will be equivalent. A ½ (first side), ⅛ (second side) is often used to achieve this result.

Sources of Overwelding

In any production operation, there are three potential sources of overwelding. The first source is Design Engineering. Since the Design Engineer specifies the fillet weld size or the joint application, this selection becomes the requirement the welders must meet. If the Design Engineer selects a weld that is larger than necessary, then overwelding results because the welders are required to make oversized welds.

The second potential source of overwelding is the welder. Once the Design Engineer specifies the weld size required, the welder must make the weld that size and length. Any weld greater than those amounts results in overwelding.

The third potential source of overwelding is parts fitup. If a weld fillet has a root opening greater than ⅛ in., the welder is required to weld a larger fillet than the engineering print specifies, which results in overwelding. If a groove weld contains an unspecified or larger than specified root opening, or has an included angle greater than specified, overwelding will occur.

Welding supervisors do not have control over Design Engineering, but do exercise supervision over the welders and, to a degree, the fitup. Therefore, the welding supervisor can affect how large a weld is being made.

Figure 1 illustrates the effect that overwelding can have on costs. The examples use a fillet weld for ease of comparison.

An Example for Overwelding

A ⅛-in. fillet weld volume per inch length is 0.0175 in.³, a ⅛-in. fillet weld volume per inch of length is 0.031 in.³. The subtraction of 0.0175 from 0.031 = 0.0135 in.³ of deposited metal savings. The 0.0135 when divided by the small fillet weld volume will show the percentage of savings.

0.0135 divided by 0.0175 = 78% volume savings when making a fillet weld to engineering size that is ⅛ in. instead of overwelding the fillet weld ⅛ in.

As shown in Fig. 1, the difference in filler metal volume can range from a 43% to a 124% increase if the weld leg size is larger than the size required by just ⅛ in. This difference can be even greater if the...
The cost of overwelding from making oversized fillet welds, either by design or by welder exceeding the design requirements.

As shown in Fig. 2, having just one leg of the fillet weld oversized can lead to significant overwelding. A further example is the effect on cost of making a 3/16-in. fillet weld with one leg oversized. This overwelding example results in a fillet with one leg 3/16 in. and the other leg 1/4 in. This increases weld metal volume by almost 26%. If the oversized leg is 1/4 in., which can happen with horizontal fillet welds, the increase in weld metal volume will be almost 52%. This results in a cost of overwelding of more than 50% in both filler metal and welder arc time.

At the same time, overwelding can also occur when doing intermittent or partial length fillet welds where the length of fillet weld is specified by the design engineer. If the welder fails to make a fillet weld of this length, but instead makes the weld longer, the additional weld length is also considered as overwelding.

The same logic for overwelding can be applied to groove welding where excessive increase in the groove angle, root opening, or penetration depth above what is specified in the design requirements results in additional filler metal material, as well as taking additional welder time.

If the Design Engineer specified a 1/4-in. fillet weld leg size on an engineering drawing, and the welder made a 3/16-in. weld, this would result in an increase in weld metal volume and, therefore, de- positioned filler metal weight of 177%. The result, independent of the deposition rate used, would require 177% more arc time per weldment to complete. For example, the welder making a 3/16-in. fillet weld 1 ft long would require 36 s, the same weld with a 1/4-in. fillet weld using the same welding parameters would require 1 min 39 s to complete. A welder could complete approximately 3 ft of weld using a 3/16-in. fillet in the same time that would be required to make a 1/4-in. fillet 1 ft long.

It is obvious that a major reduction in the amount of arc time required to make a length of weld is greatly impacted by the size of the weld being made.

Welding supervisors can do little to impact the weld size designed for the part, except to be aware of its impact and alert the Design Engineer whenever a change in weld size is warranted. Overwelding occurring due to welder performance and joint fitup is to a degree controllable by the welding supervisor. The supervisor can ensure that the welders periodically check their welds using a fillet weld or weld reinforcement gauge to verify that the welds are made to size. This practice not only prevents overwelding, but also guards against undersized welds that could lead to weld failures or repairs. The supervisor should periodically check the welders’ joint fitups to verify that welds are being made to the specified size and length. This type of monitoring can demonstrate the importance of weld sizes if the welders’ supervisor takes the time to check them.

An overlooked benefit of reducing overwelding is the effect that using less weld metal has on distortion. One of the hidden problems in welding is the effect distortion has on the outcome of a finished weldment. Distortion can lead to an unsightly appearance of the part, can cause assembly problems, and can also interfere with the operation of the welded assembly in service. All of these conditions will result in time-consuming, costly delays to rework or replace a part that is rendered unusable because of distortion from overwelding.

Fig. 1 — The cost of overwelding from making oversized fillet welds, either by design or by welder exceeding the design requirements.

Fig. 2 — The increase in wire (electrode) and labor costs when too much weld metal is deposited by 3/16-in. increments in one leg only.
Optimizing the Next-Generation Resistance Welding Cell

This article summarizes trends affecting resistance spot welding and suggests the direction that the next generation of resistance welding cells will take.

BY NIGEL SCOTCHMER, JAVIER DURAN, AND KEVIN R. CHAN

“While it may be hard to live with generalizations, it is inconceivable to live without them”

— Dr. Peter Gay, Schnitzler’s Century

The next generation of resistance welding cells can be seen as a microcosm of changes evident around us. There are a number of trends driving these developments: increasing globalization, advances in automatic and electronic controls, and a worldwide interest in standardization. These trends are echoed in welding cell developments.

This article suggests that the current resurgence of the North American automotive industry is an opportunity for companies to upgrade and reexamine the ways welding has been done in the past. The methods and processes that have worked for so many years have proven to be outdated and too costly in the current market, and inadequate for the future demands of cost and quality. Furthermore, as adversity is a powerful tool for change and improvement, this article recommends careful analysis of current practices in light of emerging trends and observed facts. It focuses on examples of features that need to be considered in designing and specifying a new welding cell.

Interrelated Trends

The recent malaise affecting North American automotive companies was neither unique nor unexpected. It involves the three interrelated issues of globalization, electronics, and standardization. The fact that they are interrelated makes the issues harder to categorize, understand, and analyze. A dispassionate view is required, as the issues themselves have both good and bad factors and consequences. To be truly effective and successful, one must be able to sift through the alternatives and pick the choices that best meet the particular — and often changing — needs of the situation.

Globalization

Globalization is a term easier to use than to define. Here, it is meant to include a number of characteristics that currently affect the resistance welding industry in particular.

1. Crashworthiness and fuel economy concerns have led to the pursuit of new thinner steels and aluminum as well as new hybrid materials and coatings that are stronger and lighter, with all their attendant unknowns of consistency, performance, and aging.

2. The use of these new materials has led to the analysis of the suitability of new processes such as riveting, laser welding, adhesive bonding, ultrasonic welding, and friction stir welding in addition to spot welding, with all their attendant unknowns. These alternatives pose a threat to resistance spot welding.

3. There is a “fall of Rome complex,” a sense that North America’s glory days following World War II are over. Many feel that management has become ossified, unions lazy, and innovation and vision clouded, with too many new products on the market that do not meet the needs of the customer. Costs are cut in the face of declining sales, experienced employees

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are let go, and research and development is curtailed.

4. There is also “the East is rising obsession.” Many in the West fear that countless young engineers in huge and nameless Chinese cities scheme late into the night, dreaming up improvements to the myriad products they produce — “all on a bowl of rice a day,” the saying goes.

5. Protectionism is gone. In an age of instant twitting of newsworthy events around the world, long-term protectionism is not going to work. If a better mouse trap is made in Russia, it will find its way onto the market. Stopping it is not a practical alternative — no more feasible than putting the H-bomb back into the genie’s bottle.

While the degree to which globalization affects the future welding cell can be debated, it is clear that, due to their sheer size, India and China will inevitably become leviathans on the world stage. Thus they will become trend setters, if not determinants, of the needs and wants in future welding cells. It is all the more important to understand where they are now, where they are headed, and why.

Electronics

Where do electronics come from today? If you design an IC chip today, where will it be made? Where do software writers live? What product today doesn’t have electronics as its most important and defining feature? Who has seen the greatest rise in issued patents in the last five years? We all know that the answers to these questions are not North America.

Electronics, and the associated controls and sensors, come more and more from the East. Whereas America once produced cameras, CNC machines, and robots, nowadays high-technology items are increasingly made elsewhere. Whereas Tonka toys were once sneered at, Americans increasingly buy Acuras, Lexuses, and the Genesis. We also need to remember that Chinese nationals now constitute the highest number of foreign graduates in the sciences in doctorate programs at American universities (Ref. 1).

At the same time, computer manufacture and design have drifted East, perhaps best symbolized by the Chinese buying the laptop business of IBM. In Shenzhen, a large industrial city just north of Hong Kong, whole sections of the city are filled with multistory buildings housing hundreds of small electronics manufacturers, who design, produce, and sell everything for your computer. Many of these small components can only be purchased there. This is a cogent sign of China’s new-found ascendency in the field of computing.

In other words, all the essential electronic hardware for the computer’s performance, its sensors, automation in general, and advanced programming logic controls are effectively in others’ hands. This raises the specter of a future where we here in North America may flip the burger, but the meat, the oven, the thermometer, even the flipper is made by someone else, somewhere else.

Standardization

Standardization has always been part of American manufacturing. Not too long ago, the American Welding Society and companies such as The Budd Co. were setting the standards for welding, and resistance welding in particular (Ref. 2). Standards and procedures for resistance welding aluminum and stainless steel alloys set by Americans in the 1920s and 1930s are still recognized as the best by Germans, for instance (Refs. 3, 4).

Increasingly, though, standardization is becoming a larger and larger issue. For example, as more robots come into use around the world, the prices drop and their hardware and software become more like commodities, while at the same time, knowledge of their proper use becomes better known.

At the same time, more people today are questioning the utility of standardization. This may sound paradoxical. On the one hand, there are those (especially in standards-setting organizations) who will argue that standardization has helped lower prices and improve living standards. There are others, however, who will suggest that standards protect incumbents and stifle innovation. Once a standard is set, it is hard to improve or change it. Thus, if you are not the incumbent who wrote the standard, then you have a hard row to hoe to gain market share. For example, if you no longer make robots, you will have to take what is on offer from other countries where practices and habits may be quite different.

In addition, with standardization there will be fewer suppliers offering a smaller selection of tools. Many would suggest that the Standard Oil Co., the chaebol of Hyundai or Baosteel did not grow in a free and open market, but rather grew through monopolistic characteristics. Some might even suggest Boeing and Airbus dictate the price for large airliners, or that Microsoft sets the price for computer operating systems.

Worse, there are also those who say there is a “dumbing down” with standardization, in that there is a desire for the lowest common denominator in the specifications of the technology. Skilled workers are gone, the knowledge is base lost, and these have been, in effect, replaced by the computer, over which you may have little control or knowledge.

Clearly, standardization is increasing and is unavoidable. But no matter how good clay bricks made on the banks of the Mississippi may be, they are not going to be shipped to Mumbai. Cost savings and efficiencies are not likely to overcome logistical common sense.

Even so, increasing standardization will also permit further specialization. This specialization will be particularly germane for resistance welding, which is already an inexpensive and effective tool for joining metal. Indeed, specialist standardization programs such as the European Union’s “Xpress” automation and flexible manufacturing program will, without doubt, further separate those who can operate economically from those who will drop by the wayside.

Summary of Trends

Lean-agile manufacturing is one of the current buzzwords, but a trendy word misses the real point, which is that the next-generation resistance welding cell will incorporate, through choice and/or necessity, those items from current welding trends. It will have to take into account, to a greater or lesser extent, the increasing role of nonresistance welding processes, increasing electronics, design criteria over which you may have little control, and the need to be flexible
enough to handle varying and changing manufacturing needs. Chances are the next-generation welding cell will be modular in design, highly automated, and very powerful.

An illustration of how quickly an innovation can make rapid and fundamental change to an industry is the Liberty Ship of WWII — Fig. 1. The Liberty Ship was a British design, but the innovative Americans welded the ship rather than riveting it and built it in an average of 42 days, five times quicker than the British, and employed one-third fewer people in the process. British shipbuilders, the biggest in the world, never recovered and faded from the world stage (Ref. 5).

The changes brought about by the Liberty fleet are an example of how American production methods had an immense impact upon the world. The unique characteristics of Canada and the United States — openness, freedom to operate, workforce flexibility, the fairness of our way of life, and the impartiality of laws — make our countries the envy of the world and the ideal environment to adopt, adapt, and improve upon the trends of globalization, electronics, and standardization. But that is if, and only if, we open our eyes to see what others are doing around us, and learn from them.

The Welding Cell

The standard automotive production line resistance weld cell today consists of a weld controller or timer, which feeds the electrical power to the physical weld gun typically held and manipulated by a robot, which in turn creates the weld on the worksheets held in place by a fixture or robot. The cell is typically loaded manually. In this case, the weld controller is programmed manually for each specific weld to be performed, and the weld sequences, or schedules, are “called out” by the programmable logic controller (PLC), which oversees the entire operation and ensures that the process is operated in the correct sequence (Ref. 6).

Each of these components can have a failure of some sort if not properly maintained and regulated, and it is not always easy to determine what has gone wrong in the event of failed welds or poor weld consistency.

The future welding cell will likely not have exclusively resistance welding equipment. It might include, for example, other processes such as adhesive bonding (for noise suppression and leak prevention), or riveting (for dissimilar materials).

The future weld cell will consist of modules able to communicate with each other and adapt to changes in the system, sensing workpieces, and adjusting accordingly. Although this goal has not yet been reached, aspects of the technology have already been developed and are in use today.

As always, the goal in production is to make welds that meet a minimum standard for size and strength consistently on every part. If the weld schedules are not programmed correctly, or are called out improperly, the weld could fail causing downtime and costly repairs.

Welding Consumables and Fixturing

Resistance welding, while employing no shielding gases or filler metals, still consumes electrodes and replaceable fixturing parts. We believe there will continue to be subtle but important improvements to consumables in the years ahead. The use of solid ceramics such as ZrO2 and SiC, already the standard in Europe and Japan, will continue to grow in North America. The speed of acceptance will increase as older robots with poor repeatability are slowly phased out and replaced with robots with easier programming and improved accuracy.

Environmental issues over leakage of oil and air, combined with the cost and inaccuracy, will ensure the servo will continue to replace hydraulic and pneumatic cylinders. New coppers and improved coatings will appear on electrodes (Ref. 7). The simple modular head design for projection welding is already proving to reduce costs significantly (Fig. 2) (Ref. 8). Sensors will improve and increase in number as more processes and steps are automated, programmed and tracked.
Weld Controllers or Timers

The resistance welding controller is the heart of the resistance spot welding process. It provides the necessary weld current for the specified amount of time as required in the weld schedule. Weld timers are available in both AC and DC secondary current, and both have their advantages and disadvantages. DC weld timers run at much higher frequencies than AC, and so lend themselves to more precise control over the current profile and any changes that occur. In most cases, the primary power to the unit is monitored, and fed through a transformer with a known turns ratio, which provides the output of the desired secondary current. In some cases, the secondary current is directly measured to ensure that the correct current is being delivered to the weld. In most cases, the weld controller will only deliver what the weld schedule calls for, and so slight adaptations and allowance for material consistency and electrode tip wear are manually compensated for by using either a weld current stepper, or other external means.

For the next-generation weld controller, several options are already available and are being used. The adaptive weld controller is one that can sense the changes or differences in the weld during the actual welding cycle, and adjust the current accordingly to ensure a sound weld is made. The ability to judge whether or not a weld is sound differs from one manufacturer to the other, but the concept of being able to sense and adapt to varying welding conditions remains the same.

Adaptive weld timers have mainly been developed in Europe and the United States. Generally the practice has shown that sensing voltage and current from the secondary circuit of the weld gun is commonly used. It is important to note that, currently, adaptive weld timers work on spot welding and not on projection welding or seam welding.

As we continue to describe the technology of adaptive timers, it is helpful to review why adaptive weld timers are useful in production plants. The weld process involves current, resistance, and power over time. The equation is

\[ E(R, I, t) = PR^2t \]

This equation shows that energy is dependent upon the current \( I \), resistance \( R \), and time. It is a very simple description of the process. Energy is required to melt the material. This energy can be brought to the weld spot by varying the current and/or the time. The resistance is a natural consequence of the materials used and cannot directly be influenced by the power source.

Research has shown that resistance is a key factor in describing the weld process. Resistance in the materials changes as it is heated and is said to be dynamic. If we were to measure this changing parameter, it would allow for variations in the weld current. Thus, the power source would react in real-time to change the welding parameters and achieve a good weld nugget. Clearly, the formula above can either change the current, the time or both. It is obvious that it is easier to vary the current, since it has a clear bigger influence as it is mathematically squared.

Unfortunately, a car can have 5000 welds and all the parameters for a perfect weld are not likely to be present for each weld. Some of the reasons for a poor weld include

1. shunting effects from alternate current paths,
2. variations in the material being welded,
3. variations of the coatings on the surface of the material being welded,
4. voltage fluctuations,
5. material stack-up and general fit of the parts,
6. electrode wear,
7. wear of the welding gun or machine components, and
8. heat in the welding gun, electrode, or material.

There are many other variations or combinations of those factors that are possible. They occur daily. These concerns have driven manufacturers to adaptive weld timers. Reducing costs, competitive pressures, improving quality, and documenting the process will lead others to adaptive controls.

For example, weld timers from Harms & Wende use a toolbox built into the MFDC inverter that is embedded in an adaptive welding package (Ref. 9). This solution provides an intelligent algorithm to control process variations. All adaptive systems on the market today are medium frequency with a minimum clock rate of 1000 Hz or higher (when a system is operating at a clock rate of 10,000 Hz, it is called high frequency). Integration of the adaptive control technology is simple. Since the current signal is provided from the coil on the secondary side of the transformer, two additional shielded cables are required for the voltage measurement — Fig. 3.

Adaptive controls provide rapid correction of irregularities in the welding process, automatically. In addition, complex materials and different combinations can be dialed in, providing speed as well as accuracy. Additionally, new high- and ultrahigh-strength materials are difficult to weld, and the ability to change the welding parameters for production inconsistencies such as poor fitup is an in calculable advantage.

Adaptive control can also assist other production setups, such as the recent Asian interest in single-sided spot welding machines. Japanese and Korean companies have shaved valuable seconds off each weld in those applications that can employ single-sided spot welding (Ref. 10). Five seconds on each of 5000 welds on 200,000 cars per year is a large saving.

It is not hard to see how the next step is a database in the adaptive control, and the user simply chooses the material combination, electrode style and shape, and the system itself selects the appropriate weld schedules. That day is arriving (Ref. 11).

Automation and Robotics

Advances in technology are expanding what can be done without the aid of humans. Robots have been used in production environments from simple parts handling to very complex cutting and welding operations. As we look forward to the next generation of automation solutions, robots will be able to sense conditions and adapt to slight changes without the need for further programming. Modular designs will allow a single robot to perform a variety of tasks, even change tools and
process, while identifying, and adjusting accordingly. With the increase in use of vision sensors, modern robots are able to verify the positioning of the parts and the tooling, as well as check the conditions of the welds after they are performed. With servo weld guns, the amount of data that can be reported and recorded for each weld and each operation is growing, allowing a tight control of process conditions in real-time. The ability to adjust the welding process as the electrode wears can greatly increase the tip life while maintaining quality and decreasing maintenance. Integration of robots and weld timers has been made quite easy with the addition of software setup screens that aide plant personnel in setup and debugging of most welding issues.

Weld Planning and Engineering

Traditionally the task of the welding engineer, the planning of the sequence of the welds and, more importantly, the specific weld schedules to be used, requires experience and expertise. With the goal of producing the best welds for the longest duration without the need for maintenance, there exists a delicate balance between undersized and oversized welds. Many differing opinions exist on the best weld schedules for use with a particular type of steel and material combination, and this leads to an almost infinite range of possible weld schedules. However, both Europe and North America are seeing many experienced engineers leaving the business and many inexperienced ones enter it in India and China.

One of the ways of addressing concerns such as these is being addressed by programs such as the European Union’s Xpress initiative. This program aims to cut ramp-up times and production costs by producing a flexible and multivariant quality process that will allow the integration of various methods and interfaces into a standardized method of control for aerospace, automotive, and electronic manufacturing. Its aim is to realize flexible manufacturing by bringing all the electronic subsystems together (Ref. 12). This program, in a sense, is preparing for the next-generation welding cell.

Many companies already use FEM and simulation software to reduce time and money expended from drawings to pre-production and from preproduction to optimized weld schedules (Ref. 13). Figure 4 shows how Sorpas software, a FEM software package, has in the last ten years moved from single, simple simulations of two sheets toward the goal of online process control at actual assembly plants and productions lines for certain large automotive companies, involving thousands of welds on different materials and stack-ups. Such a planning tool is an integral part of the drive behind the European Xpress program.

The next-generation welding cell will employ detailed optimized schedules that work in conjunction with a program such as Xpress. This will significantly reduce setup, maintenance, quality problems, and costs overall. Those that already have or are planning to employ adaptive weld controllers and modern robots have a head start in using flexible manufacturing (Ref. 15).

Costing

Specific companies in Asia and in Europe already possess sophisticated accounting systems that allow them to track and use production data far more effectively than many North American companies. Certain Japanese companies know the accurate cost per weld on the factory floor, and work out detailed margin contribution of that extra car squeezed out of the line before the end of the shift. Generalizing, we tend to be sloppier with such analysis in North America (Ref. 16). We lack the precision and the perceived need for such accounting control that is both a boon and the bane of the German and the Japanese.

Be that as it may, the next-generation welding cell will provide a vast amount of information that will be used to provide accurate and detailed accounting information. Such information will be of profound importance in a global environment where margins are likely to continue to be under attack. The recent adoption of single-sided spot welding in Asia has been an example of where, in specific situations where ‘shunting’ is not a major risk, significant production time has been saved. I assure you, North Americans have not yet realized what penny pinching can mean.

Summary

Today, the implementation of a robotic resistance welding cell requires detailed knowledge from the staff design and operation. Advanced knowledge of resistance welding is required to maximize performance and to minimize quality issues. The adoption of new materials and complex weld joints only increases the cost on startup.

In the future, CAD/CAM systems will gain access to databases to assist in rapid design and manufacture. Thus, the time from dream and sketch of an idea to production of the finished part will drop dramatically.

Intelligent MFDC systems with adaptive control modes that are already in use worldwide will improve further in terms of their ease of use and accuracy, and provide near-perfect welding by compensating automatically for fluctuations in the welding process.

Production knowledge, linked to all locations, online and in real-time, will electronically update databases and provide instantaneous reporting of quality, production, and costing information to management. New programs and production changes will be implemented even more quickly as knowledge from databases is used. More detailed costing information will be generated and summarized for management.

The next-generation resistance welding cell will be international in origin. Its success in operation will depend upon the careful choice of what you need, why you need it, and how you implement.

We believe that the natural innovative and entrepreneurial spirit of America, combined with its openness and flexibility, are ideally placed to adopt, adapt, and improve the next generation of resistance welding cells. We are actually the best guys to do this as our society is the most open — period.

![Fig. 4 — Possible timelines for implementing optimized welding schedules with online tracking (courtesy Swanteck Engineering).](image-url)
References


Ten Tips for Better Pricing

Pricing is one of the most powerful — yet underutilized — strategies available to businesses. A McKinsey & Co. study of the Global 1200 found that if companies increased prices by just 1%, and demand remained constant, on average operating profits would increase by 11%. Using a 1% increase in price, some companies would see even more growth in percentage of profit: Sears, 155%; McKesson, 100%; Tyson, 81%; Land O’Lakes, 58%; and Whirlpool, 35%. Just as important, price is a key attribute that consumers consider before making a purchase.

The following ten pricing tips can help you reap higher profits, generate growth, and better serve your customers by providing options.

Stop marking up costs. The most common mistake in pricing involves setting prices by marking up costs (“I need a 30% margin”). While easy to implement, these “cost-plus” prices bear absolutely no relation to the amount that consumers are willing to pay. As a result, profits are left on the table daily.

Set prices that capture value. Manhattan street vendors understand the principle of value-based pricing. The moment that it looks like it will rain, they raise their umbrella prices. This hike has nothing to do with costs; instead it’s all about capturing the increased value that customers place on a safe haven from rain. The right way to set prices involves capturing the value that customers place on a product by “thinking like a customer.” Customers evaluate a product and its next best alternative(s) and then ask themselves, “Are the extra bells and whistles worth the price premium (organic vs. regular) or does the discount stripped-down model make sense (private label vs. brand name).” They choose the product that provides the best deal (price vs. attributes).

Create a value statement. Every company should have a value statement that clearly articulates why customers should purchase their product over competitors’ offerings. Be specific in listing reasons...this is not a time to be modest. This statement will boost the confidence of your frontline so they can look customers squarely in the eye and say, “I know that you have options, but here are the reasons why you should buy our product.”

Reinforce to employees that it is okay to earn high profits. I’ve found that many employees are uncomfortable setting prices above what they consider to be “fair” and are quick to offer unnecessary discounts. It is fair to charge “what the market will bear” prices to compensate for the hard work and financial risk necessary to bring products to market. It is also important to reinforce the truism that most customers are not loyal — if a new product offers a better value (more attributes and/or cheaper price), many will defect.

Realize that a discount today doesn’t guarantee a premium tomorrow. Many people believe that offering a discount as an incentive to trial a product will lead to future full-price purchases. In my experience, this rarely works out. Offering periodic discounts serves price-sensitive customers, which is a great strategy, but often devalues a product in customers’ minds. This devaluation can impede future full-price purchases.

Understand that customers have different pricing needs. In virtually every facet of business (product development, marketing, distribution), companies develop strategies based on the truism that customers differ from each other. However, when it comes to pricing, many companies behave as though their customers are identical by setting just one price for each product. The key to developing a comprehensive pricing strategy involves embracing (and profiting from) the fact that customers’ pricing needs differ in...
three primary ways: pricing plans, product preferences, and product valuations. Pick-a-plan, versioning, and differential pricing tactics serve these diverse needs.

**Provide pick-a-plan options.** Customers are often interested in a product but refrain from purchasing simply because the pricing plan does not work for them. While some want to purchase outright, others may prefer a selling strategy such as rent, lease, prepay, or all you can eat. A pick-a-plan strategy activates these dormant customers. New pricing plans attract customers by providing ownership options, mitigating uncertain value, offering price assurance, and overcoming financial constraints.

**Offer product versions.** One of the easiest ways to enhance profits and better serve customers is to offer good, better, and best versions. These options allow customers to choose how much to pay for a product. Many gourmet restaurants offer early-bird, regular, and chef’s-table options. Price-sensitive gourmands come for the early-bird specials while well-heeled diners willingly pay an extra $50 to sit at the chef’s table.

**Implement differential pricing.** For any product, some customers are willing to pay more than others. Differential pricing involves offering tactics that identify and offer discounts to price-sensitive customers by using hurdles, customer characteristics, selling characteristics, and selling strategy tactics. For example, customers who look out for, cut out, organize, carry, and then redeem coupons are demonstrating (jumping a hurdle) that low prices are important to them.

**Use pricing tactics to complete your customer puzzle.** Companies should think of their potential customer base as a giant jigsaw puzzle. Each new pricing tactic adds another customer segment piece to the puzzle. Normal Normans buy at full price (value-based price), Noncommittal Nan-cys come for leases (pricing plans), High-end Harrys buy the top-of-the-line (versions), and Discount Davids are added by offering 10% off on Tuesday promotions (differential pricing). Starting with a value-based price, employing pick-a-plan, versioning, and differential pricing tactics adds the pricing-related segments necessary to complete a company’s potential customer puzzle. Offering consumers pricing choices generates growth and increases profits.

Since pricing is an underutilized strategy, it is fertile ground for new profits. The beauty of focusing on pricing is that many concepts are straightforward to implement and can start producing profits almost immediately.

What better pricing windfall can your company start reaping tomorrow morning?

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If laminated steels are to be used more widely, a fundamental understanding is needed of the material’s behavior during resistance spot welding.

BY DAVID R. SIGLER AND RICHARD A. WALDO

Sound-damping laminated steels are used in vehicles to suppress in-cabin sound levels, but manufacturing issues have hindered their expanded use. One issue is the difficulty of producing acceptable resistance spot welds under a wide variety of production scenarios. These scenarios include use of different types of welding equipment, such as weld controls and weld control software, transformer size and type (alternating or direct current), and gun design. To enable more widespread implementation of laminated steels, a fundamental understanding is needed of the material’s behavior during the resistance spot welding (RSW) process.

Laminated steels are inherently difficult to resistance spot weld because of the existence of a nonconductive, viscoelastic polymer core between the steel sheets. This core is critical because it provides sound-damping performance. Early versions of laminated steel sheet contained thermoplastic resin cores (Refs. 1-4) such as polyethylene (Ref. 2). Thermoplastic resins can be easily displaced from the electrode location by the application of sufficient heat to the resin while the electrodes are under load. Heat is supplied by establishing conductivity between the electrodes with an external shunt or bypass that allows current to flow from one electrode to the other without passing between the sheets (Refs. 1, 3-5). With sufficient heat input, the polymer core softens and flows or extrudes from between the welding electrodes to allow the two steel skin sheets to come into direct contact. At that point, the current flows directly from one sheet to the other such that the current level can be increased sufficiently to form a weld nugget. Thinner cores and electrodes with a radiused weld face have been found to decrease the time needed to displace the polymer core from between the welding electrodes (Refs. 1, 5).

The external shunt or bypass technique, however, suffers from several manufacturing issues including the use of additional tooling, i.e., shunts at numerous locations, variability of preheat associated with the distance between the shunt and weld location (Ref. 3), and long preheat times that slow production (Ref. 3). To overcome these issues and provide consistent shunt paths anywhere along the laminate panel, the core was made electrically conductive through addition of conductive particles composed of graphite (Ref. 2) or metal (Refs. 3, 4, 6).

Continued laminate development produced material with improved damping and adhesion performance by replacing thermoplastic polymers with thermoset polymers for the viscoelastic core (Refs. 4, 7, 8). Since thermoset polymers are more resistant to temperature, they also are more difficult to weld through and require excessively long preheat times with external shunts (Ref. 4). For successful production implementation, these materials required conductive particles to allow current to pass between the steel sheets, thereby locally heating the core material. A variety of conductive particles have been evaluated for both thermoplastic and thermosetting resins including nickel (Refs. 3-9), copper (Refs. 3, 6), aluminum (Refs. 3, 6), iron (Ref. 5), and stainless steel (Refs. 3, 6). Of these, nickel particles work well because they have good corrosion resistance (Refs. 3, 6), which prevents formation of electrically insulating contaminant layers on the particle surface. Particle size and hardness were also considered to play a role. Parti-

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Based on a paper presented at the AWS Detroit Section’s Sheet Metal Welding Conference XIV, held May 12-14, 2010, Livonia, Mich.
cles whose size is approximately the same or slightly larger than the viscoelastic layer thickness provide the most direct current paths for successful welding (Refs. 3–9).

Despite improvements made in laminate weldability, the inherent nonconductive nature of the viscoelastic core can still lead to welding issues. These include excessive bulging of the laminate sheet caused by decomposition and volatilization of the viscoelastic core (Refs. 4, 5, 9, 10), complete melting and perforation around the weld spot (Refs. 4, 5, 7, 9), and formation of smaller local perforations (Refs. 3, 5, 7, 9, 10) around the weld spot. Perforations produced at either the weld spot site, or locations removed from it, are considered unacceptable (Ref. 11).

Commercial laminated steels have shown a tendency for the steel skin sheet layers to perforate during production RSW with the use of standard spot welding schedules. To improve spot welding performance and particularly to eliminate the tendency for perforations, a fundamental study was undertaken to understand the behavior of this material during RSW.

Experimental

Materials

Production laminated steels 0.9 and 1.1 mm thick were studied. The steel laminates were electrogalvanized on both exterior surfaces to an approximate coating weight of 60 g/m². Zinc coatings were not applied to the interior surfaces.

Welding Equipment

Welding performance was assessed using production-style equipment installed at the GM R&D Center. The welding system consisted of both medium-frequency DC (MFDC) and conventional, single-phase AC weld controls. The MFDC transformer has a 170-kVA rating and a maximum voltage capability of 13 V. The AC transformer has a 400-kVA rating and a maximum voltage capability of 20 V.

The welding electrodes used for all tests corresponded to GM specification MWZ-6006, which is a ball-nose electrode with a small flat on the weld face. Welding forces were either 2.1 or 3.0 kN, which are both considered acceptable for welding laminated steel from 0.9 to 1.1 mm thick.

Types of Analyses Conducted

Scanning electron microscope (SEM) and energy-dispersive spectroscopy (EDS) analyses were performed using a Zeiss EVO SEM with a Noran EDS system adapted to the microscope. All EDS analyses were performed at the optimum working distance (19 mm) and sample orientation (no tilt) to ensure highest accuracy. Microscope voltage was typically set at 15 to 20 kV to accurately analyze the heavier elements. Electron probe microanalysis (EPMA) was performed using a Cameca Instruments Inc., Model SX 100. Electron beam conditions were typically 15 or 20 keV and 20-, 40-, or 100-nA beam current. Various combinations of the elements and X-rays Fe(Kα), Mn(Kα), Ca(Kα), Si(Kα), Fe(Kα), Mn(Kα), O(Kα), P(Kα), and C(Kα) were included in the X-ray mapping depending on the feature of interest. Delaminated surfaces were sputter-coated with an ~2-nm Au-Pd conductive film to prevent sample charging. The image sizes were 512 x 512 pixels with 10 ms per pixel dwell time. The step size per pixel varied from 0.5 to 10 µm (thus 250 to 5000 µm field size) to encompass the area of interest. Quantitative microanalysis (C and P concentrations) was done at 15-kV beam voltage and 100-nA beam current. The carbon concentration was calculated from a calibration curve made with a series of steel standards ranging from 0.006 to 0.61 wt-% C. Indium phosphate (InP) was used for the P standard.

Results and Discussion

As-Received Laminate and Polymer Core Analyses

The core material was removed from 1.1-mm-thick laminate material. The average mass per unit area for the core was 4.20 mg/cm² with a polymer content of 3.80 mg/cm². The inorganic component was 0.40 mg/cm² or roughly 10% of the core mass. To estimate core thickness, a density of ~1 g/cm³ was assumed for the polymer. This results in a core thickness of approximately 38 µm, which illustrates the thinness of the viscoelastic core relative to the entire laminate.

More detailed analyses were performed using SEM and EPMA to more fully understand the configuration, distribution, and composition of the inorganic material within the core. Figure 1 shows SEM secondary electron image (SEI) mi-

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### Table 1 — Inorganic Analyses of the Core of the 1.1-mm-Thick Laminate (mg/cm²)

<table>
<thead>
<tr>
<th>Thickness</th>
<th>Fe</th>
<th>Mn</th>
<th>P</th>
<th>Ca</th>
<th>Zn</th>
<th>Ti</th>
<th>Cr</th>
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<td>1.1 mm</td>
<td>0.31</td>
<td>0.011</td>
<td>0.093</td>
<td>0.011</td>
<td>0.005</td>
<td>0.005</td>
<td>0.002</td>
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</table>
were created by the pulverization of larger
consumes part of the steel sheet.
produces a low-melting-point liquid and
ture could result in a eutectic reaction that
sheet and Fe-P particles at high tempera-
point (1048
the lowest melting point compound being
have melting points below that of iron with
three of the iron phosphide compounds
intermetallics as well as the associated eu-
Fe2P, this suggests that a ratio of iron to
phosphorus of ~2 might be obtained by
Fe-P and FeP in roughly equal
phosphorus of ~26.6
micron particles found them to contain mostly
iron with high levels of phosphorus and
some manganese, which agrees with the
bulk inorganic analyses shown in Table 1.
Electron microprobe analyses were per-
determined more precisely the
composition of the particles, particularly
the iron-to-phosphorus ratio. Microprobe
analyses of a set of agglomerated parti-
cles found phosphorus to be between 26.6
and 50.9 at-%. Iron and phosphorus form
a range of intermetallic compounds in-
cluding Fe,P2, Fe,P3, Fe,P, and others. Since
bulk analyses matches the mass ratio of
Fe2P, this suggests that a ratio of iron to
phosphorus of ~2 might be obtained by
combining Fe,P and FeP in roughly equal
proportions with Fe2P.

Table 2 lists the melting points of these
intermetallics as well as the associated eu-
tectic temperatures. Table 2 shows all
three of the iron phosphide compounds
have melting points below that of iron with
the lowest melting point compound being
Fe,P2, which forms an even lower melting
point (1048°C) eutectic with iron. This
suggests that contact between the steel
sheet and Fe-P particles at high tempera-
ture could result in a eutectic reaction that
produces a low-melting-point liquid and
consumes part of the steel sheet.

Laminate Behavior during
Current Initiation

To determine the behavior of the lam-
nate at the start of current flow, samples
of the 1.1-mm-thick material were spot
welded with DC. AC was not used since
the high peak current and voltage levels
achieved as a result of the sinusoidal na-
ture of the current waveform were thought
to accelerate the welding process too
much. Typically, these materials would be
spot welded at about 10 kA for 14 cycles
each cycle is 1/100 s). A lower current and
shorter time, only ~7 kA for 2 cycles, was
used to examine the material's behavior
during welding in its earliest stages.

Figure 2 shows the interior surface of
the laminate skin sheets in contact with
the viscoelastic core after being welded as
described previously to a sheet of hot dip
galvanized (HDG) steel. The electrode
impression is clearly apparent in the fig-
ure, as are numerous black marks and dis-
continuities on the interior surface of the
sheet (indicated by arrows). A combina-
tion of melting the Fe-P conductive par-
ticles and decomposition of the polymer
layer caused the discontinuities and black
marks. For this particular area of the lam-
inate core, it appears only a small number
of Fe-P conductive particles contributed
to initial current flow.

Figure 3 gives a typical example of the
early stages of melting of a particle ag-
glomeration. Figures 3A and B show SEI
and backscatter electron image (BEI) mi-
crographs of several different features that were
formed by particles that appear to have
melted fully. Each feature appears to have
a head and a tail. Closer examination of
the heads in Fig. 4 shows they are charac-
terized by porosity and/or fracture sur-
faces. The features typically have a simi-
lar matching feature on the opposite face
of the laminate surface with a matching
fracture surface. Apparently, the molten
particles formed molten bridges or con-
nections between the two interior sheet
surfaces. Upon termination of the weld-
ing current, the molten bridges solidified.
At some point, most likely when the lam-
inate was peeled apart for examination,
the solidified connections were fractured
or broken apart, forming matching frac-
ture surfaces on the interior surfaces of
the laminate.
Influence of Conductive Particles on Nugget Structure

To determine the effect of the conductive particles on the final weld nugget structure, a thinner laminated steel material, only 0.9 mm thick, was resistance spot welded. The thinner material was chosen because it is more prone to producing weld defects than the 1.1-mm material. The material was spot welded with equipment, electrodes, and schedules selected to simulate production conditions. This included use of AC weld controls and power supplies. The material was spot welded to a HDG, cold rolled steel sheet using standard production ball-nose electrodes.

Figure 7 shows optical interference contrast micrographs of a spot weld produced in 0.9-mm-thick laminated steel consisting of two thinner sheets that overlaid a heavier sheet. An overview is shown in Fig. 7A, where a dotted line indicates the approximate position of the weld nugget. In this case, the nugget has not penetrated the upper skin sheet of the laminated steel.

Figure 7A reveals two interesting features. First, large gaps between the top two sheets overlaying the weld nugget indicate considerable delamination occurred in the vicinity of the weld spot. This is expected because of the high temperatures and gas pressures the welding process produce. Second, discontinuities formed at the location where the upper laminate skin sheet contacted the welding electrode (arrows in Fig. 7A). These discontinuities are shown at higher magnification in Fig. 7B, C. Figure 7C reveals a perforation or fissure formed in the upper skin sheet. Figure 7B reveals small microcracks (black arrows) that do not penetrate the sheet surface.

Microhardness measurements were made in these regions. Indentations from a Vicker’s diamond indenter are clearly visible in soft areas. These indentations...
Mechanism of Welding Laminated Steel with Conductive Particles

Based on the previous observations, a mechanism can be outlined describing the sequence of events that occurs during RSW of laminated steels containing iron phosphide conductive particles.

The initial function of the particles is to allow some level of current flow between the sheets to prevent a fault and shutdown of the weld control. Current flow can occur in two primary areas. First, a portion of the conductive particles will provide sufficiently good contact between both steel skin sheets that they pass current once a voltage is applied across the laminate. Second, closure of the copper welding electrodes on the laminated steel sheet will locally force the sheets into better contact with conductive particles. The pressure applied by the electrode weld flat is fairly high. Because of the high applied pressure, most current flow likely occurs through the particles in the vicinity of the electrode. Once current begins to flow through the conductive particles, they heat rapidly and melt. This likely occurs quickly within the first cycle (0.017 s) of weld time. Simultaneously, the viscoelastic core in the vicinity of the particles decomposes from the rapid heating and releases carbon-containing species, which can then act to carburize or increase the carbon level in the molten particles. The combination of molten particle temperature and composition, i.e., phosphorus and carbon contents, quickly cause the skin sheet material in contact with the molten particles to melt, providing additional iron for growth of the molten particles.

As current continues to flow through the now molten connections between the two skin sheets, sheet material in direct contact with the welding electrode begins to heat softening the viscoelastic core material. Eventually, the combination of temperature and pressure from the electrodes displaces the softened core material from the weld location. When this occurs, the two steel skin sheets are brought into direct contact. Any residual conductive particle material in the area of contact forms a liquid metal layer between the two sheets. At this point, voltage and current can be increased sufficiently to form a weld nugget since direct electrical contact has been established between the two sheets. Nugget growth initiates not at the skin...
Sheet interface, but at the faying interface between the laminated steel and steel sheet. This nugget then grows into the laminated steel. If allowed to grow sufficiently, the nugget will consume the liquid metal layer previously formed at the interface between the two laminate skin sheets.

The carbon- and phosphorus-rich molten material in the vicinity of the electrode impression modifies the weld nugget microstructure. This material consists of molten conductive particles located on the perimeter of the electrode impression as well as molten material extruded from between the skin sheets by pressure from the welding electrodes. This carbon- and phosphorus-rich molten material is located along the periphery of the nugget and after solidification results in the formation of locally very hard areas. In some cases, small microcracks can form in these hardened areas.

Skin sheet perforation can occur either remote from or adjacent to the electrode. In either case, perforation is most likely due to the application of excessive voltage across the skin sheets, which causes the molten particles to heat excessively and melt through one or both sheets. The presence of phosphorus in the molten particle as well as local decomposition of the viscoelastic core to provide carbon most likely accelerates the process. The probability of perforation would be enhanced by either a lack of conductive particles to bridge the gap between the two steel skin sheets, application of excessive voltage across the laminate, or a combination of both. In the first case, insufficient particle addition, poor particle distribution, addition of too small a particle, or too large a gap between the steel skin sheets could cause a lack of bridging conductive particles. In the second case, the type of weld control, weld control software, transformer size, and gun design can cause application of excessive voltage.

Conclusions

1. Conductivity for spot welding laminated steels is achieved through the addition of conductive particles to the polymer core. Analysis of a laminated steel core using several techniques identified the conductive particles as iron phosphide compounds.

2. Extensive microprobe, scanning electron microscopy, and metallurgical analyses of spot welded material revealed the behavior of the conductive particles during welding. Initial current flow occurs through the conductive particles, which causes them to rapidly heat and melt, and causes the surrounding polymer core to decompose.

3. Once molten, the particles begin to melt the steel skin sheet while absorbing carbon from the decomposing core. The increased carbon content of the molten particles reduces their melting points and accelerates melting of the steel sheets. These molten particles grow rapidly as they consume the steel sheet and act to electrically connect the two sheets. If the molten metal becomes excessively hot, sheet perforation can occur.

4. Continued current flow generates sufficient heat at the weld location to soften the polymer core and displace it from between the electrodes. This allows the steel skin sheets to come together, which traps liquid from the molten particles forming a carbon- and phosphorus-containing iron layer between the skin sheets. Under pressure from the electrodes, the liquid layer is displaced from the interface and eventually forms a hard, carbon-enriched region around the weld nugget.

Acknowledgments

The authors would like to acknowledge Alexander Turley and Joseph Speranza, who provided valuable technical expertise on RSW of light-gauge and laminated steels, and Noel Potter, who performed the bulk chemical analyses.

References


COMING EVENTS

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


♦ JOM-16, 16th Int'l Conf. on the Joining of Materials and
ICEW-7, 7th Int’l Conf. on Education in Welding. May 10–13. Lo-Skolens Conf. Center and Hotel, Helsingør, Denmark. Contact JOM Institute, Gilleleje, Denmark. Phone +45 48 35 54 58; jom_aws@post10.tele.dk.


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

#### Certified Welding Inspector (CWI)

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<td>Miami, FL</td>
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<td>Feb. 17</td>
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<td>Corpus Christi, TX</td>
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<td>Miami, FL</td>
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<td>Baton Rouge, LA</td>
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<td>Baltimore, MD</td>
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<td>May 14</td>
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</table>

#### Certified Robotic Arc Welding (CRAW)

**SEMINAR DATES**

- New Orleans, LA: Jan. 10–15
- Denver, CO: Feb. 7–12
- Dallas, TX: March 14–19
- Miami, FL: April 11–16
- Sacramento, CA: May 9–14
- Pittsburgh, PA: June 6–10

**EXAM DATE**

- NO EXAM

#### Certified Robot Arc Welding (CRAW)

**SEMINAR DATES**

- New Orleans, LA: Jan. 10–15
- Denver, CO: Feb. 7–12
- Dallas, TX: March 14–19
- Miami, FL: April 11–16
- Sacramento, CA: May 9–14
- Pittsburgh, PA: June 6–10

**EXAM DATE**

- NO EXAM

#### Advanced Visual Inspection Welding (AVIW)

<table>
<thead>
<tr>
<th>LOCATION</th>
<th>SEMINAR DATES</th>
<th>EXAM DATE</th>
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</thead>
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<tr>
<td>Beaumont, TX</td>
<td>Jan. 14</td>
<td>Jan. 15</td>
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<td>Miami, FL</td>
<td>Jan. 28</td>
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<td>Pittsburgh, PA</td>
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<td>Birmingham, AL</td>
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<tr>
<td>Milwaukee, WI</td>
<td>March 4</td>
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<tr>
<td>Houston, TX</td>
<td>March 11</td>
<td>March 12</td>
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<td>Chicago, IL</td>
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<tr>
<td>Miami, FL</td>
<td>April 1</td>
<td>April 2</td>
</tr>
</tbody>
</table>

#### Certified Welding Supervisor (CWS)

**SEMINAR DATES**

- Atlanta, GA: Jan. 24–28
- New Orleans, LA: April 4–8

**EXAM DATE**

- Jan. 29
- April 9

CWS exams are also given at all CWI exam sites.

#### Certified Radiographic Interpreter (CRI)

**SEMINAR DATES**

- Atlanta, GA: Jan. 17
- New Orleans, LA: Jan. 28
- Miami, FL: Feb. 23–25
- Houston, TX: March 23–25
- Miami, FL: May 4–6

**EXAM DATE**

- Jan. 28
- Feb. 25
- March 25
- May 6

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

#### Certified Welding Educator (CWE)

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

#### Senior Certified Welding Inspector (SCWI)

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

#### Certified Welding Sales Representative(CWSR)

**SEMINAR DATES**

- Los Angeles, CA: Jan. 26–28
- Miami, FL: Feb. 23–25
- Houston, TX: March 23–25
- Miami, FL: May 4–6

**EXAM DATE**

- Jan. 28
- Feb. 25
- March 25
- May 6

CWSR exams will also be given at CWI exam sites.

#### International CWI Courses and Exams

Please visit [www.aws.org/certification/inter_contact.html](http://www.aws.org/certification/inter_contact.html)

**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, 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.
STICK ELECTRODES

WELDING WIRES

WELDING MACHINES
MIG/MAG & RECTIFIERS, INVERTER, TIG, AC/DC TIG, DC TIG, Pulsed MIG/MAG, Synergic MIG/MAG, AC/MIG-MAG, Submerged Welding Machines, Air Plasma Cutting, Welding Generators

For Info go to www.aws.org/ad-index

GEDIK WELDING
Ankara Caddesi No: 306 Seyhli 34913 Pendik - ISTANBUL / TURKEY
Phone: +90 216 378 50 00 (Pbx) Fax: +90 216 378 79 36 - 378 20 44
Web: www.gedikwelding.com E-mail: gedik@gedik.com.tr
Prove your excellence in welding sales

The American Welding Society offers a new certification program for welding sales professionals

Welding sales personnel can now underscore the pivotal role they play in the success of their employers.

You provide value-added expertise to your customers on a regular basis. Now — through the AWS Certified Welding Sales Representative program — you can prove you are among the most valuable sales professionals in the welding industry.

A two-hour exam can establish your hard-earned credentials in welding sales. AWS offers a three-day test preparation seminar that can be taken at a scheduled site, or at your workplace for groups of sales personnel.

For more information and an application form, visit www.aws.org/CWSR or call 1-800-443-9353 ext. 273.

You are among the elite in welding sales. Now you can prove it, as an AWS Certified Welding Sales Representative.

- Establish a competitive advantage in your field.
- Receive valuable welding reference books that will be a lifelong asset.
- Learn key skills that can help you assist your customers.
- Taking the seminar lets you test with just two years of industry experience.
- Gain the respect you deserve for your professionalism.
- Group seminars and exams can be offered at your business location.

Here’s what sales professionals are saying:

“I wish I’d had a chance to do this years ago. The certification gives me an edge over my competitors.” Timothy Howard, WESCO Gas and Welding Supply

“We’d like to see our sales guys be Certified Welding Inspectors, and this is a real nice stepping stone.” Larry Burnett, S. J. Smith Co.

“Knowledgeable inside and outside sales people can answer any question when customers call us or walk into our stores. We believe that kind of service adds value to what we sell.” Bill Pagliaro, ABCO Welding Supply

PUBLIC SEMINAR/EXAM SITES
Custom programs are also available.
Los Angeles: Jan. 26-28
Miami: Feb. 23-25
Houston: Mar. 23-25
Miami: May 4-6
Atlanta: Jun. 8-10

www.aws.org/CWSR
Bruskotter Addresses Welding Students at Five Facilities in District 11

John Bruskotter, AWS president, recently completed a two-day tour where he presented talks and answered questions for the students and staff at five schools offering welding programs in the AWS District 11 region.


Bruskotter was joined on the tour by Donald B. DeCorte, an AWS director-at-large, who arranged the itinerary for the president and also addressed the students.

DeCorte said, “This event offered excellent student speaking venues for John and me to share the offerings and opportunities of the American Welding Society and the welding industry in general. John’s presentation wowed the ‘Northern’ audiences since most of the students have never seen the process of building, delivering, and installing offshore drilling and oil production platforms.”

DeCorte added, “The major highlights of the tour were Bruskotter’s presentation to a 200-person audience, and assisting in the awarding of 27 Detroit Section scholarships worth $32,000. The awards were made to welding engineering students during a special Detroit Section students’ night program. This well-attended event was hosted by Macomb Community College, the Detroit Section, and The Lincoln Electric Co.”

The tour offered them a grass-roots opportunity to reach about 475 students and faculty at the five schools along with many members of the Detroit, Northern Ohio, Central Michigan, and Saginaw Sections.

For details about the welding program offered at Monroe County Community College, see the Sept. 2010 Welding Journal story beginning on page 94.
A2B and A2C Subcommittees Meet in Ohio

Members of the A2B and A2C Subcommittees convened for their semiannual meeting. Shown are (from left) Dave Beneteau, John Gullottl, Chris Lander, A2 Secretary Annette Alonso, Pat Newhouse, Chuck Ford, A2B Chair Dick Holdren, Larry Barley, A2C Chair J. P. Christlein, and A2 Chair Ben Grimmett. The A2B Subcommittee worked on AWS 3.0, Standard Welding Terms and Definitions. The A2C Subcommittee met to update AWS A2.4, Standard Symbols for Welding, Brazing, and Nondestructive Examination. Ho- bart Institute of Welding Technology hosted the event in Troy, Ohio. For information on the A2 Committees’ work, contact Annette Alonso, aalonso@aws.org; (800/305) 443-9353, ext. 299.

Peter Howe Retires

Peter Howe, a CWI, recently retired from the AWS staff as managing director, Certification Technical Operations. Howe joined the Society’s Technical Department in July 2002 as a staff engineer, standards program manager, where he served as secretary to the AWS C5, D10, D14, D16, and D18 Committees. In 2004, he was promoted to director, national standards activities, where he served as secretary to the Technical Activities Committee (TAC). He chaired the D8D AWS/SAE Subcommittee on Automotive Resistance Spot Welding, and was vice chair of the D8 Committee on Automotive Welding. At Bethlehem Steel Corp., where he worked for 35 years, he was a welding research engineer. Many of his technical articles have been published in the Welding Journal. On two occasions, he was presented the William Hobart Award for outstanding papers. One detailed hydrogen-assisted cracking in high-strength pipeline steels, and the other studied resistance spot welding of electrogalvanized sheet steels.

Errata B2.1-011:2002

Standard Welding Procedure Specification (SWPS) for Shielded Metal Arc Welding of Galvanized Steel (M-1), 10 through 18 Gauge, in the As-Welded Condition, with or without Backing

The following errata have been identified and will be incorporated into the next reprinting of this document.

1. Page 3 — Electrical Characteristics Table — The Filler Metal Classification for Base Metal 11 gauge and 10 gauge should read “E6010” not “E6013”.

2. Page 3 — Electrical Characteristics Table — The Filler Metal Classification for Base Metal 11 gauge and 10 gauge should read “E6010” not “E6013”.


Specification for Welded Joints in Machinery and Equipment

The following errata have been identified and will be incorporated into the next reprinting of this document.

Page 63, Table 7, Class II row — Undercut column should read: “0.01 in. [0.25 mm] maximum depth for smoothly contoured undercut transverse to direction of primary stress. ½ in. [1 mm] maximum depth for undercut parallel to direction of primary stress.”

ISO Draft Standard for Public Review

ISO/DIS 13585.2, Brazing — Brazer qualification

Copies of this draft standard are available for review and comment through your national standards body, which in the United States is ANSI, 25 W. 43rd St., Fourth Floor, New York, NY, 10036; (212) 642-4900. Comments regarding ISO documents should be sent to your national standards body. In the United States, if you wish to participate in the development of International Standards for welding, contact Andrew Davis, adavis@aws.org; (800/305) 443-9353, ext. 466.

Technical Committee Meetings

All AWS technical committee meetings are open to the public. Persons wishing to attend a meeting should contact the staff secretary of the committee as listed below at AWS, 550 N.W. LeJeune Rd., Miami, FL 33126; telephone (305) 443-9353.


Bruskotter Addresses International Welding and Joining Conference in Peru

AWS President John Bruskotter represented the American Welding Society at the Third International Conference on Welding and Joining of Materials, held Aug. 9–11 in Lima, Peru. Sponsored by the AWS Lima Section, the event was organized by the Pontifical Catholic University of Peru and Soldexa S.A. in collaboration with the University of Illinois at Chicago.

Renowned welding experts from universities, research centers, and industrial companies worldwide participated. The International Technical Committee included John DuPont from Lehigh University; David Olson and Stephen Liu from Colorado School of Mines; and Wayne Thomas from The Welding Institute, UK. The topics included weldability of advanced alloys, mechanical behavior of welds, design and modeling of processes, distortion and residual stresses, advanced NDE techniques for welding inspection, special welding and joining processes, education and training in welding, and technology transfer.

The conference included the International Welding Show Peru 2010, a technical exhibition of local and international welding manufacturers and related industries. Peru has an emerging and market-oriented economy with a solid growth and industrialization perspective. Peru’s primary industries include mining and refining of minerals, construction, oil well and petrochemicals refining, natural gas, manufacturing, fishing, agriculture, and tourism.

Contribute Your Knowledge to These Technical Committees

Marine Construction
The D3 Committee for Welding in Marine Construction to contribute to the development of D3.5, Guide for Steel Hull Welding; D3.6, Specification for Underwater Welding; D3.7, Guide for Aluminum Hull Welding; and D3.9, Specification for Classification of Weld-Through Paint Primers. Contact B. McGrath, bmcgrath@aws.org, ext. 311.

Mechanical Testing of Welds
The B4 Committee for Mechanical Testing of Welds to contribute to B4.0, Standard Methods for Mechanical Testing of Welds. Contact B. McGrath, bmcgrath@aws.org, ext. 311.

Surfacing Industrial Mill Rolls

Magnesium Alloy Filler Metals
ASL 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.

Robotic and Automatic Welding

Thermal Spraying
C2 Committee on Thermal Spraying to update C2.16, Guide for Thermal Spray Operator Qualification; C2.18, Guide for the Protection of Steel with Thermal Sprayed Coatings of Aluminum and Zinc and their Alloys and Composites; C2.19, Machine Element Repair; C2.23, Specification for the Application of Thermal Spraying Coatings (Metalizing) of Aluminum, Zinc, and Their Alloys and Composites for the Corrosion Protection of Steel. Contact J. Gayler, gayler@aws.org, ext. 472.

Labeling and Safe Practices
SH4 Subcommittee on Labeling and Safe Practices to update AWS F2.2, Lens Shade Selector; AWS F4.1, Safe Practices for the Preparation of Containers and Piping for Welding and Cutting; and the AWS Safety and Health Fact Sheets. S. Hedrick, steveh@aws.org, ext. 305.

Submit Your Nomination for the M.I.T. Award

November 2, 2011, is the deadline for submitting nominations for the 2012 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.
Deadline Nears to Apply for Welder Workforce Development Grants

January 15, 2011, is the deadline for submitting your application to receive a grant from the AWS Foundation Welder Workforce Development Program. These grants are to be used to recruit and train entry-level welders and also to provide experienced welders with specific specialized training to promote the welder workforce needs for their companies.

To qualify, the grant requires a partnership between a company and an educational or welder training institution. The training institution commits to offering the training program as defined by the participating company and the company commits to hiring qualified graduates of the institution’s training program.

To be considered for a grant, the company and the training institution must submit a joint application to the AWS Foundation. The application must include the specific activities that will be implemented to address the company’s workforce needs. Additional information and the application form are available at www.aws.org under the heading “Foundation,” or e-mail Monica Pfarr, mpfarr@aws.org, corporate director, Solutions Opportunity Squad.

This second round of Workforce Development grants has a pool of $80,000, funded by the AWS Foundation’s generous partners. The Foundation is confident that these grants will have significant impacts on improving the welding workforce.

Two grants have been approved for funding in the first round of grants that were awarded in 2009.

Premier Fabrication, Inc., Conerville, Ill., and Illinois Central College submitted a Cooperative Education Program for Welding that was approved for funding. The AWS Foundation has agreed to award the project $10,000.

The second project was submitted by Mountain States Steel, Inc., Lindon, Utah, and Mountainland Applied Technology College. This project proposed to train 60 current employees. The program defined an eight-week curriculum for a total of 100 hours. The training is to include classroom instruction, hands-on experience in the booth and in production activities, and safety instruction.

The goal of this endeavor is to help each employee develop a specific comprehensive skill set to overcome production issues Mountain States Steel faces on a daily basis. These needs include improvements in overall production quality, an increase in the number of workers with certifications to meet customers’ requirements, and safety awareness. The Foundation agreed to award the project $19,200.

Member-Get-A-Member Campaign

Listed below are the members participating in the 2010–2011 Member-Get-A-Member (MGM) campaign effective Oct. 18, 2010. Data shown are for the period June 1, 2010, to May 31, 2011. For campaign rules and the prize list, see page 65 in this issue of Welding Journal or visit the Member-Get-A-Member campaign Web site www.aws.org/mgm. Call the AWS Membership Dept. (800/305) 443-9353, ext. 480, for more information on your member-proposer point status.

Winner’s Circle
Sponsored 20+ new members per year since 6/1/1999. The superscript indicates the number of years the member has achieved this status if more than once.

J. Compion, San Fernando Valley
E. H. Ezell, Mobile
J. Mertzhal, Peru
G. Taylor, Pascagoula
L. Taylor, Pascagoula
B. Chin, Auburn-Opelika
S. Esders, Detroit
M. Haggard, Inland Empire
M. Karagoulis, Detroit
S. McGill, NE Tennessee
D. Steyer, Niagara Frontier
W. Shreve, Fox Valley
T. Weaver, Johnstown/Altoona
S. Woomer, Johnstown/Altoona
R. Wray, Nebraska

President’s Club
Sponsored 3–8 new members
M. Pelegrino, Chicago
M. Tryon, Utah
E. Ezell, Mobile
R. Dawson, Western Carolina
J. Hopwood, Iowa
H. Cable, Pittsburgh
C. Crumpton, Florida W. Coast
R. Ellenbecker, Fox Valley
W. Sartin, Long Beach/Or. Cty.
D. Steyer, Niagara Frontier
W. Sturge, New York

President’s Honor Roll
Sponsored 2 new members
M. Allen, Charlotte
D. Berger, New Orleans
R. Fuller, Florida W. Coast
G. Hamilton, Houston
J. Hill, Nebraska
J. Hope, Puget Sound
J. Kline, Northern New York
A. Laabs, Lakeshore
T. Palmer, Columbus
W. Wall, Auburn-Opelika
D. Wright, Kansas City

Student Sponsors
Sponsored 3 or more members
M. Pelegrino, Chicago
D. Berger, New Orleans
J. Carney, W. Michigan
G. Grammell, NE Mississippi
S. Siviski, Maine
V. Facchiano, Lehigh Valley
E. Norman, Ozark
T. Buchanan, Mid-Ohio Valley
D. Schnalzer, Lehigh Valley
K. Cox, Palm Beach
M. Haggard, Spokane
W. Sartin, Long Beach/Or. Cty.
D. Steyer, Niagara Frontier
W. Sturge, New York
H. Hughes, Mahoning Valley
D. Saunders, Lakeshore
G. Seese, Johnstown-Altoona
C. Schiner, Wyoming Section
W. Davis, Syracuse
S. Robeson, Cumberland Valley
G. Kirk, Pittsburgh
J. Ciaramirano, N. Central Florida
S. Ulrich, St. Louis
A. Badeaux, Washington, D.C.
J. Boyer, Lancaster
R. Hutchinson, Long Beach/Or. Cty.
J. Kline, Northern New York
G. Sieperti, Kansas
T. Palmer, Columbus
D. Wright, Kansas City
B. Suckow, Northern Plains
W. Galvery, Long Beach/Or. Cty.
D. Kowalski, Pittsburgh
S. Mackenzie, Northern Michigan
C. Warren, N. Central Florida
M. Anderson, Indiana
S. Colton, Arizona
J. Gerdin, Northwest
J. Goodson, New Orleans
S. Miner, San Francisco
J. Seitzer, York-Central Pa.
T. Smeltzer, San Francisco
J. Sullivan, Mobile
B. Wenzel, Sacramento
D. Zabel, SE Nebraska
Shown at the Lancaster Section tour of The Leaning Barn Iron Works are (from left) Mark Stellato, Dave Watson, Tim Siegrist, Russ Ross, blacksmith Dan Alexander, Jerry Cross, Justin Heistand, Brian Gross, Chair Mike Sebergandio, and Bill McClain.

District 1
Thomas Ferri, director
(508) 527-1884
thomas_ferri@thermadyne.com

BOSTON
October 4
Activity: The Section members met at H & S Machine Co., Inc., in Lawrence, Mass. George Younker, president, gave a presentation describing many of the specialized machines the company has designed and built since its founding in 1948, then guided the group on a tour of the plant. The dinner was held at nearby Capellini’s Restaurant.

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

LONG ISLAND
October 14
Activity: The Section members met at The Nook Restaurant in Wantagh, N.Y., to discuss techniques for welding aluminum. Attendees included Harland Thompson, deputy District 2 director; Chair Brian Cassidy, Ray O’Leary, Alex Duschere, and Ken Messimer.

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

LANCASTER
September 20
Activity: The Section members visited The Leaning Barn Iron Works in Pequea, Pa., for a tour and demonstration of blacksmith operations by owner Dan Alexander. Alexander is an artist and master blacksmith renowned for his works of art crafted from metals. Russ Ross received an award of appreciation for his long-time commitment to the Section.

October 19
Activity: David Watson and Jeremy Hedegore, Lincoln Electric Co. representatives, demonstrated the VRTEX™ 360 virtual reality arc welding training system for the Lancaster Section members and local welding students. A virtual welding contest was held. Greg Houseal, a Harrisburg Area Community College welding student, earned the highest score to win an autodarkening helmet. The program was held at Lancaster County Career and Technology Center in Mount Joy, Pa.
shown at the October Lancaster Section program are (from left) Chair Mike Sebergandio, David Watson, John Ganoe, Jeremy Hedegore, and contest winner Greg Houseal.

Lancaster Section attendees learned about virtual reality arc welding instruction at the October program.

Russ Ross (right) receives an award from Mike Sebergandio, Lancaster Section chair.

Tidewater Section Chair Paul Hebert (left) and Jenord Alston, vice chair, are shown at the October meeting.

FLORIDA WEST COAST

OCTOBER 13
Speaker: Robert Clark, owner
Affiliation: Tampa Steel Erecting Co.
Topic: Bridge and complex building fabrication
Activity: Treasurer Bill Machnovitz conducted a raffle to raise funds for the scholarship fund. The Section will present the scholarships at its 19th annual golf tournament to be held Feb. 26. The meeting was held at Frontier Steakhouse in Tampa, Fla.

SOUTH CAROLINA

SEPTEMBER 16
Activity: Steve Mattson, District 5 director, performed an underwater welding demonstration at the International Diving Institute (IDI) in Charleston, S.C. Students training at the facility demonstrated underwater rigging and lifting techniques. Attending was Sam Gentry, executive director, AWS Foundation.

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

NIAGARA FRONTIER

SEPTEMBER 22
Speaker: Jess Bedard
Affiliation: Quality Technical Training Institute (QTTI)
Topic: Prequalified AWS D1.1 procedures
Activity: The program was held at QTTI in Depew, N.Y., for 18 attendees.

NORTHERN NEW YORK

OCTOBER 5
Speaker: Ken Phy, District 6 director
Affiliation: KA Phy Services, Inc., president
Topic: Use of welding symbols
Activity: Mike Todd received the Section Educator of the Year Award. Chris Lanese was awarded District 6 Educator of the Year. The program was held at Mill Road Acres Golf Course and Restaurant in Latham, N.Y.

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

COLUMBUS

SEPTEMBER 29
Speaker: Anne-Claire Christiaen, manager of advanced materials applications
Affiliation: Battelle Memorial Institute
Topic: Novel coating for anti-icing appli-
Anne-Claire Christiaen discussed a novel anti-icing application for carbon nanotubes for the Columbus area technical societies in September.

cations using carbon nanotubes
Activity: This Columbus Section program was a joint meeting with members of the local chapters of SWE, ASME, ASM International, AIAA, and NACE. The program was held at Arlington Banquets in Columbus, Ohio.

OCTOBER 19
Speaker: Bryan H. Lyons, PE., president
Affiliation: HETEN Engineering
Topic: Welding history from ancient to modern times, and a hands-on welding session
Activity: Sixty-four members of Columbus area technical societies met at The Ohio State University where they separated into two groups. One group went to the lab to receive instruction on SMAW and GMAW, then made fillet welds that were evaluated with break testing. The other group assembled in a classroom to hear Columbus Section Chair Lyons’s talk and have dinner. The two groups then changed places so everyone participated in both activities.

Shown at the Northern New York Section program are (from left) speaker District 6 Director Ken Phy, Chris Lanese, Mike Todd, and Treasurer Keith Flood.

Speaker Jess Bedard (right) is shown with Paul Swatland, Niagara Frontier Section chairman.

At the South Carolina Section program, IDI students prepare to perform an underwater pressure test.

Bill Machnovitz (center), Florida West Coast Section treasurer, solicits scholarship donations from Jennifer Thompson and Charles Crumpton.
Shown at the Pittsburgh Section executive board meeting are from left (front row) Carl Spaeder and Jim Sekely; (standing) Dave Daugherty, Chair Brad King, Tom White, Carl Ott, Roger Hilty, and George Kirk.

Shown at the Wheeling Section program are (from left) Cody James, James McCoury, Jim Walker, Kim Walker, District 7 Director Don Howard, John Smith, Dave Carroll, Tyler Dunn, Bob Hanren, Brandon Isaac, Matt Buxton, Cody Hanlin, Brent Kendziorski, John Ramsey, Alex Russell, Lance Lightfritz, John Russell, Lee Culp, Drew VanFossen, Andy Jolly, and Jesse Jones.

The Pittsburgh Section members toured Brownsville Marine Products in September.

PITTSBURGH

SEPTEMBER 28
Activity: The Section members met at Brownsville Marine Products in Brownsville, Pa. Guides Fred Ensley, Joe Kavulic, and Keith Hiles discussed the company’s welding training program and its procedures for manufacturing fiberglass-covered barges and special application vessels.

OCTOBER 14
Activity: The Pittsburgh Section executive board members met at Siba Cucina, Seven Fields, Pa., to discuss plans for upcoming weld-off events and the FABTECH show.

WHEELING

SEPTEMBER 9
Speaker: Don Howard, District 7 director
Affiliation: Concurrent Technologies Corp.
Topic: Explosion bulge testing of HSLA-65 plate and welding systems
Activity: Jimmy Walker received the Silver Membership Award for 25 years of service to the Society.

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

CHATTANOOGA

SEPTEMBER 28
Speaker: Bill Brooks
Affiliation: Holston Gases
Topic: The history of manufacturing in the Chattanooga area
Activity: The meeting was held at Komatsu America in Chattanooga, Tenn., for 17 attendees.

NORTHEAST MISSISSIPPI

SEPTEMBER 16
Activity: Ron Martucci, Lincoln Electric Co., demonstrated the VRTEX™ 360 virtual reality arc welding trainer. The program was held in Columbus, Miss.

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

AUBURN-OPELIKA

OCTOBER 7
Speaker: Jeff Fergus, associate professor of materials engineering
Affiliation: Auburn University
Topic: Dye penetrant inspection
Activity: Following the talk, the attendees gathered in the lab where volunteers per-
Shown at the Auburn-Opelika Section program are (from left) Alison Mitchell, Daniel Kim, Bryan Chin, Steve Scott, Scottie Smith, District 9 Director George Fairbanks, Kanchana Weerakoon, John Shu, and L. C. Mathison.

Jimmy Walker (left) received the Silver Membership Award from Don Howard, District 7 director, at the Wheeling Section program.

Ron Martucci demonstrated the virtual reality arc welding trainer for the Northeast Mississippi Section members.

formed dye penetrant tests. District 9 Director George Fairbanks presented the Section Meritorious Award to Alison Mitchell, Daniel Kim, Bryan Chin, Steve Scott, Kanchana Weerakoon, John Shu, L. C. Mathison, Jeff Ellison, Jay Harris, Dwayne Jones, and Marko Zunklei. Daniel Kim also received the District Meritorious Award. The District Educator Award went to Scottie Smith. The program was held at Auburn University in Auburn, Ala.

NEW ORLEANS

SEPTEMBER 15

Activity: The Section’s board members met at New Orleans Pipe Trades Local 60 in Metairie, La., to discuss plans for the

Shown at the New Orleans Section Sept. 15 board meeting are (clockwise from left) John Pajak, Bruce Hallila, Ricky Duet, Todd Toranto, Chair Don Berger, Chris Fernandez, Travis Moore, and Tony Demarco.

New Orleans Section Chair Don Berger (left) presents the sponsor-appreciation plaque to Mark Bingham at the Sept. 21 program.

Speaker David Lindsay is shown at the New Orleans Section Sept. 21 program.

Using dye penetrant to evaluate welds at the Auburn-Opelika Section event are D. J. James (left), a welding instructor at Central Alabama Community College; and Caleb Poole, a welding student at the college.
Shown at the Cleveland Section program are (from left) Richard Hart, Paul Revolinsky, Lou Verhas, speaker Vic Matthews, Chair Phil Schmidt, Todd Morris, Dan Harrison, Mark Demchek, Mike Sherman, Paul Null, and Robert Gardner.

Shown at the Central Michigan board meeting are from left (front row) Bill Mumford, Jim Farmer, and Jeff Grossman; (back row) Scott Poe, Chair Bill Eggleston, Catherine Lindquist, and Jeff Haynes.

Andy Klos (center), Detroit Section executive committee member, is shown with presenters Tim Morris (left) and David Havrilla.

Moss Point High School students are shown at the Pascagoula Section program. Far right (from right) are Chair William Harris, AWS President John Bruskotter, and welding instructor Cynthia Harris.

Shown at the Cleveland Section program are (from left) Richard Hart, Paul Revolinsky, Lou Verhas, speaker Vic Matthews, Chair Phil Schmidt, Todd Morris, Dan Harrison, Mark Demchek, Mike Sherman, Paul Null, and Robert Gardner.

Shown at the Cleveland Section program are (from left) Richard Hart, Paul Revolinsky, Lou Verhas, speaker Vic Matthews, Chair Phil Schmidt, Todd Morris, Dan Harrison, Mark Demchek, Mike Sherman, Paul Null, and Robert Gardner.

Shown at the Cleveland Section program are (from left) Richard Hart, Paul Revolinsky, Lou Verhas, speaker Vic Matthews, Chair Phil Schmidt, Todd Morris, Dan Harrison, Mark Demchek, Mike Sherman, Paul Null, and Robert Gardner.

Shown at the Central Michigan board meeting are from left (front row) Bill Mumford, Jim Farmer, and Jeff Grossman; (back row) Scott Poe, Chair Bill Eggleston, Catherine Lindquist, and Jeff Haynes.

Andy Klos (center), Detroit Section executive committee member, is shown with presenters Tim Morris (left) and David Havrilla.

annual fishing rodeo fund-raising event. Attending were Chair Don Berger, John Pajak, Bruce Hallila, Ricky Duet, Todd Toranto, Tony Demarco, Travis Moore, and Chris Fernandez.

SEPTEMBER 21
Speaker: David Lindsay
Affiliation: Entergy
Topic: Welding operations at Waterford III Nuclear Plant
Activity: The first meeting of the season was sponsored by New Orleans Pipe Trades Local 60 in Metairie, La. Chair Don Berger presented the sponsor-appreciation plaque to Mark Bingham from Entergy. Jonny Fulco from New Orleans Pipe Trades won the 50/50 raffle prize money.

PASCAGOULA
Mississippi Gulf Coast C.C. Student Chapter
SEPTEMBER 1
Speaker: John Bruskotter, AWS president
Affiliation: Bruskotter Consulting Services
Topic: Welding operations in the Gulf of Mexico
Activity: William Harris, Section chair and the MGCCC Student Chapter advisor, conducted the meeting held at the college in Gautier, Miss. The 70 attendees included representatives from local industry, postsecondary students, faculty, and counselors from Moss Point High School, and college administrators and students. The agenda included discussions on oil platforms, drilling operations, and welding procedures used in the oil and gas industry in the Gulf of Mexico. The events surrounding the Deep Water Horizon offshore oil rig disaster were discussed.

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

**Sponsor of the Year:** The individual who sponsors the greatest number of new Individual Members during the campaign will receive a plaque, a trip to the 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
  P.O. Box 440367
  Miami, FL 33144-0367
- 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 ___________________________ M.I. ___________________________
First Name ___________________________
Title ___________________________
Birthdate ___________________________

 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 ☑

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

Company (if applicable)
Address ___________________________
Address Con’t ___________________________

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

PROFILE DATA
- 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 Member?  ☐ Yes  ☐ No

If yes, add one-time initiation fee of $12 ___________________________

International Members add $10 for optional hard copy of Welding Journal (note: digital delivery of WJ is standard) ___________________________

( Mandatory)

Domestic Members add $25 for book selection ($192 value), and save up to 87% ___________ $50 ___________________________

International Members add $75 for book selection (note: $50 is for international shipping) ___________ $50 ___________________________

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

TOTAL PAYMENT ... $ ___________________________

AWS STUDENT MEMBERSHIP ... $15

Domestic (Canada & Mexico incl.) ... $15
International (excludes Canada and Mexico) ... $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

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

Job Classification (Check ONE only)
- 01 ☐ President, owner, partner, officer
- 02 ☐ Manager, director, superintendent (or assistant)
- 03 ☐ Sales
- 04 ☐ Purchasing
- 05 ☐ Engineer — welding
- 06 ☐ Engineer — other
- 07 ☐ Architect designer
- 08 ☐ Metallurgist
- 09 ☐ Research & development
- 10 ☐ Quality control
- 11 ☐ Inspector, tester
- 12 ☐ Supervisor, foreman
- 13 ☐ Technician
- 14 ☐ Welder, welding or cutting operator
- 15 ☐ Consultant
- 16 ☐ Educator
- 17 ☐ Librarian
- 18 ☐ Student
- 19 ☐ Customer Service
- 20 ☐ Other

Technical Interests (Check all that apply)
- 01 ☐ Ferrous metals
- 02 ☐ Nonferrous metals except aluminum
- 03 ☐ Aluminum
- 04 ☐ Advanced materials/Intermetals
- 05 ☐ Ceramics
- 06 ☐ High energy beam processes
- 07 ☐ Arc welding
- 08 ☐ Braze welding
- 09 ☐ Brazing and soldering
- 10 ☐ Resistance welding
- 11 ☐ Thermal spray
- 12 ☐ Cutting
- 13 ☐ LNT
- 14 ☐ Safety and health
- 15 ☐ Bending and shearing
- 16 ☐ Roll forming
- 17 ☐ Stamping and punching
- 18 ☐ Aerospace
- 19 ☐ Aviation
- 20 ☐ Machinery
- 21 ☐ Marine
- 22 ☐ U.S. Pipeline and tubing
- 23 ☐ Pressure vessels and tanks
- 24 ☐ Sheet metal
- 25 ☐ Structures
- 26 ☐ Other
- 27 ☐ Automation
- 28 ☐ Robotics
- 29 ☐ Computerization of Welding
**CLEVELAND**  
**SEPTEMBER 14**  
Speaker: Victor Y. Matthews, AWS past president  
Affiliation: The Lincoln Electric Co. (ret.)  
Topic: Careers in welding  
Activity: The meeting was held at St. Paul’s Hellenic Center in North Royalton, Ohio. Attending were District 10 Director Richard Harris, Chairman Phil Schmidt, Richard Hart, Paul Revolinsky, Lou Verhas, Todd Morris, Dan Harrison, Mark Demchek, Mike Sherman, Paul Null, Robert Gardner, Harry Sadler, and Larry Boros.

**District 11**  
Eftihios Siradakis, director  
(989) 686-8660  
ft.siradakis@airgas.com

**CENTRAL MICHIGAN**  
**JULY 7**  
Activity: The Section’s executive board members met at Delhi Café in Holt, Mich. Participating were Bill Eggleson, chairman; Scott Poe, vice chair; Jeff Grossman, secretary; Jeff Haynes, treasurer; Bill Mumford, membership committee chair; Jim Farmer, technical representative; and Catherine Lindquist, SENSE and student affairs committee chair.

**DETROIT**  
**OCTOBER 7**  
Speaker: David Havrilla, manager of products and applications  
Affiliation: TRUMPF, Inc.  
Topic: Trends in laser beam welding and processing  
Activity: The meeting was held at the TRUMPF Laser Technology Center in Plymouth Township, Mich. Following the talk, the 49 attendees toured the center’s laboratory, conducted by General Manager Tim Morris and David Havrilla.

**District 12**  
Sean P. Moran, director  
(202) 915-4144  
spmoran@charter.net

**LAKE SHORE**  
**OCTOBER 14**  
Activity: The Section members toured the Ariens plant in Brillion, Wis., to study the fabrication of lawn care and snow-removal equipment. Troy Pagel, manufacturing leader; Dan Barker, fabrication operations director; and John Melotte, welding technician, led the tour and described the company’s robotic welding of snow blower components and lean manufacturing cells.

**MADISON-BELOIT**  
**SEPTEMBER 15**  
Activity: The Section members toured the fabricating facilities of Mayville Engineering Co. in Mayville, Wis., to study its flexible use of automation, and manual and automated welding operations.

**MILWAUKEE**  
**SEPTEMBER 23**
Shown at the Milwaukee Section tour are (from left) Rob Wilson, Holly Pasciak, Raul Amor, Anni Van Dyke, Carlos Esteves, Jason Kushner, and Dave Van Buskirk.

Shown are the Racine-Kenosha Section members and Gateway Technical College students during their tour of Jensen Metal Products.

Activity: The Section members toured the Eutectic Corp. CastoLab Services facility in Milwaukee, Wis. Highlights included demonstrations of welding and thermal spray, and the company’s production and hardfacing technologies.

RACINE-KENOSHA
OCTOBER 4
Activity: The Section members met at Jensen Metal Products, Inc., in Racine, Wis., for a tour of its manufacturing facilities. John Richter, plant manager, conducted the tour, describing its design and fabrication techniques using welding, machining, laser beam cutting, punching, forming, shearing, and powder coating. Welding students from Gateway Technical College attended the event.

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

CHICAGO
SEPTEMBER 22
Speaker: Kent Potocki, district sales and technical manager
Affiliation: Hypertherm
Topic: The plasma arc cutting process
Activity: The program, held at College of DuPage, Glen Ellyn, Ill., included details on how to set up the plasma arc cutting equipment and a demonstration of the process.

Illinois Central College
East Peoria Campus
Student Chapter
SUMMER 2010
Activity: The Student Chapter apprentices with IBEW Local #34, under the guidance of Advisor Eric Ockerhausen, created the entrance gate for the Wildlife Scary Park Halloween exhibit at Wildlife Prairie Park. The gate measures 10 x 10 ft, is portable
and free-standing. Training Director Paul Flynn supplied the uni-strut and the conduits and the college supplied the materials for the posts and support plates. The project was part of the apprentices’ welding training.

**PEORIA**
**SEPTEMBER 13**
Speaker: Mark Kerley, a past chairman
Affiliation: Caterpillar Tractor Co.
Topic: Caterpillar’s welding operations
Activity: This past chairmen’s meeting was held at Lariat Club in Peoria, Ill.

**District 14**
Tully C. Parker, director
(314) 440-7750
tuliparker@charter.net

**INDIANA**
**SEPTEMBER 28**
Speakers: Matt Vislay, operations manager; Barry Shoemaker, operations group leader of welding
Affiliation: Major Tool and Machine, Inc.
Topic: Nuclear energy
Activity: The meeting was held at Major Tool and Machine in downtown Indianapolis. Following the talks, the members toured the facilities.

**LEXINGTON**
**SEPTEMBER 23**
Speakers: Trent Spackman, Pete Regrut
Affiliation: ESAB Welding and Cutting Products
Topic: Gas metal arc welding
Activity: The program was held at Bluegrass Community and Technical College in Lexington, Ky., for 70 attendees. Attending were welding instructors Alan Mattox and Carl Watson, and scholarship awardees Cody McKee and Thurman Newsom. Each received $500 from the Woodrow Scott Memorial Scholarship. The Life Membership certificate was presented to Paul Zink for 35 years of service to the Society.

**District 15**
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(612) 861-3870
macevh@aol.com

**District 16**
David Landon, director
(641) 621-7576
dlandon@vermeermfg.com

**KANSAS**
**OCTOBER 14**
Speaker: Kent Cooper, AERO Hazmat team leader
Affiliation: Airgas Mid South
Topic: Properties and hazards of using compressed, liquefied, and cryogenic gases
Activity: Airgas Mid South hosted the program at its facility in Wichita, Kan.

**KANSAS CITY**
**OCTOBER 19**
Speaker: Antonio Howard, P.E.
Shown at LeTourneau Industries prior to the East Texas Section program are (from left) students Riley Wyers, Hayden Adams, William Shepard, and Mark Fahlgren; Student Chapter Advisor Robert Warke; student Howard Record; AWS President John Bruskotter; and J. Jones, District 17 director.

Kansas Section members are shown at the Oct. 14 program.

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

CENTRAL TEXAS
SEPTEMBER 21
Speaker: John Bruskotter, AWS president
Affiliation: Bruskotter Consulting Services
Topic: Welding in the petroleum industry and the need for welders
Activity: Attending were the faculty, staff, and students at Texas State Technical College, Waco, and J. Jones, District 17 director. Following the program, a dinner was held at Buzzard Billy’s Swamp Shack.

EAST TEXAS
LeTourneau University Student Chapter
SEPTEMBER 24
Speaker: John Bruskotter, AWS president
Affiliation: Bruskotter Consulting Services
Topic: The Horizon drilling rig accident
Activity: This joint meeting of the Section and its Student Chapter was held at the university in Longview, Tex. District 17 Director J. Jones chaired the program. Prior to the meeting, the group toured LeTourneau Technologies, Inc., a manufac-
turer of front-end loaders, log stackers,
and self-elevating, mobile offshore drilling
rigs.

OKLAHOMA CITY
OCTOBER 14
Speaker: Gerald Mobley
Affiliation: Airgas Safety Western Okla-
homa
Topic: Industrial hygiene and CrVI
Activity: The program was held in Okla-
homa City, Okla.

TULSA
SEPTEMBER 16
Speaker: Kent Cooper, Hazmat team
leader
Affiliation: Airgas Mid-South
Topic: Properties and hazards of com-
pressed, liquefied, and cryogenic gases
Activity: The program was held at Baxter’s
Interurban Grill in Tulsa, Okla.

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

SAN ANTONIO
OCTOBER 12
Speaker: Rob Tessier, director of welding
applications and automation
Affiliation: Airgas Southwest
Topic: How various welding shielding gases
affect bead profile and quality
Activity: About 50 members and guests at-
tended this program, held in St. Joseph’s
Hall in San Antonio, Tex.

HOUSTON
JUNE 12
Activity: The Section held its first skeet
shoot outing at Carter’s Country in Hous-
ton, Tex. The fund-raising event was held
for Justin Gordy. The 35 attendees partic-
ipated in a variety of skeet and trap
matches.

District 19
Neil Shannon, director
(503) 201-5142
neilsshnn@msn.com

BRITISH COLUMBIA
SEPTEMBER 23
Speaker: Avaral Rao
Affiliation: Powertech Labs, Inc.
Topic: Refurbishing aging hydroelectric
equipment
Activity: The program was held at UA Piping
Trades School in Delta, B.C., for 30 at-
tendees.

AWS President John Bruskotter (far right) is shown with Tyler Jr. College welding instructor Kyle Emmons (far left), and welding students Taylor Samford (bottom), Ainsley Simmons (center), and Cooper Vernom. Bruskotter visited Tyler Jr. College in Tyler, Tex., Sept. 22, to meet with the welding students and staff. He discussed the recent Horizon drilling rig accident and detailed career opportunities with the students. Attending the event were J. Jones, District 17 director, and Bryan Baker, department chair, Industrial Trades, at the college.

Shown at the Tulsa Section program are speaker Kent Cooper (left) and Pete Goud, vice chair.
Shown at the Nevada Section program are (from left) Chair Richard Samanich, District 21 Director Nan Samanich, AWS President John Bruskotter, Donna Bruskotter, and Bill Komlos, District 20 director.

Shown at the Albuquerque Section program are (from left) Chair Pierrette Gorman, Paul Leyba, Mark Chavez, Richard Moku of Mathe-son, and Paul Baumann of Atomic Inspection.

PUGET SOUND
OCTOBER 7
Speaker: Dave Brazell, district sales manager
Affiliation: Hypertherm
Topic: Plasma cutting processes, principles, safety, and productivity
Activity: The Section awarded four $500 scholarships. The recipients were Ryan McGuire and Dan Luca at Lake Washington Tech; Steve Carlson at Renton Tech, and Cody Miller at Bellingham Tech. The meeting was held in Seattle, Wash.

District 20
William A. Komlos, director
(801) 560-2353
bkoz@arctechllc.com

ALBUQUERQUE
SEPTEMBER 24
Activity: The Section members met at CNM Community College for a presentation and demonstration of forge welding and blacksmithing a horseshoe by CNM welding instructor Robert Ulibarri. Tom Lienert, an AWS director-at-large, made a presentation to the students on the AWS scholarship program. A District 20 scholarship was presented to Paul Leyba. Mark Chavez received a Section scholarship.

COLORADO
OCTOBER 14
Speaker: Leslie DeCoste, safety consultant
Affiliation: Hellman & Associates
Topic: Protecting workers from exposure
to hexavalent chromium
Activity: This Colorado Section program was held at Colorado School of Mines in Golden, Colo.

District 21
Nanette Samanich, director
(702) 429-5017
nan07@aol.com

NEVADA
SEPTEMBER 29
Speaker: John Bruskotter, AWS president
Affiliation: Bruskotter Consulting Services
Topic: Offshore oil and gas platforms
Activity: Attending the program were Chair Richard Samanich, District 21 Director Nan Samanich, District 20 Director Bill Komlos, and Donna Bruskotter. The meeting was held in Las Vegas, Nev.

District 22
Dale Flood, director
(916) 288-6100, ext. 172
d.flood© tritool.com

SACRAMENTO
SEPTEMBER 28
Speaker: John Bruskotter, AWS president
Affiliation: Bruskotter Consulting Services
Topic: Offshore oil and gas platforms
Activity: The event was held at American River College in Sacramento, Calif.

OCTOBER 13
Speaker: David Kilburn
Affiliation: The Lincoln Electric Co.
Topic: Welding safety
Activity: This Sacramento Section program was held at Consumnes River College in Sacramento, Calif.

SAN FRANCISCO
SEPTEMBER 27
Speaker: John Bruskotter, AWS president
Affiliation: Bruskotter Consulting Services
Topic: Offshore oil and gas platforms
Activity: Attending the program were past District 22 Chairs Mark Bell and Kent Baucher and about 70 members and guests. The event was held at Spenger’s Restaurant in Berkeley, Calif.

AWS President John Bruskotter is shown with Liisa Pine, San Francisco Section chair.
New Sustaining Company
Red Ball Oxygen
609 N. Market St.
Shreveport, LA 71107
Representative: Aaron Wright
www.redballoxygen.com

Red Ball Oxygen is a major supplier of industrial and welding gases, equipment, and supplies, medical gases, robotic automation, and welding inspection and safety equipment. The company includes Red Ball Technical Gas Services, an ISO/IEC 1705:2005-accredited specialty gas laboratory, a modern cylinder-filling operation, and a full-service welding equipment service center.

AWS Member Counts
November 1, 2010

Grades
Sustaining.............................................510
Supporting............................................294
Educational...........................................544
Affiliate...................................................471
Welding Distributor.................................46
Total Corporate ..................................1,865
Individual.............................................51,734
Student + Transitional............................10,590
Total Members.................................62,324

Butler Presented Student Chapter Member Award

Charlie Butler has been selected to receive the Student Chapter Member Award by Shannon Hansen, advisor, Southeast Community College, Milford Campus, Student Chapter, Southeast Nebraska Section, District 16.

Butler, who maintains a 3.5+ GPA, served this year as the Chapter’s treasurer. He has served his community as a volunteer on several Habitat for Humanity projects and for his Neighborhood Watch program. Butler earned first-place honors in GTAW at the 2009 Nebraska SkillsUSA State Conference, first-place in GTAW and Overall Welding at the 2010 Nebraska SkillsUSA State Conference, and 24th place in Welding at the 2010 SkillsUSA National Conference.

The AWS Board of Directors established this award to recognize AWS Student Members whose Chapter activities have produced outstanding school, community, or industry achievements. This award also provides an opportunity for Chapter advisors, Section officers, and District directors to recognize outstanding students affiliated with AWS Student Chapters, as well as to enhance the image of welding within their communities. To download the nomination form, visit www.aws.org/sections/awards/student_chapter.pdf; or call the Membership Dept. at (800) 443-9353, ext. 260.

Supporting Company
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371 Hostdale Rd., Dothan, AL 36303

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Longview, TX 75604

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Savannah, GA 31405

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Cabancalan, Mandaue City 6014
Philippines

Two Named for District 15 Director Awards

Mace Harris, District 15 director, has nominated Dan Johnson and Paul Carter, members of the Northwest Section, to receive the District Director Award. This award provides a means for District directors to recognize members who have contributed their time and effort to the affairs of their local Section and/or District.

Check out the Jobs in Welding Web Site

The www.jobsinwelding.com Web site offers direct access to more than 88% of the welding jobs posted on the Internet. It makes it unnecessary to search numerous job boards. The Web site also offers a customer service contact to help answer your questions.
Guide to AWS Services

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jbruskotter@eplweb.com
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Sissibeth Lopez, slopez@aws.org

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Webster, Chamberlain & Bean, Washington, D.C., (202) 783-9900; FAX (212) 855-1824. Monitors federal issues of importance to the industry.

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Joe Kral, jkral@aws.org
Organizes annual AWS welding show, convention, space assignments, and other expo activities.

Director, Convention and Meeting Services
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Brazing and Soldering Manufacturers’ Committee
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WEMCO — Welding Equipment Manufacturers Committee
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Oversees application processing, renewals, and exam scoring.

Note: Official interpretations of AWS standards may be rendered only by sending a request in writing to Andrew R. Davis, managing director, Technical Services, adavis@aws.org. Oral opinions on AWS standards may be rendered, however, oral opinions do not constitute official or unofficial opinions or interpretations of AWS. In addition, oral opinions are informal and should not be used as a substitute for an official interpretation.

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The AWS Foundation is a not-for-profit corporation established to provide support for the educational and scientific endeavors of the American Welding Society. Further the Foundation’s work with your financial support. Call for information.
Estimating the Direct Costs of Arc Welding

The use of accurate values for estimates vs. actual cost is a fundamental cost accounting principle. Estimates for quotations to customers are sometimes developed using outdated sketches and specifications, with minimal investigation into specific welding details of the project. The resulting quote may be so inaccurate that the company loses the bid if it is too high or makes little or no profit if it is too low. Thus, the various cost factors of weldments required for a proposed project or product should be researched and verified to ensure the actual costs are known.

A data breakdown of the actual weld time and the weight of deposited metal showing the cost per hour and per pound unit weight should be created and summarized for each weldment the project requires. The final summary should contain figures representing the estimated costs, actual costs, and the difference between the two.

A cost summary provides data to aid in the following functions:
1. Validation of cost accounting for welded items
2. Preparation of accurate cost estimates and submission of appropriate quotations
3. Justification of purchases of welding and cutting equipment improvements
4. Building the company's historical database and developing confidence in its use
5. Contributing to the training of personnel involved in the weldment manufacturing and cost-summarizing processes
6. Improving communications between the various departments within a welding operation.

Table 1 presents the equations used for various cost estimations. Be aware that although the table presents a method of estimating actual welding costs, the accuracy of the equations for every application cannot be guaranteed. Both the judgment of the estimator and the accuracy of the input data influence the estimate.

<table>
<thead>
<tr>
<th>Table 1 — Equations Used to Estimate the Direct Costs of Arc Welding</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Equation</strong></td>
</tr>
<tr>
<td>$\text{Cost}_{\text{Gas}} = (G \times F) \div D$</td>
</tr>
<tr>
<td>$\text{Cost}_{\text{Power}} = (P \times V \times A) \div (1000 \times D)$</td>
</tr>
<tr>
<td>$\text{Cost}_{\text{Materials}} = M \div E$</td>
</tr>
<tr>
<td>$\text{Cost}_{\text{Labor}} = (L \times K) \div (D \times 100)$</td>
</tr>
<tr>
<td>$\text{Cost}_{\text{Overhead}} = O \div D \times (K + 100)$</td>
</tr>
<tr>
<td>$\text{Cost}_{\text{Weld per unit length of deposited metal}} = \text{Sum of Equations 1-5}$</td>
</tr>
<tr>
<td>$\text{Cost}<em>{\text{Weld per unit length of joint}} = \text{Cost}</em>{\text{Weld per unit length of deposited metal}} \times S$</td>
</tr>
<tr>
<td>$\text{Total Cost}<em>{\text{Weld}} = \text{Cost}</em>{\text{Weld per unit length of deposited metal}} \times W \times 7 \times N$</td>
</tr>
<tr>
<td>$T = W \div (D \times K)$</td>
</tr>
<tr>
<td>$W = S \times N \times C$</td>
</tr>
<tr>
<td>$T_{\text{Joint}} = W + (D \times K)$</td>
</tr>
<tr>
<td>$E = (F \times T) \div E$</td>
</tr>
<tr>
<td>Electrode or wire (lb [kg]) = W + E</td>
</tr>
<tr>
<td>SAW flux (lb [kg]) = 1.5 W \div E</td>
</tr>
<tr>
<td>$\text{Gas (ft}^3 \text{[m}^3\text{])} = (F \times T) \div E$</td>
</tr>
<tr>
<td>Key:</td>
</tr>
<tr>
<td>$A =$ Amperes</td>
</tr>
<tr>
<td>$C =$ Specific gravity of metal, lb/in.$^3$ (kg/m$^3$)</td>
</tr>
<tr>
<td>$D =$ Deposition rate, lb/h (kg/h)</td>
</tr>
<tr>
<td>$E =$ Deposition efficiency, $/\text{ft}^3$ ($/\text{mm}^3$)</td>
</tr>
<tr>
<td>$K =$ Operator factor, $/\text{hour}$</td>
</tr>
<tr>
<td>$L =$ Labor rate, dollars (or other currency) per hour ($/h$)</td>
</tr>
<tr>
<td>$M =$ Cost of materials, $/lb ($/kg)</td>
</tr>
<tr>
<td>$N =$ Length of specified weld, in. (mm)</td>
</tr>
<tr>
<td>$O =$ Overhead rate, $/h$</td>
</tr>
<tr>
<td>$P =$ Power cost ($/kWh$)</td>
</tr>
<tr>
<td>$W =$ Total weight of weld metal,$^a$ lb/ft ($kg/m$)</td>
</tr>
<tr>
<td>$S =$ Cross-sectional area of weld joint, in.$^2$ (mm$^2$)</td>
</tr>
<tr>
<td>$T =$ Total welding time, h</td>
</tr>
<tr>
<td>$V =$ Volts</td>
</tr>
</tbody>
</table>

*a Steel weighs 0.283 lb/in.$^3$ (7.8 x 10$^{-6}$ kg/mm$^3$)

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Advanced ‘How-To’ Welding DVD Videos Released

A new instructional DVD video features metalworking fabricator Ron Covell of Covell Creative Metalworking demonstrating advanced welding techniques for home hobbyists and fabricators. Highlighted topics include tips for gas tungsten arc welding chrome-moly, magnesium, bronze, titanium; pulse and waveform adjustments demystified; learn how to weld castings made from aluminum, magnesium, and bronze; and advice for machine setup, joint preparation, and weld finishing. The “Advanced TIG Welding” DVD run time is 111 minutes. Information on this program and others is posted on the Web site. Type “Ron Covell DVD” in the search window.

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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. Hardbound, 10 chapters, 8-1/2" x 10-1/2", (2010).

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Offer applies to AWS Individual Members only. Limit of one book per AWS Individual Member. To upgrade your membership, please call (800) 443-9353, ext. 480.
Each flux cored and metal cored tubular electrode is presented with its classification, detailed applications, diameters, welding positions, characteristics, typical mechanical properties, and typical deposit chemical compositions (wt-%). The well-indexed, full-color reference is organized by carbon steel, low alloy, stainless steel, nickel alloys, and hardfacing products. An Electrode Products Comparability Chart lists products by the brand names of seven manufacturers. Numerous charts and graphs simplify understanding of welding parameters, deposition rates, wire feed speed vs. current, and various shielding gases. A number of reference features include a weld metal cost comparison worksheet, an article on the history of welding electrodes and their manufacture, the technology of welding stainless steel, electrodes product development, and a discussion on electrode fume generation, among other interesting topics.

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The 46-page, full-color 2011 Training & Certification Programs — Creating Industry Experts catalog details the company’s extensive public, on-site, and international training programs and schedules. Each course is described in detail. The public course schedules are listed through December 2011 showing application deadlines, course dates, and locations. The training program categories include surface preparation and coatings application; coatings inspection; coatings technology; management; coating concrete; lead paint safety and health topics; Navy and marine; online training and e-training; and Department of Defense courses for Army, Air Force, Coast Guard, and Navy personnel. The PDF catalog can be downloaded from the Web site shown.

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A new training video covers methods and best practices for hand soldering terminals. The 37-min-long DVD-18C includes a leader’s guide, review questions, and certification documents for students who successfully complete the final exam. Pictured are the industry best practices for soldering wires to commonly used turret, cup, bifurcated, hook, and pierced terminals in accordance with the latest IPC-A-610E and J-STD-001E acceptance standards. Shown are the proper wire-wrapping techniques, use of solder heat

— continued on page 83
In 2011, WEMCO and RWMA will once again co-locate their annual meetings.

On February 24-26, 2011 WEMCO and RWMA will host their independent meetings and work groups at the PGA National Resort and Spa, in Palm Beach Gardens, Fla. Both committees have agreed to collaborate on a very relevant theme – “Opportunities in the Energy Sector.” Join us as we gain insight on this topic from first-class business speakers, key industry leaders, enlightening presentations, and dynamic business forums.

The cost to attend this 3-day annual event is:
- WEMCO and RWMA Members: $675
- WEMCO and RWMA Spouses: $285

Negotiated rate at the PGA National Resort and Spa: WEMCO and RWMA have negotiated a rate of $179 per night for all attendees. However, rooms are limited—first-come, first-served!

Register Today!

For more information on WEMCO and RWMA or to register for the annual meetings contact:
Susan Hopkins
at susan@aws.org or 800-443-9353, ext. 295

This Year’s Theme:
“OPPORTUNITIES IN THE ENERGY SECTOR”

With the country’s continued demand for oil and natural gas, America has started to ask:

Is there a better way?
Absolutely. The United States is now focusing on natural, nuclear and renewable energy as alternatives. The nuclear energy sector is a key player in the energy industry. Old, unfinished plants are now being completed, and new ones are being built. In addition, energy sources such as sun, wind and tide are gaining strength. Next on many of our minds was:

“How will this affect the welding industry tomorrow?”
With the economy focusing on “green” jobs and technology, the employment outlook is bright for workers possessing skills in various welding processes. Competent and experienced welders, as well as welding equipment/products manufacturers will be critical to the creation of the green infrastructure in the coming years.

Will your company be a part of this new movement?
It is inevitable that this is the direction of the future. Countries such as Israel and Brazil are already making significant developments in this field. Now it’s time for WEMCO and RWMA to enlighten their members as well.
Member Milestone

William A. Komlos

William A. Komlos, AWS District 20 director, and coinventor Lawrence Reaveley were granted Patent No. US 7,690,553 B2 for Methods and Systems for Mitigating Residual Tensile Stresses on April 6. The invention was the result of experiments that not only characterized the structural effects of large-scale welding for the first time, but also offered a cryogenic method to restore the connection to full strength. The process induces counteracting compressive stresses into the connection that overcome the stresses induced by welding.

Reaveley and Komlos were invited to present the Top Professor Lecture on their new process at the 2010 NASCC: The Steel Conference, held May 12–15 in Orlando, Fla. Their topic was selected for the lecture “because of its relevance to modern steel construction. As today’s steel structures grow to cover larger and larger open spaces, the individual structural members get thicker and more difficult to connect together. Connecting welds induce tensile stresses in the connections that remain to preload the structure before any service loads are applied.” The new method overcomes the welding-induced stresses to enhance the strength of the steel members.

Komlos is the owner of Arc Tech, LLC, in Salt Lake City, Utah. He is a Senior Certified Welding Inspector and a Certified Welding Educator who holds master’s degrees in civil engineering and business administration, and holds ASNT Level III and Level II certifications.

OKI Bering Names VPs

OKI Bering®, Cincinnati, Ohio, a wholesaler of welding, safety, and industrial supplies, has named Barry Mitchell vice president of product management, Ed Deeley vice president of operations and purchasing, and Roch Monahan vice president of sales, replacing David Rush who will retire at the end of the year. Prior to these promotions, Mitchell served as director of product management and Monahan was director of operations and purchasing.

WPI Names Dean of Engineering

Worcester Polytechnic Institute (WPI), Worcester, Mass., announced that Selçuk I. Gügeri will join the university in early 2011 as its inaugural Bernard M. Gordon Dean of Engineering. For the past ten years, Gügeri served as dean of engineering at Drexel University, and previously was a professor and head of the Department of Mechanical Engineering at the University of Illinois at Chicago.

Imperium Hires Sales VP

Imperium, Inc., Beltsville, Md., a supplier of ultrasound imaging cameras for nondestructive (NDT) inspection, has appointed Bruce Stetler vice president of global sales, NDT products. Prior to joining the company, Stetler was Midwest regional sales manager and West Coast regional sales manager for Olympus.

AWESCO Appoints Sales Director

AWESCO, Albany, N.Y., a national gas and welding equipment distributor, has named Dale McCooele director of sales. Before joining the company, McCooele most recently worked at a biometric technology company in Las Vegas, Nev.

Wall Colmonoy Names Business Manager

Wall Colmonoy, Madison Heights, Mich., has named Steve Miller business development manager for the Alloy Products Group — Southeast U.S.A. Before joining the company, Miller worked for 19 years at SCM Metal Products Div. where he provided technical support for automotive industry brazing applications.

Obituaries

William F. Brown Sr.

William F. Brown, 90, died Sept. 6 near Kennewick, Wash. An AWS Life Member, in 1978 he became a charter member of the Inland Empire Section, District 19, based in Richland, Wash., and served as Section chair 1979–1980. Born in Tampa, Fla., he grew up in the Cincinnati, Ohio, suburbs. In 1937 he started as a laborer at Towsley Truck, Inc., where he was promoted to superintendent of the Metal and Welding Department. During World War II, he served as a welding instructor at Aberdeen Proving Grounds where he met and married Mary, his wife of 66 years. In 1951, they moved to Columbus, Ohio, where he attended The Ohio State University. He graduated in 1935 with a degree...
in welding engineering, then went to work for General Electric Co., in Cincinnati. In 1961, he transferred to GE Hanford in Richland, Wash. Later, he worked for Battelle Northwest and completed his career at Westinghouse Hanford, where he retired in 1989 as a Fellow Engineer. Brown, a Professional Engineer, held a number of patents. At Westinghouse, he developed the pulse magnetic welding machine to weld stainless steel fuel pin rods for the FFTF reactor. He later represented the company by taking the welding process to Japan. Brown is survived by his wife, Mary, two sons, three daughters, nine grandchildren, and 17 great-grandchildren.

George C. Barnes III

George C. Barnes III, 79, died Sept. 25 in York, Pa. Barnes, an AWS Life Member, worked as a metallurgical engineer for ESAB of Hanover for 22 years before his retirement. He received his degree in metallurgical engineering from Virginia Polytechnic Institute in 1952. Following graduation, he held positions with Fansteel Metallurgical, Inland Steel Co., Teledyne-McKay Co., and Allis-Chalmers Corp., prior to joining Chemetron Corp. in 1971. At Chemetron, he worked in research, marketing, and process engineering where he served as senior research engineer in the Welding Development Group. Barnes held several executive officer positions in the AWS York-Central Pennsylvania Section, including chairman for the 1971–1972 term. He was also a member of the York Chapter of ASM International where he served as chairman 1976–1977. He participated on the AWS Board of Directors for six years as District 3 director, and served on the boards of the York Symphony Orchestra and the SPCA of York County. He is survived by his wife, Janet, two sons, and five grandchildren. Contributions may be made to the York Symphony Orchestra, 10 N. Beaver St., York, PA 17401.

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— continued from page 79

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NEW PRODUCTS
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zirconia alumina abrasives; improved performance was found across all grinding jobs, from exotic alloys and stainless steel to gray iron. The Charger RightCut features a blend of zirconia alumina and alumina oxide abrasives. The Gemini RightCut handles small jobs on a variety of metal applications from carbon to stainless steels. Also, the RightCut ultra-thin wheels for cut-off applications are available in Charger and Metal lines in 4-, 41/2-, 5-, and 6-in. sizes, in 0.040-in. thickness, in Types 01 and 27.

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NEWS OF THE INDUSTRY
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• BV Schweisstechnik GmbH will now be trading under the name EWM Hightec Welding Automation GmbH with its headquarters in the Vogtland region of Germany.

• Lincoln Electric, Cleveland, Ohio, has been given the Market Share Leadership Award for best practices in the world pipeline industry related to welding equipment and consumables.

• HTP America, Inc., is moving its offices to Grove Village, Ill. The location provides a training area for gas metal arc and gas tungsten arc school classes, plus twice as much space for warehouse operations, product development, and customer service teams.

• Linde North America has signed California Tool & Welding Supply, Riverside, Calif., to its Platinum Partner™ program.

• Konecranes, Springfield, Ohio, expanded its machine tool service business by acquiring King Tool Co., Erlanger, Ky.

• QComp Technologies, Inc., Greenville, Wis., has become a member of FANUC Robotics America Corp.'s distribution network.


• RathGibson, a manufacturer of welded, welded and drawn, and seamless stainless steel, nickel, and titanium tubing, has expanded redrawing capabilities in its Janesville, Wis., facility.

• Germantown Tool & Machine, Inc., Huntingdon Valley, Pa., recently acquired two robotic welding systems with capacities including a 65-in. reach and up to a 8-ft linear weld path.♦

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Annual FABTECH International & AWS Welding Show
Chicago, IL - November 13-16, 2011
Submission Deadline: March 25, 2011
(Complete a separate submittal for each paper to be presented.)

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Investigations of Sn-9Zn-Ag-Ga-Al-Ce Solder Wetted on Cu, Au/Ni/Cu, and Sn-plated Cu Substrates

The solderability of Zn-containing, lead-free alloys was examined to determine whether they are good candidates for use in the electronics industry.

BY H. WANG, S. XUE, W. CHEN, X. LIU, AND J. PAN

ABSTRACT

Interfacial reaction products between Sn-9Zn-0.25Ag-0.2Ga-0.002Al-0.15Ce solder and Cu, Au/Ni/Cu, Sn-plated Cu substrates were investigated by scanning electron microscopy (SEM) and X-ray diffraction (XRD), while the hardness and indentation modulus of the interface reaction products were studied by the nanoindentation technique (NIT). The SEM and XRD results indicated that interfacial reaction products between solder and substrates were Cu$_5$Zn$_8$, Ag$_2$Zn$_3$, Au$_2$Zn$_3$, and Ni$_2$Zn$_2$Sn$_3$. A Cu$_5$Zn$_8$/Sn/Cu$_2$Zn$_8$ sandwich structure formed at the interface between solder and Sn-plated substrate. The hardness and modulus values of Cu$_5$Zn$_8$ and Ni$_2$Zn$_2$Sn$_3$ obtained through NIT were noticeably high, while that of Sn-9Zn-0.25Ag-0.2Ga-0.002Al-0.15Ce solder was low, exhibiting significant plasticity. Moreover, the wetting balance test and mechanical property test indicated that Sn-9Zn-0.25Ag-0.2Ga-0.002Al-0.15Ce solder exhibited good solderability on Sn-plated Cu substrate, and the application of Au/Ni/Cu substrate may enhance the soldered joints.

Introduction

Concerns about the health and environmental hazards of lead, and legislative actions around the world drove the research community to find replaceable solder alloys for the traditional Sn-Pb alloys (Refs. 1–3). Among the lead-free candidates that have been developed, such as Sn-Ag, Sn-Cu, Sn-Bi and Sn-Zn alloy systems, Sn-Zn alloy has been receiving special attention due to its low cost, wide raw material sources, superior strength, and low melting point near to eutectic Sn-Pb material sources, superior strength, and low melting point near to eutectic Sn-Pb material sources, near to eutectic Sn-Pb material sources). Nevertheless, there are still several problems that need to be addressed in order to facilitate the practical use of this solder alloy, such as its inferior wettability and easy oxidation (Refs. 5, 6). Heretofore, a lot of research has been done to improve the performances of the Sn-Zn solders (Refs. 6–8). Recent studies also pointed out that Sn-Zn-Ag-Ga-Al-Ce alloy presented good solderability and antioxidation (Refs. 9, 10). These efforts are expected to promote the use of Zn-containing lead-free solders in the electronics industry.

Solders are typically melted on a metallic substrate, such as Cu or Ni. Formation of intermetallic compounds (IMCs) is essential in the manufacturing (Refs. 11, 12). IMCs formed at the interface are a prerequisite for good solderability. It is reported that interfacial reaction may be a dominant factor in promoting the wetting, compared with the side effect of surface roughness (Ref. 13). Moreover, IMCs formed at the interface also have a significant effect on the mechanical properties and reliability of the soldered joints (Refs. 14, 15). This is because the brittle nature of the IMCs and the joining of the two materials with dissimilar properties, such as thermal expansion coefficient, hardness, and Young’s modulus, would degrade the interface integrity between solder and substrate (Ref. 14). Thus, a comprehensive knowledge of the intermetallic phases formed at the interface and its mechanical properties is extremely important.

It is known that Cu-Zn intermetallic compounds form between Sn-Zn solders and Cu substrate (Ref. 16); however, the reaction products may change when other elements are added to the solder or various substrates are used (Refs. 15, 17). In the literature, most of the studies were carried out to find the mechanical properties of the Cu-Sn, Ni-Sn, and Cu-Ni-Sn based intermetallics that are associated with Sn-Pb, Sn-Ag, and Sn-Ag-Cu solders (Refs. 12, 18–21). However, to the best of our knowledge, the micromechanical property data for the IMCs associated with Sn-Zn solders and different substrates were rarely reported in the literature survey conducted. The aim of this study is to investigate the solderability and the intermetallic compounds formed between Sn-9Zn-0.25Ag-0.2Ga-0.002Al-0.15Ce solder and three types of widely utilized substrates: Cu, Au/Ni/Cu, and Sn-plated Cu.

Experimental Procedures

Material Preparation

Pure Sn, Zn, Ag, Al, Ga, and Ce (99.95% pure) were used in the present investigation. The raw materials were first melted in a ceramic crucible to prepare Sn-9Zn, Sn-9Zn-0.1Al, Sn-9Zn-1Ag, Sn-9Zn-2Ga, and Sn-9Zn-4Ce as master alloys. In
Wetting Balance Test

The melting process, KCl-LiCl molten salt, with the mass ratio of 1.3:1, was used over the surface of the liquid alloys to prevent oxidation during smelting. Then the experimental alloys were melted in a quartz crucible at 300°C by using the master alloys. In order to avoid oxidation and ensure the actual compositions of the alloy elements match the designed value, the entire melting process was carried out in a nitrogen atmosphere applied with middle active rosin (MAR) flux. Pure Cu, Au/Ni/Cu, and Sn-plated/Cu flakes were employed as substrates. The flakes were immersed into the molten solder for 10 s, and the immersion depth was 2 mm.

Microstructure of the Interface

In order to investigate the reaction products on the interface, pure Cu, Au/Ni/Cu, and Sn-plated/Cu substrates were dipped in Sn-9Zn-0.2Ga-0.002Al-0.25Ag-0.15Ce solder for 30 s at 235°C to achieve reaction layers. After that, some of the wetted flakes were cross sectioned for scanning electronic microscope (SEM) analysis, and the other dipped substrates were immersed into a solution, 99% CH₃OH + 0.5% HCl + 0.5% HNO₃, to remove the unreacted solder. Then the exposed IMCs were further characterized by X-ray diffraction (XRD).

Nanoindentation Test

The nanoindentation technique explored in this work is an attractive technique for extracting Young's modulus of the IMCs because of the relatively small volume tested. Indeed, the properties measured from nanoindentation are the true properties of the IMC layer. A nanoindenter SHIMADZU DUH-W201S equipped with a Berkovich 115-deg diamond-probe tip, three-sided pyramidal indenter was employed. After the area of interest was focused, the nanoindentation test was conducted under a 50-mN load. The loading and unloading rates were both 2 mN/s and held at 50 mN for 10 s.

In order to achieve thick IMC layers, the substrates were first dipped into the molten solder for 10 min at 260°C, and then annealed at 150°C for 300 h, so that at least 20 μm IMC layers would form. Thus, the size of the IMC layers in these joints was sufficient to be analyzed for the nanoindentation test. After the test, an op-
Results and Discussions

Solderability of Solder

Figure 3 shows the solderability of the solder wetted on different substrates. It is found that the solder exhibits better solderability on Sn-plated/Cu substrate, with higher wetting force and shorter wetting time, than on Au/Ni/Cu substrates. The wetting time using Cu substrate and Sn-plated Cu substrate are similar; however, the F_{max} on the Sn-plated Cu is higher than that on the Cu substrate. The higher F_{max} may be attributed to the Sn-plated layer, which can reduce the interfacial tension between solder and substrate. It is reported that Sn-plated pads can improve the solderability of Sn-Ag-Cu and Sn-Cu solders (Ref. 22). The results shown in Fig. 3 also indicated that the Sn-plated/Cu substrate can improve the solderability of Zn-bearing solder.

Interfacial Reactions between the Solder and Substrates

Figure 4 shows the backscattering electron image associated with EDS and XRD analysis of the interface between Sn-9Zn-0.2Ga-0.002Al-0.25Ag-0.15Ce solder and Cu substrate. According to Fig. 4A, it is notable that the interfacial IMCs can be clearly divided into two portions, a planar layer, and an additional scallop-like layer. According to the EDS analysis, the planar one...
EDS analysis of point C; A — XRD pattern of the IMCs.

Fig. 6 — A — Interface between Sn-9Zn-0.2Ga-0.002Al-0.25Ce solder and Au/Ni/Cu substrate; B — EDS analysis of point A; C — EDS analysis of point B; D — EDS analysis of point C; E — XRD pattern of the IMCs.

is mainly composed of Cu and Zn, while the scallop-like one contains much more Ag. The XRD pattern shown in Fig. 4B indicates that these IMCs are Cu₅Zn₈ and AgZn₃. The formation of AgZn₃ is considered that, due to the formation of Cu₅Zn₈, zinc atoms transfer from the liquid solder to the substrate and enrich at the interface. Meanwhile, silver atoms also segregate at the interface and react with zinc to form Ag₅Zn₈. The Gibb’s free energy of Ag₅Zn₈ is smaller than that of AgZn₃ and AgZn IMCs at 235°C (Ref. 23) by heterogeneous nucleation on the preformed Cu₅Zn₈ interface, since Cu₅Zn₈ and Ag₅Zn₈ exhibit identical structure and their lattice constants do not differ greatly. Furthermore, the subsequent peritectic reaction: L + γ-AgZn₃ → ε-AgZn₃ contribute to the AgZn₃ observed at the interface (Ref. 24).

Figure 5 shows the interface between the solder and Sn-plated/Cu substrate, associated with the line scanning and XRD pattern of the IMC layer. The XRD pattern indicated that the IMC is Cu₅Zn₈. According to the line scanning, a thin Sn layer still exists in the middle of the Cu₅Zn₈ layers, forming a sandwich structure. The formation of the sandwich structure is mainly because that, during the wetting period, Zn atoms diffuse through the Sn layer and then react with Cu atoms, while the Cu atoms also diffuse through the Sn layer to the molten solder and react with Zn atoms to form Cu₅Zn₈. At the same time, the Sn layer may melt to the molten solder as the wetting temperature is 235°C, a little higher than the melting point of Sn. Before the substrate was taken out of the solder, the Sn layer had not melted completely, as a result the aforementioned sandwich structure formed.

Figure 6 shows the backscattering electron image of the interface between the solder and Au/Ni/Cu substrate, associated with the EDS and XRD analysis of the IMCs layer. The XRD pattern shown in Fig. 6C indicates that the IMCs are AuZn₃ and a little AgZn₃. However, the Ni layer and the Ni-Zn IMCs layer were covered by the AuZn₃ and the remnants solder, thus they were not detected by the XRD analysis. The EDS indicated that the Ni layer was composed of Ni and Zn, according to the report in Ref. 17. We supposed that this layer was Ni₅Zn₂₁.

Indentation Test

The indentation test was carried out on both Sn-9Zn-0.25Ag-0.2Ga-0.002Al-0.15Ce solder, Cu substrate, and the four IMCs: Cu₅Zn₈, AgZn₃, AuZn₃, and Ni₅Zn₂₁. Figure 7 shows the indentation traces on different materials tested. However, a thick AgZn₃ layer can be hardly achieved, according to the report in Ref. 22, massive AgZn₃ exists in Sn-9Zn-2Ag solder, and thus the indentation test on AgZn₃ phase was carried on Sn-9Zn-2Ag solder as shown in Fig. 7D. According to Fig. 7, it is found that the indentation trace in the IMCs is smaller than that in the solder. This is because that the IMCs are much harder than the solder.

Figure 8 shows the load-displacement plots obtained by the load indentations performed on the aforementioned materials. From the load-displacement curves, a hardness and elastic modulus are measured that are useful in describing the deformation behavior of the solder and IMCs.

Analysis of load-displacement data was carried out according to the Oliver and Pharr method (Refs. 24, 25). At the maximum load, Pmax and hardness, Hₜ, is determined by Hₜ = Pmax / A(hₜ), where A(hₜ) is the projected contact area. From the slope of the unloading curve, a reduced modulus Eₜ is measured that accounts for elastic recovery of the sample and the indenter.
Indentation traces on the following: A — Cu₅Zn₈; B — Ni₅Zn₂₃; C — AuZn₃; D — AgZn₃; E — solder.

![Indentation Traces](image)

Fig. 7 — Indentation traces on the following: A — Cu₅Zn₈; B — Ni₅Zn₂₃; C — AuZn₃; D — AgZn₃; E — solder.

![Indentation Traces](image)

Fig. 8 — Plots of load vs. depth for 50-mN maximum load indentations performed on Cu, solder, and IMCs.

![Indentation Traces](image)

\[ E_r = \left( \frac{1 - v^2}{E} \right)_{\text{sample}} + \left( \frac{1 - v^2}{E} \right)_{\text{indenter}} \]

where \( E \) is the Young’s modulus and \( v \) is Poisson’s ratio. With the properties of the diamond indenter known (\( E = 1140 \text{ GPa} \), and \( v = 0.07 \)), the indentation modulus, \( E_{NI} \), is defined as \( E_{NI} = E/\left(1-v^2\right)_{\text{sample}} \). Indentation modulus is primarily what will be reported here; however, with knowledge of Poisson’s ratio of the test material, the Young’s modulus, \( E \), can be determined.

Table 2 shows the results calculated according to the data in Fig. 8. In examining the results obtained, the maximum penetration of the indenter for Sn-9Zn-0.25Ag-0.2Ga-0.002Al-0.15Ce solder is approximately four times that measured for Cu₅Zn₈. The solder is found to be very soft, with a hardness of 0.36 GPa, exhibiting significant plasticity. In contrast to the solder, the IMCs, Cu₅Zn₈, and Ni₅Zn₂₃, are significantly harder while the hardness of AgZn₃ and AuZn₃ is similar to that of Cu. The intermetallic compound had a higher modulus than either of the two components. The higher modulus of the intermetallic over that of either of the metallic components...
can be attributed to the combination of ionic/covalent bonding in intermetallic compounds, which may result in a higher modulus than that obtained from a simple rule of mixtures of the components (Ref. 26). It should be noted that although AgZn$_3$ and AuZn$_3$ are intermetallic compounds, they do exhibit some extent of plasticity.

Hardness is often used to explain the brittleness of a material. The indication is that Cu$_5$Zn$_8$ and Ni$_5$Zn$_{19}$ have the potential for brittle behavior (crack initiation) when the soldered joints were deformed by stress. AgZn$_3$ and AuZn$_3$, with a lower hardness and modulus, are actually rather soft and ductile and not a likely source of crack initiation. Actually, cracks were found located at the Cu$_5$Zn$_8$ layer, and the interface between AuZn$_3$ and Ni$_5$Zn$_{19}$ layer, as shown in Fig. 9.

**Mechanical Properties of Soldered Joints**

Figure 10 shows the results of the mechanical properties of the QFP and CR microjoints. According to Fig. 10, it is found that the joints on the Au/Ni/Cu substrate exhibit higher shear and pull force than that on the Cu substrate, while the joints on the Sn-plated/Cu substrate show lower shear and pull force than that on the Cu substrate.

It is known that Sn (Zn for Sn-Zn solders) at the solder/Cu interface reacts rapidly with Cu to form Cu-Sn (Cu-Zn for Sn-Zn solders) IMCs, which weaken the soldered joints (Refs. 24-25). Therefore, Ni is used as a diffusion barrier layer to prevent the rapid interfacial reactions between the solder and Cu layer in electronic devices. In this study, it was found that the application of Au/Ni/Cu substrate can really enhance the soldered joints. It was also found that Sn-plated/Cu substrate can improve the solderability however, it may deteriorate the soldered joints.

**Conclusions**

1) Sn-9Zn-0.25Ag-0.2Ga-0.002Al-0.15Ce solder shows better solderability on Sn-plated Cu substrate than that of pure Cu and Au/Ni/Cu; while the application of Au/Ni/Cu pads may deteriorate the solderability. A mechanical property test indicated that the application of Au/Ni/Cu substrate enhanced the soldered joints.

2) Cu$_5$Zn$_8$ and AgZn$_3$ intermetallic compounds form at the interface between Sn-9Zn-0.2Ga-0.002Al-0.25Ag-0.15Ce solder and Cu substrate, while AuZn$_3$ and AuAgZn$_2$ were present at the interface between the solder and Au/Ni/Cu substrate. When the Sn-plated Cu substrate was used, the Cu$_5$Zn$_8$ layers and the remnants Sn layer constituted a sandwich structure at the interface.

3) Cu$_5$Zn$_8$ and Ni$_5$Zn$_{19}$ may be the crack initiation point when the soldered joint was deformed by stress due to the high hardness and modules. On the other hand, Sn-9Zn-0.25Ag-0.2Ga-0.002Al-0.15Ce solder is soft and exhibits significant plasticity, while AgZn$_3$ and AuZn$_3$ also exhibit a little plasticity.

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Tool Degradation Characterization in the Friction Stir Welding of Hard Metals

Microstructural characterization identified tool-life degrading mechanisms for three tungsten-based FSW tool materials

BY B. THOMPSON AND S. S. BABU

ABSTRACT

In recent years, friction stir welding (FSW) has made significant strides in the joining of hard metals such as steel and titanium thanks to advancements in tool materials. While the joining of hard metals using FSW shows significant promise with these advanced tool materials, a limiting factor remains tool life. The combination of high welding temperatures and flow stresses in the FSW of hard metals causes significant degradation of the tool. Previous tool degradation studies have defined observed types of wear or tracked dimensionally how much a tool material has degraded. Understanding tool degradation on a microstructural level would lead to the development of improved tool materials thereby increasing the opportunity for FSW to be employed as a joining method for hard metals. This study characterized the pre- and postweld microstructures of three tungsten-based tool materials: Material A (99% W-1% La$_2$O$_3$), Material B (75% W-25% Re), and Material C (70% W-20% Re-10% HfC). Tool degradation mechanisms were identified for each tool material based upon this characterization. Material A degraded by severe plastic deformation, Material B degraded by twinning, and Material C degraded by intergranular failure.

Introduction

Previous works examining tool degradation focused primarily on gross geometric changes a tool experienced during welding (Refs. 1–3). These changes were identified as both plastic deformation and tool wear; tool wear in this case specifying material loss. Wei Gan et al. investigated the friction stir welding (FSW) of L80 steel and demonstrated that two types of effects, deformation and wear, are main contributors to tool degradation (Ref. 4). Weinberger et al. also concluded that the limiting factors for FSW tools in hard metals are wear (abrasive and adhesive), brittle fracture, and deformation (Ref. 5).

Bentley et al. investigated deformation in tungsten (W) heavy alloys fabricated by powder metallurgy. These W-based microstructures were reported to fail by two main modes: cleavage or W-W grain boundary decohesion. Which type dominated depended upon material processing conditions. However, in W microstructures where the strain threshold had been reached (approximately 70% deformation), the W grains failed by cleavage mode because they could not withstand any more plastic deformation (Ref. 6).

Due to the complexity of describing how a tool material deteriorates during welding, the term tool degradation was concluded to be the best term to describe any loss of tool material integrity as a result of the FSW process. Tool degradation consists of two major components: wear and deformation. Tool wear describes material loss and includes abrasive and adhesive wear. Abrasive wear occurs as the tool material experiences the stresses of the welding environment. Particles of the tool material will, in effect, be lost to the welded material. Adhesive wear occurs when the material that is being welded adheres to the surface of the tool. In these areas a high stress concentration occurs, promoting material loss (Ref. 7). Plastic deformation is the second component of tool degradation. Types of plastic deformation that can occur in a FSW tool material include slipping or twinning. Oftentimes, plastic deformation is the most prominent cause of gross geometric changes in FSW tools (Refs. 4, 5, 8).

While these works (Refs. 1–8) provided valuable insight into characterizing the types of degradation FSW tools undergo and their geometrical changes, they did not investigate the microstructural changes that occur in the tool material during welding. By understanding how the microstructure of the tool material changes due to the FSW process, degradation mechanisms can be identified. A better understanding of these tool degradation mechanisms will lead to improved tool materials and/or tool designs, more appropriate tool material selection, and improved welding performance.

The three W-based alloys were chosen to best represent a wide range of W-based refractory alloys. The goal of this work was to investigate the microstructural changes the material experiences during welding and relate these changes to tool degradation. The tool materials were purposely welded under conditions designed to exacerbate the various mechanisms of degradation. In this way, the study represents “worst-case” weld quality conditions and provides the best case conditions to study degradation mechanisms.

Approach

Materials

The specific tool materials selected for microstructural characterization are three refractory-based alloys labeled Materials A, B, and C. Material A is made by doping pure W with 1.0 wt-% La$_2$O$_3$. This has the effect of increasing the creep strength and recrystallization temperature. Materials B and C are mainly comprised of W and rhenium (Re). Material B is specifically comprised of 75% W and 25% Re. The Re addition to the W has the effect of increasing the recrystallization temperature, ductility, and ultimate tensile strength. The Re also refines the microstructure and reduces the ductile-to-brittle transition temperature to ~50°C (~58°F). These strengthening and hardening effects are
due to both solid-solution strengthening and grain size refinement. Elevated temperature properties of W-Re have been measured at 1926°C (3498°F) and were shown to be 143 MPa (21 ksi) for ultimate tensile strength (UTS) with a total elongation of 6% (Refs. 9–11).

Material C stands out from Material B because it has an addition of hafnium carbon (HIC) particles. Material C has a specific composition of 70% W, 20% Re, and 10% HfC. This HfC addition has a significant impact on the high-temperature strengths. At 1926°C (3498°F), an alloy with an addition of 2% HfC saw an increase in UTS to approximately 275 MPa or 40 ksi. The addition of the HfC particles to the alloy effectively prevents any grain boundary separation due to plastic deformation at high temperatures. However, these HfC particles decrease the elongation and cause the material to be very brittle at low temperatures. The addition of HfC particles also slows down the recrystallization of the alloy leading to a very fine grain microstructure (Refs. 9, 12, 13).

Each material was acquired in 4-in.- (102-mm-) long, 1.2-in.- (30-mm-) diameter bars and was cut into two sections. The first section was 3 in. (76 mm) long and was machined into a variable-penetration tool (VPT) design (U.S. Patent Nos. 7,234,626, 7,404,510, and 7,416,102). A tool design schematic referencing important pin tool locations is displayed in Fig. 1. The second section was 1 in. (25 mm) long and was cut into two pieces along the central axis. The two resulting pieces were then mounted and polished; one piece being mounted in the cross-section orientation and the other piece being mounted in the traverse orientation. These six mounts were then used for base metal characterization.

A high-strength steel (HSS), nominally 80 ksi or 550 MPa, was chosen as the material to be welded for this study. The plates were approximately 7.5 in. (190 mm) wide, 24.75 in. (629 mm) long, and 0.75 in. (19 mm) thick. The plates were prepared for welding by a machining pass to remove the mill scale and an acetone wipe.

**Welding Process**

Prior to welding, each tool was characterized dimensionally using digital profilometry and height gauge measurements. The digital profilometry system involved a laser attached to motorized, linear X-Y slides, which move the laser over the part during laser scanning. The laser used to scan the tools was a Micro Epsilon 2800 with Y and Z direction resolution of 0.0009 in. (23 μm).

All three tool material types were welded using the exact same parameters and processing conditions. The welds were completed in position control with a spindle speed of 90 rev/min, a travel speed of 3.5 in./min (89 mm/m), and a travel distance of 15 in. (381 mm). Typical plunge loads reached a peak of nominally 25,000 lbf (111 kN). These parameters were selected to achieve a cold welding condition that would be more likely to cause degradation of the tools. All welding was performed without primary or secondary shielding.

**Postweld Investigation Technique**

Postweld, each tool was again characterized dimensionally using the same digital profilometry and height gauge measurements. Each tool was then sectioned in the same manner and prepared for metallographic examination. The first cut was made perpendicular to the central axis just above the shoulder of the tool. A second cut was made along the central axis of the resulting tool tip from the first cut, effectively cutting it in half — Fig. 2. One half of this cut was mounted and polished in preparation for scanning electron microscope (SEM) and optical analysis. Typical SEM parameters included a voltage of 20.00 kV and a probe current of 100 pA.

The SEM was used to examine both the pin tip surface and the mounted cross section of each tool. For investigating the surface, backscatter imaging, secondary imaging, and energy-dispersive X-ray spectrometry (EDS) were employed. The primary areas of interest included pure tool material areas, mixed composition areas (tool material and steel), pin tip surface, pin side surfaces, and shoulder surfaces. When investigating the mounted cross sections of each pin tool, backscatter imaging, secondary imaging, and EDS were also used. The primary areas of interest for the cross sections included the tool shank, tool edge, pin tip edge, pin edge, shoulder edge, and center of the pin. Optical analysis of each mount for selected areas was also performed. Grain size measurements were completed by optically examining one of the
selected areas. Two lines were superimposed on a single grain at 90 deg to one another generating a length and width measurement for an individual grain through scale comparison. Average grain size was calculated by averaging individual grain size measurements taken within a 100-μm square area.

Results and Discussion

Characterization of Degradation Mechanisms in Tool Material A (W-La)

The raw stock of Material A is characterized by long vertical grains running parallel to the central axis. Average grain size is approximately 0.006 in. (150 μm) long and 0.002 in. (50 μm) wide — Fig. 3. When welding with this material, the tool visually deformed especially during the plunge sequence. As the tool traversed down the weld, it progressively mushroomed until the original shape was no longer recognizable. Upon retraction, the tool was visibly inspected and the severity at which it had become deformed was confirmed. The tool was also covered with a thick layer of steel extending from the pin tip up to the shoulder.

The digital profilometry data confirmed the pin length was shortened by 0.141 in. (4 mm). The shoulder diameter increased by 0.110 in. (3 mm) and the pin tip diameter increased by 0.100 in. (3 mm). In short, this tool had been compressed in length and expanded outward in diameter confirming a high-stress environment — Fig. 4.

Several instances of deformation were observed during the SEM and optical analysis of this tool material. Many areas of the tool surface showed plastic deformation as well as cracking. Observations of the mounted cross sections revealed further tool degradation in the microstructure, primarily in the form of deformation. Severe deformation of the pin tip and shoulder diameters occurred as well as compression of the pin length. The long grains characteristic of the stock material were twisted and compressed into different orientations. Some of these grains were twisted as much as 90 deg from the original orientation — Fig. 5.

Large areas of recrystallization were also noticed on both sides of the pin tip — Fig. 6. Material A (Tm of 3473 K) has a recrystallization temperature of 1873 K (Ref. 14), while typical temperatures during the FSW of steel reach approximately 900° to 1100°C (1173 to 1373 K) (Ref. 4). Recrystallization cannot occur in this material at FSW temperatures alone. Therefore, it is concluded that the combination of high temperatures and local deformation drove the recrystallization process to occur at a lower temperature.

Abrasive and adhesive wear were also observed; however, the abrasive wear appeared to have a minimal effect. Evidence of the W and steel materials alloy-
ing was also uncovered and could be possible because of the stresses and temperatures the tool material experienced during welding.

In summary, the primary tool degradation mechanism for Material A (W-La) is deformation. It appears that the grain structure was not able to withstand the high stresses experienced during welding and resulted in plastic strain causing the tool to deform from its original shape. In addition, the recrystallization of the material further decreases the ability of the tool to sustain the process loads during welding. These two factors contributed to the tool deforming under compression, causing mushrooming and loss of pin length.

Characterization of Degradation Mechanisms in Tool Material B (W-Re)

The raw stock of Material B is characterized by a fine grain structure, width of 0.004 in. (100 μm) or less, throughout the majority of the material and especially in the center of the bar — Fig. 7. Toward the edge of the bar the grains become quite large, on the order of five times larger (approximately 0.02 in. or 500 μm in width). This large grain region is approximately 0.178 in. (5 mm) wide at each edge. The cause of this difference in grain size is attributed to the material-processing conditions, and as a result, the grains have experienced recrystallization and growth. There are also indications of a possible second phase, most likely W-Re, along the grain boundaries of these larger grains.

During welding, Material B visually showed no signs of deformation or wear. Upon retraction, the tool was visually inspected and there was a light coating of steel on the pin with some slight deformation. Digital profilometry verified the pin length decreased by approximately 0.033 in. (838 μm) and the shoulder diameter increased by approximately 0.006 in. (152 μm). The pin tip diameter saw the largest change with an increase in size of approximately 0.036 in. (914 μm) — Fig. 4.

Investigation of the pin surface using the SEM revealed several instances of material deformation along with cracking, and abrasive and adhesive wear — Fig. 8. SEM analysis and optical microscopy of the pin tip cross section revealed further evidence of degradation. The grains experienced deformation in the form of twinning with subsequent changes in the tool geometry — Fig. 9. Twinning is known to be a natural process associated with increased strength levels and limited slip systems in BCC materials (Ref. 8). These effects were most prominent along the edges of the tool.

The twinning was also observed to initiate cracking, although the number of these cracks was very low — Fig. 10. While this material appears to have twinned in several locations, the occurrence must not be sufficient enough to cause severe cracking. The large grains on the outside edges of the tool were more susceptible to twinning, leading to faster shoulder wear and deformation as compared to the pin tip.

The grains throughout the entire pin experienced some degree of twinning, lesser near the center (25 twins per 0.02 in. or 508 μm square) and base of the pin tip and more severe near the pin and shoulder edges (50 twins per 0.02 in. or 508 μm square).
square). In the end, twinning was seen as the main cause of degradation in Material B. The twinning behavior was not uniform throughout the tool. It is believed this variation in behavior is related to different stress levels throughout the tool during FSW. Material B performed better than Material A due to the addition of Re. The Re significantly increases the strength and ductility of the material at higher temperatures due to solid-solution strengthening and grain refinement. Additionally, the Re raises the recrystallization temperature to 1900°C (3452°F) (Ref. 9).

Characterization of Degradation Mechanisms in Tool Material C (W-Re-HfC)

The raw stock of Material C has a very refined microstructure. Typical grain size was 0.001 in. (25 μm) wide for the W-Re grains and 0.0005 in. (3 μm) wide for the HfC particles — Fig. 11. The HfC particles were located both on the grain boundaries and inside of the W-Re grains. This material also exhibited a surfacing effect on the bar stock that occurred during the processing of the material. This surfacing effect was a layer approximately 0.06 in. (2 mm) wide, and is characterized by separation between the individual W-Re grains. EDS analysis was conducted in the separation area of a typical grain boundary. The analysis showed the region is comprised of W-Re-HfC in approximately the same compositions as the base material — Fig. 12. The occurrence of this grain separation drops off rapidly as the central axis of the tool is approached.

Material C showed very little degradation during welding. After welding, the pin was covered in a very thin layer of steel. Of all three tool materials, Material C was the most resistant to tool degradation. The pin length shortened only by 0.001 in. (25 μm), the shoulder diameter increased by only 0.002 in. (50 μm), and the pin tip diameter increased by 0.0045 in. (114 μm). As with the previous tool materials, the degradation shortened the pin length and mushroomed the pin tip and shoulder — Fig. 4.

Material C raw stock underwent very similar processing as Material B and, as such, has a similar microstructure with one exception, the grain size is much smaller. The HfC particles found both on the grain boundaries and inside the W-Re grains effectively stabilized the W-Re grains during recrystallization. This retarded the grain growth and led to a very refined microstructure. An edge effect of separated grains, approximately 0.06 in. (2 mm) wide, was observed around the outside diameter of the material. This decohesion may be caused by induced residual stresses that occurred when the material was produced.

SEM investigation of the pin surface revealed individual W particles scattered throughout the steel coating in addition to abrasive and adhesive wear. SEM analysis and optical microscopy of the cross section further confirmed the tool material was “breaking off” rather than deforming — Fig. 13. These localized intergranular fracture events appear due to the presence of
the HfC particles. The HfC particles effectively prevent softening of the tool material allowing high stresses to develop. This helps to prevent the types of deformation that leads to gross deformation as observed in Materials A and B.

Although the HfC particles provide a significant benefit, they do embrittle the microstructure. As described above, this results in numerous cracks along grain boundaries. This allows the tool material to be broken away from the tool. Once the W-Re grains are separated from their supporting HfC particles, they begin to deform — Fig. 14.

Material C also showed grain boundary decohesion near the outer diameter of the bar. This decohesion served to exacerbate intergranular failure on the outer corners of the shoulder. These grains were already beginning to separate in the as-received material and the added stress induced by the welding process accelerated their fracture.

The primary tool degradation mechanism of Material C is intergranular failure. Further tool material loss comes from abrasive and adhesive wear. Material C saw very little deformation as the HfC particles supported the surrounding W-Re grains. Material was lost from the tool because the HfC particles acted as cracking paths around the W-Re grains leading to intergranular failure. Once these grains were separated from the HfC particles, they broke off into the weld metal or deformed. Finally, the grain separation on the outer edges of this material helped to promote the intergranular cracking.

Conclusions

The degradation mechanisms of FSW tools made from three separate material types were identified. These mechanisms have been characterized for welding HSS under conditions that would promote tool degradation. For each tool material, the observed degradation was characterized in terms of wear and deformation. This characterization was based upon the inspection of the pre- and postweld tool material microstructures using optical microscopy and SEM. Specific conclusions from this study include the following:

- Tool degradation can be divided into two main categories, deformation and wear
- Material processing plays a significant role in a material’s ability to resist tool degradation
- Deformation of the grains provided the most significant source of tool degradation
- Tool materials listed by performance — Materials C, B, and A
- The primary degradation mechanism of Material A was deformation
- The primary degradation mechanism of Material B was twinning
- The primary degradation mechanism of Material C was intergranular failure.

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References

Hydrocarbon Contamination and Diffusible Hydrogen Levels in Shielded Metal Arc Weld Deposits

Oil contamination of basic H4 and H4R SMAW electrodes removes low-hydrogen characteristics on contact, and conventional baking treatments for humidity and water exposure restore electrodes to approximately the H8 designation

BY B. M. PATCHETT AND M. A. R. YARMUCH

ABSTRACT

Published literature suggest the avoidance of hydrocarbon contamination (oil or grease) of shielded metal arc welding (SMAW), submerged arc welding (SAW), flux cored arc welding (FCAW), and other flux-bearing processes has been studied for many years. The studies have concentrated on humidity and moisture effects on absorbed hydrogen levels. Hydrogen-assisted cracking (HAC) in hardenable steel weld zones is controlled by several methods — electrode flux chemistry and conditioning, procedure control (a combination of suitable preheat and heat input) in steels of relatively low hardenability, and the addition of postweld heat treatment (PWHT) on steels of high hardenability (carbon equivalent) (Ref. 1). The strength level and microstructure of low-carbon steels has emerged as another criterion (in addition to hardness) governing the susceptibility to HAC (Ref. 2). In both cases, the amount of diffusible hydrogen imparted to the weld zone is of importance in determining suitable procedural parameters. Initial assessment of the amount of diffusible hydrogen imparted to weld deposits by various welding processes was hampered by imprecision in the measurement of the diffusible hydrogen in the deposited weld metal. This was traced to the varying solubility of molecular hydrogen in the liquid media used to collect the hydrogen expelled by a weld sample (Ref. 3). Standardized tests based on the use of a liquid without measurable solubility (mercury) or vacuum extraction produced accurate and reproducible results (Refs. 4, 5). In these extraction tests, results are conventionally reported as “mL/100 g deposited weld metal,” which is a characteristic of the hydrogen collection method, not of atomic hydrogen levels in the actual weld deposit. This paper uses a dual reporting system including parts per million (ppm), a more relevant number for atomic hydrogen in solid solution. There is only approximately a 10% difference in the results. This difference is often within the typical variability of results in electrode testing.

The International Institute of Welding (IIW) designation system for hydrogen potential of welding consumables are “very low” for up to 5 mL/100 g; “low” for 5–10 mL/100 g; “medium” for 10–15 mL/100 g; and “high” for more than 15 mL/100 g of weld metal deposited. The American Welding Society assesses electrodes via a logarithmic scale for diffusible hydrogen levels in a weld deposit. H16 is for 16 mL/100 g of weld metal (17.6 ppm), H8 is for an electrode producing less than 8 mL/100 g (8.8 ppm), the common upper limit for “low hydrogen,” and H4 is for less than 4 mL/100 g or 4.4 ppm. Commercial consumables that are able to reduce the diffusible content further down the logarithmic scale (2 or 1 mL/100 g) are not reliable at present for arc welding processes involving fluxes (SMAW, FCAW, and SAW). AWS A5.1, Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding, was revised in 2004 to reflect this new optional (voluntary) designation system. The specification also permits an optional supplemental “R” suffix designator for electrode coverings that satisfy absorbed moisture limitations. Note that the H16, H8, and H4 designations should not be confused with the H1 (extra-low hydrogen ≤ 5.5 ppm or 5 mL/100 g), H2 (low-hydrogen ≤ 11 ppm or 10 mL/100 g), and H3 (hydrogen not controlled) designations in AWS D1.1 Annex XI for assessment of hydrogen cracking susceptibility via the Pam method.

Attempts to connect weld metal diffusible hydrogen to moisture in the flux (Ref. 6) and weight gains during exposure to humidity met with higher variability in the results. This is due to the fact that weight gain is partially due to carbon dioxide absorption (Ref. 7). Water exists in most low-hydrogen fluxes in the following

KEYWORDS

Hydrocarbon Contamination
Shielded Metal Arc Welding (SMAW)
Diffusible and Low-Hydrogen
H8 Levels
Low Moisture Pickup (LMP)
two forms: water of crystallization in binders or agglomeration stabilizers and adsorbed water via hygroscopic components in the flux. The former is "permanent," in the sense that total removal destabilizes the mechanical integrity of the flux, while the latter is transitory and can be removed without destabilizing the flux. This dual behavior limits the temperature of baking to approximately 400°–425°C. Published information on the subject of water content concerns the relationship between water uptake and exposure conditions, including steps to follow to minimize or reduce the net amount of deposit diffusible hydrogen. Since the water from exposure appears to be adsorbed (surface) rather than absorbed (bulk) by the flux, part of the water is dispersed into the atmosphere by resistance heating of the SMAW electrode during welding, and adsorbed water adds less diffusible hydrogen than does bound water (Ref. 8). The substantial efforts of several investigators, over many years, has shown that the diffusible hydrogen content of SMAW deposits is related strongly to water content of the flux up to approximately 0.3% water, but the relationship becomes more scattered at higher water contents (Refs. 9, 10). Diffusible hydrogen is also affected by atmospheric humidity at the point of welding, which is more noticeable in low-hydrogen electrode deposition than in electrodes producing higher hydrogen levels (Ref. 9). An equation (Ref. 9) is available that relates diffusible hydrogen to atmospheric humidity and flux water content, which is considered accurate up to about 0.3% adsorbed and crystalline water:

\[ H_D = [260a_1 + 30a_2 + 0.9b - 10]^\% \]

where \( H_D \) = IIW diffusible hydrogen in mL/100 g; \( a_1 \) = as-baked coating moisture %; \( a_2 \) = adsorbed moisture %; and \( b \) = atmospheric humidity in mm Hg.

This equation strictly applies only to the electrodes tested (manufactured in Japan) and must be used with circumspection if differing flux chemistries from other manufacturing sites are used.

These numerous investigations into the effects of humidity, adsorbed water, and water of crystallization are not matched by investigations into the effects of hydrocarbon contamination, although the deleterious effects of oil and grease contamination on diffusible hydrogen content are generally assumed. This paper is intended to provide an initial assessment of the effects of hydrocarbon contamination on diffusible hydrogen only. Complex hydrocarbons may contain other elements of interest, such as sulfur, but further investigation is necessary to study other possible contaminants.

**Experimental Program**

The electrodes used in the experimental program were of the E4918 (E7018) type, 4 mm (\( \% \) in.) in diameter. Both standard and moisture-resistant (low moisture pickup (LMP)) types were assessed. All electrodes were conditioned at 375°C (707°F) for 1 h before use. Cooled and weighed electrodes were then immersed in a graduated cylinder to 25 mm (1 in.) from the top of the flux coating in two single viscosity grade mineral lubricating oils of differing viscosity, a 10-W low-viscosity grade and a 30-W medium-viscosity grade. Multigrade oils were avoided to isolate any effect of viscosity. After various times of immersion, excess oil was stripped from the flux covering with a 1.5-mm- (\( \% \) in.-) thick flexible rubber grommet squeegee containing a hole slightly smaller in diameter than the electrode coating. The slight pressure ensured a consistent removal of surface oil. Immediate weighing determined the weight gain caused by oil immersion. Since the "dry" electrode weight varied, weight gain was defined as a percentage gain for each electrode, rather than an absolute weight gain. Welding behavior/diffusible hydrogen measurements followed within 5 min. Procedural conditions were 24 V, 190 A on electrode positive polarity and a welding speed of 200

**Table 1 — Chemical Composition of Electrode Fluxes**

<table>
<thead>
<tr>
<th>Element</th>
<th>Standard Electrode</th>
<th>Low Moisture Pickup Electrode</th>
<th>Percentage Change—Standard to Low Moisture Pickup</th>
</tr>
</thead>
<tbody>
<tr>
<td>Silicon</td>
<td>17.8</td>
<td>14.4</td>
<td>-23</td>
</tr>
<tr>
<td>Potassium</td>
<td>15.5</td>
<td>10.9</td>
<td>-42</td>
</tr>
<tr>
<td>Calcium</td>
<td>57.0</td>
<td>54.0</td>
<td>-6</td>
</tr>
<tr>
<td>Titanium</td>
<td>0.0</td>
<td>12.7</td>
<td>+ X</td>
</tr>
<tr>
<td>Manganese</td>
<td>3.5</td>
<td>3.8</td>
<td>+9</td>
</tr>
<tr>
<td>Iron</td>
<td>5.9</td>
<td>3.7</td>
<td>-55</td>
</tr>
<tr>
<td>Total</td>
<td>&gt;99</td>
<td>&gt;99</td>
<td></td>
</tr>
</tbody>
</table>

**Fig. 1 — Flux structure of standard basic low-hydrogen electrodes. A — Cross section; B — surface.**

**Fig. 2 — Flux structure of low moisture pickup basic low-hydrogen electrodes. A — Cross section; B — surface.**
mm/min, producing a heat input of 1.4 kJ/mm. Bead-on-plate (BOP) welds were produced on ASTM A36 steel pads (10 mm (¾ in.) thick, 75 mm (3 in.) wide, and 300 mm (12 in.) long) with the SMAW process to assess electrode usability characteristics after oil contamination. Weld metal diffusible hydrogen levels were determined on IIW specimens under mercury according to ISO 3690. Bakeout after hydrocarbon contamination was identical to the conditioning procedure, 375°C for 1 h.

Results and Discussion

The diffusible hydrogen contents were determined for each electrode type after conditioning to establish a base line for comparison with oil contamination levels. The standard electrodes produced an average diffusible hydrogen level (3 determinations) of 5.9 ± 1.1 ppm or 5.4 mL/100 g and the LMP types an average of 4.3 ± 0.7 ppm or 3.9 mL/100 g.

Before assessing the oil adsorption characteristics, the surfaces of the electrode fluxes were inspected in a scanning electron microscope (SEM) to assess the particle size and structure of the flux coatings. The standard electrode flux displayed discrete mineral particles of diameters ranging from about 50 to 300 micrometers in a fine matrix. The LMP flux was similar but had smaller average particle size and many small cracks in the matrix. A fractured surface of each flux showed that each contained porosity between the various mineral particles. The surface features and internal structures of the two fluxes are shown — Figs. 1, 2. The results show that the flux coatings are small-scale analogs of porous rock formations.

The chemistry of each flux type was assessed in the SEM at the same time using energy-dispersive X-ray (EDX) analysis (Table 1).

Studies of crude oil movements through porous rock have shown that permeation depends inversely on viscosity (Ref. 13) and that surface-active components dominate adsorption, with the higher molecular weight fractions adsorbing preferentially (Ref. 14). Mineral oils used for lubrication are usually paraffinic oils, which have long chain molecular structures. Higher-viscosity oils have longer molecular chains on average. In the interaction between porous rock and oil alone, the adsorption behavior is polar and the more surface-active elements of the oil are adsorbed (Ref. 12). The molecules are typically in the C20 to C70 range (number of carbon atoms in a molecule), and the boiling point is in excess of 370°C. Molecules in the C15 to C50 range (diesel fuel) boil at temperatures between 300° and 600°C (Ref. 15), indicating that the higher average molecular weight molecules in lubricating oils would have an even wider range of boiling temperature. Therefore, the normal bakeout temperature range for basic low-hydrogen electrodes (350°-400°C) may cause boiling of the lower molecular weight fractions, but not all of the higher molecular weight fractions.

There is an instant increase in dif-

### Table 2 — Bakeout Effects on Diffusible Hydrogen Levels

<table>
<thead>
<tr>
<th>Electrode</th>
<th>Oil Type</th>
<th>Exposure Time</th>
<th>Diffusible Hydrogen from Contact (mL/100 g ppm)</th>
<th>Diffusible Hydrogen after Baking (mL/100 g ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard</td>
<td>10 W</td>
<td>0.1 min</td>
<td>17.3</td>
<td>5.2</td>
</tr>
<tr>
<td>Low Moisture Pickup</td>
<td>10 W</td>
<td>0.1 min</td>
<td>21.3</td>
<td>4.8</td>
</tr>
<tr>
<td>Low Moisture Pickup</td>
<td>10 W</td>
<td>24 h</td>
<td>40.7</td>
<td>5.7</td>
</tr>
<tr>
<td>Low Moisture Pickup</td>
<td>30 W</td>
<td>24 h</td>
<td>—</td>
<td>6.9</td>
</tr>
</tbody>
</table>
viscosities used in this investigation. Short-term immersion results show that the diffusible hydrogen level jumps to about 20 ppm or 18 mL/100 g after only a few seconds of contact with the oil — Fig. 4. Long-term immersion increased the weight gain incrementally, and an apparent saturation level was reached. The diffusible hydrogen results reflect this, with the maximum of about 40–50 ppm (36–45 mL/100 g) appearing for oil exposure time up to 24 h. This is similar to diffusible hydrogen results for E7010-type cellulosic electrodes.

Baking reduces the diffusible hydrogen in the weld deposits substantially, as shown in Table 2, to the IW “low-hydrogen” (5.5–11 ppm) diffusible hydrogen level but cannot restore full IW “very-low hydrogen” behavior. On the AWS logarithmic scale, the results are at or below, the H8 designation. The diffusible hydrogen content after baking for the specific electrodes assessed is similar for both electrode coating types, both oil viscosities, and is also similar for any contamination time from 0.1 min to 24 h.

The postbaking SMAW process behavior during manual operation was acceptable for the welder and did not produce any visual flaws in BOP welds, e.g., pinholes or cracks, which were the expected results from the H8 levels of diffusible hydrogen. No formal weldability tests were conducted due to the potentially large size of a comprehensive alloy assessment program.

Conclusions

1. Contact between basic low-hydrogen SMAW electrodes and oil causes instant and incrementally increasing contamination by adsorption, leading to significantly increased diffusible hydrogen levels in deposited welds.

2. Diffusible hydrogen levels from contaminated electrodes are above about 18 mL/100 g or 20 ppm for any time of contact and for both electrodes and both oil viscosities used in this investigation.

3. Weight gain from contact with hydrocarbons is reduced by higher oil viscosity, which shows that larger molecules penetrate less rapidly. Oil thus appears to be adsorbed by the electrode flux.

4. The low-moisture-pickup flux, intended to resist adsorption of water, also reduced the rate at which oil is adsorbed, possibly by minimizing flux porosity and flow passage access.

5. Baking electrodes contaminated by oil at a typical temperature and time recommended for adsorbed water removal reduces the net diffusible hydrogen levels to the 5–10 ppm range, corresponding to IW “low-hydrogen” rather than IW “very low-hydrogen” behavior. In terms of the logarithmic AWS scale, baking causes a reduction in diffusible hydrogen to approximately the H8 level.

6. The inability of baking to completely reverse oil adsorption is likely due to a combination of molecular fraction boiling temperatures and bonding of higher molecular weight fractions to pore surfaces in the flux during adsorption.

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References


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