Select-Arc, Inc. has earned an outstanding reputation in the industry as a manufacturer of premium quality tubular welding electrodes for carbon and low alloy steel welding.

Now Select-Arc has expanded its range of exceptional products with the introduction of a complete line of austenitic, martensitic and ferritic stainless steel electrodes. Both the new SelectAlloy and Select stainless steel wires deliver the superior feedability, superb welding characteristics, consistent deposit chemistry and excellent overall performance you have come to expect from Select-Arc.

The chart below shows that SelectAlloy flux cored electrodes’ higher deposition rates improve productivity and reduce welding costs.

SelectAlloy’s smooth bead contour, easy peeling slag, minimal spatter, closely controlled weld deposit compositions and metal soundness deliver additional savings.

The Select 400-Series metal cored electrodes offer the same advantages as SelectAlloy and are ideally suited for difficult-to-weld applications, such as auto exhaust systems.

Discover for yourself the many benefits of specifying Select-Arc’s new premium stainless steel electrodes. Call us today at 1-800-341-5215 or you can visit our website at www.select-arc.com for more information.
Introducing the ALL NEW Multi Process Welding System.

**MIG, Stick, TIG.** All in one machine. With an integrated wire feeder for MIG welding, the Fabricator 1811 is the only compact, multi process machine of its kind. Extremely portable, weighing less than 33 lbs, it’s nearly half the weight of the competition’s MIG machines. For more information, contact your distributor or go to thermalarc.com

For info go to www.aws.org/ad-index
With the largest **blasting & liquid coatings** facility around, Greiner is the ideal **job shop** for your really big (and not so big) projects.

**Liquid Coatings**

81,000 square feet ... 500 feet long ... 34-foot by 34-foot doors ... a 100-ton “four-point pick-and-carry” crane system that runs the entire length of the facility.

- AISC Sophisticated Coatings Endorsement
- SSPC-QP3 Certification for the Application of Protective Coatings
- PA DEP Environmentally Compliant
- 100-Foot Long Heated Staging Area
- 100-Foot Long Steel Grit Blast Booth
- 3 Separate 200-Foot Long Coating Booths
- 31-Foot Hook Height of All Overhead Cranes
- Up to 4 Coat Epoxy Coatings
- Metalizing for Food Grade and Highly Corrosive Environments
- Personnel trained in accordance with the NACE International Corrosion Society Program to conduct surface preparation and application of coatings

Call 800-782-2110 for a free quote on your next project.  
[www.greinerindustries.com](http://www.greinerindustries.com)  
For Info go to [www.aws.org/ad-index](http://www.aws.org/ad-index)
Features

28  Machining Thermal Spray Coatings
    Most metallic thermal spray coatings are machinable, but you need to know the nature of the materials and how to handle them
    D. C. Hayden

32  Selecting Abrasives for Grinding Aluminum
    Finishing aluminum welds can be challenging, but with the right abrasives and techniques, the results are satisfying
    P. Carroll

36  Comparing Thermal Cutting Processes for Beveling
    A study was conducted comparing plasma and oxyfuel bevel cutting, which included relative costs and suitability for edge preparation for each
    J. Sorvaag

Brazing & Soldering Today

41  Brazing Titanium and Chromium Using Ion Bombardment Heating
    A plasma process that utilizes ion bombardment is suitable for brazing small electronic components using both silver- and aluminum-based filler metals
    M. Markovich, G. Fischer, and A. E. Shapiro

44  Select the Right Surface Finish to Improve Solderability
    Solderability experiments were conducted on oxygen-free copper coupons with a nickel-palladium-gold finish
    E. P. Lopez and P. T. Vianco

47  Hand Soldering Basics
    A new guideline for hand soldering is under development
    P. T. Vianco

Welding Research Supplement

153-s  Comparison between DC(+) and Square Wave AC SAW Current Outputs to Weld AISI 304 for Low-Temperature Applications
    Different submerged arc fluxes and two types of power source outputs were studied for their effects on weld metal ductility in cryogenic applications
    R. E. Toma et al.

161-s  Review: Experiments and Simulations for Small-Scale Electrical Discharges
    A review of the characteristics of electrical discharge into micro-scale gaps between platinum cathodes and gold anodes was conducted
    J. Chen et al.

171-s  Laser Engineered Net Shaping® for Repair and Hydrogen Compatibility
    This project looked into the capability of the LENS technology to repair mismatched or damaged parts with speed and agility
    P. S. Korinko et al.

On the cover: Oxyfuel cutting with a three-torch beveling station offers compound bevel cutting in a single cutting pass. (Photo courtesy of ESAB Cutting Systems, Florence, S.C.)
Brazing and Soldering Are Thriving within AWS

My initial involvement with brazing and soldering came while doing research on brazing filler metals at Oak Ridge National Laboratory, and I’ve been interested in those topics ever since. Several years ago, I was fortunate to be elected chair of the AWS C3 Brazing and Soldering Committee, and I continue to serve on C3 as well as other brazing and soldering related committees. Over the years, the science and application of brazing and soldering has greatly expanded in important industries such as aircraft, high-temperature structures, air-conditioning, and electronics to name a few. AWS is a vital conduit for disseminating information about these processes.

• Coming April 22–25, 2012, is the 5th International Brazing and Soldering Conference at the Red Rock Casino Spa in Las Vegas. Every three years, AWS and ASM International® sponsor this four-day event, recognized by industry professionals as the world’s premier event for brazing and soldering. Besides the presentation of technical papers, there will be a poster session and brazing and soldering companies will exhibit their newest and best products. You can be part of this prestigious event either as an attendee, or if your company has something special to show, send an e-mail to Zoey Oliva at zoliva@aws.org or call her at (800/305) 443-9353, ext. 264, for information regarding exhibit floor space.

• Twice a year, the Welding Journal devotes a section to applications and research in brazing and soldering. Take a close look at this issue; you’ll find the “Brazing and Soldering Today” articles color coded in gold at the top of each page to make them easy to spot. The section also includes ads focused on brazing or soldering. In 2012, the February and July issues will feature the special brazing and soldering section.

• In addition, every other month, you can find answers to your questions in the Brazing & Soldering Q&A column. Alexander Shapiro, Tim Hirthe, and Dan Kay author the column, carrying on the tradition begun by Robert Peaslee many years ago.

• AWS hosts the Brazing and Soldering Manufacturers Committee Web site at www.brazingandsoldering.com (or locate the BSMC link under “Committees/Sections” on the AWS home page menu). Here, you will find resources to help solve your brazing concerns. There are links to brazing and soldering specifications and books; Brazing & Soldering and Q&A and Soldering Topics columns published in past issues of the Welding Journal; education and training information; the Brazing Forum; and a list of universities that are involved with academic study and research projects in brazing and soldering.

• AWS volunteers write a variety of AWS/ANSI technical standards related to brazing and soldering. These include A5.8M/A5.8, A5.31M/A5.31, B2.2, B2.3, and all the C3 process specifications. In addition, AWS volunteers participate and contribute to the following international standards writing groups: ISO/TC44/WG3 — Brazing materials and processes, ISO/TC 44/WG 4 — Welding and brazing in aerospace, and ISO/TC 44/SC 12 — Soldering materials. The standards those groups have under development are ISO/DIS 13585.2, Brazing — Qualification test of brazers and brazing operators, and a new project, PWI 13134, Brazing — Qualification for brazing procedures, which is a revision of EN 13134:2000.

• In 2008, AWS volunteers developed and taught a graduate-level course on brazing and soldering for engineering students at The Ohio State University. So far, more than 80 students have taken the course. An exciting new development includes plans to modify and adapt, as appropriate, the curriculum for distance learning via AWS’s American Welding Online.

As I mentioned previously, if you take a close look at this issue of the Welding Journal, you’ll find quite a bit of information on brazing and soldering. That focus reflects what is happening with regard to brazing and soldering within the American Welding Society. Exciting progress is taking place, and brazing and soldering are thriving within AWS.
With great power comes great reliability.

Your unique skills and our premium products — destined for heroic deeds.

Together, this tremendous team tackles the most troublesome welding tasks!

Visit our website to learn more, and to nominate your own welder hero.

MillerWelds.com/hero
**Inspection Trends Earns Editorial Excellence Award**

*Inspection Trends* earned the silver Azbee Award of Excellence in the feature series category for Albert J. Moore Jr.’s four-part article detailing welding procedure specifications. The installments were published in the April, July, and October 2010, and January 2011 issues.

The Azbee awardees are selected by the American Society of Business Publication Editors (www.asbpe.org). The awards were presented at the society’s National Editorial Conference held Aug. 4, 5, in Chicago, Ill.

Albert J. Moore Jr. is vice president, Marion Testing & Inspection, Canton, Conn. He is an AWS Senior Certified Welding Inspector; American Society for Nondestructive Testing ACCP NDT Level III; and a member of the AWS Certification Committee along with the Committee on Methods of Inspection of Welds.

**Lincoln Electric Acquires TechAlloy and Torchmate**

Lincoln Electric Holdings, Inc., Cleveland, Ohio, acquired the welding operation assets of TechAlloy Co., Inc., and of its parent company, Central Wire Industries Ltd. The Baltimore, Md., based manufacturer is a privately held producer of nickel alloy and stainless steel welding consumables. TechAlloy has annual sales of approximately $70 million and employs 55 people.

In addition, Lincoln Electric acquired substantially all of the assets of Applied Robotics, Inc., a manufacturer of CNC cutting tables and accessories. Known in the welding industry by its brand name, Torchmate, it has headquarters and manufacturing facilities based in Reno, Nev. The company’s trailing 12 months of sales were approximately $13 million. It currently employs 44 people.

**Aiken Technical College Receives Welding Software, Nuclear Training Donations**

Aiken Technical College (ATC), Graniteville, S.C., has received $400,000 worth of computer software that will be used to train students in its upcoming nuclear welding program. The software was donated by Savannah River Nuclear Solutions and one of its parent companies, Newport News Shipbuilding. Eight, 10-disk programs will provide computer-based nuclear welding training while in a classroom setting.

“The donation saves us cost of development and provides us a proven training program for our credit and noncredit welding programs,” said Dr. Gemma Frock, ATC’s vice president for education and training.

Also, Savannah River Remediation, Aiken, S.C., is helping the college’s new nuclear quality control program by providing $10,000 for curriculum development. Earlier this year, the college received a Department of Energy grant to develop and implement special certification certificates in quality control and nuclear welding.

“We expect the nuclear industry to provide exceptional opportunities for future employees, including students who may be in middle school or high school today and are considering their future career path,” said Dr. Susan Winsor, ATC’s president.

**Putting ‘Trades in Focus’ to Support Industrial Skills**

The American Association of Community Colleges, Washington, D.C., through support from W.W. Grainger, Inc., a supplier of maintenance, repair, and operating products, launched Trades in Focus, an awareness campaign and new online education toolkit.

The initiative aims to strengthen the nation’s skilled workforce, including welders, by encouraging more people to consider trades and forging connections among community colleges, potential students, employers, business and industry, and community leaders.

All of the toolkit materials can be downloaded for free at the following link: www.aacc.nche.edu/Resources/aaccprograms/tradesinfocus/Pages/downloads.aspx.

**California Brazing Receives Nadcap Brazing Accreditation**

California Brazing, Newark, Calif., has earned Nadcap brazing accreditation. Its scope includes AWS C3.6, *Specification for Furnace Brazing*, and AWS C3.7, *Specification for Aluminum Brazing*. Gaining this accreditation will strengthen the company’s position in the aerospace market and benefit customers in the semiconductor, medical, and energy management markets.
“We’ve had such outstanding success with Koike that we haven’t spoken to anyone else.”

Jim Farley, Project Manager

To be the preferred supplier of welding positioning equipment to Liebherr USA, you have to do a lot of things right. And Koike Aronson does.

The Virginia facility of Liebherr, one of the world’s leading manufacturers of mining equipment, has been buying welding positioners from Koike for years. “Some of the original machines are still in operation,” reports Jim Farley, project manager. “And the service support is terrific. When it comes to responsiveness we can get directly to a person who can help.”

The guys on the floor are sold on Koike, too. “I love the Head and Tailstock,” says Fabrication Lead Man Charles Moler. “Koike worked with us so it was designed to fit our needs and reduce set-up time for each rotation.”

Visit Koike at Booth #5909 at FABTECH in Chicago.

Koike Aronson Ransome
Head and Tailstock positioning a Liebherr mining truck frame.

www.koike.com

For Info go to www.aws.org/ad-index
Stinger Welding’s New Fabrication Plant Set to Create More Than 100 Jobs

The Montana Community Development Corp. (MCDC) recently closed $17 million in financing to complete the construction of a new fabrication plant for Stinger Welding, Inc., Libby, Mont., a fabricator of major steel and bridge components.

U.S. Senator Max Baucus, MCDC, Stinger Welding, and the Urban Investment Group at Goldman Sachs each played a role to complete the financing that will create more than 100 new jobs at Stinger’s plant. Currently, the Libby location has a workforce of 43.

In addition, Stinger operates a large steel fabrication plant in Coolidge, Ariz., where it’s a major steel bridge component fabricator for the southwest. The company chose Libby over other locations because of its proximity to potential markets in the northwest, direct access to rail lines in the Kootenai Industrial District, lower comparable labor costs for skilled labor, and the economic incentive package offered by Lincoln County, Libby, and the state of Montana.

“We are excited to move forward in the completion of our new fabrication plant in Libby,” said Stinger President Carl Douglas. “Libby’s workforce is full of the type of tough, hardworking, and highly skilled individuals it takes to fabricate major steel bridges in the United States.”

The company will hire workers at various levels, with wages ranging from a $13.55/hour minimum to $16 average hourly wage. Salaried positions will be available as well. Flathead Valley Community College added welding classes at its Kalispell and Libby locations and graduated 20 welding students in April 2011 targeted to meet Stinger’s workforce requirements. Hiring has begun with applications taken through the Kootenai Job Service in Libby (wsd.dli.mt.gov/local/libby/).

The new 105,000-sq-ft plant will provide steel for bridge infrastructure projects in the northwest. Current operations have already produced steel products for use in projects in Spokane, Portland, and Seattle. Stinger expected the new construction will be completed in August. Production should begin in the fall with a ramp-up to full capacity varying with market demand.

Construction of this new facility began in 2009, but it was delayed due to financing challenges. The deal came together as a result of a federal financing program written by U.S. Senator Max Baucus and through his efforts to profile Montana’s business opportunities to national investors at his 2010 Economic Development Summit. The tax credit financing was made possible through MCDC’s 2010 allocation of New Markets Tax Credits. Additional help for the project came through a significant equity investment by Stinger Welding; $3.2 million from a previous insurance settlement reached by the Libby industrial district; an $800,000 Community Development Block Grant; and a $400,000 grant from the Big Sky Trust Fund.

“Folks in Libby need jobs more than ever, and I couldn’t be more pleased to see this opportunity going to work for a community that deserves an economic boost,” said Baucus.

Morgan Technical Ceramics Introduces Expert Custom Brazing Services

The Wesgo Metals site of Morgan Technical Ceramics (MTC) in Hayward, Calif., now offers custom brazing services. This includes active metal brazing, a process that allows metal to be bonded directly to ceramic without metallization.

MTC has developed several braze alloy compositions that will directly bond ceramic to metal or other materials, including graphite and diamond. Applications include brazing industrial diamonds onto ceramics or metal components for heat spreaders or ceramic windows, as well as brazing graphite to substrates such as titanium for stable ion traps. Alloy compositions vary and include those designed for use in a variety of settings, from very low- to high-temperature applications, around 500° to 1000°C.

For the aerospace industry, MTC offers compositions of ceramics ideal for brazing to metals for use in the high temperatures found in modern day jet engines. Applications include ceramic nozzles for turbine engines, new turbine vane systems, and superalloy engine parts. The oil industry also uses its brazing services for applications such as bonding metal drill bits with diamond or silicon carbide.

New River’s Greenbrier Valley Campus Welding Lab Accredited by AWS

The New River Community and Technical College welding lab in Lewisburg, W.Va., has been accredited by the American
Students practice pipe welding in the Greenbrier Valley Campus lab recently accredited by the American Welding Society. (Photo courtesy of Rick Barbero.)

Welding Society (AWS), Miami, Fla., as an approved testing site.

“The hard work and dedication of our program coordinator, Donovan Rhodes, and welding instructor, Sean Davies, have assured the success of the welding program and the achievement of this sought-after accreditation,” said Greenbrier Valley Campus Dean Roger Griffith.

Machine tool technology and welding are among the fastest growing technical programs at the college’s Greenbrier Valley Campus. Machine tool technology includes machining and computer numerical control programming; this fall, the program will add an AutoCAD class where students will learn to use a computer software application for 2-D and 3-D design and drafting. Also, welding includes pipefitting, pipe welding, technical math, and blueprint reading. The facility housing these programs is on Houfnagle Rd. a few miles south of the campus.

“Most classes in these programs are offered in the evening to accommodate working students or those enrolled in daytime classes,” said Donovan Rhodes. “We can also work with businesses needing to send employees for short-term training or recertification.”

A total of 27 classes are being offered this fall in this program, with plans to add a metal fabricating class in the near future. New River is also offering welding at the Advanced Technology Center in Ghent this fall. A schedule of classes can be found online at www.newriver.edu.

Chromalloy to Add Gas Turbine Engine Service Capabilities, Jobs

Chromalloy will expand its Newnan, Ga., operation and workforce, adding gas turbine engine service capabilities and up to 125 jobs at the site.

“Chromalloy is pleased to offer engine operators additional advanced repairs and services at our Greater Atlanta area facility,” said Armand F. Lauzon Jr., president. “We have worked closely with the state of Georgia, Governor Deal’s office, and the Coweta County Development Authority to bring this development and work to the area — and we look forward to significantly expanding our presence in the community.”

The company’s Newnan facility offers turbine engine compo-

— continued on page 11
Switch from weld to grind in a matter of seconds.

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

Get a free demo and keep the equipment!

Let one of our experts come to your site to help determine which equipment is best for your workers.

Call 888-422-3798 to schedule your free demo today.

Only Fibre-Metal QuickSwitch System offers two mounting designs to match your work requirements: Speedy™ Mounting Loop and Quick-Lok™ plus industry-preferred SuperEight™ SwingStrap™ caps.
nent advanced repairs and coatings. The 131,000-sq-ft operation serves users around the world, including operators of commercial aircraft engines and industrial gas turbine power systems.

Chromalloy will also add new capabilities in its existing facility, building new lean manufacturing lines to service additional turbine power systems.

Ford, TechShop Reveal Home of Detroit-Area Workshop

Ford and TechShop recently announced Allen Park, Mich., will be the home of TechShop Detroit, the communal fabrication studio where everyday inventors, from backyard tinkerers to tech-savvy engineers, can come to create their own innovations.

Ford is the first automaker to work with TechShop to open one of its centers, which offer creative minds affordable access to tools, machinery, and coaches so they can design and develop prototypes of their latest inventions, automotive and otherwise.

“We are excited to see what started as a simple idea and conversation between Ford and TechShop take physical form so quickly,” said Bill Coughlin, president and CEO, Ford Global Technologies. “We want this space to inspire all inventive individuals and communities in and around Detroit to innovate and create.”

Mark Hatch, TechShop CEO, envisions limitless possibilities for the location, especially considering its proximity to the Ford engineering campus, nearby universities, and the downtown area.

With more than $1 million invested in high-tech equipment alone, TechShop Detroit will feature prototyping tools and industrial-grade sewing and textile equipment to laser cutting, welding, and machine shop-type gear. It will be located in the Fairlane Business Park in a Ford land-owned property.

The arrival of this shop is also fueling another vision Ford Global Technologies hopes to bring to life just as quickly and at the same address — a first-of-its-kind intellectual property exchange and technology showroom where everyday inventors, industry insiders, universities, and research labs can display and license their automotive innovations and other ideas. The Innovation Exchange concept is an extension of the Detroit-based AutoHarvest Foundation.

— continued on page 96
Panasonic India’s Manufacturing Plant to become Operational in November 2012

Panasonic India’s manufacturing facility being built in Jhajjar, Haryana, which will produce welding machines, washing machines, and air conditioners, is expected to become operational by November 2012. The company, a 100% subsidiary of Japan headquartered Panasonic Corp., will invest $200 million over a five-year period at the facility in its first phase, said Panasonic India President Daizo Ito.

Construction began on the plant in April. When fully operational, it is expected to employ 3500 people. It will be the company’s first “eco ideas” factory in India. Panasonic has stated it aims to be the world’s number one green innovation company in the electronics industry by 2018, and the new plant is designed to reduce CO₂ emissions and waste generation. The products the plant will produce are mostly for the domestic market.

When fully operational, the new plant is expected to produce an estimated 1,000,000 air conditioners, 400,000 washing machines, and 25,000 welding and cutting machines a year.

Foxconn to Replace Workers with One Million Robots in Three Years

Taiwanese technology giant Foxconn will replace some of its workers with 1 million robots in three years to cut rising labor costs and improve efficiency, Terry Gou, founder and chairman of the company, said recently.

According to a report from Xinhua, the Chinese state news agency, the robots will be used to do routine work such as spraying, welding, and assembly, these tasks are now assigned to workers. The company currently employs 1.2 million people, with about 1 million of them based on the Chinese mainland. The company currently has 10,000 robots; that number will be increased to 300,000 next year and to 1 million in three years.

Foxconn manufactures laptops, mobile devices, and other hardware for Apple, Nokia, and Sony. The company has been in the spotlight because of a string of suicides of workers at its massive Chinese plants, which some have blamed on tough working conditions.

In related news, Foxconn announced plans to increase its investment in China’s central Henan Province. The company plans to invest in 19 new projects in Henan, including factories that will produce camera lenses and LED lighting rigs, as well as more branches of Foxconn’s retail chain Cybermart, Guo said during a recent economic forum in Taipei.

Swedish Company to Take over Joining of Subframes for Volvo

Finnveden Metal Structures, a division of FinnvedenBulten, Göteborg, Sweden, recently signed an agreement with Volvo Cars regarding the joining of subframes. The agreement, which runs at least three years, is a step toward streamlining customer/supplier relations between the companies.

Volvo Car Body Components has been renting space in the factory in Olofström, Sweden, since Finnveden took over the factory. Finnveden will take over assembly of the subframe structures utilizing two welding lines and a processing line. Training of Finnveden Metal Structures’ staff under Volvo’s management has been ongoing.

“Discussions have been ongoing for some time, and it feels like a natural step for both operations that we take over the assembly of these structures. We will continue to deliver subframes to Volvo Car Corp., while we also open up the possibility of increased production in the segment,” said Johan Westman, president and CEO of FinnvedenBulten.

Laser Cladding Facility Opens in Shanghai

Höganäs (China) Co. Ltd., Coherent, Inc., and ABB have opened a laser applications center at the Höganäs facility in Shanghai. The facility features a Coherent HighLight 4000L, 4-kW, direct diode laser system mounted on an ABB IRB 2600 robot, which will be used for laser cladding at the facility. Höganäs is a producer of iron and metal powders.

“Direct diode laser cladding offers several practical advantages over traditional arc welding and thermal spraying methods. For example, the laser technique avoids heat distortion of the part, thus eliminating the need for postprocessing. It also delivers a clad having extremely low dilution, reduced porosity, and good surface uniformity,” said Frank Gaebler, director of marketing for Coherent. “The direct diode laser delivers lower cost of ownership and beam characteristics better suited to cladding when compared to other laser types.”

Technip to Weld Pipe for UK North Sea Project

Technip was recently awarded an engineering, procurement, construction, and installation contract worth approximately $99.3 million for the East Rochelle development in the UK North Sea. The field is located approximately 115 miles northeast of Aberdeen, Scotland, in 460 ft of water. Endeavour Energy UK, a subsidiary of Endeavour International Corp., awarded the contract.

The contract covers full project management and detailed design, fabrication, installation, and precommissioning of 18.6 miles of pipe-in-pipe, flexible riser, free issue umbilical, subsea isolation valves, and manifolds. It also covers tie-in spools, trenching, backfill, and rock dumping work.

The pipe-in-pipe will be welded at Technip’s spool base in Evanton, Scotland, while the flexible riser will be manufactured at the company’s flexible pipe plant in Le Trait, France.

Ford and Sollers Establish Joint Venture in Russia

Ford Motor Co. and Sollers OJSC recently signed an agreement to establish a 50-50 joint venture in Russia named Ford Sollers. The Ford Transit medium-sized commercial vehicle will be among a number of new Ford products the new company will build.

Sollers is Russia’s second-largest producer of passenger and light commercial vehicles. It will support the new venture through its manufacturing capabilities, knowledge of the Russian market, experience in distribution, and work with the Russian supply base.

Ford offers its extensive manufacturing experience and a dealer network of 107 sales and service sites in 71 Russian cities. The Ford Sollers operation will include the Ford plant in Vsevolozhsk, which currently builds the Ford Focus and Ford Mondeo, and two Sollers production facilities in the Republic of Tatarstan.
Time and again, our revolutionary ideas take the welding community by surprise. As they did with Cold Metal Transfer (CMT), a weld process that really is "cold" compared to conventional MIG welding. That ensures a stable arc and exact process-control. CMT lets you weld joins between aluminum and steel, and light-gauge sheets from only 0.3 mm (0.01 in) thick. Other advantages: minimal spattering, excellent gap bridgeability, 100% reproducibility of results. Want to know more?

10421 Citation Drive, Suite 1100, Brighton, Michigan 48116, USA
Tel: 810-220-4414, Fax: 810-220-4424
Email: sales.usa@fronius.com, www.fronius-usa.com

Visit us at the 2011 Fabtech International & AWS Show - Booth #6109

A «COLD» WELDING PROCESS WAS LONG CONSIDERED A COMPLETE IMPOSSIBILITY. WE WEREN'T PREPARED TO LEAVE IT AT THAT.
A Canadian reader inquired about Clause A7.21 in AWS A5.4/A5.4M:2006, Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding. The clause concerns E316-XX covered electrodes, but not E316L-XX covered electrodes. The portion of the clause that is of interest states, "Rapid corrosion of Type 316 weld metal may occur when the following three factors coexist:

1. The presence of a continuous or semicontinuous network of ferrite in the weld metal microstructure;
2. a composition of the weld metal giving a chromium-to-molybdenum ratio of less than 8.2 to 1; and
3. immersion of the weld metal in a corrosive medium.

Attempts to classify the media in which accelerated corrosion will take place by attack on the ferrite phase have not been entirely successful. Strong oxidizing and mildly reducing environments have been present where a number of corrosion failures were investigated and documented. The literature should be consulted for the latest recommendations."

The reader’s question concerns the origin of the above statement and any supporting data for the 8.2 to 1 chromium-to-molybdenum ratio.

A: I did not know the answer, so I made some inquiries of very knowledgeable stainless steel welding experts, but none of them knew either. Then, I consulted current and prior editions of the AWS A5.9 and A5.22 specifications, in addition to prior editions of A5.4. Interestingly enough, the same statement is made in regard to ER316 wires (Clause A8.21 in AWS A5.9/A5.9M:2006, Specification for Bare Stainless Steel Welding Electrodes and Rods) but not in regard to ER316L. However, the statement is absent from Clause A8.2.16 describing E316TX-X flux cored electrodes in AWS A5.22/A5.22M:2010, Specification for Stainless Steel Flux Cored and Metal Cored Welding Electrodes and Rods, although it is present in Clause A8.3.21 describing EC316 metal cored electrodes in that same standard.

It is understandable that the statement is attached to the metal cored electrode because the metal cored electrodes were only moved from the A5.9/A5.9M specification to the A5.22/A5.22M specification in the 2010 edition, and all of the descriptions for metal cored electrodes (which had been the same as for solid wires) were simply transferred intact.

Following the trail in the AWS A5.9 specification, I found the statement in the 1992 edition (Clause A7.20) and in the 1981 edition (Clause A5.19). However, the statement is not in the 1978 edition, nor in the 1969, 1962, 1955, 1948, nor the original 1946 editions.

The AWS ASD Subcommittee is responsible for the content of the filler metal specifications concerning stainless steels. So, the AWS ASD Subcommittee considered it appropriate to add the statement to the A5.4 specification sometime between 1978 and 1981.

Following the trail in the AWS A5.9 specification, I found the statement in the 1993 edition (Clause A8.21), in the 1981 edition (Clause A5.18), in the 1977 edition (Clause A5.13), and in the 1969 edition (Clause A1.14.1). However, the statement is absent from the 1962 edition and from the 1953 edition (the original edition). It seems curious that the statement appears already in 1969 for bare wires, but not until 1981 for covered electrodes.

I obtained the minutes of the AWS ASD Subcommittee meetings of March 1969 and May 1968, but could not find any record of when the statement was approved by the ASD Subcommittee.

The AWS staff secretary for the A5 Committee was unable to locate any other minutes of the ASD Subcommittee from 1962 to 1968, so it seems likely that the subcommittee did not meet for some years. Many of the members of the ASD Subcommittee in the 1960s are now deceased. The members I could locate, including Robert J. Christoffel, chair of the AWS ASD Subcommittee in 1968, do not recall the origin of the statement.

I note that the last sentence of the clause in question is, “The literature should be consulted for the latest recommendations.” I examined all issues of the Welding Journal from present day back to 1940 without once finding any reference to the 8.2 to 1 chromium-to-molybdenum ratio. In fact, there is very little information in the Welding Journal concerning corrosion resistance of 316 weld metal. Two interesting papers including information about corrosion of 316 weld metal both appeared in 1950. In the January issue, pp. 13-s to 31-s, Anton (Tony) Schaeffer and R. David Thomas Jr., authored “Corrosion of Molybdenum-Bearing Stainless-Steel Weld Metals,” including discussions by several other contributors.

Many of their weld metals were given a postweld heat treatment (PWHT) because they were not low carbon, and the authors noted sigma phase precipitation in the ferrite as a result of the PWHT, with adverse effects on corrosion resistance. The low-carbon version of the alloy, termed “316elc”, was just appearing at that time and did not suffer adverse effects on corrosion resistance from PWHT. But no chromium-to-molybdenum ratio is mentioned.

In the August 1950 Welding Journal, pp. 361-s to 404-s, Helmut Thielsch provided an extensive review of “Alloying Elements in Chromium-Nickel Stainless Steels.” The section of that review concerned with molybdenum includes reference to the work of Schaeffer and Thomas, as well as to that of a number of other researchers. Again, adverse corrosion resistance effects in 316 weld metal are noted, but no chromium-to-molybdenum ratio is mentioned.

So, it would appear that the origin of the statement concerning adverse corrosion resistance of 316 weld metal with a chromium-to-molybdenum ratio less than 8.2 to 1 in the AWS A5.4 and A5.9 standards would have been data published between 1950 and 1969, but I have been unable to find it.

So, I turn this question back to my readers. Does anyone recall the origin of the statement concerning adverse corrosion resistance in 316 weld metal when the chromium-to-molybdenum ratio is less than 8.2 to 1? If so, can you cite the reference? I will let everyone know what is uncovered, in a future column.

BY DAMIAN J. KOTECKI

DAMIAN J. KOTECKI is president, Damian Kotecki Welding Consultants, Inc.; treasurer and a past vice president of the International Institute of Welding; a member of the AWS ASD Subcommittee on Stainless Steel Filler Metals and DIK Subcommittee on Stainless Steel Structural Welding; a member and past chair of the Welding Research Council Subcommittee on Welding Stainless Steels and Nickel-Base Alloys; a past chair of the A5 Committee on Filler Metals and Allied Materials; and was president of the American Welding Society (2005–2006). To contact Dr. Kotecki, e-mail your questions to damian@dami ankotecki.com, or mail to Damian Kotecki, c/o Welding Journal Dept., 550 NW LeJeune Rd., Miami, FL 33126.
ANY TIP
ONE TORCH
ANY GAS

NOW THAT’S
BEING FLEXIBLE

Choose Victor® – Choose Versatility

- Universal Mixer – One Torch for All Fuels
- Built In Flash Back Arrestors and Reverse Flow Check Valves – Ultimate Safety
- EDGE™ Regulators – Safest & Highest Performance Regulator
- Professional Outfits – Equipped with T-Grade Hose
- Complete Offering – Available for Acetylene and Alternative Fuel Applications
- Vanguard™ Straight or Combination Torches – Whatever the Need

www.victorequip.com

© 2011 Thermadyne Industries, Inc. All rights reserved.
For Info go to www.aws.org/ad-index
Q: My company is in the process of quoting several new assemblies that require resistance spot welding, and I am concerned that the specified widths of the flanges are too small for the required electrodes. Are there sources for flange width design recommendations that I can reference so as to determine whether or not the proposed concept is capable of supporting the required resistance spot weld?

A: The subject of a required minimum flange width, also referred to by many design guidelines or standards as flange overlap, is a source of continual debate within the resistance welding community, and from my perspective (for reasons I’ll detail shortly), the issue appears to becoming more controversial as time progresses. For clarification, the discussion here does not focus on the minimum accessibility requirements of a resistance spot welding gun. Minimum accessibility is an important topic but very much separated from the various aspects related to flange width requirements. Instead, we look at the actual portion of the part that is welded in an attempt to help clarify this issue.

As is common in the creation of any product, there are often multiple factors or design considerations involved that must first be acknowledged, then understood, and eventually addressed as the design process moves forward. As a result of the differing and sometimes competing motivations of the individuals responsible for addressing the various design considerations, the iterative process that eventually leads to a final design is subject to the changing priorities of the organization or even the personalities of those involved. The following summarizes just a few of the many potential interests that can impact the final design of a welding flange:

**Purchasing.** The driving force here is no secret as every industry seeks to reduce costs by minimizing the use of raw materials. The fact that the reduction in material, most likely by way of a reduced-size blank, driven in part by narrowing the flange, may drive up costs in another area — sometimes actually increasing the total expenditure for producing the final assembly to the point of negating the savings in materials — is often overlooked.

**Product.** The goal of almost any new design is to improve on what is already available. One common metric where these improvements can be measured and tracked is the reduction of mass in the final product. The width of the welding flanges definitely falls into this area.

**Marketing.** The driving force behind marketing’s need for a new design may vary but can include a shift in market forces or the desire/need to show continual improvement and provide something new for the customer.

**Manufacturing.** While the majority of folks in manufacturing are not insensitive to the aforementioned items, their major concern is simply to have a robust design that is tolerant to the inherent build variations of the assembly process. Unfortunately, this is not always the case for the design they are asked to assemble. Another potential driver for a new design would be a change in the manufacturing process.

The above should shed a bit more light on the design process and help bring into focus the challenges facing the product designer. Also, it should now be a bit clearer as to why the subject of something as seemingly innocuous as the welding flange’s width can be an important consideration and source of debate from concept to final execution in any welded assembly. One fairly recent event reveals the level of the behind-the-scenes back and forth that can occur. At a recent review meeting, the design team made it known that all of their target weight and cost savings could be achieved if they could eliminate the welding flanges on every part that constituted the assembly. They were curious what impact this would have on manufacturability and if we could employ any other joining processes to make this new design possible. After a brief discussion, it was decided the weld flanges would stay basically as they were, and the design team needed to focus on other aspects of the assembly to achieve their targets.

To help answer your question regarding the necessary minimum welding flange width, there are several references available, but as is the case in most situations regarding welding, there is not one hard-and-fast answer. The RWMA Resistance Welding Manual (revised 4th Edition) and AWS C1.1:2000, Recommended Practices for Resistance Welding, contain guidelines

---

**Table 1 — Minimum Flange Widths Based on Governing Metal Thickness (GMT) (dimensions in millimeters)**

<table>
<thead>
<tr>
<th>Approximate GMT</th>
<th>AWS C1.1</th>
<th>RWMA Manual</th>
<th>OEM 1</th>
<th>OEM 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.8</td>
<td>13.0 (12.7)</td>
<td>11.1 (12.7)</td>
<td>12.0 (n/a)</td>
<td>16.5 (13.0)</td>
</tr>
<tr>
<td>1.6</td>
<td>16.8 (15.8)</td>
<td>15.8 (15.8)</td>
<td>17.0 (n/a)</td>
<td>19.5 (16.0)</td>
</tr>
<tr>
<td>2.4</td>
<td>20.4 (19.0)</td>
<td>19.0 (15.8)</td>
<td>21.0 (n/a)</td>
<td>23.0 (20.0)</td>
</tr>
</tbody>
</table>
for flange overlap (Refs. 1, 2). These recommendations are based on input from member companies and represent a good generic starting point for your investigation. The data in Table 1, which include the results of two different automotive OEMs, help to illustrate this point: As detailed, it should be readily apparent that no one agrees what the proper flange width should be.

What is not shown in the table are the varied methodologies each design guideline utilizes to determine its respective minimum flange widths. Examples of these differing approaches are prevalent when reviewing the applicable OEM documentation. While only two OEM design guidelines are shown as part of this discussion, a review of other applicable OEM documents resulted in myriad approaches to important elements such as electrode diameter, governing metal thickness (GMT), and angle of access. A few of the design guidelines also consider the strength of the material, no doubt based on guidance from their stamping organization, while others take a more basic approach and list a single value for minimum flange width regardless of the application. Another important item to consider is how the weld flange data are presented. Some design guidelines group the minimum welding flange width by a specified electrode diameter while others continuously vary the flange width based on the GMT of the parts being joined. The OEM design guidelines may also contain detailed representations of the various potential joint combinations — Fig. 1. These representations may indicate particular dimensional criteria that must be considered and adhered to in the final design or they may just be generic in nature. Again, as stated earlier, no one is in agreement on this topic.

It was good to see in your question the concern you raised regarding electrode usage. The utilization of narrower than recommended flanges can have real consequences when it comes to welding electrodes. As electrode selection is typically driven by both GMT and the required weld size, any weld flange configuration that does not support use of the needed electrode geometry should be viewed with suspicion (reference the RWMA Q&A in the May 2009 Welding Journal for more details). AWS D8.6:2005, Specification for Automotive Resistance Spot Welding Electrodes, details a wide variety of electrodes, including a number that, if necessary, are tailored to narrower flanges. A word of caution regarding use of narrow flange electrodes: To achieve the physical characteristics necessary for applying the required welding force and current in a confined space, many of these electrodes are designed to be asymmetrical. This loss of symmetry means it may be possible to install the electrode improperly with the end result being variation in the weld location (potentially to the point of missing the part) or, in a worst-case scenario, the part and/or welding machine being damaged by the physical act of closing the electrodes. Also, due to the nature of their construction, many of the narrow flange electrodes have smaller water cavities and/or a greater distance between the water cavity and the contact face, with the predictable loss in thermal capabilities, and may not be able to support a high welding rate. To add insult to injury, their less frequent use typically drives a higher piece cost.

This discussion does not detail several important elements that should be considered when determining the required minimum flange width. These will be addressed in another column.

**Acknowledgment**

The author would like to thank Tom Morrissett, former AWS D8 chair, for his invaluable perspective on minimum flange width requirements.

**References**


---

**Donald F. Maatz Jr.** is a laboratory manager, RoMan Engineering Services. He is chair of the AWS Detroit Section, serves on the D8 and D8D Automotive Welding committees, is vice chairman of the Certified Resistance Welding Technician working group and of the RWMA Technical Committee. He is a graduate of The Ohio State University with a BS in Welding Engineering. This article would not have been possible were it not for the assistance from members of the RoMan team. Send your comments or questions to Maatz at dmaatz@romaneng.com, or to Don Maatz, c/o Welding Journal, 550 NW LeJeune Rd., Miami, FL 33126.

---

**Commercial Diving Academy**

- Accredited & Licensed
- Accredited by ACCET
- Montgomery GI Bill
- 20-Week Program
- Financial Aid Available
- For those that qualify
- On-Campus Dorms
- Meal Plans Available
- Underwater Welding
- Dive Med Tech Technician
- Underwater Burning
- NDT Level I & II
- Rigging & Crane Operation

For info go to www.aws.org/ad-index
Reader States ‘Industry Knows What’s Best for Them’

This letter responds to the comments President Barack Obama made about the shortage of skilled trades workers. (Press Time News, July 2011 Welding Journal) Obama recently announced a partnership with industry groups, including AWS, that plans to provide 500,000 community college students with industry-recognized credentials to help secure manufacturing jobs.

I commend President Barack Obama for acknowledging publicly that the professional and trades labor force is at a dangerously low level. However, that’s where my appreciation stops.

His goal is to make sure that a piece of paper helps labor get a promotion or job. He has no control over that. Getting a promotion or job is based on things such as trades proficiency, talents, and skills. That takes time, years of hard work, daily diligence, and constant ongoing self-improvement.

He isn't coming up with anything new; others before him tried similar things. Their programs weren’t successful because the government has to get out of the business of telling industry what’s good for them and how to improve their operation.

A skilled welder isn’t made in a tech-trade school. Tech schools are supposed to teach and train in the basics. Industry develops the trade. Organizations such as AWS, ASME, API, and NACE develop standards and procedures for industry to follow.

I know plenty of highly skilled welders who have never spent one day in a formal training facility, but I’m a very strong advocate of tech-trade schools and formal education programs of all kinds. Tech-trade schools can shorten the time necessary to develop the skill and add meaning to the trade.

Industry will do just fine if the government concerns and controls are reduced, and some eliminated. Industry knows what’s best for them, better than Uncle Sam. Allow industry to breathe and see what happens to our economy.

Phil Evans
AWS CWI, CWE
Pulaski, Tenn.

Dear Readers:

The Welding Journal encourages an exchange of ideas through letters to the editor. Please send your letters to the Welding Journal Dept., 550 NW LeJeune Rd., Miami, FL 33126. You can also reach us by FAX at (305) 443-7404 or by sending an e-mail to Kristin Campbell at kcampbell@aws.org.
Change Is Good.

Change Is Profitable.

Switching from a 15% silver alloy to Harris Dynaflow in your brazing operations can reduce your costs by up to 30%. Dynaflow is made in the USA from only the purest raw materials. Joints made with Dynaflow have consistently fewer leaks.

Need proof? Maybe it’s time for a cost reduction analysis by one of our application specialists.
Weld Grinding Tool Designed for Finishing Various Metals

The KNSE 12-150 fillet weld grinding tool finishes various metals, including stainless steel. With an extended nose, it’s used for finishing and polishing hard-to-access fillet welds typically found on handrails or inside welds on enclosed areas. Also, a flat design enhances the tool’s overall operation and maneuverability. Weighing 6.6 lb and equipped with the company’s Marathon motor, it’s designed with double gear reduction for strong power delivery. Standard features include a winding protection grid, auto-stop carbon brushes, and thumbwheel for speed preselect. The Vario Tacho Constamatic full-wave electronic speed control keeps the tool’s speed nearly constant under any load. Safety features include electronic soft-start, tool-free adjustment for the grinder’s protective cover, overload protection, and power interruption protection. Additionally, the tool can take a weld from raw to mirror finish using the available accessories.

Metabo Corp.
www.metabousa.com
(800) 638-2264

Cutting, Profiling Systems Offered for Handrail Market

The MasterTube™ Cutter (MTC) and MasterPipe™ Profiler (MPP) models are useful for small- to medium-sized shops. The 5-axis MTC offers the capacity for 1–8 in. round (1–12 in. outside diameter) and rectangular (7.5 in. cross section) pipe and tube cutting via plasma or oxyfuel. With a servo-driven rotating chuck, it provides rotation and longitudinal motion and its two additional profiling axes allow for torch angle and linear motion. This system is useful for high-production/high-volume handrail and fencing fabricators. Also, the 2-axis MPP is capable of handling cutting and profiling operations for pipe with an outside diameter of 1–12 in. and a length of up to 40 ft. This is recommended for small shops and fabricators. To support these systems, the company offers VE-Assist™, an online customer service tool.

Vernon Tool™ Co.
www.vernontool.com
(760) 433-5860

Brazing System Gives 5 kHz Fast Feedback

The IPB-5000A inverter power supply provides metallurgical bonding of tin-plated copper ribbon and buss bar interconnects for PV panel manufacturing. The resistance brazing system, consisting of a power supply, transformer, and brazing head, is easily integrated into most PV panel manufacturing operations. It offers 5 kHz fast feedback as well as a full-color LCD to show all parameter traces. The system operates in constant current, voltage, or power feedback modes and is capable of welding in combination mode. A precheck function determines resistance prior to the weld, while comparator and envelope functions monitor the weld.

Miyachi Unitek Corp.
www.miyachiunitek.com
(626) 303-5676

Sawing Systems Enable Quick Blade Changeovers

The AMSAW® high-speed, production saw machines are designed to use carbide blades to improve the cutting speed of ferrous and nonferrous material, bars or billets, rails, profiles, pipes, and tubes. Standard design features include the following: hardened spindle gears ground for minimum backlash; saw blade guide and dampening device for accurate cutting to stabilize the blade and prolong tool life; dry operation with no coolant needed; saw

Weiler Corp.
www.weiler corp.com
(800) 835-9999

Weld Cleaning Brush Features Short Trim Length

The 4½-in. Roughneck weld cleaning brush is designed for use on 4½-in. mini-grinders. The brush is designed for good cleaning action and long product life on small angle grinders and also has a high knot count and short trim length. It’s available in carbon steel and Type 302 stainless steel wire with a variety of arbor hole options.

Weiler Corp.
www.weiler corp.com
(800) 835-9999

Vernon Tool™ Co.
www.vernontool.com
(760) 433-5860

SEPTEMBER 2011
blade changeover in less than 3 min; double and triple measurement strokes for extra length cuts; and fast chip disposal. Options include stock size measuring, automated length measuring systems, bar manipulating systems, infeed and outfeed systems, and stackers.

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

Hand Torches Designed for Soldering and Brazing

A new series of soldering and brazing hand torches can use propane or MAP-Pro™ 1-lb, nonrefillable cylinders. HTS99 is a swivel torch with auto-ignition, single tube, adjustable brass regulator, burn tip swivel of 360 deg, and piezo igniter for instant flame. HTM9 is a swivel torch with manual ignition, single tube, adjustable brass regulator, and burn tip swivel of 360 deg. HTM11 is a swivel torch with manual ignition, double tube, adjustable brass regulator, burn tip swivel of 360 deg, and a double barrel tip. HSLT604HD is a high capacity and temperature, trigger torch with auto-ignition and ignition button lock, piezo igniter, and regulating valve.

The Harris Products Group
www.harrisproductsgroup.com
(800) 733-4043

Sander Fit for Large-Scale Metal Finishing

Featuring electronic controls, a soft-start feature, and a variable speed dial,
the company’s flap drum sander is engineered to not slow down while making shadow-free finishes. It also has an overload protection feature, weighs 7.9 lb, provides 4 in. of working tool width, and features an 11-A input and 700-W output. Additionally, the flap wheel drum line consists of four types of 4- by 4-in. drums with keyhole arbors. These drums are coated with aluminum oxide, zirconia aluminum oxide, interleaf, and nonwoven. Available in 40- through 120-grit sizes, they work coolly on a variety of metals. Interleaf flap wheel drums are available in 40- to 240-grit sizes. The nonwoven flap wheel drums are available in coarse through very fine grits.

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

Cutting Machine Allows Timed Piercing Sequences

The PNC-10 Elite portable cutting machine is compact, simple to operate, provides both oxyfuel and plasma cutting capabilities, and offers drawing-to-part ability with easy transportability. Features include a 45-shape library, kerf compensation, and timed piercing sequences. It can be used as a stand-alone machine or one can purchase the complete package that has the machine and a table.

Koike Aronson, Inc./Ransome
www.koike.com
(800) 252-5232

Thermocouple Protection Tubes withstand 2000°C

A thermocouple protection tube material made from CaO-stabilized zirconia can withstand a furnace’s maximum working temperature of up to 2000°C. According to the company, these zirconia thermocouple protection tubes offer corrosion and chemical resistance at higher temperatures than can be achieved with alumina tubes. The material can be used in directional solidification system furnaces, where temperatures are about 1600°C and the thermocouple tubes are sitting in a graphite bed.

Morgan Technical Ceramics
www.morgantechnicalceramics.com
(800) 433-0638
Ceramic Flap Discs Provide Faster Stock Removal

Sigma ceramic flap discs feature a slight angle that provides a greater contact area with the metal for faster, smoother, grinding control and stock removal. Made with ceramic abrasive grains bonded to a proprietary treated material that is layered and stacked, these Type 29 ceramic flap discs are self sharpening, durable, and require minimal pressure. Suited for heavy weld removal in fabrication shops, the discs are available in 4½, 5, and 7 in. diameter x ⅛ in. sizes and offered in 36 and 60 grit versions, with or without ⅛-11 adapters.

Rex-Cut Products, Inc.
www.rexcut.com
(800) 225-8182

Furnace Includes Motorized Vertical Lift Door

No. 921 is an electrically heated, 2000°F heavy-duty box furnace. Work-space dimensions measure 24 in. wide x 48 in. deep x 24 in. high. Heat to the work-load is provided by 34 kW of power installed in nickel-chrome wire coils, supported by vacuum-formed ceramic fiber. An in-door heating element provides improved temperature uniformity. The unit features 7-in.-thick insulated walls, comprising 5 in. of 2300°F ceramic fiber and 2 in. of 1700°F ceramic fiber while the 6½-in. floor insulation consists of 4½ in. of 2300°F firebrick and 2 in. of 1900°F block insulation. The furnace has a ¾-in. steel
plate reinforced shell and \( \frac{1}{2} \)-in. steel front plate construction, motor-operated vertical lift door, digital programming temperature controller, and manual reset excess temperature controller with separate contactors.

The Grieve Corp.  
www.grievecorp.com  
(847) 546-8225

Cutting Head Operates at up to 55,000 lb/in.\(^2\)

The company’s high-flow abrasive-jet delivers up to 3.5 lb/min (5.95 L/min) of abrasive and up to 8.6 gal/min (31.15 L/min) of ultrahigh-pressure water for abrasive waterjet cutting applications. It’s helpful for cutting thick materials such as reinforced concrete or making separation cuts in steel plates or pipes. Also, it’s capable of operating at up to 55,000 lb/in.\(^2\) (3800 bar), suited for use with lower-pressure, high-flow water jet pumps, and can be used with any manufacturer’s waterjet system.

Jet Edge  
www.jetedge.com  
(800) 538-3343

Plugs Available for DC Applications

The DSDC Series plugs and receptacles provide safer connections for direct current applications of up to 200 A at 250 VDC, up to 100 A at 600 VDC, or up to 30 A at 750 VDC. The product line offers a dead-front safety shutter that prevents user access to live parts and a padlockable pawl that enables easy locking in the connected or disconnected mode. The plugs and receptacles utilize solid silver-nickel...
contact surfaces along with spring-loaded, butt-style contacts.

Meltric Corp.
www.meltric.com
(800) 433-7642

Welding Table Contains Pattern of 28-mm Bores

With high mix and low volume, weld fixtures need to adapt quickly, yet accurately to changing requirements. The 50-ft-long augers that move the grain require alignment and stability. Positive stops provide the alignment for this auger drive housing. This fixture is constructed from elements of the company’s modular fixtureg system for welding. The 5-sided welding table has a regular pattern of 28-mm (1/8-in.) bores on 100-mm (4-in.) centers. The surfaces are all hardened to 55 Re. The locating stops and angles are also hardened and machined with matching bores and precision slots for flexibility in building fixtures. Joining these components together, a positioning and clamping bolt allows for fast assembly while providing 26.5 kN (6000 lb) clamping force.

Bluco Corp.
www.bluco.com
(800) 535-0135

Submit a New Products Item for Consideration

If your company has a new welding, fabricating, or manufacturing product readily available, the details required to be considered for possible publication in the Welding Journal are as follows:

• Press release with the product’s name, important features, and specific industries it’s aimed for
• High-resolution jpg or tiff photo (266 or more dpi).

Please e-mail submissions to Associate Editor Kristin Campbell at kcampbell@aws.org.
Hosted by: American Welding Society

14th Annual Aluminum Welding Conference

September 20 – 21, 2011
Fort Lauderdale, Fla.

At this conference, a distinguished panel of aluminum-industry experts will survey the state of the art in aluminum welding technology and practice. The 14th Aluminum Welding Conference will also provide several opportunities for you to network informally with speakers and other participants, as well as visit an exhibition showcasing products and services available to the aluminum welding industry.

Attendee Registration
AWS Members: $550
Nonmembers: $680

Exhibitor Registration
AWS Members: $750
Nonmembers: $880

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

Earn PDHs toward your AWS recertification or renewal when you attend the conference!
Welcome Remarks
Tony Anderson, Conference Committee Chair

The Aluminum Designation System & Characteristics of Aluminum Alloys
Mark Burke, Indalco Alloys

Aluminum Welding Metallurgy
Bruce Anderson, MAXAL International

Metal Preparation for Aluminum Welding
Frank Armao, The Lincoln Electric Co.

Filler Alloy Selection Primary Characteristics
Tony Anderson, ITW Global Technology Center

Gas Metal Arc Welding of Aluminum Alloys
Mark Burke, Indalco Alloys

Increasing Performance & Production in Aluminum GMAW
Thom Bums, AlcoTec Wire Corp.

Aluminum Weld Discontinuities: Causes and Cures
Kyle Williams, Alcoa Technical Center

Design and Performance of Aluminum Welds
Bruce Anderson, MAXAL International

Application of the AWS D1.2 Structural Welding Code—Aluminum
Kyle Williams, Alcoa Technical Center

Overview of Solid-State Welding Processes for Aluminum
Donald J. Spinella, Alcoa Technical Center

Friction Stir Welding and Processing of Aluminum Alloys
John Hinrichs and Chris Smith, Friction Stir Link Inc.

The Use of Automation in the Aluminum Welding Industry
John W. Smith, Panasonic Welding Automation

Resistance Spot Welding of Aluminum
Donald J. Spinella, Alcoa Technical Center

The Fundamentals of GTAW Welding of Aluminum
Brent Williams, Miller Electric

Aluminum Extrusions for Joining and Welding
Nick Parson, Rio Tinto Alcan

Welding Aluminum for Marine Applications
Jerry Mirgain, AlcoTec Wire Corp.

The Functionality of Feeding Aluminum Wire in GMAW Systems
David B. Veverka, ESAB Welding and Cutting Products
These tips will help you understand the nature of thermal spray coatings and how to handle them during machining.

Thermal spray coatings can provide wear and corrosion resistance, and can quickly build up dimensions on metallic components that have worn down or been mismachined. They’re fast, affordable, and effective, and they are way off the radar of many of the engineers and machinists who might use them. The result is that, despite this technology’s flexibility and utility, there aren’t many prints out there that call for thermal spray coatings. And, when they do, manufacturers, programmers, engineers, and machinists seldom know how to work with them. Thermal spray coatings are functional and highly effective, when used properly. But, to the uninitiated, they can be brittle, tough, flaky, and frustrating to work with.

The intent of this article is to shed some light onto the nature of these materials and how to handle them when they’re being machined.

Depending on the application, thermal sprayed materials are used as is, in their as-applied condition, or they are required to be finished to a specific dimension and/or surface finish. When finishing is required, grinding is often preferable because coating materials are often hard and respond well to the slow material removal rate typical of a grinding operation. Grinding is the only finishing option for very hard metallic coatings, and for tungsten carbide composite coatings and ceramics. Most metallic thermal sprayed coatings though, can be tooled, provided the proper care is taken, and this alternative may be attractive for reasons such as speed, price, and portability of the tooling process. Since tooling is a more technique-sensitive finishing method, we’ll focus on the fundamentals of tooling thermal sprayed coatings.

Preparation

It is important for the machinist to understand that thermal sprayed coatings...
are not wrought materials, and they won’t tool like them. First, the bonding mechanism is mechanical, not ionic or covalent. The structure is like a tightly packed and very hard sandcastle. Particles of coating lock into the particles around them, using high heat and pressure, and the strength of the bond is dependent upon the intricacy of the interlocking joint and the yield strength of the sprayed material. What’s more, as the coating is built thicker, often the tensile stresses within the coating will accumulate, fighting against the mechanical forces holding the coating in place, and reinforcing the coating’s tendency to pop. In compression, even heavy, high-shrink materials might continue to perform. But, with the application of an additional mechanical stress in opposition to the bonding mechanism, failure at the bondline and within the coating is highly likely.

A further aggravation to this already sensitive system is the presence of features within the coated geometry that could lead to an uneven distribution of stresses within the coating. When a coating is wrapped over a sharp corner or peak, as it cools, more of the coating’s internal stresses will accumulate over that feature — Fig. 1. Less effort will be required to initiate a failure at that point than at another, less irregular region of the coating.

Areas where the coating integrity is compromised also produce failure-prone regions with the coating system. A common example is a coating applied to an undercut region, such as you might find on the outside diameter of a shaft, where a damaged area has been repaired with thermal spray. If the undercut is prepared with straight sides, soot, fines, and other impurities can become trapped in the sharp relief, making the coating in that area more porous and less well bonded than the adjacent coating structure. Since this phenomenon occurs at the edge of the coating, a failure here will allow the rest of the coated area to be attacked from the side, interfering directly with the bondline and, more likely than not, leading to catastrophic coating failure.

For these reasons, it is best to ensure that thermal sprayed coatings are never applied over potential stress risers, that coating geometries do not tend to leave coated areas exposed to potential attack from impact or gouging stresses, and that, when the coating is applied within a prepared undercut pocket (often the best practice), that the pocket is prepared with chamfered or radiused borders — Fig. 2.

Following these basic guidelines will ensure that the coating performs well and withstands only the abuse for which it was designed.

The most common reason thermal spray coatings are tooled, rather than ground, is that the application must be done in the field, and tooling equipment is more portable than grinding. Thermal spray is well suited to repairing damage and bringing failed equipment back online in short order because the coating can be applied and finished in the field. Spun bearings and failed seals are good examples. The resulting damage is typically on a mission-critical diameter that is now undersized and possibly irregular. For the equipment to return to service, the diameter must be cleaned up, restored to size, and brought to a suitable finish. A uniform buildup on cylindrical work is easy to achieve because the consistent surface speed required for thermal spray coating can be achieved by rotating the shaft and slowly traversing the spray gun. The coating can then be tooled with a portable lathe and brought to finish with emery, sometimes without removing the piece from its service location.

Materials

Materials for repair must have performance characteristics at least equivalent to the original base material. They must also be relatively easy to machine because rework will only exacerbate the time lost to downtime.

Stainless steels in the 300 and 400 series are readily available in powder and wire. Whether plasma, flame, or arc sprayed, they can usually be tooled, and some respond well to being built to fairly heavy thicknesses without risk of failure. In addition to their flexibility for a variety of applications, these materials also tend to be hard and durable, a good fit for the repair of rotating equipment that has seen significant material loss. Another attractive feature of these materials is the ease with which a quality repair can be made using arc spray. Since this spray process has few utility requirements, only power and compressed air, it is often a simple matter to get the hardware in place to do a repair in the field, even under less than favorable conditions.

High bonding alloys like nickel aluminate, aluminum bronze, and molybdenum also make great repair and salvage materials, depending on the application. Like the steels, they can easily be built to significant thickness without risk of failure, and can be tooled, rather than ground. Though some of these materials are softer than steel, this may not be a concern, for example, in corrosive environments, where wear is less a concern than chemical attack or galling.

Applications

Following are some generic application categories where coatings are commonly applied and then machined to dimension for repair purposes. The selection is designed to illustrate commonly successful types of repairs rather than unusual or exotic applications.

As mentioned previously, journal and bearing area repair is common because of the depth and breadth of rotating equipment in service. In nearly any instance where a machine component includes a spinning shaft, that shaft will be supported by some kind of bearing, and that bearing is protected by some kind of lubrication system. When the lubrication system fails,
if the machine continues to operate, the deterioration of the shaft beneath the bearing can be quick and significant. To repair an area where a bearing has seized or spun, the area must usually be excavated to restore the diameter to some uniform dimension. Again, it is important to make the undercut with chamfered sides. Depending on the thickness of the coating required to restore dimension, either a high-building steel or a bond coat with steel top coat will likely be used. A tight fit with a close tolerance is usually required for bearing areas, and, while this usually requires grinding between centers, a field repair can be brought into approximate finish by tooling and then polishing with emery tape.

Military standard procedures for the repair and overhaul of marine equipment have been in place for decades. While becoming qualified to perform these repairs for government agencies can be time consuming and difficult, the procedures demonstrate the usefulness of corrosion-resistant thermal sprayed materials for the salvage of mission-critical equipment in hard wearing and corrosive environments. In typical applications, the material applied for repair or rework is similar to the base material, e.g., aluminum bronze or nickel aluminum for naval bronze castings, Monel™ or nickel copper for nickel-based alloys, and austenitic steels for carbon and low-alloy stainless steels. For pump housings and impellers, valves, hatches, and other components that come in contact with seawater, effective cleaning prior to coating is essential. Oxides remaining on the surface prior to coating can negatively impact bond strength and cause the coating to delaminate under lower stress. Depending on the geometry and the nature of the repair, either hand spray or automation can be used. Most materials used in these applications are easily tooled, so the accuracy of the spray application is less critical than for many other jobs. Hand blending, including die grinding and sanding, can be used to effect many repairs.

A large percentage of commonly applied roll coatings are used as surface enhancements. Traction coatings are often applied and used in their as-sprayed condition. Hard coatings used to extend the life of roll surfaces are typically ground, rather than tooled. The chief exception is restoration of dimension. When diameter is critical, and a roll has been ground or reground and is now under the minimum serviceable diameter, its life can be extended almost limitlessly by rebuilding the surface and then toothing it back to size. This can be especially valuable for the salvage of rolls that have suffered minor damage such as gouges or dings — Fig. 3. Twin arc sprayed 400-series stainless steel is often compatible, in terms of chemistry and coefficient of thermal expansion, with most roll shells. It can be applied quickly and built to significant thickness, and it is easily tooled to a decent finish. Gouges and other inconsistencies in the surface are often best treated by machining the entire circumference undersize in the affected zone, until the damage has been eliminated, and then blasting and rebuilding. Alternately, coating the entire roll face and then toothing to smooth can be used to clear up multiple small blemishes and/or restore cylindricity.

As with spun bearings, sealing or packing areas on rotating shafts often develop circumferential wear patterns that can be significantly under the original shaft diameter. Unlike bearing fits, deterioration in these zones can happen far more slowly and with less obvious consequences. Nonetheless, proper functioning of a seal or packing is essential to the proper operation of valve stems and pump shafts, and restoration of the lost dimension will eliminate leaking and restore the sealing integrity of the coupling. Materials used for the repair of sealing and packing areas must typically be hard enough to withstand the constant sliding wear of the active seal, but must also be free from porosity, voids, cracks, or other discontinuities that can lead to premature deterioration of the sealing or packing material. Nickel-chromium alloys are particularly well suited to the repair of wet-service components in sealing applications. The alloys are largely corrosion resistant and wear very well, but also tend to exhibit good homogeneity; there are no hard carbide particles, choppy oxides, or excessive porosity that can tear into and abrade sealing components. They also can be tooled and polished fairly easily.

**Tooling Fundamentals**

Tooling thermal sprayed coatings is not overly complex, so long as it is understood that the material cannot be treated as if it is solid or wrought. Understanding that there are limits to the bond strength of the coating, and that tooling forces must be controlled in order to remain clear of these limits is the fundamental challenge. Largely, the practice of taking light cuts with a sharp tool at lower-than-usual surface speeds will translate to success in ma-
chining sprayed coatings. Erring on the side of caution is also helpful. Some more specific practices are as follows:

Avoid attempting to machine any applied material with a nominal hardness in excess of 55 HRC. Many thermal sprayed coatings, particularly those discussed previously, fall well below this limit, but attempting to tool a harder material, or overworking a work-hardening material, will lead to excessive tool wear, poor cut quality, and probably cracking, failure of the overlay, and frustration.

Be sure to mount tools rigidly, with the tool holder as close as possible to the cutting point. Any possibility of vibration or deflection of the tool that might compromise the quality of the cut will lead to premature tool wear and the headaches that follow.

Keep tools sharp. Once a tool begins to wear, the friction imparted will begin to heat the coating, eventually leading to rubbing and blistering of the coating. At its first sign of anything other than an easy, consistent cut, replace or rotate the insert and continue the cut. Use a smaller infeed or slower traverse if an interrupted cut is essential.

A sharp pointed tool, such as a threading insert or grooving tool, will typically wear too quickly, and some amount of radius (0.0156 to 0.125 in.) will help extend the effective tool life. In general, though, the tool radius should be as small as can be tolerated for the finish required. A larger nose radius will lead to a wider cut, with more surface area in contact with the tool, which will increase the risk of overheating the coating.

Across the board, harder inserts are better. Although the material being tooling may not be hard in its typical form, thermal spraying can often lead to the development of oxides within the coating structure. These hard formations can be aggressively damaging to low-grade tools, and higher quality, harder inserts will tend to perform better longer. Tungsten carbide is a de facto choice. Cubic boron nitride and diamond tools have been used, but the additional cost is typically unnecessary.

Feeds and Speeds

Zero degrees of rake (vertical tool pitch) is a safe position for machining most sprayed coatings. Negative rake (down angle) will just lead to dragging and loading, and the coating will quickly fail. Positive rake is possible, but only to a limited degree and only on fine cuts, as there is a significant risk of gouging the coating or catching a void and lifting the material away, resulting in catastrophic failure. Bear in mind that once a tool has gotten beneath a coating, the coating will lift off, like when paint is scraped.

In general, harder materials will require slower feeds and speeds in order to cut effectively. You’ll quickly know that you’re moving too fast when the tool either snaps or grinds away. Provided the inserts are sharp, and you are taking care to proceed gently with the cutting effort, some combination of feeds and speeds will cut nearly any metallic commonly sprayed. Table 1 provides a good rule of thumb for most coatings:

- Not keeping the inserts sharp, or not replacing inserts often enough — Fig. 4. This can allow the tool to plow or burr —nish the coating rather than cut it. When this excess heat is imposed, the coating may blister and fail.
- Attempting to make an interrupted cut in a coated zone, such as a keyway, may lead to the coating chipping at the far side of the interruption. It is preferable not to tool an interrupted coating, but, if you must, consider filling the gap with a carbon or brass insert.
- Attempting to cut too quickly will dull the tool, leading to the aforementioned plowing and blistering.
- Failing to keep the tool cool can cause some coating materials to work harden, which can quickly make a material uncuttable.
- As with any coating, there are risks of taking too much material off and breaking through in one or more areas, which will introduce a failure prone zone in the coating. Carefully addressing runout prior to machining should ensure that the coating thickness is consistent on all sides.
- On the other side of the same coin, the spray technician must be sure to apply enough coating so that the machinist can restore the required dimension without leaving a low spot where the tool fails to take a chip.

Working carefully and taking light cuts will help you avoid nearly all of these mistakes. Again, it is most helpful to remain aware that the material being cut is a coating on top of the original piece and not an integral part of the component. Approaching the tooling of a coated surface as if it were a thin, hard shell on a mandrel, which to some extent it is, should guide a machinist to make smarter choices about tool selection and feeds and speeds. From a practical standpoint, the much lower stock removal rates characteristic of a grinding or lapping process might make this a better option than tooling, when the option is available. Grinding also offers an improved range of surface finishes and the ability to cut very hard materials like tungsten carbide and ceramic coatings by using superabrasive grinding wheels. Grinding thermal spray coatings also has its own set of peculiarities, but this is a topic for another time.

---

### Table 1 — Feed Rates and Spindle Speeds for Commonly Sprayed Metals

<table>
<thead>
<tr>
<th>Coating Hardness</th>
<th>0.002 in. Infeed per Spindle Revolution</th>
<th>0.005 in. Infeed per Spindle Revolution</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 to 35 HRC</td>
<td>20-50 ft/min, 0.020 in. depth of cut</td>
<td>30-60 ft/min, 0.050 in. depth of cut</td>
</tr>
<tr>
<td>35 to 50 HRC</td>
<td>0.002 in. infeed per spindle revolution</td>
<td>0.010 in. infeed per spindle revolution</td>
</tr>
<tr>
<td>50 to 55 HRC</td>
<td>Grind, do not tool</td>
<td></td>
</tr>
<tr>
<td>&gt; 55 HRC</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

CHAMPION WELDING ALLOYS®
Lake Linden, MI 49945
Toll Free: 800.321.9353  Phone: 216.252.7710  Fax: 216.252.7716
www.ChampionWelding.com  INFO@ChampionWeldingAlloys.com

We are now ISO9001:2008 registered.

Champion Welding Alloys can supply you with the AWS A5.5 chromoly electrodes and related welding consumables that you need. We manufacture B1, B2, B3, B5, B6, B8 and B9 electrodes. We also manufacture the low carbon grades for select alloys. Call, visit our website or email us for more information.
Selecting Abrasives for Grinding Aluminum

Knowing the characteristics of the abrasive media and the right grinding techniques will help you produce the best finish on aluminum

BY PATRICK CARROLL

Depressed Center Wheel from Norton Abrasives is used to grind aluminum.

Weld grinding is required in the finishing process for deburring and cleanup in some aluminum manufacturing applications. Aluminum weld grinding is a challenging proposition, and the right abrasives and techniques should be used to ensure the best results.

Aluminum is used in a broad range of applications ranging from auto manufacturing to construction to cooking utensils and others, making it the most widely used metallic element in the world. In its pure form, aluminum is silvery white and lightweight. Aluminum blends readily to make strong alloys, and it conducts both heat and electricity well.

However, aluminum melts easily and has a tendency to coat the abrasive disc, covering the grit and exposing only bits of aluminum. This generates heat at the point of contact. Continued grinding produces more heat, which produces more melting. And the natural response of the operator is to push harder on the grinding wheel, causing more friction and greater heat to the disc.

Understanding this, there are three main abrasive products used on aluminum: depressed-center wheels, fiber discs, and flap discs. We will discuss these technologies as well as two alternative methods used in grinding aluminum. Applying the right disc to an application will yield the best results.

Depressed-Center Wheels

These “rocks” are best for deburring and offer the longest life. Many manufacturers offer a wheel especially for aluminum. These wheels normally contain no wax or rubber fillers, which helps to retard loading on hard-to-grind aluminum.

The depressed-center design allows the flange/lock nut to recess within the wheel so it can be used for various grinding and cutting applications. Depressed-center wheels are designed to handle the most severe right-angle grinding applications ranging from heavy stock removal to rough blending — Fig. 1. More recently, depressed-center wheels have been designed to increase utility of the tool for cut-off applications. Additional applications include grinding, stock removal, edge chamfering, beveling.

PATRICK CARROLL (patrick.h.carroll@saint-gobain.com) is a senior product manager for the Coated Abrasives Div. of Norton/Saint-Gobain in the Watervliet, N.Y, facility with headquarters in Worcester, Mass.
Fiber Discs

A piece of Zirconia grain –
* Key – ability to “micro-fracture”, keeping sharp cutting points exposed

Fig. 1 — Examples of depressed-center wheels. The wheels are designed to handle the most severe right-angle grinding applications.

Fig. 2 — The advantage of fiber discs made of zirconia grain is that sharp cutting points are continually exposed.

Fig. 3 — Newer types of flap discs, such as Norton’s Bluefire R884, feature a zirconia grain that provides sharp cutting points throughout the grind and polyester flaps that extend the disc’s service life.

Fig. 4 — Examples of how to best use Type 27 and 29 flap discs.

and weld blending.

Following are some of the advantages of depressed-center wheels:
• Up to 5x the life of flap discs, resulting in less downtime
• Up to 100x the life of fiber discs, resulting in less downtime
• Rigidity for severe operations and high-power grinders.

Fiber Discs

Fiber discs are best for cleanup and provide an excellent finish. Many manufacturers offer a disc using zirconia grain for grinding aluminum. An advantage of zirconia grain is as the operator grinds, each piece of grain “microfractures,” allowing sharp cutting points to continue to be exposed, which retards loading — Fig. 2.

With regard to coated abrasive discs, fiber discs are the most heavy duty. They feature resin over resin construction on heavy-duty vulcanized fiber backing. The discs are designed for applications ranging from heavy stock removal to surface blending. Fiber discs are used with both air-cooled and smooth-faced backup pads with a standard 5/8-in. hole.

Flap Discs

Flap discs combine the best attributes of both depressed-center wheels and fiber discs. Flap discs allow for simultaneous deburring and cleanup finishing, saving time and money.

Flap discs have three components including the backing plate, adhesive, and abrasive cloth. The abrasive cloth is layered, providing a cushioned substrate resulting in heavy stock removal rates and surface blending action.

In weld grinding applications, flap discs offer many advantages over depressed-center wheels including:
• Higher and faster stock removal rates
• Smoother finish with no gouging
• A cooler cut with less glazing
• Lighter weight and easier to control
• Low vibration with less operator fatigue
• Quieter
• Ability to debur and clean in one operation.

Similarly, flap discs offer many advantages over fiber discs including:
Hand Arm Vibration During Grinding

Fig. 5 — Measuring hand/arm vibration during grinding. The depressed-center wheel demonstrated the highest vibration level, which lowers the amount of time the operator can safely use the product. The fiber disc was lower, but still showed higher vibration levels than the flap disc. Since the flap disc has a larger mass than the fiber disc, it would be expected to have higher levels of vibration. In this test, it was not the case. This may be due to the backup pad for the fiber disc being out of balance. With a well-balanced backup pad, the fiber disc may have lower vibration. In situations where better surface finish is required, it is better to use a product with lower levels of vibration. This allows the operator to maintain better control of the tool and reduces the likelihood of gouging.

- Up to 20x longer life, resulting in reduced abrasives cost
- Fewer disc changes, resulting in reduced labor cost
- More consistent finish
- No backup pad required
- Easier storage, no curling
- Reduced loading (important on aluminum)
- Ability to deburr and clean in one operation
- Use flap discs in one grit size coarser than fiber discs, except in 36 grit.

Flap disc technology continues to advance. For example, a new flap disc for grinding aluminum and stainless steel has recently been introduced. The flap disc features a sharp zirconia grain for aggressive cut and long life, as well as polyester flaps for added durability — Fig. 3. The disc includes a semi-open coat that retards loading, which is key for aluminum. This disc technology is best for deburring and cleaning aluminum in one easy step, and makes fast work when aluminum weld grinding.

To obtain the best grinding techniques for flap discs (Fig. 4), the recommendation is to use the following:

T29 (conical) at a 15-deg angle for maximum stock removal and to provide greater surface contact for the most aggressive action. This is the best choice when speed is important.

T27 (flat) at a flatter angle. This type of disc is used for smooth finishing and works best on flat surfaces. This is the best option for cleaning.

Figure 5 shows hand/arm vibration grinding measurements for depressed-center wheels, and flap and fiber discs. The figure shows the weighted hand/arm vibration measurements from all three products. The values were weighted according to ISO 5349, and the weighting is based on a curve that gives a higher weighting to the lower frequencies that cause operator fatigue and injury over time. The values were obtained using a triaxial accelerometer mounted to the right-angle grinder.

In addition to the three primary ways for grinding aluminum (depressed-center wheels, fiber discs, and flap discs), two additional means for grinding include nonwoven and quick-change discs.

Nonwoven Discs

Nonwoven right-angle discs have three components: a strong, synthetic fiber mesh and quality abrasives that are bonded together with a smear-resistant adhesive. Nonwoven products provide excellent cutting action while improving surface finish. The nonwoven web is attached to a fiberglass backing plate for direct mounting. Applications include medium-to-light material removal, deburring, blending, cleaning, finishing, and polishing of aluminum and other substrates.

Advantages of nonwoven right-angle grinding discs include the following:
- Deburring, blending, and finishing with one product, reducing the number of steps
- Provides a controlled, sustained finish
- Prevents undercutting and gouging
- Provides a cooler grinding action to lessen the chance of warping or discoloration
- Reduces loading on hard-to-grind materials like aluminum, as well as fiberglass, adhesives, and soft metals
- Less vibration and quieter for high operator acceptance
- Provides a safe alternative to wire brushes.

Quick-Change Discs

Tool-free, twist on and off fastening systems make fast work of disc changes to maximize productivity by minimizing downtime — Fig. 6.

Quick-change discs are beneficial when grinding aluminum due to their smaller sizes, which range from % to 4 in. in diameter. The discs are ideal for use in aluminum applications when using portable tools to clean and remove imperfections on metal surfaces; clean, deburr or finish a variety of surfaces; blend weld joints or create decorative finishes. Quick-change discs are available in multiple backing options, with the most popular being cloth for light- to medium-pressure grinding, blending, leveling, and finishing. The discs are used on contours or flat surfaces.

A thorough examination of the weld grinding aluminum application, along with knowing the characteristics for abrasives will enable the most suitable disc or wheel to be selected. In addition, applying the proper grinding techniques will provide the best results.
Introducing the

Intelligent Darkening Filter

Manual Adjustments from 5-14
Auto-Variable from 5-14
Special iTIG Mode
8 Custom Memory Settings
Unique to Each Welder

How Intelligent

Price - Performance - Quality
WWW.ARC1WELDSAFE.COM
For Info go to www.aws.org/ad-index
Comparing Thermal Cutting Processes for Beveling

These tips will help you select the best process for your beveling operations

BY JOE SORVAAG

Designing edge bevel preparations that you can’t manufacture costs — and costs big. More to the point, in today’s challenging and hypercompetitive world, weld joint designs must meet the requirements needed for the welded joint but should also consider, when possible, the overall cost of manufacturing the desired edge to the desired tolerance. In some cases, we have found that the edge preparation, as designed, was simply desired, rather than actually required to achieve the weld result. In other cases, reducing the value of the included angle reduced the amount of filler metal required, but had the unintended consequence of significantly increasing the cost of producing the edge preparation. To maintain a competitive advantage and improve the overall cost of manufacture, cutting and welding professionals should work cooperatively to develop the required joint design at the lowest manufacturing cost.

The purpose of this discussion is to provide a comparison of plasma and oxyfuel cutting including relative costs and suitability for edge preparation. To do this, we consider three primary areas related to plasma and oxyfuel bevel cutting.

1. Relative cost of plasma vs. oxyfuel cutting
2. Basic capability of plasma and oxyfuel beveling for these three points:
   - Edge bevel type required
   - Material type and thickness compatibility
   - Part size and contour shape compatibility
3. Accuracy expectations when bevel cutting with plasma and oxyfuel

All of these discussions assume the most typical, commercially available automated contouring bevel cutting stations

JOE SORVAAG (jsorvaag@esab.com) is project development manager, ESAB Cutting Systems, Florence, S.C.
for plasma or oxyfuel, and certainly do not apply to every beveling station or torch. From the standpoint of a plasma and oxyfuel equipment manufacturer, there are unique applications that require unique capabilities. These are not addressed in this article.

**Relative Costs**

Looking at comparative costs for consumables only between plasma and oxyfuel (Fig. 1), we see that 200-A plasma cutting consumables are 13 times higher in cost than oxyfuel, and 400-A plasma cutting consumables are 29 times higher in cost than oxyfuel cutting. (As there are multiple variables that contribute to consumables cost, these values are provided for relative reference only.) This relative comparison sets the stage for a discussion regarding the best choice of cutting process for a particular edge preparation. For that discussion, we need a common reference for edge bevel types.

**Bevel Types**

Figure 2 shows four common edge bevel preparations. When choosing a cutting process for these edge bevel preparations, remember that a typical oxyfuel beveling station utilizes up to three oxyfuel torches simultaneously, while a typical plasma bevel cutting station utilizes only one torch. Therefore, oxyfuel bevel stations can produce each of the common edge bevel preparations shown here in a single cutting pass, while plasma bevel stations require multiple cutting passes to produce the compound bevels shown.

With this fairly simplistic overview, oxyfuel cutting seems to have all the advantages. However, typical oxyfuel three-torch bevel stations have material thickness and part contour limitations that must be considered. Oxyfuel cutting speeds are also considerably lower than plasma cutting speeds. The cutting speed differential between plasma and oxyfuel becomes much smaller as material thickness increases, so a more detailed evaluation of total process time vs. a simple comparison of cutting speeds is required.

**Material Thickness, Bevel Type, and Part Contour Requirements**

Table 1 shows a rough outline of the carbon steel thickness range and bevel types most commonly suited for plasma or oxyfuel cutting.

For the most part, plasma beveling stations are more suited to material from 0.25 to 2 in. thick, while oxyfuel beveling stations have inherent geometric limitations of the torch positioning that requires material of at least ¼-in. thickness for compound beveling. Oxyfuel beveling is most suited for material thicknesses from 1.25 to 3 in. It is here that the debate starts to get a little more intense. The question is always asked, "If I can cut plasma bevel in up to 2 in. thickness, why would I use oxyfuel beveling on 1.25 in. thickness? After all, plasma cuts several times faster than oxyfuel, right?" Well, yes, that is correct. However, plasma cutting speeds on 2-in. plate are only three to four times faster than oxyfuel cutting. Furthermore, to produce a compound bevel with plasma beveling stations, the plasma must make several passes on the same edge. For a K bevel, plasma cuts three times on the same edge, so the total process time is significantly increased.

It is very convincing to watch plasma cutting on ¼-in. material at eight times the speed of oxyfuel and then automatically assume that this cutting speed difference will carry over to bevel cutting as well. But, of course, cutting 1.25-in. material at a 45-deg bevel is really done at 1.75-in. cutting speeds, so the cutting speed advantage of plasma is reduced when you consider both the actual thickness that the plasma is cutting through and the requirement for multipass cutting on compound bevels.

When you examine the overall cost of cutting between plasma and oxyfuel, and the true cycle time of plasma multipass cutting for compound beveling vs. three-torch, oxyfuel single-pass beveling for the same cut, oxyfuel beveling becomes much more attractive for material thicknesses of 1.25 to 1.5 in. and thicker.

Unfortunately, typical oxyfuel beveling stations have contour limitations. For example, small parts (less than 12 in. square), small internal holes (less than three to four times the material thickness), or parts that require variable bevels or variable bevel types on the same side of the part are more difficult to accomplish with automated oxyfuel bevel stations than they are with plasma beveling stations. If you are cutting small parts that require bevel edge preps, consider plasma for thicknesses less than 2 in.

**Accuracy Expectations**

What you can reasonably expect with regard to the accuracy of your beveling operation is the single most important point we will discuss. After all, if the result of the process selection does not produce a weldable part, then the discussion is only academic. Here is the framework: Given a most suitable environment, smaller part sizes, and properly maintained equipment, finished part accuracy can be significantly better than anything depicted here. However, in the real world of large plate fabrication, these things may not always meet our day-to-day produc-

![Relative Cutting Cost (Consumables Only)](image)

![Fig. 1 — Comparing the relative cost of 200- and 400-A plasma arc cutting consumables to that of oxyfuel consumables.](image)

![Fig. 2 — Examples of common edge bevel preparations.](image)

<table>
<thead>
<tr>
<th>Bevel Cutting Process</th>
<th>V Bevel</th>
<th>Y Bevel</th>
<th>X Bevel</th>
<th>K Bevel</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min</td>
<td>Max</td>
<td>Min</td>
<td>Max</td>
</tr>
<tr>
<td>Plasma Bevel</td>
<td>0.25</td>
<td>1.75</td>
<td>0.375</td>
<td>2</td>
</tr>
<tr>
<td>Oxyfuel Bevel</td>
<td>0.375</td>
<td>3</td>
<td>0.875</td>
<td>3</td>
</tr>
</tbody>
</table>
tion realities. So, with the confidence we’ve gained from years of working with hundreds of bevel cutting applications, let’s pursue consideration of accuracy expectations in the production of compound bevels using plasma or oxyfuel.

The cutting machine that supports a plasma or oxyfuel beveling station has a positioning tolerance. For example, let’s consider that our cutting machine has a positioning accuracy of ±0.01 in. over a 6-ft cutting area. In addition, there are positioning tolerances for the positioning of the torch(es) to a bevel angle (maybe ±0.2 deg), the position of the torch(es) above the plate (maybe 0.006 in.), and ability of the torch to accurately maintain a center point as it rotates around a part to produce a beveled edge on each side. Finally, there is an overall achievable accuracy based upon the cutting process (plasma or oxyfuel) itself. All of these tolerances must be considered to produce a final, stacked tolerance of the entire system.

When cutting a bevel, the cutting torch elevation (torch height above the plate while cutting) must be strictly controlled, predicting the outcome of bevel cutting significantly impact part accuracy. If these changes are not properly controlled, predicting the outcome of a compound bevel becomes impossible.

The stacked tolerance of the beveling system becomes even more problematic when plasma beveling because compound beveling requires several cut passes. So if our beveling machine has a positioning tolerance of ±0.01 in., and the bevel edge preparation requires three passes (“K” bevel), the actual machine position could be displaced by 0.01 in. on each bevel pass. As we stack the tolerance of torch height on top of the machine positioning tolerance, the deviation for each cut pass is increased. Add on the tolerance for angle position, torch center point, and other factors like consumable wear or tip maintenance, and you quickly come to the conclusion that bevel cutting with plasma or oxyfuel has tolerance limitations that must be seriously considered.

A discussion of bevel part accuracy would not be complete without consideration of the included angle. While smaller included angles can reduce the number of weld passes and quantity of filler metals, the trigonometry of all of these stacked tolerances cannot be ignored. Without demonstrating the mathematic gymnastics of the impact of stacked tolerances with respect to bevel angle, suffice it to say that a smaller bevel angle has a larger potential for an out-of-tolerance condition during the cut. While not always possible or desirable, the most accurate results for thermal cutting are delivered when the included angle is 60 deg or larger.

And, finally, all of these stacked tolerances do not consider the potential for plate movement during thermal cutting or how level the plate is with respect to the cutting machine. With all of these factors considered, a reasonable expectation of finished part tolerance when bevel cutting with plasma or oxyfuel is ±0.04 to 0.08 in. While it may be possible to improve this accuracy through control of plate position, cooling of the plate during cutting, or utilizing cutting strategies that heat plate more evenly, it is unreasonable to assume that these tactics will significantly improve the accuracy value.

Conclusions

Consider the following when developing your joint designs.

- Thermal cutting machines can provide precise positioning and quality cutting, but they cannot control material movement or warping during the cut. Joint accuracy requirements of less than 0.06 in. (1.5 mm) may require significant investment to reliably produce.

- Plasma and oxyfuel beveling provide the most accurate and reliable results when included angles are 60 deg or greater.

- The cost/benefit analysis for bevel cutting on carbon steel 1.25 in. or greater should include a review of oxyfuel cutting as well as plasma. Part size and contour requirements must be given consideration.

- Plasma beveling is often most cost effective for single-pass (V) or dual-pass (Y) bevel requirements.

Change of Address?  Moving?

Make sure delivery of your Welding Journal is not interrupted. Contact Maria Trujillo in the Membership Department with your new address information—(800) 443-9353, ext. 204; mttrujillo@aws.org.
POLIFAN®-CURVE Gives You A Big Edge on Fillet Weld Finishing

**PERFECT CIRCLE**
Here’s a totally new flap disc that has fillet weld finishing covered all the way around. It not only grinds from here, but from here. You get faster, easier grinding with a level of precision not possible before. It brings a whole new meaning to working on the edge.

**New PFERD POLIFAN®-CURVE**
Features Radical Design for Ultimate Grinding Precision

**PERFECT FIT**
POLIFAN®-CURVE flaps are actually layered around and over the entire circumference of the disc, giving it a complete, circular grinding edge. It fits into fillet welds comfortably and grinds aggressively. Jobs are finished with less effort and more precision.

**PERFECT PITCH**
You might say this CURVE is the perfect pitch because it works so effectively. You can see a demo video on our website but you’ll want to see it live to believe it. Your local PFERD distributor can arrange that. Call him today or contact us at solutions@pferdusa.com and we’ll set it up. See how POLIFAN®-CURVE gives you the edge in solving tricky fillet welds.

See us at FABTECH booth #6309
For Info go to www.aws.org/ad-index
JOIN US!

Join fellow industry leaders from around the U.S., Canada and Mexico for this year's GAWDA Annual Convention in New York City. This event is packed with dynamic speakers and amazing networking opportunities concluding with the Farewell President’s Gala on the historical Intrepid Museum. There's also a wide array of local activities to look forward to. They include special city tours, Broadway opportunities, a sponsored Comedy Show and a spouse program featuring a presentation from one of the “Housewives of New York City”. Don’t be left out, come be a part of it!

For more information visit: www.gawda.org/New-York

NOT A MEMBER? JOIN US!

Meet our members and see what GAWDA has to offer for Distributors, Suppliers and Manufacturers’ Representatives. For the first time, GAWDA is offering non-members the opportunity to be a part of this prestigious industry event. Learn about GAWDA’s member benefits first hand and experience the value GAWDA has to offer!

For more information and detailed member benefits visit: www.gawda.org/Membership or call us at 1-877-382-6440

What GAWDA Members are saying...

The GAWDA Annual Convention is formatted to attract business owners and the companies’ top decision-makers. It addressed the market’s opportunities and threats on the ‘big picture’ level and provides occasion for strategic networking with the industry’s leaders.

Networking with other distributors allows an opportunity for members to gain different perspectives and lessons-learned on addressing a variety of issues associated with ownership (i.e., operations, sales, suppliers, etc.).
Brazing Titanium and Chromium Using Ion Bombardment Heating

A new method with both silver-based BAg-7 and aluminum-based BAlSi-4 filler metals is suitable for manufacturing small-size parts of electronic devices as well as relatively massive structures of other industrial applications.

BY MICHAEL MARKOVICH, GEORGE FISCHER, AND ALEXANDER E. SHAPIRO

The application of gas and metal plasmas close to local thermodynamic equilibrium (LTE) for thin-film deposition and surface thermal treatment is well known and widely used in the industry.

The highly ionized, intense plasmas generated during physical vapor deposition (PVD) by arc evaporation are also suitable for intense heating of metallic parts. The common feature of these methods is bombardment with energetic particles. This, in turn, in addition to heating, also provides effective cleaning and activation of exposed surfaces.

To date, plasmas only occasionally have been utilized for joining applications. This is due to the lack of experience and insufficient knowledge of liquid-solid reactions between base and filler metals under plasma heating and ion bombardment, and the specifics of joining process control.

An example of applying an abnormal glow discharge plasma to the brazing of small ceramic parts is described in Ref. 1, demonstrating the suitability of process plasmas for joining purposes. Plasma brazing is well suited to joining parts with large open surface-to-volume ratios, with effective coupling of energy from the incident ion flux into the workpiece, making the process especially suitable for joining small parts, such as electronic components.

Also, good candidates for this approach are structures made of active metals, such as titanium, chromium, vanadium, or zirconium, that require rapid heating and careful prevention of oxidation or other forms of passivation of faying surfaces before brazing or welding.

MICHAEL MARKOVICH and GEORGE FISCHER (georgefischer@ivactech.com) are with Ion Vacuum (IVAC) Technologies Corp., Cleveland, Ohio. ALEXANDER E. SHAPIRO (ashapiro@titanium-brazing.com) is with Titanium Brazing, Inc., Columbus, Ohio.
Brazing titanium to titanium and titanium to chromium in a titanium vapor cathodic arc discharge. Control of the thermal cycle and microstructure of the resulting joints are also discussed.

Materials Required to Carry Out the Research

For the experiments, 2-4 in. (50-100 mm) diameter, 1-2 in. (25-50 mm) thick Grade 2 titanium and hot isostatic pressed (HIP-ed) chromium (100% theoretical density from powder with purity >99% and maximum grain size of 0.315 mm) discs were used. The faying surfaces were polished, cleaned with acetone in an ultrasonic bath for 10 min or wiped with a lint-free cloth, and dried in air immediately before assembling with filler metal preforms. The chromium surface was polished to a “mirror” finish.

AWS BAg-7 filler metal in the form of 0.015 in. (0.4 mm) thick Grade 2 titanium and hot isostatic pressed (HIP-ed) chromium (100% theoretical density from powder with purity >99% and maximum grain size of 0.315 mm) discs were used.

The faying surfaces were polished, cleaned with acetone in an ultrasonic bath for 10 min or wiped with a lint-free cloth, and dried in air immediately before assembling with filler metal preforms. The chromium surface was polished to a “mirror” finish.

AWS BAg-7 filler metal in the form of 0.015 in. (0.4 mm) thick Grade 2 titanium and hot isostatic pressed (HIP-ed) chromium (100% theoretical density from powder with purity >99% and maximum grain size of 0.315 mm) discs were used.

Production vacuum brazing of titanium parts for aerospace, automotive, and other applications is an expensive, energy-intensive process (Refs. 2, 3). While brazing titanium is well developed in the industry, brazing chromium is done seldom due to its high reactivity and the formation of stable surface oxides, which starts at 538°C even in vacuum of 10^-4 Torr (Ref. 4). Therefore, chromium brazing requires higher vacuum and short processing time at the lowest possible process temperature.

This article describes brazing titanium to titanium and titanium to chromium in a titanium vapor cathodic arc discharge. Control of the thermal cycle and microstructure of the resulting joints are also discussed.

Fig. 2 — A — Titanium sample used for the setup brazing thermal cycle upon melting and spreading the BAISi-4 filler metal. 1 — Titanium samples; and 2 — melted and solidified brazing filler metal; B — chromium sample used for the setup brazing thermal cycle upon melting and spreading the BAg-7 filler metal. 1 — Sample of sintered chromium (the top section is an as-fractured surface, while the bottom is machined); 2 — titanium base metal; and 3 — melted and solidified brazing filler metal.

Step-by-Step Details of the Testing Process

The process was carried out in the following steps:

1. Preheating to 500°C.
2. “Soaking” to minimize the temperature gradient between the surface and the interior of the brazed structures. Equilibration could be ascertained by observing the cooling rate of the surface while the ion bombardment is disrupted.
3. Continue the bombardment to heat the parts to the brazing temperature as evidenced by the appearance of molten filler metal in the gap between the parts. The heat-up rate was carefully limited to ensure low volatile impurity desorption rates, so that the chamber pressure remained below 5 x 10^-5 Torr for the duration of the process.
4. The ion bombardment was stopped 30 s after melting and spreading of the filler metal. The brazing temperature for Ti-Ti parts with BAlSi-4 was in the range of 620°-650°C, while it was in the range of 750°-780°C for Ti-Cr parts with BAg-7.

5. The brazed parts were cooled in the chamber under vacuum to 200°C before opening the chamber.

Brazing filler metals BAlSi-4 (Fig. 2A) and BAg-7 (Fig. 2B) can be seen after melting and spreading, and an operation mode is set up after one or two tests of the thermal cycle. Melting and spreading of the filler metal was ascertained visually through a quartz window. Heating could be monitored by an infrared thermometer — Fig. 3.

Brazed titanium-to-chromium parts are shown in Fig. 4, and brazed titanium-to-titanium parts are shown in Figs. 5 and 6. Possibly due to zinc evaporation, upon melting of the BAg-7 filler metal, the plasma color turned reddish. At the moment of melting, a pressure transient could be observed where the desorption integral (the area under the pressure vs. time curve) was a measure of the release of volatile impurities from the melt.

Macro and microstructure of titanium-to-chromium brazed joints made with AWS BAg-7 filler metal and heating by ion bombardment are shown in Figs. 7 and 8. As can be seen from these figures, the joint metal contains no porosity: It is fully dense, and there is good wetting and fillet formation on both base metals. No intermetallic phase formation is seen at the joint metal/chromium interface, while there are a thin intermetallic layer (likely TiCu2) and a diffusion zone at the titanium side of the joint. The joint metal has a fine, even, completely eutectic structure, which is common for this class of brazing filler metals. It is likely that the filler alloy possesses sufficient plasticity due to the fine-grained microstructure of the Ag-Cu-Zn eutectic and uniform distribution of dendrites, even in fillet zones.

Conclusions

1. Metal ion bombardment is applicable to brazing such active base metals as titanium and chromium in a wide range of brazing temperatures from 600° to 800°C using silver-based or aluminum-based filler metals.

2. In comparison with traditional vacuum furnaces, brazing by ion bombardment has the following advantages:
   - Possibility of using Zn-containing filler metals that enable brazing at lower temperatures;
   - Rapid cooling due to processing in a cold chamber, resulting in the formation of a uniform, fine-grained microstructure of joint metal;
   - Absence or insignificant formation of brittle intermetallics at the interface with titanium; and
   - Visual observation of the brazing process, allowing accurate control of the heating and temperature regimes, thus avoiding both under or overheating, and enabling the manufacture of high-quality joints of reactive base metals.

References


New surface finishes are being sought by both structural and electronics marketplaces to improve the solderability of common and advanced base materials as well as to address environmental regulations that restrict the use of lead (Pb). Ideally, any new surface finish would be compatible with either conventional Sn-Pb or Pb-free solder applications. It is necessary to test the solderability behavior of these alternative finishes prior to their use on materials for assembly operations. One such surface finish that is currently capturing industry interest is Electroless Nickel (Ni)-Electroless Palladium (Pd)-Immersion Gold (Au) or ENEPIG. In this layer stack, the Ni layer is the solderable finish to which the solder joint is actually formed at the completion of the soldering process. The Pd layer is a protective finish to maintain the solderability of the Ni layer. The thin Au layer is a protective finish, as well, maintaining the solderability of the Pd layer because the latter forms a very thin oxide layer that slows the wetting and spreading of Sn-based solders.

The ENEPIG finish improves upon the good solderability of the original electroless nickel-immersion gold (ENIG), but with two benefits provided by the Pd addition. First, Pd eliminates the black pad solder joint defect (Ref. 1). The term “Black Pad” was first used in the late 1990s to describe a specific kind of nickel corrosion on ENIG surface finishes. This corroded nickel compromises the solderability of the part. In cross sections of the failed joint, Ni₃Sn₄ (for Sn-Pb solder joints) or (Cu,Ni)₅Sn₅ (for SAC alloy solder joints) intermetallic (IMC) is found on the solder side, and a phosphorous (P) content higher than that of the bulk Ni(P) plating is detected on the pad side (Ref. 1). Secondly, Pd slows the diffusion of Ni into the Au layer, resulting in longer shelf life and higher reliability for printed wiring assemblies exposed to harsh operating environments.

Experimental/Discussion

In the study reported here, the solderability of the ENEPIG finish was evaluated on oxygen-free-electronic (OFE) grade copper (Cu) coupons. The coupons were tested in the as-fabricated condition and after exposure to two accelerated storage environments. The two accelerated storage environments included the following: 1) Exposure to a Battelle Class 2 environment and; 2) steam aging per ANSI J-STD-002C, Solderability Tests for Component Leads, Terminations, Lugs, Terminals, and Wire (2007) (Ref. 2). The Battelle Class 2 test is a mixed flowing gas test containing 10 ppb H₂S; 200 ppb NO₂; 10 ppb Cl₂; 70% relative humidity (RH); at 30°C. The Battelle Class 2 accelerated environment was selected because it represents long-term storage under the conditions of a light industrial/manufacturing environment (Ref. 2). The length of the Class 2 accelerated aging test represents the equivalent of 3 months to 10 years for contact materials such as copper and silver. As such, the test is designed to accentuate plating defects. Steam-aged test coupons were exposed for 8 and 24 h within an atmosphere of 90% RH and temperature of 85°C. For brevity, the discussion below focuses only on the solderability behavior after exposure to the Battelle Class 2 environment.

The ENEPIG finish was obtained from two vendors denoted “1” and “2.” Copper coupons plated by Vendor 1 had nominal layer thicknesses shown below:

Vendor 1:

The second supplier, Vendor 2, pro-
vided two variants of the ENEPIG finish with the following thicknesses:

Vendor 2:

The difference between the two Vendor 2 variants was the thickness of the Pd layer: 6–7 μin. (“thick”) and 2–4 μin. (“thin”). A thin Pd layer reduces the material cost of the ENEPIG finish; however, the potential tradeoff is a reduced barrier function between the Ni and Au layers. The solderability of the test specimens was evaluated using a rosin-based, mildly activated (RMA) flux with an eutectic 63Sn-37Pb (wt-%) solder. The solder bath was held at 245°C.

The metric of solderability was the contact angle, \( \theta_c \). The lower the contact angle, the better is the solderability. The value of \( \theta_c \) was determined by the combination of two test methods. The first method is the meniscometer test. This test measures the meniscus height, \( H \), or vertical movement of a solder meniscus up the side of the coupon, using a traveling microscope — Fig. 1A. Five trials were performed per each test condition. A mean value for \( H \) and standard deviation were determined from those tests.

The second test method utilized a wetting balance (Fig. 1B) to measure the weight of the meniscus that forms on the coupon. Five separate tests were performed with this technique. The meniscus weight was described by the mean of those five values and one standard deviation. When the flux-coated coupon is immersed into a solder bath, initially an upward force is exerted on the sample. The upward force is caused by: a) the solder displaced by the sample volume; plus b) the solder that is displaced by the nonwetting or “negative” meniscus prior to the start of the wetting action. As wetting and spreading of the molten solder progresses up the coupon, the negative meniscus is lost, and the solder then generates a downward force because of its weight. However, the buoyancy force is not lost; it remains pushing up on the coupon and, as such, must be taken into account when calculating the net force or weight, \( w \), of the molten solder meniscus on the coupon. Once these measurements have been obtained, the value of \( \theta_c \) is calculated using Equation 1, where \( \rho \) is the solder density, \( g \) is the acceleration due to gravity, \( P \) is the sample perimeter (cm), and \( H \) is the meniscus height.

\[
\theta_c = \sin^{-1} \left[ \frac{4w^2 - (pgPH^2)^{1/2}}{4w^2 + (pgPH^2)^{1/2}} \right] \tag{1}
\]

In general, solderability is considered good-to-excellent for electronic and structural applications when the value of \( \theta_c \) is less than 30 deg. Solderability is adequate as long as \( \theta_c \) remains less than 50 deg as has been validated by the use of Pb-free solders on printed wiring assemblies (Ref. 3-6). A more inclusive guideline is shown in Table 1 (Ref. 7).

A second parameter that is obtained from the wetting balance test is the wetting rate. The wetting rate indicates the speed with which the molten solder meniscus climbs the coupon. Although this parameter is not used within industry standards, testing at Sandia National Laboratories has determined that it provides a correlation between the laboratory test and performance in fielded processes.

**Test Results — Contact Angle \( \theta_c \)**

The contact angle data for Vendors 1 and 2 are plotted in Fig. 2 as a function of the exposure time in the Battelle Class 2 environment. If the actual storage environment is a Class 2 environment, the following correlation between the accelerated test exposure time and the actual storage lifetimes is as follows:

- 8.4 h corresponds to ~3 months;
- 33.6 h ~1 yr;
- 168 h ~5 yrs; and
- 336 h ~10 yrs.

It is clear that the ENEPIG finishes, used in conjunction with the Sn-Pb solder and RMA flux, exhibited excellent solderability that was not degraded by even the longest exposure to the Class 2 conditions. In fact, the contact angles of the Vendor 1 finish actually decreased slightly after exposure to the Battelle Class 2 conditions. Although both “thick” and “thin” variants from Vendor 2 have only been aged for 168 h (~5 yrs), the contact angles remained very low and unaffected by the Class 2 exposure. More importantly, it is also apparent that the two Pd thicknesses were described by the mean of those values and one standard deviation. When the flux-coated coupon is immersed into a solder bath, initially an upward force is exerted on the coupon. The upward force is caused by: a) the solder displaced by the sample volume; plus b) the solder that is displaced by the nonwetting or “negative” meniscus prior to the start of the wetting action. As wetting and spreading of the molten solder progresses up the coupon, the negative meniscus is lost, and the solder then generates a downward force because of its weight. However, the buoyancy force is not lost; it remains pushing up on the coupon and, as such, must be taken into account when calculating the net force or weight, \( w \), of the molten solder meniscus on the coupon. Once these measurements have been obtained, the value of \( \theta_c \) is calculated using Equation 1, where \( \rho \) is the solder density, \( g \) is the acceleration due to gravity, \( P \) is the sample perimeter (cm), and \( H \) is the meniscus height.

\[
\theta_c = \sin^{-1} \left[ \frac{4w^2 - (pgPH^2)^{1/2}}{4w^2 + (pgPH^2)^{1/2}} \right] \tag{1}
\]

The metric of solderability was the contact angle, \( \theta_c \). The lower the contact angle, the better is the solderability. The value of \( \theta_c \) was determined by the combination of two test methods. The first method is the meniscometer test. This test measures the meniscus height, \( H \), or vertical movement of a solder meniscus up the side of the coupon, using a traveling microscope — Fig. 1A. Five trials were performed per each test condition. A mean value for \( H \) and standard deviation were determined from those tests.

The second test method utilized a wetting balance (Fig. 1B) to measure the weight of the meniscus that forms on the coupon. Five separate tests were performed with this technique. The meniscus weight was described by the mean of those five values and one standard deviation. When the flux-coated coupon is immersed into a solder bath, initially an upward force is exerted on the sample. The upward force is caused by: a) The solder displaced by the sample volume; plus b) the solder that is displaced by the nonwetting or “negative” meniscus prior to the start of the wetting action. As wetting and spreading of the molten solder progresses up the coupon, the negative meniscus is lost, and the solder then generates a downward force because of its weight. However, the buoyancy force is not lost; it remains pushing up on the coupon and, as such, must be taken into account when calculating the net force or weight, \( w \), of the molten solder meniscus on the coupon. Once these measurements have been obtained, the value of \( \theta_c \) is calculated using Equation 1, where \( \rho \) is the solder density, \( g \) is the acceleration due to gravity, \( P \) is the sample perimeter (cm), and \( H \) is the meniscus height.

\[
\theta_c = \sin^{-1} \left[ \frac{4w^2 - (pgPH^2)^{1/2}}{4w^2 + (pgPH^2)^{1/2}} \right] \tag{1}
\]

In general, solderability is considered good-to-excellent for electronic and structural applications when the value of \( \theta_c \) is less than 30 deg. Solderability is adequate as long as \( \theta_c \) remains less than 50 deg as has been validated by the use of Pb-free solders on printed wiring assemblies (Ref. 3-6). A more inclusive guideline is shown in Table 1 (Ref. 7).

A second parameter that is obtained from the wetting balance test is the wetting rate. The wetting rate indicates the speed with which the molten solder meniscus climbs the coupon. Although this parameter is not used within industry standards, testing at Sandia National Laboratories has determined that it provides a correlation between the laboratory test and performance in fielded processes.

**Test Results — Contact Angle \( \theta_c \)**

The contact angle data for Vendors 1 and 2 are plotted in Fig. 2 as a function of the exposure time in the Battelle Class 2 environment. If the actual storage environment is a Class 2 environment, the following correlation between the accelerated test exposure time and the actual storage lifetimes is as follows:

- 8.4 h corresponds to ~3 months;
- 33.6 h ~1 yr;
- 168 h ~5 yrs; and
- 336 h ~10 yrs.

It is clear that the ENEPIG finishes, used in conjunction with the Sn-Pb solder and RMA flux, exhibited excellent solderability that was not degraded by even the longest exposure to the Class 2 conditions. In fact, the contact angles of the Vendor 1 finish actually decreased slightly after exposure to the Battelle Class 2 conditions. Although both “thick” and “thin” variants from Vendor 2 have only been aged for 168 h (~5 yrs), the contact angles remained very low and unaffected by the Class 2 exposure. More importantly, it is also apparent that the two Pd thicknesses

---

**Fig. 2 — Vendor 1 ENEPIG thick Pd, Vendor 2 ENEPIG thin Pd, and Vendor 2 ENEPIG thick Pd contact angle as a function of Battelle Class 2 aging, Sn63-Pb37, RMA flux, 245°C.**

**Fig. 3 — Wetting rate as a function of Battelle Class 2 aging for both vendors, Sn63-Pb37, RMA flux, 245°C.**
of these ENEPIG finishes provided comparable solderability performances, which opens the door to using the less-expensive, thinner Pd layer.

**Summary**

The electroless Ni, electroless Pd, and immersion Au (ENEPIG) surface finish is capturing the attention of both the structural and electronics soldering communities as a means to enhance the solderability of common base materials for a range of applications. Solderability testing has illustrated the robustness of this finish after simulated storage aging using the Battelle Class 2 environment. For the various ENEPIG finishes in this study, the excellent performance was sensitive to supplier but not to the thickness of the Pd layer. Only a slight decrease in wetting rate was observed after exposure to the Battelle Class 2 conditions. Auger electron spectroscopy identified two possible sources of the reduced wetting rate: a) Pd diffusion to the Au surface and its oxidation and; b) the small buildup of carbon compounds detected by AES on the Au surface. The small decreases in wetting rate would not impact an actual manufacturing process.

**References**

The origins of soldering can be traced back several thousands of years to artisans in the Mediterranean region who used it to fabricate items ranging from household utensils to jewelry. The obvious advantage was the low melting temperature of the filler metals that allowed soldering to be used with the modest heat sources that were available at the time. Because artisans practiced soldering as a craft, they considered materials and processes to be proprietary information. Even today, some soldering methods are not readily divulged between craftsmen in the jewelry-making community.

Soldering remained largely an artisan’s craft up to the Industrial Revolution in the nineteenth century. As populations grew and inhabited cities, it was necessary to develop an infrastructure that could deliver centralized services such as water, waste removal, and gas for lighting purposes. Services were brought to dwellings by iron, copper, and steel conduits that were joined together with solder filler metals—Fig. 1. The availability of portable energy sources, including combustible gases followed by electricity, allowed pipe systems to be assembled on-site, which significantly reduced the project cost. All of the work was performed by craftsmen who formed the ranks of plumbers and other pipefitters.

The twentieth century brought about the increased use of electricity, and with it, the development of radio and other electronic components. Soldering was a very effective means to connect copper wires as well as to assemble rheostats, transformers, and other devices. At that time, all of the soldering was performed by hand. There became an increased awareness of hand soldering as an industrial process, albeit primarily still as a craft and certainly not yet as a technology.

Today, soldering is considered a technology driven by the electronics industry. It is critical that engineers understand materials’ compatibility, process control, and long-term solder joint reliability. Yet, in spite of the many advances that have been made toward optimizing large-volume manufacturing processes, applications remain that are performed by hand soldering because of technical and/or economic advantages. In the electronics industry, there are accredited certification programs administered by professional organizations (e.g., IPC-Association Connecting Electronics Industries) that train individuals in the soldering of circuit boards and related electronic interconnections. Those same organizations provide acceptance specifications that assess the quality of such solder joints.

However, in the case of structural hand soldering, there is a noticeable lack of accredited certification programs and specifications, in spite of the long history that hand soldering has had in the trades and artists’ communities. The American Welding Society provides a quality-related document pertaining to structural soldering titled B2.3: 2008, Specification for Soldering Procedure and Performance Qualification. Otherwise, most certification programs are in-house and typically address the fabrication of solder joints that are relevant to that company’s products and services. Often, operators are provided with only a sufficient amount of information to maintain the assembly line throughput.

The C3B Soldering Subcommittee of the AWS C3 Brazing and Soldering Committee has long-recognized that there is a gap in the availability of accredited specifications and certification programs. But, more so, there is a gap in the fundamental knowledge base that is crucial to support hand soldering as an engineering technology. Therefore, the C3 Committee has taken action toward eliminating that knowledge gap. The first step was to begin developing American National Standards
The first draft has been completed and the document is currently in initial layout at AWS. The guideline is ideally suited for operators as well as manufacturing and process engineers. It is also an excellent resource for engineering and product managers.

Here is a summary description of the chapter topics. The first four chapters address the fundamental aspects of soldering, including base materials, filler metals, as well as fluxes and controlled environments. These chapters are not intended to be in-depth treatises on these topics; for that level of detail, the reader is referred to the corresponding chapters in the AWS Soldering Handbook, which was published in 2000. Instead, these chapters are intended to provide sufficient information to support the operator and manufacturing engineer in the development of new hand soldering processes as well as troubleshooting of problematic processes.

The fifth chapter examines process development and is the heart of the text. The chapter is divided into 11 sections. The sections that address specific hand soldering practices are listed below:

- Soldering with an iron,
- Soldering with a torch (flame),
- Soldering with hot air or a hot inert gas,
- Resistance soldering,
- Induction soldering,
- Other hand soldering techniques.

Each section begins with a brief introduction. Next, the specific equipment is described that is used in the process. Then, the steps are listed for the general soldering process, including the placement of flux and heat source on the base materials. In several sections, the soldering procedure details are further broken down into applications that are best suited for preforms, solder paste, or wire as the method to supply filler metal to the joint. In other chapters, the distinction is also made between soldering procedures for lap joints vs. those for butt joints.

There are sections within this chapter that address preassembly cleaning and fixtures, as well as postassembly cleaning. There is also a section that examines rework and repair of solder joints when they are performed by hand soldering.

The sixth chapter provides environmental safety and health information. It has two sections: The first looks at the hazards of hand soldering while the second section examines regulations and guidelines. The objective of the latter section was not to provide an up-to-date list of relevant federal, state, and local regulations. Such a goal would be untenable, given their quantity as well as the rapid pace with which such regulations are changing at the present time. Rather, this chapter provides basic safety and environmental information for the operator and manufacturing engineer to consider when executing a hand soldering process. The user of the guideline is encouraged to obtain further details for their particular need or application.

An important feature of this guideline is the illustrations. The author is all too familiar with the fact that solder joint aspects are not well presented using standard light photography. Shiny surfaces and extraneous shadows cause misleading surface artifacts. Therefore, photographs are used sparingly. Rather, greater use is made of schematic illustrations to demonstrate solder flow and fillet geometries — Fig. 2.

The C3 Committee members are enthusiastic about this new guideline. The document creates a technical framework from which to develop, and then properly execute, a hand soldering process that is appropriate for the choice of base materials, filler metal, and heat source for an application.

Acknowledgment

Microstructure and Electrochemical Properties of the Stainless Steel Bonding Zone Joined with a Fe-Based Amorphous Foil

The effect of temperature and holding time on the microstructure and corrosion resistance of the junction zone of AISI 316L stainless steel (SS) bonded to itself with Fe<sub>75</sub>Cr<sub>10</sub>P<sub>10</sub>B<sub>7</sub> filler alloy was investigated at the Instituto de Investigaciones Metalurgicas, Mexico (Ref. 1). The brazing alloy was prepared in the form of amorphous ribbons, and its melting temperature was determined by differential thermal analysis to be 1571 K. The joining process was carried out in a chamber with controlled argon atmosphere by self-diffusion bonding at solid state at 1173 K for 20 min and by diffusion brazing at 1273 K for different holding times <40 min.

When joined by self diffusion, the change to the noncrystalline structure of the amorphous alloy and the formation of different phases made the dissimilar nature of the alloys more significant and promoted selective dissolution coupled with crevice corrosion.

The joints produced at 1273 K for 40 min exhibited no porosity in the reaction zones and presented the best quality. Scanning electron microscopy (SEM) characterization of the bonding zone revealed an improvement in the quality of the joints brazed at 1173 K for 20 min and longer. These samples had continuous base metal-filler alloy interfaces with minimum porosity. At 1273 K, the bonding interfaces diffused and for the samples held for 40 min completely vanished and porosity disappeared. Even the presence of particle precipitates in the bonding zone showed acceptable resistance to localized corrosion in nonaggressive electrolytes.

The SEM study revealed that irregularly precipitated particles and other phases of about 10 microns in size formed in the interlayer during the joining process. The presence of a phase in samples bonded at 1273 K promoted preferential dissolution in the bonding zone in NaCl solution.

Imidazole Containing Surface Treating Agent to Improve the Solderability of Printed Circuit Boards with Lead-Free Solders

A surface-treating agent, which significantly improves wetting and spreading of lead-free solders on copper substrate, was invented and tested by Shikoku Chemicals Corp., Kagawa, Japan (Ref. 2). The active component in the surface-treating agent is an imidazole compound such as 2-Benzyl-5-methyl-4-(4-octylphenyl)imidazole or 2-(40Bu1ylbenzyl)-5-hexyl-4-phenylimidazole added in the amount of 0.15-0.20 wt-%.

Also, the surface treating agent contains acetic acid 20-30 wt-%, levulinic acid 10 wt-%, copper acetate 0.05-0.10 wt-%, zinc acetate 0.9-2 wt-%, potassium chloride, or bromide, or iodide 0.05-0.07 wt-%, copper iodide 0.02 wt-%, and optionally formic acid 5 wt-%. All components are dissolved in deionized water, and the pH is adjusted to the value of 2.7 with ammonia water.

A printed circuit (or wiring) board is dipped in the surface-treating agent for
120–180 s at 400C, washed with water, and dried. The solderability test was carried out using the standard tin-lead eutectic solder and a lead-free solder Sn-3Ag-0.5Cu at 245°C in air. The solder flow-up rate reached 100% for the Sn-Pb solder and 94–96% for the lead-free solder after the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively. Spreading of both solders on the surface treatment, while comparative test showed only 72–77% and 40–44%, respectively.

Transient Liquid Phase Soldering of Copper Using Tin Interlayer

An original transient liquid phase (TLP) soldering process of copper under 2%H/98%N forming gas and slight combustion was studied in The University of Nottingham, UK (Ref. 3). A thin interlayer of pure tin foil 25 microns thick was sandwiched between two pieces of 100 microns thick copper foil as a base metal, compressed by 122 g loose weight and reflowed at 260°, 300°, and 340°C for 5–480 min.

Two adjacent layers of Cu₃Sn₅ and Cu₅Sn intermetallics were observed at the interface between Sn and Cu, whereby microstructures showed Cu₃Sn₅ scallops and Cu₅Sn columnar crystal morphologies. There is the pronounced difference in thicknesses of the Cu₃Sn₅ and Cu₅Sn layers formed at the two original boundary planes in the Cu/Sn/Cu samples.

After the residual Sn had been consumed completely, the Cu₃Sn layer grew at the expense of the previously formed Cu₅Sn₅ layer until it disappeared. The final TLP joint consisted of two layers ~2 microns thick of Cu₅Sn₅ columnar crystals that were perpendicular to the original Cu/Sn boundary planes. Diffusion kinetics of the interfacial reactions in the Cu/Sn/Cu system is characterized by activation energy 84.59 ± 25.84 kJ/mol, and the Cu₅Sn₅ and Cu₃Sn growth is derived from a range of Sn interlayer thicknesses. A type of grain boundary/molten channel-controlled growth of Cu₃Sn₅ has a time dependence similar to that for the volume diffusion-controlled growth.

These results provide new insight into the mechanism and kinetics of the interfacial reaction between liquid tin and solid copper, and other similar metallic liquid/solid systems.

A Wedge Fracture Toughness Test for Brazed Joints

It is well known that standard specimens used for testing fracture toughness of solid materials are not well suited for testing brazed joints because they are difficult to reproducibly precrack by fatigue. Scientists at the University of California, Santa Barbara, Calif., designed and tested a new original, double cantilever beam (DCB) specimen to measure fracture toughness of brazed joints, which allows promotion of crack stability using a simple precracking fixture (Ref. 4).

The specimen (Fig. 1) is loaded with a 30-deg silicon nitride wedge and simply supported. For the brazed joint measurements, the specimen dimensions are as follows: a = 2.54 mm, b = 6.35 mm, d = 3.81 mm, h = 4.76 mm, L = 9.17 mm, and t = 1.27 mm. The design of the DCB specimen is guided by analytical solutions for energy release rate and compliance.

Measurements of fracture toughness use both fractographic and compliance methods to ascertain crack length.

The approach confirming test was carried out with 304 stainless brazed joints and Nicrobraz® 31 filler metal. The joints had fracture toughness ~ 1 kJ/m² that is significantly greater than that for intermetallic constituents. Approximately half of the toughening was attributed to plastic stretch of the ductile phase within the eutectic. The rest was attributed to dissipation within a plastic zone of the joint, where the crack was attracted to the interface.

For info go to www.aws.org/ad-index
A Solder Glass Frit for Joining Alumina Ceramic

Despite the relatively low strength of joints, glass solders have many advantages for bonding ceramics. These include the following: a) chemical compatibility with a base ceramic material; b) comparable coefficient of thermal expansion; c) good wetting and adherence to ceramics; and d) melting, viscosity, and flowability controlled in a wide range.

Authors from the Singapore Institute of Manufacturing Technology have studied the process of bonding Al₂O₃ ceramic plates using Schott® Solder Glass G017-393 and measured bonding strength depending on surface treatment, spreading, and voids in the glass (Ref. 5).

Soldering was carried out in a vacuum furnace at 425°-575°C (795°-1067°F) for 5-25 min under pressure 5 kg. Surface treatment with phosphoric acid provided the best conditions of wetting ceramic resulting in a contact angle of 10 deg compared to 22 deg of the alumina ceramic as received and 17 deg of ceramic treated with sulfuric acid.

However, it was found that surface treatment is not necessarily positive in promoting bonding strength. In opposite to metal solders, the capillary effect does not work effectively during ceramic bonding by glass solders because the bonding strength is not governed by wetting the contact angle. Ceramic joints in “as-received” conditions exhibited significantly higher strength, while ceramic joints treated for the lowest contact angle had the lowest tensile strength.

Testing results showed that bonding strength of joints is mainly governed by the soldering temperature and time, and surface roughness of ceramic. The lower bonding temperature of 425°C provides the highest tensile strength of joints, while rising the temperature to 575°C decreased strength for about 40%. Besides, samples bonded above 500°C displayed porous joints.

Au-Sn-In Solder for Processing Compatibility with Lead-Free, Tin-Based Solders

Currently, semiconductor devices are sealed using gold-tin solder with the gold content ranging 78-81 wt-% and tin content 19-21 wt-%. This Au-Sn eutectic solder has been in use for more than 40 years, and has a melting temperature of 280°C (536°F), which is compatible with all traditional Sn-Pb solders that have soldering and post-sealing temperatures below 245°C. Lead-free, Sn-Ag-Cu solders that came to the industry in the last decade have a melting temperature at 217°C and require processing at 270°C that is dangerously close to the 280°C melting point of the Au-Sn alloy used for sealing electronic devices.

A new Au-Sn-In solder invented by Williams Advanced Materials, Inc., Buffalo, N.Y., has a melting temperature of 300°-320°C (572°-608°F) that makes it compatible with a semiconductor die attach and hermetic sealing of electronic packages after soldering using contemporary lead-free solders (Ref. 6).
The solder contains 17.5~20.5 wt-% of tin, 2~6 wt-% of indium, and gold in the balance; the exemplary solder contains Sn 19.3 wt-% and In 4.5 wt-%. Advantageously, the new solder permits post sealing operations at temperatures greater than 270°C (518°F) without reflowing and subsequent loss of seal integrity.

**Modified Water Drop Method of Evaluating Soldering Fluxes for Electrochemical Migration Propensity**

Electrochemical migration (ECM) is a unique corrosion-related reliability concern in consumer electronic products because it results from a combination of such factors as applied electric potential, humidity, and ionic contaminants. The traditional temperature-humidity-bias (THB) test is long; the native water drop (WD) method is quicker and requires a large number of samples for statistical evaluation that increase the cost of testing. The alternative water drop (WD) method is quicker by a factor of 100 at a fraction of the cost. However, reproducibility is a problem with the WD method.

A modified WD method for soldering flux evaluation was developed and tested by Nokia, Irving, Tex. (Ref. 7). Though the scatter in data was significant, this WD test method can be used to identify fluxes that performed significantly better than others. The following four principles were selected to provide comparing the relative propensity of ECM depending on the flux type during soldering of printed wire boards: (a) Select different finishes such as Cu, Ag, and Sn. It was expected that more than one metal may participate in the ECM dendrite formation; (b) select a voltage gradient that is representative of actual portable consumer electronics, esp. 7.5 V/mm; (c) select different fluxes used in lead-free soldering; and (d) perform WD tests using deionized water to rank alternatives based on propensity for ECM related failure.

Results indicated that a clear ranking was established among four soldering fluxes. In addition, among the different metals, the silver finishing was found to have the highest ECM propensity across all fluxes.

**High-Velocity Cold Spraying Powders for Cleaning Surface and Applying Brazing Filler Metals onto a Substrate**

General Electric Co., Schenectady, N.Y., developed a cost-effective method for applying brazing filler metals onto superalloy parts of gas turbine engines (Ref. 8). Cold gas dynamic spraying (or kinetic metallization) is a process that uses fine metal powders that are accelerated by a gas stream and impacted against a surface to form a coating. The metal particles collide with the surface, resulting in plastic deformation and bonding of these particles to the substrate. There is no melting of the particles.

The braze filler metal powder is then performed onto the substrate acts as a blasting media and cleans the surface to be brazed by removing a thin layer of surface material. The layer removed is more than zero and less than 1 micron, but it is sufficient to substantially remove any surface oxides. After the braze filler powder removes the oxide layer, the powder begins to adhere and bond to the surface.

For example, a braze alloy layer was formed using Ni-7Cr−3Fe−3B−4.1Si powder at an argon spray temperature of about 315°C (600°F). The formed layer was about (80 microns) 0.003 in. thick. The formed layer had no oxides between the braze alloy layer and the superalloy substrate, which was then successfully brazed in a vacuum furnace.

**Vacuum Brazing of Carbon-Fiber Composites with Aluminum Filler Metals**

Brazing of carbon-fiber composites at a low temperature can be done using aluminum filler metals. This process was tested, and the strength of brazed joints was measured in Shandong University, Jinan, China (Ref. 9). Pure aluminum and Alloy Al-5Ti-1B (wt-%) were applied as brazing filler metals. Vacuum brazing of C/C composite with aluminum was carried out at 700°C (1292°F) and 730°C (1346°F), while brazing with the Al-5Ti-1B filler metal occurred at 720°C (1328°F) and 750°C (1382°F) for 20–30 min. Flat parts to be joined were compressed at 0.375 MPa (0.054 ksi) during heating and cooling.

Aluminum filler metals exhibited sat-
BRAZING & SOLDERING TODAY
TECHNOLOGY NEWS

isfactory wetting of the base material at a temperature above 700°C, but also poor flowability. However, diffusion of liquid filler metals into porous carbon composite under pressure resulted in the formation of solid, dense joint metal characterized by shear strength 9.1-9.4 MPa (1.3 ksi) for Al filler metal, and 10.6 MPa (1.5 ksi) for Al-5Ti-1B filler metal.

Increasing the brazing temperature not only improves the fluidity of brazing alloys, but it also prevents coarsening grains in the joint microstructure and improves the quality of brazed joints. Slightly lower strength of aluminum brazed joints can be explained by a bigger thickness of the joint zone, about 200 microns, while joints brazed with the Al-5Ti-1B alloy had a thickness of only 60 microns. Boron proved to be a grain refiner that also resulted in better quality of the joint metal.

References

Information provided by ALEXANDER E. SHAPIRO (ashapiro@titanium-brazing.com) and LEO A. SHAPIRO, Titanium Brazing, Inc., Columbus, Ohio.
14th Annual Aluminum Welding Conference
September 20, 21
Ft. Lauderdale, Fla.

Aluminum lends itself to a wide variety of industrial applications because of its light weight, high strength-to-weight ratio, corrosion resistance, and other attributes. However, because its chemical and physical properties are different from those of steel, welding aluminum requires special processes, techniques, and expertise.

A distinguished panel of aluminum-industry experts will survey the state of the art in aluminum welding technology and practice. The conference will also provide opportunities for you to network informally with speakers and other participants, as well as visit an exhibition showcasing products and services specifically for the aluminum welding industry.

2011 FABTECH Conference Schedule
Chicago, Ill.

National Welding Education Conference
November 13

Presented by the National Center for Welding Education and Training (Weld-Ed), this conference is designed to bring together educators for professional development and networking opportunities. Weld-Ed’s focus is on the preparation of welders, welding technicians, and welding engineers to meet the needs of industry. This conference will include presentations on topics such as Weld-Ed accomplishments in the last year, the partnership between Weld-Ed and AWS, welding industry workforce needs, recruitment tips and tools for educators, competency models, externship programs for educators, tips on partnering with other secondary and postsecondary schools, welding education trends, curriculums, materials science education and applications, distance learning updates, new technology applications, and presentations from welding educators who will share their best practices. For additional information, contact Monica Pfarr at mtpfarr@aws.org.

Welding Technology to the Rescue
November 14

A number of major research efforts and technological wizardries are beginning to pay off in big ways throughout industry. The effects are numerous, including huge improvements in productivity, reduced costs, and improvements in quality. Solutions to lingering problems are also being discovered. The trend in new developments is bound to introduce more science into the overall welding scene.

8th Conference on Weld Cracking
November 15

The most perplexing problem in the welding industry has to be weld cracking. This conference is for those who want to get a handle on controlling weld cracking situations. The different types of cracking, their causes, and their solutions will be discussed. Learn how to identify the types of cracks, and more importantly, what to do about them.

What’s New in Power Sources?
November 16

Learn about the advanced features and capabilities available on the latest welding power supplies, including multiprocess operation. Transformer-rectifiers and inverters are on a roll. Experts will be on hand to explain many of these innovations.

Thermal Spray Technology: High-Performance Surfaces
November 16

The International Thermal Spray Association (ITSA) and the American Welding Society have organized this one-day educational coatings conference to introduce and highlight various advantages of the thermal spray process. This program will benefit both potential users and those actively involved with thermal spray coatings as it will focus on actual applications and new developments in thermal spray technology. In addition, on Tuesday, Nov. 15, ITSA will sponsor a free half-day tutorial on thermal spray fundamentals titled Thermal Spray Basics: Putting Coatings to Work.

For more information, please contact the AWS Conferences and Seminars Business Unit at (800) 443-9353, ext. 264, or e-mail zoltva@aws.org. You can also visit the Conference Department Web site at www.aws.org/conferences for upcoming conferences and registration information.
COMING EVENTS


TUBOTECH, 6th Int'l Trade Fair for Pipes, Valves, Fittings, and Components. Oct. 4–6, Imigrantes Exposicoes Exhibition Center, Sao Paulo, Brazil. Organized by Messe Düsseldorf North America and Grupo Cipa (Brazil); www.mdna.com.


Notes: A DIAMOND (♦) DENOTES AN AWS-SPONSORED EVENT.
ICALEO®, 30th Int'l Congress on Applications of Lasers & Electro-Optics. Oct. 23–27. Hilton Hotel, Walt Disney World® Resort, Orlando, Fla. AWS is a Cooperating Society of this event and AWS members receive the same discounted conference registration fee as LIA members. Presented by Laser Institute of America (LIA); www.icaleo.org.


China Aerospace & Aviation Technology Show(CAATS), Nov. 1–5. SNIEC, Shanghai, China; www.caats.aero/.


♦FABTECH. Nov. 14–17. McCormick Place, Chicago, Ill. This exhibition is the largest event in North America dedicated to showcasing the full spectrum of metal forming, fabricating, tube and pipe, welding equipment, and myriad manufacturing technologies. Contact American Welding Society,(800/305) 443-9353, ext. 264; www.fabtechexpo.com or www.aws.org.


sort, Cancún, Mexico. Sponsored by American Welding Society and other organizations; www.flogen.com/FraySymposium, or contact Florian Kongoli, chairman, fkongoli@flogen.com.


♦ **5th Int’l Brazing and Soldering Conf.** April 22–25, Red Rock Casino Resort Spa, Las Vegas, Nev. A joint activity of the American Welding Society and ASM International®, it will bring together scientists and engineers from around the world who are involved in the research, development, and application of brazing and soldering. www.asminternational.org/IBSC.


**Educational Opportunities**


**Fundamentals of Brazing Seminar.** Sept. 27–29, Crowne Plaza Irvine, Orange County, Calif. For designers, processing, manufacturing, and quality engineers, managers, production supervisors, and brazing operations personnel with all levels of brazing experience. Lucas-Milhaupt, www.lucasmilhaupt.com; (800) 558-3856.

**Grounding Courses.** Oct. 20, 21, Chicago, Ill. Instruction on how
Plan ahead.

Even if your nine-year recertification deadline is years away, you can fulfill it now with a CWI® endorsement.

Expand your credentials with an endorsement that fulfills your recertification requirements. Recertification every nine years requires either 80 hours of documented continuing education, retaking the "Part B" Practical Exam, or an endorsement to your certification. You can do this at any time, so why not do it now and secure the prestige and enhanced career potential of a credential in an additional welding code?

A CWI or SCWI can take a Supplemental Inspection Exam anytime during the nine-year cycle. Qualifying for and passing one of these exams meets the requirements for recertification. Endorsements are listed on your endorsement card. Endorsements to codebooks require passing a two-hour Open-Book Code Application exam on one of the following codes:

- AWS D1.1 Structural Welding
- AWS D1.2 Aluminum
- AWS D1.5 Bridge
- AWS D15.1 Railroad
- API 1104 Pipeline
- ASME Section IX, B31.1 and B31.3 Boiler and Pressure Vessel
- ASME Section VIII, Div. 1 and Section IX Boiler and Pressure Vessel

Seminars to prepare you for the two-hour exam on D1.1 or API 1104 are available at numerous seminar sites across the country. Three new code clinics will be offered at FABTECH in Chicago:

- D1.5 Bridge Code Clinic – Nov. 14
- D15.1 Railroad Code Clinic – Nov. 14
- ASME Section IX, B31.1 and B31.3 Code Clinic – Nov. 15

One other stand-alone credential can serve as an endorsement credit and also fulfills your recertification requirement. At any time during your nine-year cycle, if you meet the prerequisites, you can apply to become certified as an AWS Certified Radiographic Interpreter (CRI). The five-day CRI seminar is designed to ensure that you have the knowledge to properly assess indications produced on radiographic media. It will prepare you for the CRI certification exam, which is given at the end of each seminar week. This is a valuable certification that fulfills your nine-year requirement. Upcoming seminars and exams for CRI are:

- Pittsburgh – Oct. 17-22
- Allentown – Nov. 7-12

If you don’t want to take any exams at all, you can fulfill the 80-hour education requirement by attending a six-day AWS 9-Year Recertification Course. Courses are scheduled for:

- Dallas – Oct. 17-22
- New Orleans – Nov. 7-12
- Miami – Dec. 12-17

One more option is to recertify by taking the "Part B" CWI Practical Exam. This exam and refresher Visual Inspection Workshop seminars are offered at convenient CWI seminar/exam sites across the country. Our new Advanced Visual Inspection Workshops in Miami are specifically designed to prepare you for this exam.
Seminars, Code Clinics, and Examinations

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

### Certified Welding Inspector (CWI)

<table>
<thead>
<tr>
<th>Location</th>
<th>Seminar Dates</th>
<th>Exam Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Houston, TX</td>
<td>Sept. 11-16</td>
<td>Sept. 17</td>
</tr>
<tr>
<td>Minneapolis, MN</td>
<td>Sept. 11-16</td>
<td>Sept. 17</td>
</tr>
<tr>
<td>St. Louis, MO</td>
<td>Sept. 18-23</td>
<td>Sept. 24</td>
</tr>
<tr>
<td>Miami, FL</td>
<td>Sept. 18-23</td>
<td>Sept. 24</td>
</tr>
<tr>
<td>New Orleans, LA</td>
<td>Sept. 18-23</td>
<td>Sept. 24</td>
</tr>
<tr>
<td>Tulsa, OK</td>
<td>Oct. 16-21</td>
<td>Oct. 22</td>
</tr>
<tr>
<td>Long Beach, CA</td>
<td>Oct. 16-21</td>
<td>Oct. 22</td>
</tr>
<tr>
<td>Newark, NJ</td>
<td>Oct. 16-21</td>
<td>Oct. 22</td>
</tr>
<tr>
<td>Nashville, TN</td>
<td>Oct. 16-21</td>
<td>Oct. 22</td>
</tr>
<tr>
<td>Portland, OR</td>
<td>Oct. 23-28</td>
<td>Oct. 29</td>
</tr>
<tr>
<td>Roanoke, VA</td>
<td>Oct. 23-28</td>
<td>Oct. 29</td>
</tr>
<tr>
<td>Cleveland, OH</td>
<td>Oct. 23-28</td>
<td>Oct. 29</td>
</tr>
<tr>
<td>Detroit, MI</td>
<td>Oct. 23-28</td>
<td>Oct. 29</td>
</tr>
<tr>
<td>Miami, FL</td>
<td>Oct. 23-28</td>
<td>Oct. 29</td>
</tr>
<tr>
<td>Atlanta, GA</td>
<td>Oct. 30-Nov. 4</td>
<td>Nov. 5</td>
</tr>
<tr>
<td>Dallas, TX</td>
<td>Nov. 6-11</td>
<td>Nov. 12</td>
</tr>
<tr>
<td>Sacramento, CA</td>
<td>Nov. 6-11</td>
<td>Nov. 12</td>
</tr>
<tr>
<td>Spokane, WA</td>
<td>Nov. 6-11</td>
<td>Nov. 12</td>
</tr>
<tr>
<td>Chicago, IL</td>
<td>Exam only</td>
<td>Nov. 17</td>
</tr>
<tr>
<td>Syracuse, NY</td>
<td>Dec. 4-9</td>
<td>Dec. 10</td>
</tr>
<tr>
<td>Miami, FL</td>
<td>Dec. 4-9</td>
<td>Dec. 10</td>
</tr>
<tr>
<td>Houston, TX</td>
<td>Dec. 4-9</td>
<td>Dec. 10</td>
</tr>
<tr>
<td>Reno, NV</td>
<td>Dec. 4-9</td>
<td>Dec. 10</td>
</tr>
<tr>
<td>Los Angeles, CA</td>
<td>Dec. 4-9</td>
<td>Dec. 10</td>
</tr>
<tr>
<td>St. Louis, MO</td>
<td>Exam only</td>
<td>Dec. 10</td>
</tr>
<tr>
<td>Corpus Christi, TX</td>
<td>Exam only</td>
<td>Dec. 31</td>
</tr>
</tbody>
</table>

### Certified Welding Supervisor (CWS)

<table>
<thead>
<tr>
<th>Location</th>
<th>Seminar Dates</th>
<th>Exam Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miami, FL</td>
<td>Sept. 12-16</td>
<td>Sept. 17</td>
</tr>
<tr>
<td>Norfolk, VA</td>
<td>Oct. 17-21</td>
<td>Oct. 22</td>
</tr>
</tbody>
</table>

CWS exams are also given at all CWI exam sites.

### Certified Radiographic Interpreter (CRI)

<table>
<thead>
<tr>
<th>Location</th>
<th>Seminar Dates</th>
<th>Exam Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chicago, IL</td>
<td>Sept. 12-16</td>
<td>Sept. 17</td>
</tr>
<tr>
<td>Pittsburgh, PA</td>
<td>Oct. 17-21</td>
<td>Oct. 22</td>
</tr>
<tr>
<td>Allentown, PA</td>
<td>Nov. 7-11</td>
<td>Nov. 12</td>
</tr>
</tbody>
</table>

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

### Certified Welding Sales Representative (CWSR)

<table>
<thead>
<tr>
<th>Location</th>
<th>Seminar Dates</th>
<th>Exam Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indianapolis, IN</td>
<td>Sept. 21-23</td>
<td>Sept. 23</td>
</tr>
</tbody>
</table>

CWSR exams will also be given at CWI exam sites.

### Certified Welding Educator (CWE)

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

### Certified Robotic Arc Welding (CRAW)

<table>
<thead>
<tr>
<th>Week of</th>
<th>Location</th>
<th>Contact</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sept. 19</td>
<td>OTC Daihen, Inc., Tipp City, OH</td>
<td>(937) 667-0800</td>
</tr>
<tr>
<td>Sept. 19</td>
<td>Wolf Robotics, Ft. Collins, CO</td>
<td>(970) 225-7736</td>
</tr>
<tr>
<td>Oct. 24</td>
<td>Lincoln Electric Co., Cleveland, OH</td>
<td>(216) 383-8542</td>
</tr>
<tr>
<td>Oct. 31</td>
<td>OTC Daihen, Inc., Tipp City, OH</td>
<td>(937) 667-0800</td>
</tr>
<tr>
<td>Nov. 7</td>
<td>ABB, Inc., Auburn Hills, MI</td>
<td>(248) 391-8421</td>
</tr>
<tr>
<td>Dec. 12</td>
<td>OTC Daihen, Inc., Tipp City, OH</td>
<td>(937) 667-0800</td>
</tr>
</tbody>
</table>

On request: MATC, Milwaukee, WI | (414) 297-6996 |

### Certified Welding Engineer (CWEng)

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

### Senior Certified Welding Inspector (SCWI)

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

---

**International CWI Courses and Exams Schedules**

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 $250 Fast Track fee.
BUY. SELL. SUCCEED.

Nothing compares to the power of a live event — and nothing in Canadian manufacturing compares to CMTS. Face-to-face interaction and live demonstrations of the latest machine tools, automation technologies and production methods allow suppliers to put their best face forward, and buyers to make informed purchasing decisions.

Set yourself up for success in 2011 and beyond. Contact us today! cmts.ca or 888.322.7333

Organized by: Society of Manufacturing Engineers

For Info go to www.aws.org/ad-index
The AWS Foundation is proud to announce its

2011-2012

Howard E. and Wilma J. Adkins Memorial Scholarship

Joseph Bailey
LaToucheau University
Materials Joining Engineering & Mechanical Engineering

'I am honored and blessed to be selected as the recipient of the 2011-2012 Howard E. and Wilma J. Adkins Scholarship. Over the past two years I have enjoyed not only the financial support but also the training and leadership opportunities offered through AWS. For example, this year I served as an officer for the LaToucheau AWS student chapter. I hope to continue working with this prestigious society for the rest of my career. My sincere thanks extend to the Adkins family, the AWS Foundation, and all current members.'

Airgas – Jerry Baker Scholarship

Andrew Pfaffler
Ferris State University
Welding Engineering Technology

'I am extremely honored to have been selected as the recipient of the Airgas-Jerry Baker Scholarship through the AWS. The excellent support from my instructors and the AWS has shown me that they are truly committed to my education at Ferris State University and to the welding industry.'

Airgas – Terry Jarvis Memorial Scholarship

Brady Lafrinere
Ferris State University
Welding Engineering Technology

'It is a honor to be this year's recipient of the Airgas-Terry Jarvis Memorial Scholarship. I would like to thank the American Welding Society and all of the people involved with the scholarship program. The AWS foundation will help me further my education, to becoming a welding engineer. Thanks again for all the support given to me, and other welding students across the country.'

Ashaan Amirikian Engineering Scholarship

Erik Burlinbine
The Ohio State University
Welding Engineering

'I am extremely honored to be chosen as the 2011 recipient of the Ashaan Amirikian Scholarship. I would like to thank the American Welding Society for their help and all the AWS students and professors for their support.'

Edward J. Brady Memorial Scholarship

Ryan McCollum
Pennsylvania College of Technology
Welding and Fabrication Engineering Technology

'I would like to thank the AWS for their continued support in my education. Not only has the AWS been a big contributor towards my education but a large motivational factor as well. I am very honored to be this year’s Edward J. Brady Memorial Scholarship recipient. I would like to thank everyone at the AWS for this generous and meaningful scholarship.'

William A. and Ann M. Brothers Scholarship

Zackery Miller
Ferris State University
Welding Engineering Technology

'I want to thank the American Welding Society for awarding this scholarship to me. I would also like to thank Miller Electric Mfg. Co. for making this scholarship possible. This award greatly helps me achieve my goal of becoming a welding engineer.'

ESAB Welding and Cutting Scholarship

Mason Winters
Weber State University
Manufacturing Engineering – Welding Emphasis

'As the thankful recipient of the Brothers Scholarship, I would like to sincerely express my gratitude to the scholarship sponsors and the entire AWS organization for making it possible for me to further my education, and to further become an asset to the welding industry.'

Donald F. Hastings Scholarship

Peter M. Wanco, Jr.
Ferris State University
College Welding

'I am honored and very grateful to be the recipient of the ESAB Welding and Cutting Scholarship. I would like to thank the American Welding Society for their generosity. Your generosity will help me to further my education beyond just my welding degree. This scholarship will help me to achieve my goals in the welding industry, across a much broader spectrum. Thank you again and thank you for your support.'

Ferris State University
Welding Engineering

'Cameron Kuperus
The Ohio State University
Welding Engineering Technology

'It is a privilege and honor to be the recipient of the Robert L. Peaslee – Detroit Brazing and Soldering Division Scholarship. I am very thankful for the financial support the AWS Foundation has offered to me, as well as other welding students. By supporting us in our educational endeavors, you are supporting the future and the growth of welding engineering. Thank you again for this opportunity and your generosity.'

Cutting Scholarship

Lucas Crumley
The Ohio State University
Welding Engineering

'I am truly honored and thankful to be the recipient of the 2011-2012 Donald F Hastings Scholarship. I would like to express my sincere thanks to you for your support.'

Robert L. Peaslee – Detroit Brazing and Soldering Division Scholarship

Conrad Raffelo
Ferris State University
Welding Engineering Technology

'Receiving the Miller Electric Mfg. Co. scholarship is a great honor and privilege. I am very thankful for the contributions the AWS and Miller Electric provide students in welding and welding engineering. This scholarship will assist me with continuing my educational goal of becoming a welding engineer.'

Past Presidents Scholarship

Joseph Russell
LaToucheau University
Materials Joining Engineering Technology

'It would be a privilege and an honor to be recognized by such a great organization as both a privilege and an honor. This scholarship will help me be able to take the next step in the field of welding.'

Robert L Peaslee – Detroit Brazing and Soldering Division Scholarship

Cameron Kuperus
The Ohio State University
Welding Engineering Technology

'It is a privilege and honor to be the recipient of the Robert L. Peaslee – Detroit Brazing and Soldering Division Scholarship. I am very thankful for the financial support the AWS Foundation has offered to me, as well as other welding students. By supporting us in our educational endeavors, you are supporting the future and the growth of welding engineering. Thank you again for this opportunity and your generosity.'
National Scholarship Recipients

Jack R. Barckhoff Welding Management Scholarship

Christopher Bamhill
The Ohio State University
Welding Engineering

“I am honored to be the recipient of the Donald and Shirley Hastings Scholarship. I would like to thank the AWS Foundation for providing the opportunity for this scholarship. The support will help further my education at The Ohio State University and one day allow me to provide contributions to the welding industry.”

William B. Howell Memorial Scholarship

Mark Hahn
The Ohio State University
Welding Engineering

“I am honored to be the recipient of the William B. Howell Memorial Scholarship. I would like to thank the donors of the scholarship and the AWS Foundation for their continued support of the welding engineering field and the opportunity they have given me to excel as I continue my education at The Ohio State University.”

Miller Electric Mfg Co. World Skills Competition Scholarship

Devan DePair
Ferris State University
Welding Engineering Technology

“It is a tremendous privilege to receive the Praxair International Scholarship. I owe a great deal of gratitude to the American Welding Society and its donors for their tireless efforts to promote and improve our industry as well as their generous support of education. I would also like to extend my sincerest appreciation to the truly outstanding faculty and staff at Ferris State University.”

D. Fred and Marian L. Bovie Scholarship

Jason Rausch
The Ohio State University
Welding Engineering

“What a great honor to be the chosen recipient of the D. Fred and Marian L. Bovie Scholarship. How encouraging it is to have the Bovie family generously invest in my academic pursuits so I seek to become a Welding Engineer through study at The Ohio State University. May God grant me the grace to bear the responsibility of this gift to my fullest potential in both my present schooling and future career in the welding industry.”

Matsuo Bridge Company Ltd. of Japan Scholarship

Joe Young
Eastern Michigan University
Technology Management Minor - Welding

“Joe won the silver medal for welding at the 40th WorldSkills Competition held in Calgary, Alberta, Canada in September 2009. This earned him a $40,000 scholarship courtesy of Miller Electric Mfg. Co.”

D. Fred and Marian L. Bovie Technical Scholarship

Ethan Showers
Advanced Technology Institute
Machinist Welding

“Thank you...for choosing me as the recipient of the D. Fred and Marian L. Bovie Scholarship. It is an honor accepting this grant and knowing that there is such generous support available in the field of welding from AWS. I will continue to uphold the highest standard of welding technology throughout my education and career. It is truly an honor to be part of the AWS and the welding profession. Thank you again for this generous gift.”

Each year, the American Welding Society Foundation provides scholarship funds to help hundreds of students who otherwise would be unable to afford a welding education. We are the only industry foundation with the specific mission of helping to fund the education of welding students. In so doing, we create the careers that sustain and grow our industry.

We get these funds from your contributions. The more you contribute, the more students we can help educate.

To make a scholarship contribution or to set up your own District, Section or National Named Scholarship, contact Sam Gentry at the AWS Foundation. Call 800-443-9353, x331, or email to sgentry@aws.org.

Thank you for your continued support.
Brazing Filler Metals for Joining Refractory Metals

Refractory metals include tungsten, molybdenum, niobium, and tantalum. They are important for their superior strength, corrosion resistance, and the ability to withstand high-temperature service. The aerospace industry frequently uses them in structures and components for airframes and rocket engines. Metallurgical researchers continue to investigate and improve the materials and methods for brazing the refractory metals.

The properties of tungsten, molybdenum, niobium, and tantalum include very high melting temperatures, high recrystallization temperatures, high to very high densities, low specific heats, and low coefficients of thermal expansion. The body-centered cubic crystal structure of these metals presents a significant characteristic—a well-defined ductile-to-brittle transition behavior.

The transition temperature for these metals is not a fixed property of the metal but is influenced by the strain rate, alloying additions, impurities, heat treatment, and the fabrication process.

Brazing is an excellent joining process for fabricating assemblies of refractory metals, particularly those for thin sections. However, only a few filler metals have been specifically designed for both high-temperature and high-corrosion applications.

The characteristics of refractory metals that must be considered when brazing procedures are established are the ductile-to-brittle transition behavior, recrystallization temperature, and the reaction with gases and interstitial elements such as carbon.

The properties of tungsten, molybdenum, niobium, and tantalum include very high melting temperatures, high recrystallization temperatures, high to very high densities, low specific heats, and low coefficients of thermal expansion. The body-centered cubic crystal structure of these metals presents a significant characteristic—a well-defined ductile-to-brittle transition behavior.

The transition temperature for these metals is not a fixed property of the metal but is influenced by the strain rate, alloying additions, impurities, heat treatment, and the fabrication process.

Brazing is an excellent joining process for fabricating assemblies of refractory metals, particularly those for thin sections. However, only a few filler metals have been specifically designed for both high-temperature and high-corrosion applications.

Table 1 — Brazing Filler Metals for Refractory Metals*

<table>
<thead>
<tr>
<th>Brazing Filler Metal</th>
<th>Liquidus Temperature °C</th>
<th>°F</th>
<th>Brazing Filler Metal</th>
<th>Liquidus Temperature °C</th>
<th>°F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nb</td>
<td>2416</td>
<td>4380</td>
<td>Mn-Ni-Co</td>
<td>1021</td>
<td>1870</td>
</tr>
<tr>
<td>Ta</td>
<td>2997</td>
<td>5425</td>
<td>Co-Cr-Si-Ni</td>
<td>1899</td>
<td>3450</td>
</tr>
<tr>
<td>Ag</td>
<td>960</td>
<td>1760</td>
<td>Co-Cr-W-Ni</td>
<td>1427</td>
<td>2600</td>
</tr>
<tr>
<td>Cu</td>
<td>1082</td>
<td>1980</td>
<td>Mo-Ru</td>
<td>1899</td>
<td>3450</td>
</tr>
<tr>
<td>Ni</td>
<td>1454</td>
<td>2650</td>
<td>Mo-B</td>
<td>1899</td>
<td>3450</td>
</tr>
<tr>
<td>Ti</td>
<td>1816</td>
<td>3300</td>
<td>Cu-Mn</td>
<td>871</td>
<td>1600</td>
</tr>
<tr>
<td>Pd-Mo</td>
<td>2860</td>
<td>5171</td>
<td>Nb</td>
<td>1190</td>
<td>2175</td>
</tr>
<tr>
<td>Pt-Mo</td>
<td>3225</td>
<td>5774</td>
<td>Ag</td>
<td>1100</td>
<td>1920</td>
</tr>
<tr>
<td>Pt-30W</td>
<td>2299</td>
<td>4170</td>
<td>Ni</td>
<td>1038</td>
<td>1900</td>
</tr>
<tr>
<td>Pt-50Rh</td>
<td>2049</td>
<td>3720</td>
<td>Ta</td>
<td>2094</td>
<td>3800</td>
</tr>
<tr>
<td>Ag-Cu-Zn-Cd-Mo</td>
<td>619–701</td>
<td>1145–1295</td>
<td>Ti-V-Cr-Al</td>
<td>1649</td>
<td>3000</td>
</tr>
<tr>
<td>Ag-Cu-Zn-Mo</td>
<td>718–788</td>
<td>1324–1450</td>
<td>Ti-Cr</td>
<td>1481</td>
<td>2700</td>
</tr>
<tr>
<td>Ag-Cu-Mo</td>
<td>780</td>
<td>1435</td>
<td>Ti-Si</td>
<td>1427</td>
<td>2600</td>
</tr>
<tr>
<td>Ag-Mn</td>
<td>971</td>
<td>1780</td>
<td>Ti-Zr-Be</td>
<td>999</td>
<td>1830</td>
</tr>
<tr>
<td>Ni-Cr-B</td>
<td>1066</td>
<td>1950</td>
<td>Zr-Cb-Be</td>
<td>1049</td>
<td>1920</td>
</tr>
<tr>
<td>Ni-Cr-Fe-Si-C-B</td>
<td>1066</td>
<td>1950</td>
<td>Ti-V-Be</td>
<td>1249</td>
<td>2280</td>
</tr>
<tr>
<td>Ni-Cr-Fe</td>
<td>1249</td>
<td>2290</td>
<td>Ta-V-Cb</td>
<td>1816–1927</td>
<td>3300–3500</td>
</tr>
<tr>
<td>Ni-Cr-Si</td>
<td>1121</td>
<td>2050</td>
<td>Ta-V-TF</td>
<td>1760–1843</td>
<td>3200–3350</td>
</tr>
</tbody>
</table>

a. Not all of the filler metals listed are commercially available.
b. Depends on the specific composition.

FROM START TO FINISH

IT’S ALL HERE. Discover the most innovative technologies, resources and ideas. Engage with industry experts. Find solutions to improve productivity and keep your business competitive.

Get the most out of your time at FABTECH, with career-enhancing programs from AWS!

Special events at

November 14-17, 2011
McCormick Place • Chicago
AWS Conferences at FABTECH

AWS conferences and the RWMA Resistance Welding School present innovations and insight you can use in your career and enterprise, while affording the opportunity to network and exchange information with your peers. All conferences include lunch, breaks, and Q&A time.

Welding Technology to the Rescue
Mon., Nov. 14 • 8:30-4:00
$345 members/$480 nonmembers
A number of major research efforts and technological wizardries are paying off in big ways throughout industry. The effects are numerous. Some are in huge improvements in productivity. Others are in quality. There are brand-new solutions to lingering problems. This trend in new developments is bound to introduce more science into the overall welding scene.

Advancements in CO₂ Shielded Gas Metal Arc
Bill Guest, OTC-Daihen Inc.
Computed Radiography
R.W. Kruzic, Chicago Bridge & Iron Co.
Quality Assurance in Field Heat Treatment
Gary Lewis, Superheat FGH
DeltaSpot — Resistance Spot Welding with Process
Stefan Mayr, Fronius USA LLC
Reciprocating Wire Feed Systems for Plate Products
Randy Dull, Edison Welding Institute
20 kW Hybrid Laser Arc Welder
Duncan Pratt, GE Global Research
Thermal Spray for Wear Mitigation on Oilfield Tubulars and Tools
Karma Slusarshuk, WearSox
Cladding Wear Surfaces on Non-Magnetic Drill Collars
Joe L. Scott, Devasco International, Inc.
Automated Back Gouging of Thick Plate Weld Joints for DDG 1000 Construction
Bruce Horn, Concurrent Technologies Corp.
A New Hybrid Laser Arc Welding Center Opens Up
Doug Zoller, American Tank & Fabricating Co.

8th AWS Conference on Weld Cracking
Tues., Nov. 15 • 8:30-4:00
$345 members/$480 nonmembers
At AWS’s eighth conference on weld cracking, the different types of cracking, their respective causes, and their solutions will be thoroughly examined. No incident causes so much alarm as a weld crack. The different types of cracking, their causes, and their solutions will be discussed. This program will identify and analyze the types of cracks — and more importantly — what to do about them.

Understanding Weld Cracking in Steels
Joseph C. Bundy, Hobart Brothers Co.
Crack Avoidance in Creep Strength-Enhanced Ferritic Steels
William F. Newell, Jr., Euroweld Ltd.
Hot Cracking in Austenitic Stainless Steels
Damian J. Kotecki, Damian Kotecki Welding Consultants
How to Prevent Cracking When Welding Aluminum Alloys
Tony Anderson, ITW Global Welding Technology Center
Hydrogen Induced Cracking in Welding High Performance Steels
Yonit Adonyi, LeTourneau University
Investigation of Weld Metal Cracking in a Hydrotreater Vessel
Robert W. Warke, LeTourneau University
Preventing Cracking in Nickel-Base Alloys
Donald J. Tillack, Tillack Metallurgical Consulting, Inc.
Phased Array Ultrasonics for Detecting and Sizing Cracks in Welds
Michael Moles, Olympus NDT
Pressure Vessel Crack Prevention in Weld Repairs and Alterations
James T. Worman, The National Board of Boiler and Pressure Vessel Inspectors

National Welding Education Conference
Tues., Nov. 15 • 9:00-4:00
$149 members/$149 nonmembers
Presented by the National Center for Welding Education and Training (Weld-Ed), this conference is designed to bring together educators for professional development and networking opportunities. Weld-Ed’s focus is on the preparation of welders, welding technicians, and welding engineers to meet the needs of industry. This conference will include presentations on topics such as Weld-Ed accomplishments in the last year, the partnership between Weld-Ed and AWS, welding industry workforce needs, recruitment tips and tools for educators, competency models, externship programs for educators, tips on partnering with other secondary and post-secondary schools, welding education trends, curriculum, materials science education and applications, distance learning updates, new technology applications, and presentations from welding educators who will share their best practices.

What’s New in Power Sources
Wed., Nov. 16 • 8:30-4:00
$345 members/$480 nonmembers
The latest welding machines are equipped with greatly improved capabilities, including multi-process operation. Meet the experts and understand the relative benefits of emerging power source technologies, for example, transformer-rectifiers and inverters. The experts will be on hand to compare these innovations.

Modern Power Source Technology That Drives Process Improvement
Todd McEllis, Miller Electric Mfg. Co. and ITW
AC Pulse GMAW for Aluminum, Mild and Stainless Steels
Phil Mosquera, OTC-Daihen Inc.
Advances in Production Monitoring
Bruce Charity, The Lincoln Electric Co.
Advanced GMA Welding
Wesley Doneth, Fronius USA LLC
High Performance GMAW - New Machines. New Techniques Will Provide a Boost in Performance
Paul Blomquist, Applied Thermal Sciences, Inc.
WeldScore - Embedded Weld Data Quality Monitoring
Gold Track VI
Robert Tollett, Liburdi Automation Inc.
Controlled Short Circuit GMAW Process Competes Favorably with SMAW, GTAW
Jim Cuhel, Miller Electric Mfg. Co.
RWMA Resistance Welding School
Wed., Nov. 16 (7:45-5:30) — Thurs., Nov. 17 (8:00-3:45)
$475 members/$695 nonmembers
This intensive two-day course covers the basics of resistance welding. The school is designed to give operators, production supervisors, engineers, and others the opportunity to study, better understand, and further their knowledge in the theory, applications, and equipment used in the resistance welding process.

Electrodes and Tooling
Bill Brafford, Tuffaloy Products, Inc.

Welding Controls
Don Sorenson, ENTRON Controls, LLC

Electrical Power Systems
Mark Siehling, RoMan Manufacturing Inc.

Welding Processes and Machines
Tim Foley, Automation International, Inc.

Troubleshooting and Maintenance
Bruce Kelly, Kelly Welding Solutions

Initial Machine Setup
Robert Matteson, Taylor-Winfield Technologies, Inc.

Thermal Spray Technology: High-Performance Surfaces
Wed., Nov. 16 • 9:00-5:00
$345 members/$480 nonmembers
The third joint conference of AWS and the International Thermal Spray Association (ITSA) will introduce the thermal spray process and its uses to new potential users with morning and afternoon sessions focusing on actual applications and new developments in thermal spray technology.

Conference chairs: David Wright and Dan Hayden.

Industrial Applications and Technical Challenges of Thermal Spray
Daryl E. Crawmer, Thermal Spray Technologies

Advancing Cold Spray Applications to Industry Markets
David W. Wright, Accuwright Industries, Inc.

“How Should We Offer Thermal Spray Coated Fabricated Products?”
What a Steel Fabricator Should Know About Thermal Spray
Applied Anodic Coatings
James Weber, James K. Weber Consulting

What is Thermal Spray?
Larry F. Grimenstein, Nation Coating Systems, Inc.

Quality Control of Thermal Spray Coatings
Joseph P. Stricker, St. Louis Metallizing Company

High Density Twin Wire Arc Spray Coatings
Frank Rogers, Thermion, Inc.

Corrosion Protection Technology Without Size Limitations
Fred van Rodijnen, Sulzer Metco Europe GmbH

Fretting Wear Resistant Coatings for Aerospace Components
Satish Dixit, Plasma Technology, Inc.

Thermal Sprayed Zinc and Aluminum Coatings for Atmospheric Corrosion Protection
Dan Hayden, Hayden Corporation

Much Ado About Nothing: Why the Concern About Porosity
Dale Moody, Plasma Powders and Systems

Using Robotic Offline Programming for Improved Thermal Spray
Kevin Nelson, Blue Technik LLC

Measurement and Sensing Requirements for Improved Plasma Spray Process Capabilities
Dennis Radgowski, Cyber Materials LLC

Keep up with all the AWS events at FABTECH with the free mobile app installed on your smart phone, with maps, schedules, alerts, networking tools, and much more. Visit the Apple Store or Android Market on your mobile device. Search for “AWS Fabtech,” click, and install now!

www.aws.org/show
**AWS Professional Program**

Pick and choose between concurrent sessions on the latest in welding research and commercial developments. Pay by the day or register for the entire four-day program.

**Mon., Nov. 14**

**SESSION 1: International Trends in Welding Research**

Chair: Stephen Liu, Colorado School of Mines

State of the Welding Related Industries and Trends of Welding Research & Development in Singapore by Ang Chee Pheng, President of the Singapore Welding Society ................................................................. 8:00

International Topics in Welding Research ...................................................... 9:00

**SESSION 2: NSF I / UCRC Sponsored**

Chair: Stephen Liu, Colorado School of Mines

Separating the Good Welds from the Bad Welds by John P. H. Steele, Colorado School of Mines ................................................................. 2:00

Development of a High-Chromium Nickel-base Filler Metal with Improved Weldability for Nuclear Power Plant Construction and Repair Applications by Adam T. Hope, Eric Fusner and John C. Lippold, The Ohio State University, and Steve L. McCracken ...................................................... 2:30

Weldability of A356+0.5Cu and Its Nanocomposites by Dake Wang, Hongseok Choi, Xiaochun Li and Sindo Kou, University of Wisconsin .......................... 3:00

Welding of Stainless Steel-Effect of Sulfur on Weld Pool Phenomena by Sindo Kou, University of Wisconsin, C. Linnmanvechlo, King Mongkut’s University of Technology-Thonburi, and P.S. Wei ...................................................... 3:30

Newly Developed Low Transformation Temperature (LTT) Welding by Tariq Alghamdi and Stephen Liu, Colorado School of Mines ........................................ 4:00

Weld Solidification Behavior of Ni-base Superalloys for Use in Advanced Supercritical Cool-fried Power Plants by David Tung and John C. Lippold, The Ohio State University ...................................................... 4:30

**SESSION 3: Solid-State Processing**

Chair: Yoni Adonyi, LeTourneau University

Friction Stir Welding of ISO 3183 X80M Steel by Antonio J. Ramirez, Tahiana F. C. Hermenegildo and Tiago F. A. Santos, Brazilian Synchrotron Light Laboratory, and Conrado R. M. Afonso and Ricardo R. Marinho, CENPES-Petrobras ...................................................... 2:00

Adaptation of Al-to-Steel FRW-I to Thick Sections by Wendell L. Johnson and Jerry E. Gould, Edison Welding Institute ...................................................... 2:30

Solid-State Welding of High Performance Steels by Nathan Dix, Josh Hammond and Yoni Adonyi, LeTourneau University ...................................................... 3:00

Friction Stir Welding of Lean Duplex Stainless Steel by Tiago F. A. Santos, Marina Magnani and Antonio J. Ramirez, Brazilian Synchrotron Light Laboratory ...................................................... 3:30

Susceptibility of Carbon Steel Welds to Hydrogen Embrittlement by Wei Zhang, Zhili Feng, John Wang and Larry Anovitz, Oak Ridge National Laboratory ...................................................... 4:00

Mechanical and Microstructural Evaluation of Friction Stir Processed Diffusion Bonded Magnesium and Magnesium Metal Matrix Composites by Scott Gordon and Stephen Liu, Colorado School of Mines ...................................................... 4:30

**Tues., Nov. 15**

**SESSION 4: Shipbuilding**

Chair: Maria Posada, Naval Surface Warfare Center-Carderock Division

Fracture Toughness of Welded NUCu-140 by Brett Leister, John DuPont and Jeffrey Farren, Lehigh University ...................................................... 8:00

Microsampling of Friction Stir Welded Ti Alloys by Sal Nimer and Marc Zupan, UMBC-University of Maryland, and Jennifer Wolk, Naval Surface Warfare Center-Carderock Division ...................................................... 8:30

Automated Welding Technology for VCS Submarines by Nancy C. Porter and Steve Massey, Edison Welding Institute, and Ned Kaminski, General Dynamics Electric Boat ...................................................... 9:00

Ultrasonic Impact Treatment of Aluminum 5456 Plate and Welds by Kim N. Tran and Caroline Schack, Naval Surface Warfare Center Carderock Division, Lourdes Salamanca-Riba, University of Maryland – College Park, and Marc Zupan, University of Maryland – Baltimore County ...................................................... 9:30

Understanding the Effect of Tool Design in Friction Stir Welding of HSLA-85 Steels by David Lammlein and Maria Posada, Naval Surface Warfare Center – Carderock Division ...................................................... 10:00

Fusion Welding Repair of 5xxx Series Aluminum Friction Stir Welds by Maria Posada, Naval Surface Warfare Center – Carderock Division ...................................................... 10:30

Underwater Friction Stir Welding of HY80 Steel by Terry R. Mcnelley, Sarah K. Menon, Garth W. Young and William C. Stewart, Naval Postgraduate School, and Murray W. Mahoney, Consultant ...................................................... 11:00

Nondestructive Testing False Positives on Friction Stir Weld Applications by Bruce H. Halverson, Marinette Marine Corporation ...................................................... 11:30

**SESSION 5: Arc Welding Processes**

Chair: Daniel Hartman, Manufacturing Behavioral Science

Double Electrode GMAW with One Welding Power Supply by Jinsong Chen, Adaptive Intelligent Systems, and Yi Lu and YuMing Zhang, University of Kentucky ...................................................... 8:00

Submerged Arc Welding of High Strength Steel by Cold Wire Feed by Biswajyoti Basu, Naval Materials Research Laboratory, India, R. Rahul and E. Jeevasaran, National Institute of Technology, India, and S. Jerome and Arun Kumar Shah, Panipat Institute of Engineering Technology ...................................................... 8:30

Welding Arc Interruptions in Tandem Pulsed GMAW by Ruham Pablo Reis, Federal University of Rio Grande ...................................................... 9:00

Study of Silicate Islands in GMAW by Richard Derenlen, Stephen Liu, and Erik Lord, Colorado School of Mines ...................................................... 9:30

Full Penetration Welding Using Laser Enhanced GMAW by Yi Huang and YuMing Zhang, University of Kentucky ...................................................... 10:00

Submerged Arc Welding Line Pipe with Three Electrodes by Stephen Kenny, University of Alberta ...................................................... 10:30

Residual Stress Analysis in Machining of Duplex Welds by Carolina Payares-Aspino and Patricia Muñoz-Escalona, Universidad Simón Bolívar, and Anamélis Sanchez, Fundación Instituto de Ingeniería ...................................................... 11:00

Selection of Welding Consumables for Metal Arc Welding Under Oil (MAW-UO) by Hamad H. Almostanee, Stephen Liu, and David L. Olson, Colorado School of Mines ...................................................... 11:30

Droplet Heat Content in Nickle Sheeted WC-Cored GMAW Wires by Kevin Scott and Patricio Mendez, University of Alberta ...................................................... 12:00

**SESSION 6: NSF I / UCRC Sponsored**

Chair: John DuPont, Lehigh University

Corrosion Behavior of Nickel Based Alloy Coatings by Andrew W. Stockdale and John DuPont, Lehigh University ...................................................... 2:00

Thermal Stir Welding of Steel by Feng Pan and Sindo Kou, University of Wisconsin, and R.J. Ding, Marshall Space Flight Center ...................................................... 2:30

Preventing Dissimilar Metal Weld Failures by Gregory J. Brentrup, John DuPont, Brett M. Leister, Brett S. Snowden, and Joachim L. Grenestedt, Lehigh University ...................................................... 3:00

Hot Bending of Armor Alloys by Nicholas A Kullman and Boian T Alexandrov, The Ohio State University ...................................................... 3:30

Stress Rupture Evaluation of Steel Welding Consumables by Chai Xiao and Sindo Kou, University of Wisconsin ...................................................... 4:00

Laser Impact Welding by Huimin Wang, The Ohio State University ...................................................... 4:30

**SESSION 7: Weld Modeling**

Chair: Zhili Feng, Oak Ridge National Laboratory

Surface and Interface Phenomena in Thermoelectric Element Welding by Ihnham Glumac, Ben Sokolove, and Yoni Adonyi, LeTourneau University ...................................................... 2:00

A Computational Modeling Tool for Welding Repair of Irradiated Materials by Zhili Feng, Oak Ridge National Laboratory, and Eric Willis and Ken Wolfe, Electric Power Research Institute ...................................................... 2:30

3D Weld Pool Surface Characterization by XueWu Wang, YuMing Zhang and WeiJie Zhang, University of Kentucky ...................................................... 3:00

Modeling and Microstructure Evolution Analysis of Friction Stir Processing of Magnesium Alloy by Zhenchen Yu, Wei Zhang and Zhili Feng, Oak Ridge National Laboratory, and Hahn Choo, University of Tennessee ...................................................... 3:30

Examination of Cross Tension Test for DP Steels by Murali Tumuluru and David J. Radakovic, U.S. Steel ...................................................... 4:00

**Wed., Nov. 16**

**SESSION 8: Laser Materials Processing**

**Chair:** Tom Lienert, Los Alamos National Laboratory

- Characterization of a Materials Processing Laser by T.J. Lienert, J.O. Sutton, M.S. Pitch and P. Burgardt, Los Alamos National Laboratory...**8:00**
- Issues with Laser Welding Through a Fused Silica Window by T.J. Lienert, J.O. Sutton, M.S. Pitch, R.T. Forsyth and P.A. Papin, Los Alamos National Laboratory...**8:30**
- Reducing Alloying Element Vaporization from Stainless Steel Weld Pools Produced by Pulsed Laser Welding by T. DebRoy, Penn State University, and T.J. Lienert, Los Alamos National Laboratory...**9:00**
- Properties Variation in Stainless Steel Laser Welds by Charles V. Robino, Brad L. Boyce and Corbett C. Batallie, Sandia National Laboratories...**9:30**
- Modeling of Laser Spot Micro-Welding of Silicon by Ashwin Raghavan, Penn State University...**10:00**
- Scaling Thermocapillary Weld Pool Shape by Peng S. Wei, C.L. Lin and H.J. Liu, National Sun Yat-Sen University, and T. DebRoy, Penn State University...**10:30**
- Comparing Laser and Resistance Interconnection Welds by Gerald A. Knorovsky, Danny O. MacCallum and Louis A. Malizia Jr., Sandia National Laboratories...**11:00**

**SESSION 9: Filler Metals, Overlays and Repair**

**Chair:** Patricio Mendez, University of Alberta

- Welding Fume Study for Certain SMAW Electrodes Used in the Mining Industry by Kin-Ling Sham and Stephen Liu, Colorado School of Mines...**8:00**
- Analysis of Molten Surface End Face of Al-Mg Filler Metal Alloy and Mota, Marcus Vinicius Ribeiro Machado, and Louriel Oliveria Vilarinho, Wireless Embedded System for Signal Monitoring by Carolina Pimenta...**4:30**
- Modeling and Control of Droplet Development in Laser Enhanced GMAW by Yan Shao and YuMing Zhang, University of Kentucky...**4:30**
- Adaptive Fill Algorithm in Varying Weld Groove by Yong-Baek Kim, Jeon-Goo Kim, Hyeong-Soon Moon and Ji-On Kim, Hyundai Heavy Industries...**5:00**

**SESSION 11: Joining Metallurgy**

**Chair:** Suresh Babu, The Ohio State University

- Ultrasonic Soldering for Dissimilar Material Joining by Edward D. Herderick, Edison Welding Institute...**2:00**
- Au-Al Intermetallic Formation in a Resistance Weld by Donald F. Susan, Gerald A. Knorovsky and Paul T. Vianco, Sandia National Laboratories...**2:30**
- Constitution Diagram for Dissimilar Metal Welds by Elijah K. Gould, BP America, and John C. Lippold and Boian T. Alexandrov, The Ohio State University...**3:00**
- Weld Behavior of Ultra-High Strength Egin Steel by Daniel H. Bechetti Jr. and John N. DuPont, Lehigh University...**3:30**
- Advanced Brazing Technologies for Nuclear Fuel Cladding by Edward D. Herderick, Kirk Cooper and Nate Ames, Edison Welding Institute...**4:00**
- Microstructure of Alloy 825 Weld Overlay by Cleiton Carvalho Silva, Conrado R. M. Afonso, Hélio Cordeiro de Miranda and Jessualdo Pereira Farias, Federal University of Ceará, and Antonio J. Ramirez, Brazilian Synchrotron Light Laboratory...**4:30**
- Effect of Ti on Toughness of 700 MPa Weld Metal by Hee Jin Kim and Jun Seok Seo, Korea Institute of Industrial Technology, and Changhee Lee, Hanyang University...**5:00**

**Thurs., Nov. 17**

**SESSION 12: Materials Weldability**

**Chair:** Boian Alexandrov, The Ohio State University

- Application of Cold Cracking Tests for Determining the Preheating Temperature in High Strength Steels by Monzica Zalazar, Universidad Nacional del Comahue, and Eduardo Asta, ESAB Argentina...**8:00**
- Hydrogen Assisted Cracking in Dissimilar Metal Welds by Boian T. Alexandrov, Jeffrey M. Rodelas and John C. Lippold, The Ohio State University, and Shu Shi, Shell International Exploration and Production...**8:30**
- Impermeable Low Hydrogen Covered Electrodes by Alexandre Queiroz Bracarense, Claudio Turani, Ezequiel Calves Pereira Pessoa, and Ivanizte Felizardo, Federal University of Minas Gerais...**9:00**
- Characterization of Grade 91 Steels to Tempering by Daniel Saltzman, Boian T. Alexandrov and John C. Lippold, The Ohio State University...**9:30**
- Development of Welding Technology for Bicycle Frame by Mok-Yung Lee and Woong-Seong Chang, RIST, and Norman Zhou, University of Waterloo...**10:00**
- Effect of Oxide/Ferrite Phase on the Toughness of SDSS by Kim Dae Joo, Bae Sang Doek and Choi Jun Tae, Hyundai Heavy Industries...**10:30**

**SESSION 13: Industrial Technology**

**Chair:** Joe Scott, Devasco International

- Automated Narrow Gap GTAW by Barbara K. Henon, Arc Machines, and Jonathan T. Salikin, Arc Applications...**8:00**
- Green Stud Welding Technologies Save Energy and Labor by Chris Hsu, Naislon Stud Welding...**8:30**
- Welding 4130 Steels for Oilfield Equipment by Joe Scott, Devasco International, and David R. Benridge, CRA Technologies...**9:00**
- Arc Welding Ultra HSLA Steels by Joe Scott and Tomas Brashear, Devasco International...**9:30**
- Increase Joint Success with an Internal Groove by Larry Zinker, Marv Harker and Kyle Kofford, Idaho National Laboratory...**10:00**
- Product and Process Comparisons of Welding Fumes by Stanley E. Ferree and Frank Lake, ESAB...**10:30**
- Mechanization of Short Welds in Heavy Fabrications by Steve Massey and Nancy Porter, Edison Welding Institute...**11:00**
- Wrapped Textile Cord Process for Welding Wire Finish by Kai Boockmann, Michaela Boockmann and Gerhard Boockmann, Boockmann GmbH...**11:30**
Free AWS Events at FABTECH

**Professional Welders Open Competition**  
*Mon., Nov. 14 — Wed., Nov. 16*  
Watch contestants compete for hard cash and the title of best welder in America. Awards presented Thurs., Nov. 17 at 11 a.m.

**Free Seminar Sample Sessions**  
Attend a special one-hour portion of an AWS exam seminar.  
*Mon., Nov. 14*  
- Certified Welding Sales Rep .................................................. 1:00-2:00  
- Certified Welding Inspector .................................................. 2:00-3:00  
*Tues., Nov. 15*  
- Certified Welding Supervisor ............................................... 8:00-9:00  
- Certified Radiographic Interpreter ...................................... 9:00-10:00  

**IIW and 2012 Annual Assembly Session**  
*Mon., Nov. 14 • 11:30 - 1:00*  
Everything you wanted to know about the American Council of the International Institute of Welding (IIW) and the 2012 IIW Annual Assembly in Denver. Light lunch and refreshments will be provided.

**Thermal Spray Basics: Putting Coatings to Work**  
*Tues., Nov. 15 • 1:00 - 5:00*  
Presented by the International Thermal Spray Association (ITSA), this intro to the benefits of thermal spraying will cover processes, equipment, applications, and industry usage.

**Education Annual Program**  
Valuable free programs for educators and trainers are held every day of the show.

**Career Counselor & Welding Educator Workshop**  
*Mon., Nov. 14 • 10:30 — 5:00*  
Representatives from AWS, the welding industry and trade unions will make short presentations on career paths, scholarships and job outlook. A walking tour of exhibits on the show floor will highlight high-tech topics in welding related to the most rewarding career opportunities.

**Topics in Welding Education**  
*Mon., Nov. 14*  
- Using Practical Welding Metallurgy Object Lessons .............. 8:00-9:00  
- Common Errors in Applying AWS A2.4 Welding Symbols ........ 9:00-10:00  

**Lectures in Welding Education**  
*Tues., Nov. 15*  
- Plummer Memorial Award Lecture ...................................... 10:30-12:00  
- Adams Memorial Membership Award Lecture ....................... 1:30-2:30  
- Howard E. Adkins Memorial Instructor Membership Award Lecture .................................................. 2:30-3:30  
- Panel Discussion with Award Recipients .......................... 3:30-5:00  

**Educators’ Program**  
*Wed., Nov. 16*  
- Writing Engaging Lesson Plans Workshop ......................... 9:00-10:00  
- Complying with National and State Standards ..................... 11:00-12:00  
- E-learning on a Budget: Introducing Interactive Tools in the Classroom .................................................. 1:00-2:00  
- Recruiting Students into Welding Programs ....................... 2:00-3:00  
- Techniques for Developing Accurate and Fair Welding Assessments .................................................. 3:00-4:00  
- Developing a Welding Curriculum .................................. 4:00-5:00  

**Thurs., Nov. 17**  
- Project and Community Based Curriculum Design ............... 9:00-10:00  
- Structuring the Welding Shop Experience ......................... 10:00-11:00  
- Implementing the SENSE Program .................................. 11:00-12:00
AWS Conference on
What's New in Power Sources?

This one-day conference on welding power sources will feature industry experts presenting the latest developments in welding equipment and machinery, highlighting improved capabilities that lead to highly productive and efficient operation.

November 16, 2011 at FABTECH in Chicago

AWS Members: $345
Nonmembers: $480
Register at www.fabtechexpo.com

For the latest conference information, visit our website at www.aws.org/conferences or call 800-443-9353, ext. 264.
The American Welding Society and Weld-Ed will conduct a major roundtable on solutions to the problem of developing an adequate welding industry workforce. You are encouraged to attend.

The program will begin in the morning with a Facilitated Executive Dialogue that will focus on developing a set of recommendations for industry, education, and government to drive action to improve the development of the future workforce.

The following topics will be among those addressed during this session:

- Challenges faced by employers in recruiting, training, and retaining welders and other welding professionals
- Challenges faced by educators in recruiting, educating, and retaining students in welding-related programs
- Organizational impacts from new technologies, advancements in welding, and globalization
- Creative solutions and partnerships to educate and hire the right people

Continental breakfast and lunch will be served.

After lunch, a working session on Development of Solutions/Pilot Projects will include participants from the morning executive roundtable and audience. Participants will develop ideas and frameworks for pilot projects that address challenges heard in the morning dialogue. Participants are encouraged to offer ideas and suggestions, and to commit their organizations to participate in pilot projects.

A final report will be issued by the American Welding Society with recommendations for industry, education, and government. These recommendations will drive action and create a series of projects that address key challenges to recruiting, educating, and retaining a skilled welding industry workforce.

Reserve your place at this event by registering at www.aws.org/roundtable or calling (800) 443-9353 ext 212.

September 9, 2011
Crowne Plaza Chicago O’Hare Hotel
O’Hare International Airport, Chicago
9:00 am to 3:00 pm
13th AWS Leadership Symposium Presented in Miami

The 13th annual AWS Leadership Symposium was held Aug. 1-3 at AWS headquarters in Miami, Fla. Section leaders representing all 22 AWS Districts participated this year.

The purpose of the symposium is to develop leadership and communication skills to enhance each attendee’s effectiveness in the performance of their Section duties.

Listed here are the District number, attendee's name, and Section. 1) Jennifer Eastley, Green & White Mountains; 2) Herbert Browne, New Jersey; 3) Tracy Davenport, Reading; 4) Mark Gilbert, SW Virginia; and Robert Simpson, Charlotte; 5) Gilly Burrion, South Florida; 6) Harry E. Carlson, Niagara Frontier; 7) Bruce Scherer, Cincinnati; 8) David Carwyle, NE Mississippi; 9) Brenda Amos, Mobile; 10) Bob Brenner, Stark Central; and Mike Sherman, Cleveland; 11) Kristine Post, W. Michigan; and Tom Sparschu, Detroit; 12) Tony Stute, Madison-Beloit; 13) Mark Stevenson, J.A.K.; 14) John Durbin, Tri-River; and Mike Arand, Louisville; 15) Chris Hensiak, Northwest; 16) Mike Vincent and Dennis Wright, Kansas City; 17) Paul Witttenbach, Tulsa; 18) Misty Rails and John Rails, Corpus Christi; 19) Sjon Delmore, Olympic; 20) Paul Tremblay, Idaho/Montanta; 21) Robert Jozwiak, Arizona; and Dean Wilson, L.A./Inland Empire, the incoming AWS vice president; and 22) Jason Rafter, Sacramento.

The Leadership Symposium is conducted each year by Ron Gilbert, senior partner and principal management consultant for Gilbert Education & Management Systems, www.gilbertems.com, and a professor of management in the Chapman Graduate School of Business at Florida International University.

Assisting Dr. Gilbert again this year was Lee Kvidahl, an AWS past president, and manager of welding/manufacturing engineering at Huntington Ingalls Industries, Pascagoula, Miss. The participating AWS staff members included Cassie Burrell, deputy executive director; Rhenda Kenny, director, Member Services Dept.; and Alfred Nieves, coordinator, Member Services.

Notice of AWS Annual Meeting

The Annual Meeting of the members of the American Welding Society will be held Monday, Nov. 14, 2011, beginning at 9:00 AM at McCormick Place, Chicago, Ill. The regular business of the Society will be conducted, including election of officers and ten members of the Board of Directors. Any business properly brought before the membership will be considered.

Nominations Sought for AWS Officers

AWS members who wish to nominate candidates for President, Vice President, Treasurer, and Director-at-Large on the AWS Board of Directors for the term starting Jan. 1, 2013, may

1. Send their nominations by Oct. 4, 2011, to Gricelda Manalich, gricelda@aws.org, c/o John C. Bruskotter, chairman, National Nominating Committee, or
2. Present their nominations in person at the open session of the National Nominating Committee meeting scheduled for 2:00 to 3:00 PM, Tuesday, Nov. 15, 2011, at McCormick Place, Chicago, Ill., during the FABTECH show. Nominations must be accompanied by biographical material on the candidate, including a written statement by the candidate as to his or her willingness and ability to serve if nominated and elected, letters of support, plus a 5- x 7-in. color portrait. Note: Persons who present their nominations at the show must provide 20 copies of the biographical materials and written statement.
Errata AWS D17.1 and D17.2 Aerospace Welding Specifications


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

Page 9 — Figure 5.1, S.S. No. — Remove “S.S. No.” from the top of the suggested test record form.

Page 18 — Figure 5.7, Note — Correct “Suggested dimension” to “Where member differ in thickness more than 10% of the thicker member, the cap sheet shall be the thicker member”.

Page 18 — Figure 5.7, Footnote a — Correct “Where member differ in thickness more than 10% of the thicker member, the cap sheet shall be the thicker member” to “Suggested dimension”.

Page 22 — 5.4.2 Procedure Qualification, Numbering sequence — Correct “(8) filler metal used” to “(9) filler metal used”, “(9) joint design” to “(10) joint design”, “(10) electrical characteristics” to “(11) electrical characteristics”, “(11) preheat requirements” to “(12) preheat requirements”, “(12) postweld heat requirements” to “(13) postweld heat requirements”, and “(13) other variables required by the Engineering Authority” to “(14) other variables required by the Engineering Authority”.

Page 34 — Table 7.1, Mismatch Between Members after Welding — Correct “Refer to Paragraph 6.14.4 & Figure 6.2 Includes A, B & C Class of Welds” to “Refer to Paragraph 7.5.2.1 & Figure 7.2 Includes A, B & C Class of Welds”.

Page 36 — Figure 7.1, WIDTH OF WELD FACE OR INDIVIDUAL SURFACE BEAD, W — Correct “W > % in TO W < 1 in [25 mm]” to “W > % in [8 mm] TO W < 1 in [25 mm]”.

Page 36 — Figure 7.1, Footnote a — Correct “Refer to 4.3.8.2.” to “Refer to 5.3.8.2.”

Page 37 — Figure 7.2, Extra horizontal line within table — Remove horizontal line between “OFW, SMAW, GTAW, GMAW” and “PAW, VP.PAW, FCAW, SAW”.

Page 49 — Figure A.1(d), Missing horizontal line within table — Add horizontal line between “PAW” and “GMAW FCAW SAW”.

Page 58 — Table A.1, Comparable Filler Weld Size for Same Strength (in [mm]) — Correct “1.23 [21.2]” to “1.23 [31.2]”.

Page 65 — Table C.3, Missing line within table — Add vertical line between “T1” and “W”, “Max.” and “Min.”, and “6” and “7”.

Page 82 — G4.14 Welding and Weldments — Correct “6.2 dictates maximum mismatch at the completed weld joint.” to “Figure 7.2 dictates maximum mismatch at the completed weld joint.”.


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

Page 14, Figure 7, annulus width — Correct “0.15 Sn” to “0.15 Rm”.

Official Interpretation

D1.1, Structural Welding Code — Steel

Subject: Qualifying two welders on one joint for pipe
Code Provision: 4.30.3.1 and 4.19.1.1
AWS Log: D1.1-06-120

Inquiry: Based on 4.30.3.1, is it allowed to qualify two welders on the same joint, each of them welding half pipe circumference, from top center to bottom center (either uphill or downhill progression)?

Response: No.

ISO Standards for Welding

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. Copies of draft international standards are available for review and comment from your national standards body, which in the United States is ANSI, 25 W. 43rd St., 4th Fl., New York, NY 10036; (212) 642-4900. Send comments regarding ISO documents to your national standards body.

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.


Oct. 10–12, C3 Committee and Subcommittee on Brazing and Soldering. Providence, R.I. Call: S. Borrero, ext. 334.
Opportunities to Contribute to AWS Welding Standards and Codes

Volunteer to serve on an AWS technical committee to help develop the standards that serve industry’s ever-changing needs. Currently, more than 1800 volunteers participate on the 160 AWS technical committees and subcommittees.

Membership on AWS technical committees is open to everyone. Review the committee openings outlined here, then contact the committee secretary listed to learn more about the advantages and responsibilities for contributing to this important work. E-mail the committee secretary listed, or call (800/305) 443-9353 at the extension shown.

Local Heat Treating of Pipe Work

The D10P Subcommittee for Local Heat Treating of Pipe to revise D10.10, Recommended Practices for Local Heating of Welds in Piping and Tubing. Contact B. McGrath, bmcmgrath@aws.org; ext. 311.

Joining Wrought Nickel Alloys

The G2C Subcommittee on Nickel Alloys seeks volunteers to review G2.1M/G2.1. Guide for the Joining of Wrought Nickel-Based Alloys, and participate in the meetings and teleconferences. Contact Alex Diaz, adiaz@aws.org; ext. 304.

Oxyfuel Gas


Thermal Spray


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 Rakesh Gupta, rgupta@aws.org, ext. 301.

Surfacing Industrial Mill Rolls


Nominate Your Candidate for the M.I.T. Prof. Masubuchi Award

November 2, 2011, is the deadline for submitting nominations for the 2012 Prof. Koichi Masubuchi Award. It 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. Nominations should include the candidate’s experience, publications, honors, and awards, and at least three letters of recommendation from fellow researchers. E-mail your nomination package to Todd A. Palmer, assistant professor, The Pennsylvania State University, tap103@psu.edu. Sponsored by the Dept. of Ocean Engineering at Massachusetts Institute of Technology (M.I.T.), this award includes a $5000 honorarium.

District 17 Director Awards Presented

District 17 Director J. Jones has nominated the following to receive the District Director award:

IWTS Gas and Supply, Oklahoma City

IWTS Gas and Supply, Tulsia

Jarrod Lipsy, North Texas

Red Ball Oxygen, North Texas

Brent Evans, Praxair, Ozark Section

Paul Mueller Co., Ozark Section

Marcia Sommer, Ozark Section

Carr DuPuy, Central Texas Section

Arkansas Career Institute, Central Arkansas

Jimmy Brewer, Central Arkansas

Cary Reeves, Oklahoma City

Stacy Bell, Ryerson Steel, Inc., East Texas

The District Director Award provides a means for District directors to recognize those who have contributed their time and effort to the affairs of their local Section and/or District.

Member-Get-A-Member Campaign

Listed below are the members participating in the 2011–2012 AWS Member-Get-A-Member Campaign. Standings are as of July 18. For campaign rules and a prize list, see page 81 of this Welding Journal. For complete campaign rules, visit www.aws.org/mgm. Call the AWS Membership Department at (800/443-9353, ext. 480, with any questions about your member proposer status.

Winners’ Circle

Listed are the sponsors of 20 or more Individual Members/year, since June 1, 1999. The superscript denotes the number of years the member earned Winners’ Circle status.

E. Ezell, Mobile 8

J. Compton, San Fernando Valley 7

J. Merzthal, Peru 2

G. Taylor, Pascagoula 2

L. Taylor, Pascagoula 2

B. Chin, Auburn 1

S. Esders, Detroit 1

M. Haggard, Inland Empire 1

M. Karagoulis, Detroit 1

S. McGill, NE Tennessee 1

B. Mikeska, Houston 1

W. Shreve, Fox Valley 1

T. Weaver, Johnstown/Altoona 1

G. Woerner, Johnstown/Altoona 1

R. Wray, Nebraska 1

President’s Club

Sponsored 3–8 new members

G. Bish, Atlanta — 3

President’s Honor Roll

Sponsored 2 new members

G. Fehrmann, Philadelphia — 2

T. Palmer, Atlanta — 2

H. Suthar, Charlotte — 2

Student Sponsors

Sponsored 3+ Student Members

G. Bish, Atlanta — 50

R. Belluzzi, New York — 33

J. Bruskotter, New Orleans — 17

E. Norman, Ozark — 16

T. Palmer, Atlanta — 14

C. Kipp, Lehigh Valley — 9

J. Jones, Joplin — 6

R. Hutchinson, Long Beach/Oc. — 3

WELDING JOURNAL
South American International Agent Visits AWS Headquarters

Mauricio Ibarra, from Indura® in Chile, visited AWS July 15 to discuss the company’s educational and certification activities related primarily to the AWS Certified Welding Inspector (CWI) program. Shown with him are (from left) Priti Jain, director, AWS international business and certification programs; Cassie Burrell, AWS deputy executive director; and Melissa Gomez, AWS senior international certification coordinator. Indura® is an AWS International Agent operating in Chile, Argentina, Colombia, Ecuador, and Peru.

Mendoza Meets the National SkillsUSA Welding Champs

AWS President John Mendoza (far left) is shown with (from left) Joshua Ellrod, Brennen Clelland, and Jared Martinez. These students were the top three scorers in the SkillsUSA Welding Fabrication category at the 47th Annual National Leadership and Skills Conference held June 19–24 in Kansas City, Mo. They represented the Municipal Schools Career and Technical Education welding program, Farmington, N.Mex.

AWS Life Members Get Free FABTECH Professional Program

AWS Life Members get free admission to the upcoming FABTECH expo plus complimentary registration for the entire Professional Program — a $325 value. FABTECH is scheduled for Nov. 14–17, 2011, at McCormick Place in Chicago, Ill.

The free registration entitles Life Members to attend any of the technical sessions presented during the four-day period. Life Members are urged to take advantage of this valuable benefit. Registrations forms are available in issues of the Welding Journal, as well as in the Advance Program that was mailed to members previously. You may also request the form from the Membership Dept. at (800) 443-9353, ext. 260.

To obtain your free registration, mark “AWS Life Member: Free Registration” at the top of your Registration Form. Then FAX both sides of the form to (305) 443-7559, Attn: Ruben Lara, accounting director; or mail the form to Ruben Lara, AWS, 550 NW LeJeune Rd., Miami, FL 33126.
Aiken Technical College Student Chapter members are from left (front row) Ronald Simmons, Alvin Johnson, John Doucet, Patrick Jones, Candace Shepherd, Alexander Ware, Dorothy Williams, Shane Wood, Todd Blume, and Harry Lowe; (standing) Adam Callahan, Mary Boatwright, Ivan Panko, Eric Norton, Andrew Britton, Advisor Jean Palmer (middle), Josh Byers, Cecil Strawbridge, Charles Voldness, Shane Smith, Josh Macklin, Jory Wright, Tavares Green, Chris Fail, Robert Dibiase, and Christopher Downs.

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

District 2
Harland W. Thompson, director
(631) 546-2903
harland.w.thompson@us. ul.com

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

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

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

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

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

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

ATC Student Chapter
FEBRUARY–APRIL
Activity: Lead welding instructor and Chapter Advisor Jean Palmer, along with 32 members of the Aiken Technical College (ATC) Student Chapter designed and welded a large abstract-art Christmas tree for use as a stage prop for a production of the play “Rent,” presented at Aiken Community Playhouse in Aiken, S.C. The tree was constructed from myriad roadside collectibles including hub caps, springs, metal pots, a lamp, tableware, drill bits, and other debris. A motorcycle frame was used for the foundation. The project required three months and more than 45 hours of extracurricular work to complete. Very pleased with her students’ work, Palmer said the project enhanced their knowledge of welding and helped to develop their leadership and organizational skills.
John Bohr (left) receives his past chairman’s plaque from Donald Maatz Jr., incoming Detroit Section chair.

Shown at the Pittsburgh meeting are from left (front) John Menhart, Dave Daugherty, and Ray Knobbs; (back) Chair Brad King, Carl Spaeder, Carl Ott, and Tom White.

Benefactor Mike Albers is shown at the Northwest Section’s golf fund-raising event.

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

District 11
Robert P. Wilcox, director
(734) 721-8272
rmwilcox®wowway.com

DETROIT
JUNE 25
Activity: The Section hosted its annual spouses’ night program at Karl’s Cabin in Plymouth, Mich., to recognize their contributions to the Section’s activities. Outgoing Chair John Bohr received a plaque in recognition of his services from incoming Chair Donald Maatz Jr.

District 12
Daniel J. Roland, director
(715) 735-9341, ext. 6421
daniel.roland®us.fincantieri.com

District 13
W. Richard Polatin, director
(509) 694-5404
rpolatin®icc.edu

CHICAGO
MAY 31
Activity: Chair Craig Tichelaar conducted an executive board planning meeting at Bohemian Crystal Restaurant in Westmont, Ill. Participating were Marty Vondra, Eric Purkey, and Eric Krauss.

District 14
Robert L. Richwine, director
(765) 378-5378
bobrichwine®aol.com

LOUISVILLE
JANUARY
Activity: The Section members attended a demonstration of new gas metal arc welding technology presented by OTC representative Mel Clifford. Participating were Brandon Solter, Greg Smith, Denny Voyles, William Mastroser, James Shepard, Blake Miller, Cody Frank, Bobby Wimsatt, Jeremy Willis, John Livers, Joe Daughtery, Irv Zigler, and Ted Schalousky.

FEBRUARY
Activity: The Louisville Section members visited Welders Supply of Louisville for a plant tour and to study its gas-filling operations. Attending were Ron Richard, Mark Misback, Irv Zigler, Mike Arrand, Cody Frank, Tony Soboloski, Bud Merrill, Danny Duncan, Ben Coons, Joe Kent, and James Shepard.

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

NORTHWEST
JUNE 20
Activity: The Section hosted its annual golf outing at Sundance Golf and Bowl in Dayton, Minn. The event raised about $5000 for the Section’s scholarship fund. Mike Albers of Production Engineering Corp. donated $1000, as he has done for the past eleven years. Other donors and hole sponsors were District 15 Director Mace Harris, Mike Hanson, Todd Bridgum, Jay Gerdin, Menards, Inc.; Miller Electric; Minneapolis Oxygen; Minnesota Twins, Northland Fastening Systems; Oxygen Service Co.; Ridgewater Technical College; St. Paul Saints; South St. Paul Steel Supply; State Chemical Solutions; Weld Safe Midwest; Western Int’l Gas & Cylinders. Advantage Marketing, Arnold Machinery, Chart Industries, Dan Bradley LLC, and Golf Galaxy.
District 16
David Landon, director
(641) 621-7576
dandon@vermeermfg.com

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

District 17 Conference
June 10, 11
Activity: Leaders of the District 17 Sections met in Oklahoma City for the annual conference. Attending were District 17 Director J. Jones, Paul Wittenbach, Jerry Knapp, Bill Drake, Cary Reeves, Ed Norman, Dennis Pickering, and Bill Hall; (front row) Jim Bridwell, Dick Hoffman, Martica Ventura, District 17 Director J. Jones, Oren Reich, and Bryan Baker.

District 17 Conference
June 10, 11
Activity: Leaders of the District 17 Sections met in Oklahoma City for the annual conference. Attending were District 17 Director J. Jones, Paul Wittenbach, Jerry Knapp, Bill Drake, Cary Reeves, Ed Norman, Dennis Pickering, and Bill Hall; (front row) Jim Bridwell, Dick Hoffman, Martica Ventura, District 17 Director J. Jones, Oren Reich, and Bryan Baker.

OKLAHOMA CITY
May 2
Activity: The Section held its annual golf tournament at Cimarron National Golf Club in Guthrie, Okla. Taking first place was the team representing W&W Steel, including Casey Murphy, Ronald Murphy, Harold Murphy, and Donald Murphy.

First-place team members in the Oklahoma City Section golf outing are (from left) Casey Murphy, Ronald Murphy, Harold Murphy, and Donald Murphy.

Louisville Section members are shown during their February tour.
District 19

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

District 19 Conference
JUNE 4
Activity: Neil Shannon, District 19 director, held the meeting in Delta, BC, Canada. The British Columbia Section hosted the event. The AWS representative was Wendy Sue Reeve.

BRITISH COLUMBIA
JANUARY
Speaker: James Outerbridge, construction coordinator
Affiliation: PCL Constructors Westcoast, Inc.
Topic: Replacing the BC Place Stadium roof
Activity: The Section holds all of its business meetings at the Piping Industry Apprenticeship Board UA Piping Trades School in Delta, BC, Canada.

FEBRUARY 23
Speaker: Pam Ryan, communications counsel
Affiliation: Transportation Investment Corp.
Topic: The Port Mann Bridge project

APRIL 19
Speaker: Ken Mui, PE
Affiliation: Lincoln Electric Canada
Topic: Submerged arc welding

MAY 25
Speaker: Ken Mui, PE
Affiliation: Lincoln Electric Canada
Topic: Weld defects, prevention, and repair
Activity: At this British Columbia Section program, Steve Prost received an award for his services as chairman from Eric Waterfield, education committee chair.

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

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

ARIZONA
JUNE
Activity: The Section held its installation of officers. Outgoing Chair Aldo Perrazone introduced incoming Chair Rob Jozwiak.
WIN 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 2011-2012 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.

PRIZE CATEGORIES

- **Resident’s Honor Roll**: Recruit 2 new Individual Members and receive an AWS Sportpack bag.
- **Resident’s Club**: Recruit 3-8 new Individual Members and receive an AWS hat and an AWS Sportpack bag.
- **Resident’s Guild**: Recruit 20 or more new Individual Members and receive an AWS Messenger Bag, an AWS polo or Limited Edition T-shirt, a one-year free AWS Membership, the Neitzel Ritter Member Proposer Award Certificate and membership in the Winner’s Circle.

SPECIAL PRIZES

Participants will also be eligible to win prizes in specialized categories. Prizes will be awarded at the close of the campaign (June 2012).

- **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 2012 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 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 2011, as well as in February and June 2012.

- **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 2012 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.
AWS MEMBERSHIP APPLICATION

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

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

Last Name
First Name
Middle Initial
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 □

ADDRESS

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

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

☐ Who pays your dues? ☐ Company ☐ Self-paid ☐ Sex: ☐ Male ☐ Female ☐ Education level: ☐ High school diploma ☐ Associate's ☐ Bachelor's ☐ Master's ☐ Doctoral

PAYMENT INFORMATION (Required)

ONE-YEAR AWS INDIVIDUAL MEMBERSHIP __ $80
TWO-YEAR AWS INDIVIDUAL MEMBERSHIP __ $160 __ $135

New Member? ☐ Yes ___ ☐ No

If "YES," add one-time initiation fee of $12 ____________

International Members add $50 for optional hard copy of Welding Journal (note: digital delivery of WJ is standard) ____________ $50

Individual Members add $25 for book selection (up to a $192 value) ____________ $25

(Total: $250 up to $192 value)

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

TOTAL PAYMENT __ $160 __ $135

AWS STUDENT MEMBERSHIP __ $15

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

Domestic (Canada & Mexico incl.) ____________ $15
International ____________ $50

TOTAL PAYMENT __ $160 __ $135

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

☐ Check ☐ Money Order
☐ American Express ☐ Diners Club ☐ Carte Blanche ☐ MasterCard ☐ Visa ☐ Discover ☐ Other

Your Account Number __________________________ Expiration Date (mm/yy)

Signature of Applicant: __________________________ Application Date: ____________

Office Use Only

Check # ____________ Account # ____________

Source Code WJ

Learn more about each publication at www.awspubs.com

BOOK/CD-ROM SELECTION

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

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

ONLY ONE SELECTION PLEASE:
☐ Jefferson's Welding Encyclopedia (CD-ROM only)
☐ Design & Planning Manual for Cost-Effective Welding
☐ Welding Metallurgy
☐ Welding Handbook (9th Ed., Vol. 4)
☐ Welding Handbook (9th Ed., Vol. 3)
☐ Welding Handbook (9th Ed., Vol. 2)
☐ Welding Handbook (9th Ed., Vol. 1)

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

NEW MEMBER RENEWAL

A free local Section Membership is included with all AWS Memberships. Section Affiliation Preference (if known):

Type of Business (Check ONE only):
☐ Contract construction
☐ Chemicals & allied products
☐ Petroleum & coal industries
☐ Primary metal industries
☐ Fabricated metal products
☐ Machinery except elect. (incl. gas welding)
☐ Electrical equip., supplies, electrodes
☐ Transportation equip. — air, aerospace
☐ Transportation equip. — automotive
☐ Transportation equip. — boats, ships
☐ Transportation equip. — railroad
☐ Utilities
☐ Welding distributors & retail trade
☐ Misc. repair services (incl. welding shops)
☐ Educational Services (univ., libraries, schools)
☐ Engineering & architectural services (incl. assns.)
☐ Misc. business services (incl. commercial labs)
☐ Government (federal, state, local)
☐ Other

Job Classification (Check ONE only):
☐ President, owner, partner, officer
☐ Manager, director, superintendent (or assistant)
☐ Sales
☐ Purchasing
☐ Engineering — welding
☐ Engineering — design
☐ Engineering — manufacturing
☐ Engineer — other
☐ Architect designer
☐ Metallurgist
☐ Research & development
☐ Quality control
☐ Inspector, tester
☐ Supervisor, foreman
☐ Technician
☐ Welder, welding or cutting operator
☐ Consultant
☐ Educator
☐ Librarian
☐ Student
☐ Customer Service
☐ Other

Technical Interests (Check all that apply):
☐ Ferrous metals
☐ Nonferrous metals except aluminum
☐ Advanced materials/Intermetallics
☐ Ceramics
☐ High energy beam processes
☐ Arc welding
☐ Brazing and soldering
☐ Resistance welding
☐ Thermal spraying
☐ Cutting
☐ Safety and health
☐ Bending and shearing
☐ Roll forming
☐ Stamping and punching
☐ Aerospace
☐ Automotive
☐ Machinery
☐ Marine
☐ Pressure vessels and tanks
☐ Sheet metal
☐ Structures
☐ Other
☐ Automation
☐ Robotics
☐ Computerized Control of Welding

AMERICAN WELDING SOCIETY

550 N.W. LeJeune Rd
Miami, FL 33126
Telephone (800) 443-9353
Fax (305) 443-5647
Visit our website: www.aws.org

Member Services Revised 8/2/10
Incoming Arizona Section Chair Rob Jozwiak (left) is shown with Aldo Perrazone, past chair.

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

SACRAMENTO
May 18
Speaker: Greg Childs, inspector
Affiliation: Universal Technical Institute
Topic: I-Car welding qualification
Activity: A welding machine, donated by Praxair, was won by Don Black, director of UTI, presented by incoming Section Chair David Kilburn. The meeting was held at the Institute in Sacramento, Calif.

International Section

SAUDI ARABIA
Calendar
The 14th Middle East Corrosion Conference & Exhibition is scheduled for Feb. 12–15, 2012, at Gulf International Convention Center Gulf Hotel, Kingdom of Bahrain. Contact Dr. Moufaq Jafar, chairman, technical committee, moufaq.jafar@aramco.com; or visit www.mecconline.org.

Honorary Meritorious Awards
The deadline for nominating candidates for these awards is December 31 prior to the year of the awards presentations. Send candidate materials to Wendy Sue Reeve, wreeve@aws.org; 550 NW LeJeune Rd., Miami, FL 33126.

William Irgang Memorial Award
This award is given to the individual who has done the most over the past five years to enhance the Society’s goal of advancing the science and technology of welding. It includes a $2500 honorarium and a certificate.

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

George E. Willis Award
This award is given to an individual who promoted the advancement of welding internationally by fostering cooperative participation in technology transfer, standards rationalization, and promotion of industrial goodwill. It includes a $2500 honorarium.

Honorary Membership Award
This award acknowledges eminence in the welding profession, or one who is credited with exceptional accomplishments in the development of the welding art. Honorary Members have full rights of membership.

Int. Meritorious Certificate Award
This honor recognizes recipients’ significant contributions to the welding industry for service to the international welding community in the broadest terms. The award consists of a certificate and a one-year AWS membership.

Shown at the Sacramento Section meeting are incoming Chair David Kilburn (left) with Don Black.

Steve Prost (left) is shown with Eric Waterfield at the May British Columbia Section program.

James Outerbridge is shown with Pat Newhouse at the January British Columbia Section meeting.

Ken Mui addressed the British Columbia Section at the April and May technical programs.
Sustaining Members
Specialized Institute for Engineering Industries (SIEI)
Saudia/Hilla Hwy., Baghdad, Saudia 51066, Iraq
Representative: Abbas Hussein
www.sie.gov.iq (in English)
Specialized Institute for Engineering Industries has been established with the objective of serving engineering industries to improve their technological capabilities. The main objective is to assist by developing their industrial products through improving quality and quantity in helping companies solve their technical problems and stressing the importance of high quality with the goal of achieving ISO 9000.

Urschel Laboratories, Inc.
2503 Calumet Ave.
Valparaiso, IN 46384
Representative: Deborah Dean
www.urschel.com
Urschel Laboratories, Inc., is a leader in the design, manufacture, and marketing of precision food-cutting equipment. Its products include commercial potato chip slicers, cheese shredders, fruit dicers, French fries cutters, meat dicers, peanut butter mills, poultry dicers, lettuce shredders, vegetable cutters, and other types of food-processing machines.

Supporting Companies
LMW Engineering Group LLC
2539 Brunswick Ave.
Linden, NJ 07036

Midstate Manufacturing Corp.
750 W. Third St.
Galesburg, IL 61401

Educational Institutions
Arkansas State University-Beebe
Heber Springs and Searcy Campuses
1507 W. Center St.
Beebe, AR 72012

Central Nine Career Center
1999 U.S. 31 S.
Greenwood, IN 46143

Great Onyx Job Corps
3115 Ollie Ridge Rd.
Mammoth Cave, KY 42259

Ivy Tech Community College
4475 Central Ave.
Columbus, IN 47203

Kerala Institute of Welding & Research
Fact Training Centre Campus
Udyogamandal (PO) Ernakulam
Kochi, Kerala 68350, India

Lincoln College of Technology
2915 Allouette Dr.
Grand Prairie, TX 75052

Northern Westmoreland Career & Technology Center
705 Stevenson Blvd.
New Kensington, PA 15068

San Bernardino Valley College
701 S. Mount Vernon
San Bernardino, CA 92410

Texarkana Community College
2500 N. Robinson Rd.
Texarkana, TX 75599

Affiliate Companies
African Resources Pty Ltd.
11 Kabel Kring Alton, Kwa Zulu Natal
Richards Bay 3901, South Africa

Cincinnati Sub-Zero Products
12011 Mosteller Rd.
Cincinnati, OH 45241

Icon Lifting & Rigging Inspections
Km 3 Nta/Choba Rd., PO Box 5415
Trans Amadi Industrial Layout
Port Harcourt Rivers 234, Nigeria

Kapa-Taf Avete
5th Km Arta-Gavria
Arta Arta 47100, Greece

Kelley Iron Works
410 Hwy., 150
Chehalis, WA 98816

Magnum Piering
6082 Schumacher Park Dr.
West Chester, OH 45069

Saiful/Bouquet, Inc.
385 E. Colorado Blvd. #200
Pasadena, CA 91101

Sunland Welding, Inc.
3311 E. Horse Mesa Trail
San Tan Valley, AZ 85140

Tron Mechanical, Inc.
331 W. 2nd St., PO Box 691
Mt. Vernon, IN 47620

Welding Distributor
Automatizacion de Procesos y Robotica
Industrial S.A. de C.V.
Cofre de Perote No. 27
Puebla Puebla 72210, Mexico

AWS Member Counts
August 1, 2011

Grades
Sustaining..............................514
Supporting.............................305
Educational............................569
Affiliate................................459
Welding Distributor...................51
Total Corporate.......................1,898
Individual..............................57,149
Student + Transitional..............10,795
Total Members.......................67,944

Overview of AWS Member Benefits

Individual Member
Subscription to the Welding Journal plus members-only discounts on FedEx shipping, Liberty Mutual auto and home insurance, health insurance plans, auto rentals, T-Mobile services, credit cards, and major discounts on certifications, education, technical publications, and AWS products.

Supporting Company Member
Includes five Individual memberships, the engraved Supporting Company Member plaque, a listing on the AWS Web site, major members-only discounts.

Educational Institution Member
Includes three Individual memberships, engraved plaque, institution name listed on the AWS Web site with option to add a hyperlink to your Web site.

Affiliate Company Member
Includes one Individual membership, Affiliate Company Member certificate, your company name listed on AWS Web site, three Everyday Pocket Handbooks, storefront window decal.

Welding Distributor Member
Includes five Individual memberships, free listing on Distributor Locator Map (interactive map on AWS Web site that allows end-users to find your locations quickly), Distributor Company Member plaque, and options for adding a hyperlink to your Web site.

Visit www.aws.org/membership or call (800/305 443-9353, ext. 480, for complete information about AWS memberships.
Guide to AWS Services
550 NW LeJeune Rd., Miami, FL 33126; (800/305) 443-9353; FAX (305) 443-7559; www.aws.org
Staff extensions are shown in parentheses.
Quick-Change Plugs Pictured in Catalog

The company’s 231-page 2011-2012 Product Catalog illustrates and describes the Decontactor series switch rated plugs and receptacles that permit quick change-out of welding machines, motors, and other electrical equipment. The integral switching capability ensures that the contacts are always deenergized before the plug can be withdrawn from the receptacle. The NEC-approved parts are UL-approved for both branch circuit and motor circuit disconnect switching up to 200 A or 60 hp, and rated to withstand short circuits up to 100 kA. New plugs and receptacles for direct current applications are included. Visit the Web site to view the catalog or download the PDF version.

Meltric Corporation®
www.meltric.com
(800) 443-7642

5-Star Service™ Center Detailed in Brochure

A full-color, four-page brochure offers an overview of the company’s 5-Star Service Center to support the company’s vibratory feeders, drum magnet separators, X-ray inspection equipment, eddy current separators, wet drum separators, and suspended electromagnets. The services are intended to reduce equipment downtime — continued on page 88
To keep pace with the evolving needs of welders, the American Welding Society (AWS) has created a Membership exclusively for welders...

the AWS Welder Membership.

Welders who are committed to making their jobs, as well as their lives easier, are candidates for the AWS Welder Membership.

The AWS Welder Membership will allow you to save on welding equipment that you use every day, give you direct access to a health insurance program that fits your needs, provide you with the latest information in the industry and much more.

You’ll connect with the materials joining community through educational seminars, informal get-togethers and special events. You’ll be tuned into the latest happenings and trends. You’ll get the discounts and benefits that you’ve been looking for.

- Discounts on welding equipment and tools of the trade offered by participating GAWDA distributors
- Health Insurance Program
- Publications exclusively for welders
- Discounts on auto and home insurance
- Discounts on dental, vision and pharmacy programs
- The Welder’s Exchange bulletin board on the AWS web site
- and more...

Membership in AWS is a great way to nurture your professional development. Whether you’re just starting out or a veteran welder, you’ll benefit from becoming a member. Join today!

Call: (800) 443-9353, ext 480, or (305) 443-9353, ext. 480
Visit: www.aws.org/membership

American Welding Society
Text Covers Friction Stir Welding and Processing

The book *Friction Stir Welding and Processing VI* covers all aspects of the topic. It includes 27 papers written by leaders in the field. A few of the topics include aluminum and magnesium alloys, novel techniques for corner joints using friction stir welding (FSW), FS processing as a base metal preparation technique, methods to control FSW power with spindle speed changes, FS spot welding, etc. The book, published by John Wiley and Sons Ltd., lists for about $162. For a complete listing of contents, visit the Web site and enter Friction Stir in the search window.

Research and Markets
www.researchandmarkets.com
(513) 754-2000

Do It with Copper Videos Expanded on Web Site

The popular how-to video series has been expanded with a second installment of do-it-yourself architectural and plumbing how-to videos. The 14 videos, about five min and shorter in length, are designed to illustrate exactly how one can use copper in plumbing, architecture, and building and construction projects. Detailed are building techniques such as vertical lap seams, flat seams, and standing seams for architectural copper systems, and bending and flaring, structural adhesives, and a continuation of brazing techniques used in plumbing applications. Each video explains which tools are needed for the application while giving a step-by-step tutorial that is easy to understand for anyone from the average do-it-yourselfer to the seasoned professional. The series is available for free download from the Web site shown and are also featured on the association’s YouTube channel.

Copper Development Assn.
www.copper.org/applications/doityourself/homepage.html
(212) 251-7200
Join us for the
2012 RWMA & WEMCO
Colocated Annual Meeting

Learn insider secrets on
Social Media:
How We Connect and Market Our Businesses

Featuring industry experts
including renowned economist
Alan Beaulieu
Institute for Trend Research (ITR)

February 23-25, 2012
Miramonte Resort & Spa
Indian Wells (Palm Springs), California

For more information, please contact:
Susan Hopkins
at susan@aws.org or
800-443-9353, ext. 295

Natalie Tapley
at tapley@aws.org or
800-443-9353, ext. 444
Increased Productivity
Smart Work Handling
Means Increased Productivity

---

**Model 200 Positioner**
3 models available:
- 100 pound, 200 pound and
- 500 pound capacity.

**Model 1200 Pipemate**
Rotates pipe and tube from 1 1/4" to 17" diameter, up to 1200 pounds.

---

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


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

**CWI/CWE Course and Exam.** Troy, Ohio. A two-week preparation and exam program. Hobart Institute of Welding Technology; (800) 332-9448; www.welding.org.

**CWI/CWE Prep Course and Exam and NDT Inspector Training.** Courses. An AWS Accredited Testing Facility. Courses held year-round in Allentown, Pa., and at customers' facilities. Welder Training & Testing Institute; (800) 223-9884; customers' facilities. Welder Training & Testing Institute; (800) 223-9884; info@wtti.edu; www.wtti.edu.

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

---

**Consumables: Care and Optimization.** Free online e-courses on the basics of plasma consumables for plasma operators, sales, and service personnel; www.hyperthermcuttinginstitute.com.

**Crane and Hoist Training for Operators.** Konecranes Training Institute, Springfield, Ohio; www.konecranesamericas.com; (614) 739-8950; FAX (860) 739-6732.


**EPRI NDE Training Seminars.** Training in visual and ultrasonic examination and ASME Section XI. Sherryl Stogner (704) 547-6174; sstogner@epri.com.

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

**Fabricators and Manufacturers Assn. and Tube and Pipe Assn. Courses.** (815) 399-8775; visit www.finanet.org.

**Gas Detection Made Easy Courses.** Online and classroom courses for managing a gas monitoring program from gas detection to confined-space safety. Industrial Scientific Corp.; (800) 338-3287; www.indsci.com.

**Hellier NDT Courses.** Hellier, 277 W. Main St., Ste. 2, Niantic, CT 06357; (860) 739-8950; FAX (860) 739-6732.

**Inspection Courses on ultrasonic, eddy current, radiography, dye penetrant, magnetic particle, and visual at Levels 1-3. Meet SNT-TC-1A and NAS-410 requirements. TEST NDT, LLC; (714) 255-1500; www.testndt.com.

**INTEG Courses.** Courses in NDT disciplines to meet certifications to Canadian General Standards Board or Canadian Nuclear Safety Commission. The Canadian Welding Bureau; (800) 844-6790; www.cwbgroup.org.


---

For info go to www.aws.org/ad-index
Get the information you need quicker than ever before. The AWS Welding Buyers Guide allows online searchers to easily locate products and services unique to the welding industry, without the clutter of a general Internet search engine. Save valuable time, visit awsweldingbuyersguide.com!

**BENEFITS FOR CONSUMERS:** When leaders in the industry are looking for products and services, they turn to awsweldingbuyersguide.com to quickly get to the right source. Users can easily locate products and services unique to our industry with keyword-driven or category-specific searches. The AWS Welding Buyers Guide gives welding professionals a faster and easier way to find great vendors.

**BENEFITS FOR COMPANIES:** Purchasing a listing in the AWS Welding Buyers Guide will ensure that your company’s brand and message are easily accessible to the buyers who matter most to you. The AWS Guide includes Request for Information (RFI) functionality. This feature allows users to contact participating suppliers with a click of their mouse. Additionally, the guide includes a product showcase that allows you to highlight specific products and special offers on the front page of the guide. Visit the site to post your listing today!
Lincoln Elects COO

Lincoln Electric Holdings, Inc., Cleveland, Ohio, has elected Christopher L. Mapes COO of the company, effective Sept. 1. Mapes most recently served as executive vice president of A. O. Smith Corp. and president of its Electrical Products unit since 2004.

Joining Technologies Taps Engineering Manager

Joining Technologies, Inc., East Granby, Conn., a provider of precision fusion processes and weld system design, has promoted Salay Stannard to materials engineering manager. Stannard previously worked on laser applications at the Connecticut Center for Advanced Technology.

Intelligrated® Names VPs

Intelligrated®, Cincinnati, Ohio, a provider of automated material-handling equipment, has named Chuck Harris vice president, Midwest operations distribution and fulfillment; and appointed Chris Arnold vice president, operations and solutions development. Harris previously served the company in operations management and sales management roles for its Midwest operations. Arnold has more than 20 years’ experience in warehousing, distribution, fulfillment, logistics, and general management with high-volume retail and e-commerce companies.

ILMO Makes Staff Changes

ILMO Products Co., Jacksonville, Ill., has named Doug Gandy program manager for the newly formed ILMO Propane, Jayna Hunt appointed purchasing and inventory control manager for ILMO Prod-

— continued on page 94
The AWS Foundation is pleased to announce recipients of the 2011 workforce development grants.

The Foundation is awarding a total of $79,704 to five projects. Many applications were received, and five outstanding projects were chosen to receive funding. We will recognize one recipient each month in upcoming issues of the Journal. These awards are made possible by the Miller Electric Mfg. Company, Hobart Brothers Company, Hobart Institute of Welding Technology, OKI Bering, and Bohler Thyssen Welding USA.

We would like to recognize

Regional Technical Education Center and Kolberg-Pioneer, Inc. Yankton, South Dakota.

Representatives from the Regional Technical Education Center (RTEC) and Kolberg-Pioneer, Inc. (KPI), both located in Yankton, SD, recently celebrated the announcement that their joint application had been chosen to receive a $12,850 Workforce Development Grant from the American Welding Society Foundation. The grant will allow RTEC and KPI to work together and select several individuals to participate in a special business-industry training partnership over the course of the next year. The end goal is for individuals to successfully complete the training at RTEC, become AWS certified and ultimately become employed at KPI.

Pictured, from left, are: Josh Svatos, RTEC General Manager and Vice Chairman of the AWS Siouxland Section; Nick Morrison, AWS Siouxland Section member; Kelly Kleinwolterink, Chairman of the AWS Siouxland Section; Bob Olson, CWI/CWE and long-time AWS Siouxland Section member; Mark Luchtel, Kolberg-Pioneer Manufacturing Manager; and Rhonda Kocer, Kolberg-Pioneer Human Resources Manager.
and Josh Crews has been promoted to analytical lab technician for ILMO Specialty Gases. Gandy previously served FerrellGas for 13 years in sales and management. Hunt, with 18 years in the purchasing and materials management sector, previously worked for Panduit and The Pampered Chef. Crews, with the company for five years, formerly served as a purchasing assistant.

**Weld Tooling Staffs Its Subsidiary Weld.com**

Weld Tooling Corp., Canonsburg, Pa., parent company of Bug-O Systems, has named Norm Sted sales and marketing director and Todd Clouser marketing and social media specialist for its subsidiary Weld.com. Sted has more than 30 years of welding and business experience as a regional manager for a manufacturer of arc welding products with international markets in the Caribbean and Latin America. Clouser has experience in social media and emerging marketing technologies.

**Eriez® Consolidates Its North American Sales Team**

Eriez®, Erie, Pa., a provider of inspection systems, magnets, flotation columns, and sorters, recently combined its Canadian and United States sales organizations into a consolidated North American sales team. Dave Heubel was promoted to the newly created position of director — North American sales; Darrell Milton was promoted to market manager — metals recycling; and Dan Zimmerman, director of business development, will now manage all company sales efforts for the metalworking market in the United States and Canada. Previously, Heubel served as national sales manager, Milton was Canadian sales manager, and Zimmerman was responsible for only United States sales.

**Worthington Cylinders Appoints President**

Worthington Industries, Inc., Columbus, Ohio, has named Andrew Billman president, succeeding Harry Goussetis who retired in July. Billman has served the company in various positions for more than 15 years, most recently as vice president of corporate purchasing. The company is a provider of pressure cylinders, hand-held torches, industrial tanks, and steel pallets and racks.

**DE-STA-CO Appoints President**

DE-STA-CO, Auburn Hills, Mich., a supplier of robotic tooling, work-holding, and flexible industrial automation solutions, has appointed John Podczerwinski president. For more than three years, Podczerwinski has led VSG, North and South Americas, a Dover Company, as vice president and general manager.

**S&S Cycle Names President**

S&S Cycle, Inc., Viola, Wis., a manufacturer of performance engines and replacement parts for v-twin motorcycles, has named Stephen K. Iggens president. Since 2008, the duties of president were handled by George B. Smith, executive chairman and CEO. Smith will continue as CEO and chairman of the board of directors. Iggens returns to the company where he served from 2003 to 2006 as executive controller, director of finance/CFO, and CFO/vice president of finance.

**An Important Event on Its Way?**

Send information on upcoming events to the Welding Journal Dept., 550 NW LeJeune Rd., Miami, FL 33126. Items can also be sent via FAX to (305) 443-7404 or by e-mail to woodward@aws.org.
World Class Benefits for Your World Class Members

NEW FOR 2011
World Class Benefits has five new enhancements to your association’s member benefits program. Here is a brief summary of each plan:

### CoreHealth Insurance
- Guaranteed-acceptance, individual and family health insurance plans
- No medical questions or exams required
- Low-cost, affordable rates – Plans start at just $92 per month
- Freedom to choose any doctor or hospital
- Next day coverage available
- Benefits include: doctor office visits, routine checkups, hospital and emergency room benefits, surgery, anesthesia, accident medical benefits, prescription drug discount card and more!

### BioIQ Home Diagnostic Tests
- At home testing for cholesterol, triglycerides, and diabetes
  - Members Receive an 18% Discount & One Year of Free Health Coaching
- Save hundreds versus the cost of doctor visits for lab test orders and expensive lab and testing fees

### Term Life Insurance – Up to $500,000 – Quote and Apply Online
- Convenient, low-cost term life insurance – highest face amounts of its type
- No medical exams, no blood tests – just a comprehensive online health assessment
- Most policies issued in days, not weeks or months like traditional plans

### HR Mentor – On Demand Human Resource Services for Small Businesses
- Free Initial 20-minute consultation for members
- Company Handbooks, Compliance, Training, Wage Systems, Audit, Professional Job Descriptions, Employee Feedback, Hiring Assistance, COBRA assistance and more

### Discounted Disability Income Insurance
- Members can now protect their most valuable asset…their ability to go to work and earn a living
- Discounted rates for members from a 100-year old company
- Additional discounts for non-smokers
- Business class upgrade discount for experienced welding professionals
- Insurance that works for you when you can’t work due to an illness or an injury

For More Information Call 800-955-0418 or e-mail info@wwins.com
North American Robot Orders Jump 41% in First Half of 2011

The North American robotics industry jumped 41% in the first half of 2011, according to new statistics released by Robotic Industries Association (RIA), Ann Arbor, Mich.

A total of 8879 robots valued at $577.8 million were ordered by North American companies in the first six months of the year. When orders from outside North America are added, the totals are 10,476 robots valued at $667.9 million.

“This was the best first half for our industry since 2007,” said Jeff Burnstein, president of RIA.

The second quarter was strong, posting gains of 50% in units and 55% in dollars over the same period in 2010. Burnstein attributed the majority of growth to increased orders from automotive manufacturers and their suppliers. Nonautomotive orders increased 23% through June, led by gains in metalworking.

ITW Acquires Despatch Industries

Illinois Tool Works, Inc. (ITW), Glenview, Ill., has acquired Despatch Industries, Lakeville, Minn., a provider of thermal processing equipment for the solar, carbon fiber, and other thermal technology markets. Terms of the transaction were not disclosed.

With full-year 2011 revenues expected to exceed $200 million, Despatch Industries products include solar cell firing furnaces, carbon fiber process ovens, and thermal processing equipment. Its furnaces and industrial ovens primarily serve users in the solar energy, advanced materials, and electronics industries.

The Ohio State University Receives $400,000 Grant from Alcoa Foundation

The Alcoa Foundation recently awarded a $400,000 grant to The Ohio State University's Institute for Materials Research in support of design and manufacturing technologies that will enable the creation of lighter, more environmentally friendly vehicle structures.

The grant is part of Alcoa Foundation’s $4 million “Advancing Sustainability Research: Innovative Partnerships for Actionable Solutions” initiative.

Ohio State’s Institute for Materials Research will receive a $400,000 grant from the Alcoa Foundation in support of technologies to permit lighter, more environmentally friendly vehicle structures. Pictured (from left) are Leo Rusli, Nolan Windholtz, Anthony Luscher, Steven Woodward, John Defouw, and Glenn Daehn. (Photo courtesy of Jane Carroll.)

Professor Glenn S. Daehn of Ohio State’s Department of Materials Science and Engineering will serve as project lead, with Prof. Anthony Luscher in the Department of Mechanical and Aerospace Engineering serving as coinvestigator.

“There is a growing recognition that the lightest weight and most affordable vehicles in the future will not be made from one material, but many different ones,” said Daehn. “Alcoa Foundation is providing us with support for this important research and giving students the opportunity to experience first-hand the challenges and triumphs of materials development in a real-world environment.”

The Institute for Materials Research, working closely with Daehn and Luscher, will help engender this industry-wide change by educating engineers in training and practicing engineers on a holistic approach to multimaterials structural joining.

Dr. Leo Rusli, a research scientist in mechanical and aerospace engineering at Ohio State, recently advised a team of undergraduate students who tested the multimaterial concept.

“We utilized a tie rod made from aluminum tube with steel end pieces for the Baja SAE off-road competition in Kansas and Illinois,” said Rusli. “The course is designed to fail the vehicles, but the tie rods held through the course and the electromagnetically formed joints did not experience failure. The new design results in a weight saving of over 55%.”

Industry Notes

• Aargas, Inc., extended its commitment to Operation Homefront, a charity that supports America’s service members, by presenting a donation of $100,000 at company headquarters in Radnor, Pa., marking its fourth annual contribution.

• ACE Production Technologies delivered and installed a second KISS-104 in-line selective soldering system at the Pruszków facility of Kongsberg Automotive, Poland.

• Verify, Inc., Irvine, Calif., a provider of supply chain management and technical support services, expanded its capability to provide American Welding Society (AWS) Certified Welding Inspector support on critical supplier audit initiatives. Also, AWS awarded the Certified Welding Fabricator designation to crane manufacturer SPANCO, Inc., Morgantown, Pa., and Rigid Lifelines, the company’s fall protection division.

• The pressure cylinders segment of Worthington Industries, Inc., Columbus, Ohio, purchased the BernzOmatic business from Irwin Industrial Tool Co.

• A new technical studies degree will be offered at Salina Area Technical College, Salina, Kans., starting this fall. Additionally, Davidson County Community College is offering three programs this fall, including shielded metal arc welding, that will be available in the evening on the Davidson Campus, Thomasville, N.C.

• Cooper Crouse-Hinds, Syracuse, N.Y., a provider of electrical and instrumentation products, opened a new manufacturing facility to support its Pauluhn line of products.

• The Airco Distributor Association, a large buying group in the U.S. industrial gases industry, is changing its name to reflect its relationship with Linde North America, Murray Hill, N.J., and is now the LDA, Linde Distributor Association.

• During the ABB Robotics Partner Seminar in Sweden, AWL-Techniek received the award for best achievement in long-term partnerships and business development in welding solutions.
**Senior Technical Director**

Select-Arc, Inc., the manufacturer which sets The Standard of Excellence in Tubular Welding Electrodes, is currently seeking a Senior Technical Director for our headquarters in Fort Loramie, OH.

**Job Scope:**

The Senior Technical Director manages the technical aspects of product development, product quality and maintenance of the product line. This person also interfaces with sales, applications engineering, production and marketing to provide the customer with the products and performance required.

**Job Responsibilities:**

- Supervise and direct Development Engineers in the development of new products and in the maintenance of existing products. The Senior Technical Director formulates new products and maintains existing products as needed.
- Reduce product cost through innovative product design and evaluation of raw materials.
- Interact with customers to determine product needs and answer technical questions.
- Provide data sheets and technical literature as needed by sales and marketing.
- Maintain MSDSs for all products. Keep up to date on health and safety issues and regulations.
- Ensure that agency approvals (CWB, ABS, etc.) are performed and maintained on a timely basis.
- Participate on those AWS committees whose activities affect our product line.
- Maintain all aspects of the Quality System, including supervision of the Quality Manager.

**Education and Experience:**

Bachelor of Science in Metallurgy or Materials Science required. Degrees in other related fields with a background in materials will be considered. Experience should include a background in welding. Formulation experience and knowledge of slag systems is a plus. The position offers a comprehensive benefits package and a competitive salary.

Please e-mail, fax or mail your résumé to:
Dale Stager, Select-Arc, Inc., P.O. Box 259, Fort Loramie, OH 45845.
Fax: (888) 511-5217.
E-mail: dstager@select-arc.com.
No phone calls, please. Select-Arc, Inc., is an equal opportunity employer.

---

**Machine & Welding Supply Company**

is seeking a Welding Equipment Repair Technician to join a family business (since 1925) in North Carolina. Experience is preferred, good electrical/electronics knowledge, experience with welding helpful. Good pay and benefits.

Contact: (800) 571-1583 x 6110 or jobs@mwsc.com

---

**Top Notch Marketing Director/Manager Available**

B2B marketing director looking for employment or contract work. Experienced in manufacturing and related fields, including senior level welding, occupational health and safety and commercial and residential building. Managed all marketing duties for two division manufacturers, including detailed planning through strategy and creative development and implementation. Expertise in corporate and brand identity, advertising, print, packaging, displays, trade shows and websites.

Contact tbarr5@comcast.net or call 847.414.7553 direct.

---

**经济发展**

- 2011 FABTECH 2011 Show Preview Oct. 6
- Welding for High-Tech Applications Nov. 3
- Weld Inspection Nov. 1
- Bonus: The American Welder
- Business Forecast for 2012 Nov. 1
- The Latest Thermal Spraying Technology

**Contact Frank Wilson,**
Senior Advertising Production Manager
(800) 443-9353, ext. 465
fwilson@aws.org

---

**Reserve Ad Space Today and Grow!**

Call Rob Saltzstein at 800-443-9353 Ext. 243 or Lea Garrigan at Ext. 220 for more information. E-mail us at salty@aws.org or garrigan@aws.org, or fax to 305-443-7559 for us to contact you.
Development Engineer

Select-Arc, Inc., is seeking a Development Engineer to work at its Fort Loramie, Ohio, facility. The primary job responsibility entails developing new products for the welding of carbon and low-alloy steels, stainless steels, nickel alloys, and for hard-surfacing. Candidates should have a Bachelor of Science degree in Metallurgy or Materials Science. Degrees in other related fields with a background in materials will be considered. Welding experience is a plus.

Job responsibilities include:

- Formulating new products as required.
- Maintaining and upgrading current products.
- Reducing product cost through innovative product design and evaluation of new raw materials.
- Developing technical data on new products.

Competitive salary and a comprehensive benefits package are offered. E-mail, fax or mail résumé to Dale Stager at Select-Arc, Inc., 600 Enterprise Dr., PO Box 259, Fort Loramie, OH 45845.
Fax: (888) 511-5217
E-mail: dstager@select-arc.com. No phone calls, please.

AWS, Weld-Ed Web Site Promotes Welding Careers

The American Welding Society (AWS) and National Center for Welding Education & Training (Weld-Ed) Web site at www.CareersInWelding.com offers the following details: people and companies in the welding industry; fun facts; salary information; industry news; videos; articles; and upcoming training opportunities, seminars, and events.

Additionally, the site features pages geared directly for students with scholarship information and a welding school locator; for welding professionals to build a résumé, find welding-related jobs, and learn about AWS certifications; and for educators to discover tips for teachers and guidance counselors, information about curriculum, professional development, and other resources.

This Web site serves a valuable tool for students, parents, educators, counselors, and welding professionals. It also allows visitors to send questions, comments, or ideas for people profiles.

Purge Dams & Flow Meters
Oxygen Analyzers for Pipe Welding
www.OrbitalWelding.com
(408) 773-0231

SERVICES

AISC Training
QA/QC Inspection Services
Weld Inspection Training
Skidmore Training

312-861-3000 | info@atena.com
www.atena.com

WORLDSPEC ONLINE NDT & CWI TRAINING PROGRAM

The world’s first and only completely online NDT & CWI training program!
NDT Training to meet global standards including SNT-TC-1A, ISO 9712, etc.
Visit www.worldspec.org today and save $100 instantly by entering the discount code: aws59c2
Call toll free: 1-877-506-7773
MITROWSKI RENTS
Made in U.S.A.
Welding Positioners
1-Ton thru 60-Ton
Tank Turning Rolls
Used Equipment for Sale
www.mitrowskiwelding.com
sales@mitrowskiwelding.com
(800) 218-9620
(713) 943-8032

MARKING PEN DEPOT
Paint markers for professionals
ArroMark, Artline, Dixon, Dykem, Markal, Posca, Sakura, Sharpie, SKM, UniPaint.
The world's best selection of markers!
Order Online at markingpendepot.com or call 866-396-8848

JOE FULLER LLC
We manufacture tank turning rolls
3-ton through 120-ton rolls
www.joefuller.com
email: joe@joefuller.com
Phone: (979) 277-8343
Fax: (281) 290-6184
Our products are made in the USA

VERSATIG™
MULTIPLE TIG TORCH SELECTORS
www.versatig.com

WELDING JOURNAL CUSTOM REPRINTS
Open Your Editorial Exposure.
REPRINTS ARE IDEAL FOR:
■ New Product Announcements
■ Sales Aid For Your Field Force
■ Recruitment & Training Packages
■ Trade Shows/Promotional Events
■ PR Materials & Media Kits
■ Conferences & Speaking Engagements
■ Direct Mail Enclosures
■ Customer & Prospect Communications/Presentations
For additional information, please contact Foster Printing Service, the official reprint provider for Welding Journal.
Call 866.879.9144 or sales@fosterprinting.com

FOSTER PRINTING SERVICE

Quality-Checked Pre-Owned Equipment
An Excellent Selection of Used Welders, Welding Positioners, Welding-Related Specialty Equipment and Generators.
View at reddarc.com or call us toll-free.
Red-D-Arc Welderentals. 1-866-733-3272
reddarc.com

800-343-6926  www.escotool.com
The world’s very best portable end prep tools and abrasive saws
For sale or rent
esco tool®
Supplement to the Welding Journal, September 2011
Sponsored by the American Welding Society and the Welding Research Council

Comparison between DC(+) and Square Wave AC SAW Current Outputs to Weld AISI 304 for Low-Temperature Applications

A change in the electrical welding output and flux type can enhance the mechanical properties of AISI 304 stainless steels for low-temperature applications

BY R. E. TOMA, S. D. BRANDI, A. C. SOUZA, AND Z. MORAIS

ABSTRACT

Welded equipment for cryogenic applications is utilized in chemical, petrochemical, and metallurgical industries. One material suitable for cryogenic application is austenitic stainless steel, which usually doesn’t present ductile/brittle transition temperature, except in the weld metal, where the presence of ferrite and micro inclusions can promote a brittle failure, either by ferrite cleavage or dimple nucleation and growth, respectively. A 25-mm- (1-in.-) thick AISI 304 stainless steel base metal was welded with the SAW process using a 308L solid wire and two kinds of fluxes and constant voltage power sources with two types of electrical outputs: direct current electrode positive and balanced square wave alternating current. The welded joints were analyzed by chemical composition, microstructure characterization, room temperature mechanical properties, and CVN impact test at -100°C (-150°F). Results showed that an increase of chromium and nickel content was observed in all weld beads compared to base metal. The chromium and nickel equivalents ratio for the weld beads were always higher for welding with square wave AC for the two types of fluxes than for direct current. The modification in the Cr_{eq}/Ni_{eq} ratio changes the delta ferrite morphology and, consequently, modifies the weld bead toughness at lower temperatures. The oxygen content can also affect the toughness in the weld bead. The highest absorbed energy in a CVN impact test was obtained for the welding condition with square wave AC electrical output and neutral flux, followed by DC(+) electrical output and neutral flux, and square wave AC electrical output and alloyed flux.

Introduction

Cryogenics can be defined as the science and technology of temperatures below -153°C (120 K). This limiting temperature was proposed based upon the boiling point of the main atmosphere gases, as well as methane, which are below this temperature (Ref. 1). According to Lebrun (Ref. 2), cryogenics arose two centuries ago from the search to liquefy the atmospheric gases considered until that time incondensable. In 1877, L. Cailletet and R. Pictet liquefied air for the first time, and in 1883, K. Olszewski and S. Wroblewski separated oxygen from nitrogen. However, the increase in cryogenics applications started in 1908, when H. Kamrelingh Onnes made the first helium liquefaction. There is also equipment in the chemical and petrochemical industries that work in temperatures as low as -100°C, which is not exactly a cryogenic application according to the definition presented above. In both cases (cryogenics or low-temperature applications), the 300 stainless steels series is widely used, and the AISI 304 and 304L stainless steels are usually employed. They are recommended for these applications because their ductile/brittle transition temperature is negligible at temperatures above -269°C (Ref. 3). On the other hand, the ductile/brittle transition temperature in ferritic and martensitic stainless steels occurs a few degrees below zero, depending on the steel chemical composition and grain size.

According to Hertzberg (Ref. 4), the temperature effect on the necessary energy to crack the material is related in the ferritic steels to a change in the mechanism of microscopic fracture, which happens due to cleavage at low temperatures and has a brittle behavior. On cleavage, fracture occurs on the crystallographic planes of different grains, and the fracture surface presents a morphology similar to a river.

For structural applications, it is necessary to have an adequate combination between the fracture resistance (KIC, JIC, or CTOD) and the yield point (σy), depending on the service temperature. However, these properties are inversely proportional at any given temperature. The toughness in stainless steels, as a function of temperature, decreases monotonically with the yield point and the temperature (Refs. 5, 6).

At low temperatures above the range of cryogenic applications, stainless steels tend to fail exclusively by a ductile rupture mechanism, in which occurs a coalescence of dimples, generated by second-phase particles present in the material. Therefore, the fracture resistance is controlled by the volumetric fraction, size, distribution, and morphology of second-phase particles. The interface between second phase and the matrix can be easily separated at low plastic deformation associated with low temperatures. In this case, the

KEYWORDS
Cryogenics
Low Temperature
Stainless Steel
Petrochemical
Submerged Arc Welding
toughness measured by Charpy V-notch (CVN) absorbed impact energy or crack tip opening displacement (CTOD) decreases with temperature.

Furthermore, in the case of stainless steel weld metal, the matrix is a dual-phase type, with ferrite and austenite, depending upon the solidification mode (Refs. 7–10). The presence of ferrite, even in small amounts, usually less than 10%, can also generate a ductile or a brittle path, depending upon the test temperature. At high and room temperatures, ferrite is ductile and, consequently, its volumetric fraction and its morphology don’t control the rupture mechanism. In this case, the fracture mechanism is due to the volumetric fraction of inclusions. At low or cryogenic temperatures, ferrite can be brittle and can lead to reduction in the toughness of the weld by a cleavage mechanism.

The ferrite morphology and its volumetric fraction in the weld metal are important in determining the cracking mechanism at low and cryogenic temperatures. Solidification mode, ferrite morphology, and its amount are determined

Table 1 — Tension Test Results for All Tested Samples

<table>
<thead>
<tr>
<th>Experimental Condition</th>
<th>Number of Test</th>
<th>Tensile Strength (MPa)</th>
<th>Minimum Tensile Strength (MPa)</th>
<th>Sample Failure Localization</th>
</tr>
</thead>
<tbody>
<tr>
<td>1(Ac/N)</td>
<td>1</td>
<td>601</td>
<td>606.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>611</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2(DC/N)</td>
<td>1</td>
<td>606</td>
<td>607.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>608</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3(DC/A)</td>
<td>1</td>
<td>601</td>
<td>598.5</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>596</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4(AC/A)</td>
<td>1</td>
<td>604</td>
<td>606.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>608</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
by chemical composition (Cr\textsubscript{eq}/Ni\textsubscript{eq} ratio) and by the orientation between \(\langle 100 \rangle\gamma\) direction and heat flow flux direction during weld pool solidification (Refs. 11–13).

As presented before, the Cr\textsubscript{eq}/Ni\textsubscript{eq} ratio is one factor that determines the weld pool solidification mode, ferrite morphology, and the volumetric fraction of delta ferrite in the weld bead (Refs. 7–10). If Cr\textsubscript{eq}/Ni\textsubscript{eq} ratio is below 1.48, the solidification mode produces a weld bead with an austenitic microstructure. When the Cr\textsubscript{eq}/Ni\textsubscript{eq} ratio is between 1.48 and 1.95, a ferrite-austenite solidification mode takes place in the weld pool, which produces an austenitic-ferritic microstructure with 2 to 10% ferrite. Vermicular ferrite morphology is more frequent than lath ferrite when Cr\textsubscript{eq}/Ni\textsubscript{eq} ratio is in the lower part of the 1.48 to 1.95 range. Lath ferrite usually occurs more often than vermicular morphology while Cr\textsubscript{eq}/Ni\textsubscript{eq} ratio is closer to 1.95. As Cr\textsubscript{eq}/Ni\textsubscript{eq} ratio is higher than 1.95, a primary ferrite microstructure is produced in the weld bead, with austenite precipitation during cooling by ferrite decomposition.

The weld pool chemical composition can be changed due to thermochemical and electrochemical reactions on the molten droplet at the wire tip, during droplet transfer, and in the weld pool in contact with the electric arc or molten slag in submerged arc welding (SAW) and electroslag welding (ESW) processes (Refs. 14–17). According to Blander and Olson (Ref. 14), the anodic reaction (electrode positive) at the molten droplet-slag interface in the wire tip is responsible for the oxide formation, and the anodic reaction (electrode negative) of the metal ion is responsible for the electrodeposition of metals at the weld pool. The chemical composition due to cathodic reactions is adjusted by chemical reactions. Also, the welding pool chemical composition can be changed due to dilution. Usually, direct current (electrode positive) polarity produces a higher penetration and direct current (electrode negative) increases deposition rate, using the same SAW process flux type. Thus, using direct current (electrode positive) or alternating current during SAW can produce a different chemical composition in the weld pool. Therefore, the change in chemical composition can alter the ferrite morphology. The heat flow flux condition can also affect the ferrite morphology. In the case where \(\langle 100 \rangle\gamma\) directions and heat flow

<table>
<thead>
<tr>
<th>Experimental Condition</th>
<th>Mean Absorbed Energy (J)</th>
<th>Mean Lateral Expansion (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1(AC/N)</td>
<td>65 ± 5</td>
<td>0.783 ± 0.097</td>
</tr>
<tr>
<td>2(DC/N)</td>
<td>56 ± 5</td>
<td>0.740 ± 0.068</td>
</tr>
<tr>
<td>3(DC/A)</td>
<td>36 ± 5</td>
<td>0.661 ± 0.087</td>
</tr>
<tr>
<td>4(AC/A)</td>
<td>53 ± 6</td>
<td>0.694 ± 0.134</td>
</tr>
</tbody>
</table>
flux direction during weld pool solidification are parallel, delta ferrite can be formed with a lath or vermicular morphology, depending upon the existence, or not, of Kurdjumov-Sachs orientation relationship between delta ferrite and austenite (Ref. 12). On the other hand, if the \(<100\>\gamma \) direction and heat flow direction during weld pool solidification are not parallel, the delta ferrite morphology is vermicular (Ref. 12).

These delta ferrite morphologies and volumetric fraction are also related to the toughness of the microstructure. Depending upon the temperature, a small-scale yielding (cryogenic temperature) or a large-scale yielding (low temperature, room temperature, and above) condition takes place during crack propagation. Lath ferrite usually presents better toughness than vermicular ferrite in an austenitic-ferritic matrix for small-scale yielding (Ref. 12). This is due to the crack propagation in the ferrite at low or cryogenic temperatures. Vermicular ferrite is usually a more continuous and aligned ferrite than lath ferrite, which has a ferrite crack propagation mean path lower than vermicular ferrite, mainly due to the ductile austenite that acts as a crack arrests.

The objective of this work is to determine the differences in chemical composition and low-temperature mechanical properties of an AISI 304 base metal weld joint caused by changing submerged arc welding parameters such as flux type (neutral and alloyed fluxes) and electric condition (direct current electrode positive or square wave alternating current).

**Experimental Procedure**

A 25-mm (1-in.) thick AISI 304 stainless steel base metal was welded by the SAW process using an AWS A5.9 ER308L filler metal with 3.25-mm (\( \frac{1}{8}\)-in.) diameter and two kinds of fluxes: neutral and chromium autocompensating alloys. The welds were made by a constant voltage power source with two electrical output types: direct current electrode positive and balanced square wave alternating current. Samples 1 and 4 were made with alternating current, balanced square wave with a 70-Hz frequency with neutral (AC/N) and chromium autocompensating alloyed fluxes (AC/A), respectively. Samples 2 and 3 were welded with continuous current electrode positive, using neutral (DC/N) and chromium autocompensating alloyed fluxes (DC/A), in that order. All four samples were welded with a mean heat input close to 2.2 kJ/mm (0.87 kJ/in.) and a double-V bevel type.

The welded joints were analyzed by different methods. The chemical composition of base metal, weld metal, and filler metal were analyzed using an optical emission spectroscopy and LECO® equipment for carbon, sulfur, oxygen, and nitrogen measurements. Dilution was determined by a ratio between melted base metal area to weld metal area. Microstructure characterization was done using an optical microscope and scanning electron microscope with an energy dispersive microanalysis. Samples observed in the optical microscope...
were electrolytically etched using a 10% solution of oxalic acid. The volumetric fraction of ferrite in the weld metal was measured by a magnetic technique, using a ferritoscope equipment.

Mechanical properties were measured at room temperature (tensile test) and CVN notch-toughness impact test at -100°C (-73°F), repeated five times sample per welding condition. Charpy sample surface fractures were also observed in a scanning electron microscope.

Results and Discussion

Chemical Composition

The Cr and Ni chemical composition of the weld beads is presented in Fig. 1 for all experiments. Analyzing these values, one can notice an increase in chromium content for all welding conditions. The highest values were achieved welding with a neutral flux and a balanced square wave alternating current electrical output (AC/N) followed by welding with an alloyed flux (chromium compensating flux) and a balanced square wave alternating current electrical output (AC/A). The result for AC/A condition was expected, since an alloyed flux was utilized to compensate for variations in chromium content during welding. On the other hand, the increase in chromium content using a neutral flux and a balanced square wave alternating current (AC/N) should be explained by other ways besides flux type, such as electrical output and weld bead dilution.

As an AC square wave electrical output was used, the change in chemical composition can be related to the change in polarity during welding by electrochemical reactions. When the welding pool is negative during AC welding, a Cr electrochemical reaction takes place, depositing chromium, nickel, and other metals. When the polarity is changed to positive, a Cr oxidation in the welding pool occurs. The opposite reactions occur in the molten droplet at the wire tip. To analyze these reactions, a change in element content of the weld metal was compared to the base metal chemical composition. A positive-value means a pickup of the element in the weld pool. The result is depicted in Fig. 2.

In analyzing Fig. 2, all tested welding conditions presented Cr and Ni contents higher than in the base metal. The chromium content using the AC/Neutral flux condition presented almost the same amount of AC/A flux, and both presented a higher increase in chromium content in the weld pool than DC/N and DC/A.
fluxes. These results follow the same trend proposed by Frost et al. (Ref. 15) when they analyzed the increase in chromium content, by electrochemical reaction, comparing AC and DC submerged arc welding of a carbon steel. In these results, they used an AC wave with a sinusoidal shape. When an AC square wave is utilized for welding, the arc voltage and welding current are almost kept in the setup value, with almost no change when compared to a sinusoidal wave shape. Thus, the electrochemical reactions using a square wave shape are maintained with the same charge density for each half cycle, given a favorable electrochemical reaction rate compared to sinusoidal wave shape.

Dilution can also affect the chemical composition of weld metal, since it represents the base metal portion in the weld metal, which usually has a higher amount of impurities than base metal. Thus, the higher the dilution, the lower the amount of impurities, taking into account only the base metal melted volume and the deposited filler metal volume. Figure 3 shows the dilution of weld metal for AC and DC experimental conditions. Analyzing this figure, the AC electrical output depicted a dilution lower than DC electrical output, for the same flux type. Submerged arc welding process typically presents a high penetration in DC(+) and a high deposition rate in DC(−) electrical output. As the AC electrical output is a balanced square wave, these two effects act a half time each during the AC current cycle, justifying the difference between DC(+) and AC dilution results. Examining the same electrical output and different flux types, the neutral flux presents a lower dilution than the alloyed flux, which also correlated to oxygen quantity in the weld pool.

Usually, for DC(+), the increase in the amount of oxygen increases the penetration of the weld bead, which can also raise the dilution of the weld bead. In the case of AC welding, the change in polarity can alter the amount of oxygen due to electrochemical reactions. Figure 4 presents the amount of oxygen and nitrogen in weld metal for the experiments.

The oxygen weld metal amount in DC electrical output follows the same trend presented by the weld joint dilution. The change in dilution with oxygen content may be caused by a Marangoni flow induced by the amount of oxygen in the weld bead. In the case of AC electrical output, the electrochemical reaction produces the same trend in weld metal oxygen content, which is lower than in DC electrical output. These behaviors are similar to the results reported by Frost (Ref. 15) for carbon steels. The amount of oxygen in weld metal is also a function of the basicity index (BI) of the flux. The neutral flux used in this work has a BI of 2.70, and the alloyed flux presents a BI of 0.97. The higher the BI, the lower is the content of oxygen in the weld bead, reaching up to a minimum constant amount of oxygen, for DC(+) and carbon steels (Refs. 18, 19). The results for stainless steels follow the same trend, when comparing results for the same electrical output. Nitrogen weld metal content does not present a significant change with the experimental conditions.

The amount of C, S, and P are also important for weld bead shape and cryogenic or low-temperature mechanical properties. The amount of these elements in weld metal may be also controlled by an electrochemical reaction. In the case of carbon and phosphorus, the neutral flux presented a higher pickup of these elements than the alloyed flux for the DC(+) condition. The dilution of DC/A should be taken into account to analyze these compositions since DC/A presented the highest dilution and, consequently, less impurities were introduced into the weld pool. Comparing this result for AC electrical output, the result is opposite mainly due to the different chemical composition of the welding flux; that is, the increase in carbon and phosphorus is higher for the alloyed flux. Also, the dilution of the AC output weld bead has almost the same dilution, and the effect of the melted base metal has almost the same influence in the chemical composition of these weld beads. Figure 5 depicts the carbon, sulfur, and phosphorus for the experimental conditions.

To analyze the effect the electrical output has on weld metal chemical composition, a change of C, S, P, O, and N elements is compared to base metal chemical composition. These results are shown in Fig. 6.

There is no change in carbon pick up for DC(+) and the two flux types. On the other hand, in the AC condition, there is an increment in the carbon content for the neutral flux when compared to alloyed flux. Examining the carbon pickup, AC electrical output presented a lower value than DC(+), for both flux types. These results show a trend similar to the carbon pickup by electrochemical reaction reported in Ref. 16.

Investigating the sulfur composition change in the weld bead, it was found that change occurs only when the electrical output is changed, and it is kept constant for the same flux type. In this case, the sulfur pickup in weld metal may be due to the change in the flux basicity, which is related to the desulfurization reaction in the weld pool that is enhanced by a basic slag produced by a basic flux.

In the case of a change of phosphorus in the weld bead, there was a loss of this element for all experiments. For the same electrical output, the reduction in P was higher for the same flux type and neutral, which is a basic flux type, than for alloyed flux. In this case, a dephosphorization reaction takes place, which is promoted by flux with a high basicity index. Also, the electrochemical reaction acts together to reduce the P amount, as suggested by Ref. 16.

The change in oxygen content also follows the effect of the flux basicity index and electrochemical reactions, as discussed previously.

Metallographic Characterization

Delta Ferrite Volumetric Fraction

Delta ferrite volumetric fraction was measured by magnetic measurements, using a Ferritoscope, in seven different regions along a weld bead cross section. The results of ferrite mean value are presented in Fig. 7. All experimental conditions presented a ferrite volumetric fraction below 10%, as usually recommended for welding with 300 austenitic stainless steel series. All delta ferrite volumetric fractions have close values. The higher amount of delta ferrite was found in condition 3 (DC/A) followed by condition 4 (AC/A), condition 2 (DC/N), and condition 1 (AC/N). These results should be analyzed by the pickup of all alloying elements that are present in the chromium and nickel equivalent equations in particular for the alloying elements with higher amounts, such as Cr and Ni.

As presented previously, the delta ferrite morphology can be predicted by the chromium equivalent/nickel equivalent ratio. Figure 8 presents the Cr\textsubscript{eq}/Ni\textsubscript{eq} ratio for the experiments. According to the results shown in Fig. 8, samples with a Cr\textsubscript{eq}/Ni\textsubscript{eq} ratio
ratio close to 1.95 tends to produce more lath ferrite than vermicular ferrite morphology. On the other hand, a $C_{eq}/Ni_{eq}$ ratio close to 1.8 tends to produce more vermicular ferrite than lath ferrite morphology. The AC electrical output produced a weld bead microstructure with more lath delta ferrite than vermicular ferrite. In the case of a DC (+) welding condition, the $C_{eq}/Ni_{eq}$ ratio, which means a tendency to produce more vermicular ferrite than lath ferrite. Figure 9 depicts a typical microstructure of AISI 304 stainless steel weld bead for 3(DC/A) experiment.

Figure 9A presents a typical microstructure for both ferrite morphologies, lath and vermicular, predominating vermicular ferrite. Figure 9B shows a detail of a microstructure transition region, with lath ferrite morphology in the upper left corner and vermicular ferrite in the lower right corner. Figure 9B depicts an oxide micronucleation in the transition region.

Ferrite morphology is also influenced by the heat flow flux direction compared to the ductile-type crack potential to produce more vermicular ferrite than lath ferrite. Figure 9 depicts a typical microstructure transition region, with lath ferrite morphology in the upper left corner and vermicular ferrite in the lower right corner. Figure 9B depicts a typical microstructure transition region, with lath ferrite morphology in the upper left corner and vermicular ferrite in the lower right corner. Figure 9B depicts an oxide micronucleation in the transition region.

Ferrite morphology is also influenced by the heat flow flux direction compared to the ductile-type crack potential to produce more vermicular ferrite than lath ferrite. Figure 9A presents a typical microstructure for both ferrite morphologies, lath and vermicular, predominating vermicular ferrite. Figure 9B shows a detail of a microstructure transition region, with lath ferrite morphology in the upper left corner and vermicular ferrite in the lower right corner. Figure 9B depicts an oxide micronucleation in the transition region.

Ferrite morphology is also influenced by the heat flow flux direction compared to the ductile-type crack potential to produce more vermicular ferrite than lath ferrite. Figure 9A presents a typical microstructure for both ferrite morphologies, lath and vermicular, predominating vermicular ferrite. Figure 9B shows a detail of a microstructure transition region, with lath ferrite morphology in the upper left corner and vermicular ferrite in the lower right corner. Figure 9B depicts an oxide micronucleation in the transition region.

Ferrite morphology is also influenced by the heat flow flux direction compared to the ductile-type crack potential to produce more vermicular ferrite than lath ferrite. Figure 9A presents a typical microstructure for both ferrite morphologies, lath and vermicular, predominating vermicular ferrite. Figure 9B shows a detail of a microstructure transition region, with lath ferrite morphology in the upper left corner and vermicular ferrite in the lower right corner. Figure 9B depicts an oxide micronucleation in the transition region.
these samples. The presence of secondary cracks by ferrite cleavage is an enhancing toughness mechanism, which can produce CVN absorbed energy higher than an energy obtained only by a pure mechanism of dimple nucleation and growth, as presented schematically in Fig. 11B. The presence of secondary cracks can also explain the higher toughness of lath ferrite when compared to vermicular ferrite, as observed experimentally in References 11 and 12.

Conclusions

Based on the materials, welding procedure, and results analysis techniques one can conclude the following:

1) There is a difference in the weld bead chemical composition when the balanced AC square wave electrical output is used for welding AISI 304 stainless steel, for both fluxes. The amounts of chromium and nickel were increased when compared to the base metal chemical composition for all experiments. The best results were obtained for the samples welded with active flux using square wave AC current type followed by neutral flux and square wave AC current. Same trend was observed for oxygen and phosphorus. In the case of oxygen, there was a pickup of oxygen, which presented the lowest values for square wave AC current, both flux types, and the highest value to DC(+)+ and alloyed flux. In the case of P, a dephosphorization reaction took place in the weld pool and the amount of this element was decreased for all experiments. The P lost was higher for AC balanced square wave and neutral flux. Some results among experimental conditions may be influenced by the weld bead dilution that was higher for DC/A flux experimental condition.

2) The Cr/eqNi/eq ratio was greater for balanced square wave AC than for DC(+), for both flux types. AC/A flux condition presented the highest ratio (1.90), followed by AC/neutral flux (1.88) and DC/neutral flux (1.86). The lowest value was obtained by DC/A flux condition (1.83). These results can be arranged in two groups: one with a higher Cr/eqNi/eq ratio (1.86–1.90 range) and another with a lower Cr/eqNi/eq ratio (1.83). The former presents a microstructure with more lath ferrite than vermicular ferrite morphology. The second group presented a microstructure composed mainly of vermicular ferrite, with some amount of lath ferrite.

3) Although all samples achieved a resistance higher than the minimum required by the standard, tension test results presented a lower tensile strength for sample DC/ alloyed flux. The mechanism of fracture is controlled by dimple nucleation, growth, and coalescence. Dimple is nucleated at oxide inclusions, which volumetric fraction can be inferred by oxygen content. The higher the oxide volumetric fraction, the nucleation rate is higher and the dimple size is decreased when coalescence takes place. DC/alloyed flux presented the highest amount of oxygen of all tested conditions, and as a consequence, the lowest dimple mean size measured at the tension test surface fracture.

4) The CVN impact test at -100°C (-73°F) showed the best result for samples welded with square wave AC and neutral flux followed by DC(+)+ polarity and neutral flux; square wave AC and alloyed flux; and DC(+)+ polarity and alloyed flux, respectively. These results were analyzed taking into account the oxygen content and ferrite morphology, which is related to the ferrite cleavage and ferrite orientation in the microstructure. The mechanism of failure in stainless steel weld metal CVN samples can be by a ductile mechanism (dimple nucleation and growth in austenite) or by a brittle mechanism (delta ferrite cleavage and crack mean free path). The CVN sample with lowest absorbed energy presented the highest amount of oxygen and also a vermicular ferrite morphology, which is a more continuous and aligned type.

5) Secondary cracks were observed in all samples with a predominant lath ferrite. The ferrite cleavage occurs in a plane with different orientation to the main crack propagation plane. This is a mechanism to enhance the toughness of the lath ferrite microstructure.

Acknowledgment

The authors appreciate the welding of the samples and also the funding for mechanical tests and chemical analysis provided by Lincoln Electric of Brazil.

References

Review: Experiments and Simulations for Small-Scale Electrical Discharges

The characteristics of, and electrode modifications by, electrical discharges in gaps between platinum nanotip cathodes and plane gold film anodes were studied

BY J. CHEN, L. HE, D. F. FARSON, AND S. I. ROKHLIN

Introduction

The thermal energy generated by electrical discharges in macroscale gaps has been used for fusion welding of metal for well over a century (Ref. 1). For example, the gas tungsten arc welding process generates heat input with enough intensity to join all metals and has widespread application and usefulness. In contrast, the characteristics and potential welding and materials processing applications of electrical discharges in nanoscale and submicron scale gaps have been much less studied. The work reviewed in this article (Refs. 2–7) was aimed at studying characteristics and developing fundamental understanding leading to the eventual development of materials processing and joining applications of electrical discharges in small gaps.

In air at ambient pressure and conditions, the mean free path of electrons is about 500 nm (Ref. 8). Consequently, electrons emitted from a cathode in small gaps have fewer collisions with ambient gas atoms or molecules and development of an ionized discharge by avalanche breakdown is more difficult. The investigations reviewed in this article studied the breakdown of submicron scale gaps and the mechanisms associated with the maintenance of discharges in such small gaps. In particular, the influence of materials evolved from electrodes on the initiation, evolution, and maintenance of electrical discharges in small gaps was studied.

A unique feature of some of the reviewed research is the pulsed laser stimulation of discharges in nanoscale and microscale gaps that are triggered by the application of DC potentials on the electrodes. These laser pulses stimulated electrical breakdown in nanoscale and microscale gaps between sharpened metal cathodes and plane metal anodes. The importance of mechanisms responsible for the limited duration of current pulses and the heat input and extent of melting of plane anodes produced by these discharges was also investigated.

The objectives of the work reviewed in this article were to experimentally and numerically determine the following: 1) the conditions necessary for formation of discharges in nanoscale and microscale ambient-atmosphere gaps between sharpened metal cathodes and plane metal anodes by application of DC electrical potential; 2) the effects of voltage source resistance on duration of discharge current pulses; 3) mechanisms responsible for stimulation of discharges by the application of femtosecond laser pulses to the gaps excited by DC potentials; 4) mechanisms responsible for the limited duration of current pulses; and 5) the heat input and extent of melting of plane anodes produced by these discharges.

Experimental Apparatus and Procedures

The apparatus used in the experiments (shown schematically in Fig. 1) consisted of a scanning probe microscope system (Quesant Q-Scope 250), a source-measure unit (SMU, Keithley SMU 236) operated in constant-voltage mode, and a chirp-pulse amplified Ti:Al₂O₃ femtosecond pulsed laser (Clark-MXR CPA 2110). In the experiments dealing with laser-triggered discharges, the tip of the probe was illuminated by a focused femtosecond laser pulse.
Fig. 1 — Experimental apparatus showing the STM system, source measure unit, voltage source, current limiting resistance, current probe, and femtosecond laser illumination. The inset shows a video microscope image used to align the laser beam focus spot to the probe tip, positioned 500 nm over a reflective gold film.

Fig. 2 — Conceptual diagram of regions for formation of laser-stimulated discharges in terms of primary process variables of applied potential, gap length, and laser irradiance.

Fig. 3 — A — Variation of gap length for untriggered breakdown as a function of applied potential in air. Histograms of a gap length for 50 experiments are shown at each potential, along with maximum, minimum, and standard deviation (displayed by error bars); B — variation of untriggered self-breakdown gap length as a function of applied potential in air and argon gas. The data points represent the average and standard deviation of a sample set of 50 experiments and shows that atmosphere has no effect at these small gap lengths; C — variation of untriggered breakdown mean field vs. gap distance in air and argon gas. The breakdown fields were almost identical in both atmospheres and are comparable to electrical breakdown fields of macroscale vacuum gaps.

Laser beam, which had a pulse repetition rate of 2 kHz and pulse length of 150 fs. The pulse energy was controlled by rotating the angle of the linearly polarized beam with respect to the plane of a polarizing beam splitter. Prior to delivery to the probe tip/substrate gap, the beam polarization was set parallel to the STM tip. The laser beam was controlled by a mechanical shutter with opening time of 1 ms. Thus, 2 to 3 full-strength pulses were incident on the tip-substrate gap for each shutter opening “trial.” The beam was focused by a 200-mm achromatic lens to a spot diameter of approximately 100 μm. The laser focus was centered on the tip-substrate gap with the aid of a video camera image obtained through a long-standoff microscope lens — Fig. 1.

An AC current probe (Tektronix CT-1) with a bandwidth from 25 kHz to 1 GHz was used to measure cathode current pulse signals due to gap breakdown from applied potential and/or laser irradiation. The current pulse signals were displayed on a 300 MHz, 2.5 Gs/s digital oscilloscope (Tektronix 3032B). In experiments, the circuit current was limited by series carbon film resistors of various resistances or constant current diodes (CLDs) with regulation current levels of 35 μA, 500 μA, and 2 mA. The CLD is a two-terminal junction field effect semiconductor device that presents a varying resistance to regulate the current in the forward-biased direction to a specified value whenever the voltage drop across the device is above a threshold value (Ref. 9).

The cathodes were electrochemically etched 250-μm 80% platinum-20% iridium wires, and the anode was 100-nm gold film on silicon wafers. For most experi-
Fig. 4 — A — Threshold laser irradiance for stimulation of a breakdown and irradiance for reliable stimulation of breakdown in 500-nm and 4-μm air gaps as a function of applied potential. Irradiance of 0.35 TW/cm² was used in subsequent experiments; B — threshold laser irradiance for stimulation of a breakdown and irradiance for reliable stimulation of breakdown in 500-nm and 4-μm air gaps as a function of applied mean electrical field. (For both images, please refer to discussion in the text for definitions of these irradiances.)

Fig. 5 — A — Experimental cathode current waveforms for low-magnitude current pulses formed at selected applied potentials from 20 to 35 V; B — high-magnitude current pulses were sometimes observed at potentials at 27.5 V and above. The duration of these high-magnitude current pulses was two orders of magnitude longer than low-magnitude current pulses plotted in image A and was limited by cathode tip melting.

The principal variables affecting the formation of laser-stimulated electrical discharges in small gaps between nanoprobe tip cathodes and conductive anodes are gap distance, applied potential, and laser irradiance. The various effects that define the limits of these variables for laser-stimulated discharges are sketched in the conceptual diagram in Fig. 2. Untriggered self-breakdown discharges, which were not a desired mode of operation, were formed for sufficiently large applied potentials and short gap lengths. At high laser irradiance, damage to the nanoprobe tip by ablation and melting occurred. Conversely, no discharges were triggered when applied potential and laser irradiance were too low or the gap was too large. An additional lower bound

*WELDING JOURNAL*
on feasible gap length (large inverse gap length) was imposed by electrical shortage between the probe tip to the substrate during the discharge. These effects combined to define the upper and lower bounds for existence of laser triggered discharges. Between the lower and upper feasible bounds was a region in which laser stimulation of discharges was possible, although a transition between unreliable and relatively reliable stimulation was observed along each axis.

**Untriggered Self Breakdowns**

Prior to discussing results for laser-stimulated discharges, it is helpful to present results for untriggered discharges for comparison. In these experiments, cathode current pulses occurred when the mean electrical field in the gap due to the applied potential and gap length was sufficiently large. Variation of self breakdown gap length with applied potential in two ambient atmospheres is shown in Fig. 3A–C. Figure 3A clearly shows that there is considerable variation in the gap length at which an electrical discharge formed in a gap with applied potential. The distribution of air breakdown gap lengths at various applied potentials are shown in Fig. 3A approximated the expected Weibull distribution (Ref. 10). The pressure-gap length product of the breakdowns ranges from 0.025 Pa m at 80 V to 0.004 Pa m at 20 V. These values are well below the large-gap Paschen minimum for air of approximately 0.6 Pa m (Ref. 11).

As shown in Fig. 3B, the average and standard deviations of self breakdown gap lengths in air and argon atmospheres were nearly the same. This result is notable because the difference in electron attachment cross section for air and argon typically causes a significant difference in macroscale gap breakdown characteristics (Ref. 12). The breakdown potential increased linearly with an average gap length over the experimental range. The slope of the gap vs. breakdown potential line was 286 V/μm. At tip-to-substrate potential of 20 V, the average breakdown gap was 45 nm, and the mean breakdown field was 20 V/0.045 μm = 440 V/μm. At 80 V potential, the average breakdown gap length was 240 nm, corresponding to a mean breakdown field of 329 V/μm. The mean self-break-
down fields are more than two orders of magnitude times the generally accepted breakdown field for macroscale plane-parallel air gaps, which is approximately 0.3 V/μm (Ref. 13). Our experimental breakdown fields are comparable to the mean breakdown fields for clean metal point plane vacuum gaps, which are on the order of 100 V/μm (Ref. 14). The steady increase in both average and standard deviation of the breakdown field that occurred at smaller gap lengths in both air and argon atmosphere is also noted. Prior researchers have also reported increased variability of the breakdown field at small breakdown gap lengths for both air and vacuum breakdowns (Ref. 15).

The similarity of breakdown gap lengths in air and argon suggests that the ambient atmosphere was not significantly involved in the self breakdown of gaps plotted in Fig. 3B and C. The fact that the experimental gap length range (40–250 nm) is comparable to the elastic mean free path of low-energy electrons in ambient air (about 200 nm, Ref. 16) suggests that the gap breakdown mechanism in the current experiments could be similar to those for vacuum breakdowns. This is consistent with the finding that the observed mean breakdown fields are similar to vacuum breakdown fields. An accepted mechanism for initiation of vacuum breakdown discharges is cathode and/or anode heating, melting, and vaporization due to field emission from cathode asperities (Refs. 17–19). A comprehensive review of vacuum breakdown literature has been published (Ref. 20). The prior research has established that, depending primarily on material properties, cathode asperity shape and gap, field emission current may lead to failure of cathode asperities, melting, and ejection of material from the anode surface or perhaps both.

Laser-Stimulated Discharges

The stimulation of discharges by femtosecond laser pulses was first studied experimentally at fixed 500-nm gap lengths.
in air, a value large enough to prevent spontaneous self-breakdown discharges at the studied applied potentials. For a given gap length and applied potential, a minimum laser pulse irradiance below which no detectable (by our instrumentation) current pulse was stimulated in 50 trials was determined. As laser irradiance was increased, the probability of detection of a current pulse increased. For this research, the threshold laser pulse irradiance for stimulation of a breakdown was defined as the largest irradiance for which no discharges were stimulated in 50 trials, and the irradiance for reliable stimulation of breakdown was defined as the smallest irradiance for which 47 discharges were observed in 50 trials. The plot in Fig. 4A shows the threshold laser pulse irradiance for simulation of current pulses (denoted as Pr = 0%) and the laser pulse irradiance for reliable stimulation of current pulses (denoted as Pr > 95%) at various applied potentials. The error bars for the data points in this plot correspond to the fluctuation of the output power of the laser as measured by a silicon semiconductor power meter. The 0.35 TW/cm$^2$ irradiance marked in the plot was chosen for subsequent experiments that further investigated laser stimulation of discharges. The applied voltage and gap length data plotted in Fig. 4A was used to calculate the corresponding mean field, which is plotted as a function of laser intensity in Fig. 4B. These mean fields are one to three orders of a magnitude smaller in comparison to the self-breakdown fields plotted in Fig. 3C, a difference that illustrates the effectiveness of ultrafast laser pulses for dis-

### Table 1 — Thermal Properties of Gold Used in the Calculations

<table>
<thead>
<tr>
<th>Property</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Melting temperature (K)</td>
<td>1337</td>
</tr>
<tr>
<td>Boiling temperature (K)</td>
<td>3129</td>
</tr>
<tr>
<td>Thermal conductivity at 1000 K (W/m K)</td>
<td>278</td>
</tr>
<tr>
<td>Heat capacity at 1000 K (J/kg K)</td>
<td>150</td>
</tr>
<tr>
<td>Thermal diffusivity at 1000 K (m$^2$/s)</td>
<td>$0.93 \times 10^{-4}$</td>
</tr>
</tbody>
</table>
charge stimulation.

Laser polarization had no effect on the laser irradiance needed for stimulation of detectable current pulses shown in Fig. 4A, B (detailed data are presented in a recent publication, Ref. 21). This is a notable result because femtosecond laser polarization is known to have significant effects on emission of photoelectric current from nanoprobe tips (Refs. 22, 23). The fact that current pulse stimulation was found to be independent of polarization indicates that photoemission of electrons from the sharpened cathode was not critical for formation of detectable current pulses in our experiments.

Current Waveforms and Effects of Current-Limiting Resistance

Typical cathode current waveforms obtained for laser-stimulated discharges in circuits with no current limiting resistor at various applied potentials and 500-nm gap length are shown in Fig. 5. At potentials of 30 V and smaller, the current pulse durations were less than 10 ns and peak currents were less than 0.15 A. The magnitudes of experimental current pulses plotted in Fig. 5A increased from 2 to 150 mA as applied potential was increased from 20 to 35 V. In this paper, such pulses are referred to as “low-magnitude current pulses.” As applied potential was increased, “high-magnitude current pulses” with much larger duration and magnitude were more likely to be observed. Figure 5B contains two examples of such waveforms. These larger current pulses were typically several amperes in magnitude and several microseconds or more in duration. Invariably, the durations were limited by catastrophic melting of the cathode tip and associated increase in cathode-anode gap length. In contrast, the macroscale appearance of cathode tips was not changed by low current pulses (more detailed results concerning microscopic tip modifications are discussed below).

The probability of occurrence of low current pulses and the variation of experimentally measured low-current pulse magnitude versus applied potential are plotted in Fig. 6. The probability of an experimental current waveform being a low-current pulse was 100% (out of 30 trials) at applied potentials of 20 and 25 V. When applied potential was increased to 27.5 V, 93% of measured current waveforms were low-current pulses. The probability of a discharge waveform being a low-current pulse decreased as applied potential was further increased, being only 3% at 40 V and 0% at higher potentials.

The effect of series resistance in the spark circuit between the voltage source and cathode tip at large applied potential was studied. Laser-stimulated discharge cathode current waveforms measured at applied potentials of 80 V and several different series resistances are plotted in Fig. 7. At the large applied potential used in these experiments, large magnitude current pulse waveforms would be expected. However, the series resistance dramatically reduced the magnitude and duration of the current pulses. The current waveforms consisted of an initial spike with a duration of approximately 4 ns and magnitude of 250-300 mA and a lower-magnitude trailing portion with variable duration. The magnitude of the leading current spike was smaller at higher series resistances, but the duration was nearly the same at all resistances. The total discharge duration was limited to 50 ns or less at resistances of 220 Ω, and larger resistances produced current pulses with shorter durations. The trailing portion of the waveform was totally eliminated in all four of the waveforms measured at a series resistance of 1500 Ω. Further tests showed that further increases in resistance produced spike-shaped current pulses with about the same duration, but even lower peak currents. A series limiting resistance of 1 MΩ was used in the remainder of the experiments to limit heat input to the anode surface.

Current waveforms with 1 MΩ series resistance and various initial discharge voltages are shown in Fig. 8. Without laser stimulation, the electrical discharge current waveforms reached a peak value in approximately 2 ns and ended within 4 ns — Fig. 8A. The peak values decreased from 80 to 10 mA as applied potential was decreased from 80 to 20 V. The breakdown gap lengths decreased with applied potential as noted on the plot. When laser pulses were applied to stimulate electrical discharges in the same gap lengths as those without laser stimulation (Fig. 8B), nearly identical current waveforms and peak currents were observed. When a constant gap length of 500 nm was used (Fig. 8C), current waveforms had similar shapes, but the peak values were slightly (on the order of 10%) lower. The maximum current was about 70 mA at 80 V and decreased linearly with a voltage to 15 mA at 40 V. At an applied potential of 20 V, gap of 500 nm, and 1 MΩ series resistance, the peak current was only 2 mA.

Cathode Tip and Anode Substrate Modifications

The effects of laser irradiance and the number of experiment trials on nanoprobe cathode tips were studied first. Sharp STM tips (minimum radii on the order of 10 nm) were analyzed by FE-SEM before and after laser irradiation. No potential was applied for these tests, and the laser irradiance was equal to or smaller than the value (3.5 x 10⁻¹¹ W/cm²) used in the laser-stimulated discharge experiments discussed previously. FE-SEM images in Fig. 9A–10C show that there was observable tip modification for a single laser illumination trial (1-ms shutter opening at 2-kHz laser pulse repetition frequency) at a laser irradiance of 3.5 x 10⁻¹¹ W/cm². Less modification was observable for a trial at irradiance of 3.2 x 10⁻¹¹ W/cm² and none was observed for a single trial at 2.5 x 10⁻¹¹ W/cm². However, as shown in Fig. 9D, ten experimental trials produced clearly detectable tip damage even at this lower irradiance. This finding, combined with the lack of dependence on laser polarization, strongly suggests that laser stimulation of discharges in our experiments was more related to femtosecond laser ablation of cathode tip material than to laser-stimulated field emission from the sharp cathode tip. For comparison with results from literature, it is noted that the laser irradiance of 3.5 x 10⁻¹¹ W/cm² corresponds to a fluence of 0.05 J/cm² and irradiance of 2.5 x 10⁻¹¹ W/cm² corresponds to a fluence of 0.04 J/cm². Our results showed damage to the Pt80Ir20 tips at this fluence, which is comparable to previously determined thresholds for detectable damage of flat surfaces of Ti (0.03 J/cm²) (Ref. 24) and Cu (0.02 J/cm²) (Ref. 25).

FE-SEM images of gold surface anode modifications produced by laser stimulated discharges with 1 MΩ current limiting resistance and at different discharge potentials are depicted in Fig. 10. The shapes of modifications were similar, but the maximum size decreased from about 1 μm to 200 nm as the voltage decreased from 80 to 30 V. The images show that the modified regions of gold surface were modified by the discharge. See Refs. 4, 5 for a more detailed characterization of anode surface modifications. Also, note that the predicted maximum anode temperatures in Fig. 15 are above the melting temperature of gold.

The peak currents associated with breakdown discharges and resulting diameters of the modified regions produced at gold film anodes by laser-stimulated breakdown discharges in 500-nm gaps with 1 MΩ series resistance are summarized in Fig. 11. No modified gold film regions could be detected at 25 or 20 V, indicating that the minimum potential for surface melting is between 25 and 27.5 V. The modified region formed with a laser-stimulated discharge at 27.5 V and 1 MΩ circuit resistance had a maximum diameter of 70 nm.

Numerical Simulation of Discharges and Anode Melting

Refinement of nanodischarge-based processes requires understanding of the physical mechanisms and characteristics of femtosecond laser-stimulated electrical discharges in nanoscale gaps. The experimental results presented above suggest that the femtosecond laser stimulation of microdischarges in submicron gaps is...
caused by laser ablation of cathode asperities and accompanying release of charge carriers. The \textit{particle-in-cell/Monte-Carlo-collision (PIC-MCC) simulation method} (Ref. 26–30) was used to study the effects of principal experimental variables (gap and mean applied field) as well as ablated cathode materials on the formation of breakdown discharges and discharge properties in argon gas at ambient pressure and room temperature. Brieﬂy, PIC-MCC models predict the phase space distribution of locations and velocities of a collection of charged particles by solution of the Boltzmann equation. The forces on the particles arise from electric and magnetic fields associated with the particle distribution, these ﬁelds being computed at fixed simulation grid points at each simulation time step.

A two-dimensional domain with the symmetry axis at the bottom of the sketch in Fig. 12 was simulated. The gold anode surface was deﬁned as a grounded conductor, and the platinum cathode tip geometry was represented as a truncated cone with a 100-nm end radius and spaced 500 nm from the anode. A $5 \times 5 \mu m^2$ ax-symmetric simulation domain was chosen based on simulation tests that demonstrated negligible boundary effects at this size. Similarly, a value of 100 physical particles per simulated computer particle was likewise chosen as a value that demonstrated minimal parameter dependence. For stability and accuracy, the mesh size and simulation time step were determined based on estimates of Debye length, plasma frequency, and a Courant condition given by Equations 1–3 (Refs. 12, 31).

The minimum Debye length and plasma characteristic time ($2/\omega_p$) observed from our simulations were 22 nm and 35 fs, respectively. Based on an approximation that an electron travels from the cathode to the anode without collisions, the estimated highest velocity was taken as $5 \times 10^6$ m/s. From these calculations, the mesh size of 20 nm ($5/256 \mu m$) and time step of 2.5 fs were chosen for the PIC simulation.

\begin{align*}
\Delta r, \Delta z &< \lambda_D \quad \text{(1)} \\
\Delta t &< 2/\omega_p \quad \text{(2)} \\
v_x \cdot \Delta t &< \Delta r ; \quad v_y \cdot \Delta t < \Delta z \quad \text{(3)}
\end{align*}

In the above equations, $\Delta r, \Delta z, v_x,$ and $v_y$ denote mesh size and electron drift velocity along two axes, $\Delta t$ is time step, and $\lambda_D$ and $\omega_p$ are Debye length and plasma frequency.

Self-breakdowns without laser irradiation were first simulated so that results could be compared to subsequent laser-stimulated discharge simulations. It was found that 200 VDC potential applied to the cathode tip was sufﬁcient to cause self-breakdowns of 500-nm gaps with the simulated conditions. At this cathode potential, electrons emitted from the cathode tip by Fowler-Nordheim field emission were accelerated to large enough energy that they ionized neutral argon gas atoms during collisions. A comparable experimental value of approximately 155 V for breakdown of a 500-nm gap is obtained by extrapolating the curve in Fig. 3B.

 Femtosecond laser ablation of materials (positive and negative ions and neutral atoms) from surfaces occurs over a period of nanoseconds or longer as discussed above and in previously cited literature (Ref. 31). Moreover, other cathode processes such as asperity explosion (Ref. 17) and thermal evaporation from both the cathode and anode also emit charged particles and neutral atoms into the gap. It is also noted that some significant vaporization of material from the anode can be expected at any temperature above melting (Ref. 32).

For an initial assessment of the effects of electrode vaporization duration on current pulse durations, simulations that introduced ablation products into the discharge gap at a constant rate for a speciﬁed adjustable time were performed.

The time-histories of cathode current pulses at an applied potential of 40 V for a simulation with a constant, continuous plasma source consisting of single ionized platinum ions, electrons, and neutral platinum atoms generated at a rate of $1 \times 10^{18}$ cm$^{-3}$ s$^{-1}$ and for a simulation with a source of the same rate but terminated at a time of 180 ps are compared in Fig. 13. It was found that discharge current ﬂow was continuous when sufﬁciently large plasma source rates were used for the simulation. For a simulation where a sufﬁciently large plasma source was terminated at 180 ps, the anode current pulse decayed to almost zero by 400 ps. These results show that constant evolution of material from the cathode tip at a sufﬁcient rate signiﬁcantly increased the duration of the predicted current pulses. The fact that predicted discharge current decreased and eventually ceased after termination of the plasma source demonstrates that the duration of the cathode current pulse was effectively determined by the duration of particle phase plots in these simulations.

To better deﬁne the mechanisms responsible for cessation of discharge current ﬂow in the simulations, the time-varying electric ﬁelds and gap potentials for 40-V discharges with constant source and terminated constant source simulations were compared at a time of 400 ps. The time-varying anode ﬁelds were similar for the discharges with both the constant source and terminated constant source. In contrast, the cathode field diminished steadily in magnitude after the constant plasma source was terminated. Due to the sensitivity of the Fowler-Nordheim emission current on cathode ﬁeld magnitude, a relatively small cathode ﬁeld magnitude was associated with the cessation in cathode current depicted in Fig. 13.

Because a detailed study of electrode ablation kinetics was beyond the scope of the present investigation, an alternative approach was taken to modeling of the self-terminating, low-magnitude current pulses. Electrode ablation species consisting of single ionized platinum ions, electrons, and neutral platinum atoms and electrons were initially preloaded before the start of simulations with a Gaussian distribution as described earlier and a peak density of $7 \times 10^{14}$ cm$^{-3}$. This peak density is consistent with laser ablation at the intensities used in experiments discussed in this article (Ref. 5). Figure 14 shows an example of the time history of the species number and current from such PIC simulations at an applied potential of 40 V. This applied potential was selected as a representative of a relatively high energy discharge. The inset plot in Fig. 14 shows the time history of the number of argon and platinum ions and free electrons within the first 25 ps of discharge simulation. The simulations predicted that the number of argon ions and free electrons began to increase immediately, and the discharge electron current began to arrive at the anode at a delay time of about 2 ps. The inset plot shows a small, sharp anode current pulse that vanished less than 1 ps after the start of the simulation. Analysis of particle phase plots revealed that this current spike, which was smaller than 4 mA in magnitude, was due to collection of preloaded electrons on the anode. The preloaded ions, having lower mobility, remained near the cathode tip throughout the simulation time. These ions enhanced the negative field on the cathode tip and increased the Fowler-Nordheim emission to a level that caused an avalanche breakdown of the background gas and preloaded platinum neutrals. The numbers of argon ions and electrons both increased approximately in unison and reached saturation levels within 50 to 75 ps, depending on applied potential. The saturation number of platinum ions was an order of magnitude smaller than that of argon ions or electrons because neutral and ionized platinum was only preloaded near the cathode surface and with a peak density less than that of the neutral argon background gas. An abrupt (approximately exponential) increase in the anode current occurred at about 20 ps for 40 V applied potential. As time progressed, the discharge plasma reached a stable conﬁguration and current…
ceased to flow to the anode. This occurred at approximately 200 ps after initiation of the 40 V discharge simulation. The charged particle numbers decreased slightly, although the sequence of events described above was similar for discharges formed at all applied potentials.

The temperature rise of the gold film anode surface was calculated based on an analytical solution of the heat equation. The energy flux \( f(r,t) \) due to the summed energy of incident particles \( \sum E_{i,r} \) on a radial anode segment \( r \) during a simulation time step \( \Delta t \) at time \( t \) was calculated as

\[
  f(r,t) = \frac{\sum E_{i,r}}{A_r \Delta t}
\]

In order to apply an available analytical solution for the temperature rise, the Gaussian radial distribution

\[
  f(r,t) = F(t) \exp\left(-r^2 / d^2(t)\right)
\]

was fitted to the simulated distributions by adjusting the radius \( d(t) \) and flux at the center of the Gaussian spot \( F(t) \) to obtain values that minimized the squared error between the Gaussian radial distribution function and the radial fluxes in Equation 4. The time variation of the flux at the center of the distribution was normalized by the flux at the center of the Gaussian spot at the time of its maximum value \( F_{\text{max}} \) so that

\[
  p(t) = \frac{F(t)}{F_{\text{max}}}
\]

The resulting time-varying, best-fit radii and peak values were used to calculate the surface temperature \( T(r,t,z) \) of a semi-infinite gold substrate according to the relationship (Ref. 33)

\[
  T(r,t,z) = T_\text{ref}(r,t) + \left[\frac{\pi}{2} \left(\frac{K}{\rho c} \int_{0}^{t} \frac{dE}{dt} \right) \right]^{1/2} \exp\left[\frac{-z^2}{4Kt} - \frac{r^2}{4Kt + d^2(t)}\right]
\]

where \( z \) is distance below the anode surface, \( p(t) \) is normalized heat input pulse magnitude \((0 < p(t) < 1)\), \( \kappa = K/\rho c \) is thermal diffusivity, \( K \) is thermal conductivity, \( \rho \) is density, and \( c \) is heat capacity. The thermal properties of gold used in the calculations, assumed as invariant with temperature, are summarized in Table 1 (Refns. 34, 35). In these simulations, all temperatures are surface temperatures, calculated for \( z = 0 \).

As noted above, the durations of current pulses simulated by the material preloading technique were several orders of magnitude shorter than those measured from experiments. Based on comparison of the continuous plasma source simulation results and the preloaded material simulations, it is hypothesized that sustained evolution of neutral and/or charged particles from the electrodes was the primary reason that experimental current pulse durations were much longer than durations of simulated current pulses generated using preloaded material. This hypothesis was also motivated by prior research publications related to vacuum discharges that has shown significant out-gassing of chemisorbed species from electrodes (Ref. 36) and effects on discharges. Additionally, the laser intensities used for discharge stimulation in this work cause super-peripheral ablation of the nanoprobe cathode tips as shown in Fig. 9 and associated ejection of charged and neutral species into the discharge gap. Prior experiments have shown the ablation of materials from surfaces irradiated by femtosecond laser pulses occurs over a period of nanoseconds or longer (Refs. 37–39). Because of the disparity between the durations and amount of charge transferred by current pulses simulated with preloaded electrode ablation material and experimental pulses, the time axes of energy flux waveforms were scaled for use in anode temperature calculations. The time scales of the simulated heat flux waveform for a given applied potential were “stretched” by multiplying simulation time steps by the charge transfer ratio. This technique normalized the time scales of the simulation waveforms by a factor that depended on applied voltage so as to ensure equal amounts of charge were transferred by experimental and simulated current pulses. It is emphasized that this correction was only based on the amount of electrical charge transferred by the cathode current pulse. The amount of heat input to the anode surface, which is also fundamentally dependent on the energy of the condensing particles, was only indirectly affected by this correction. Thus, the extent of anode melting predicted by the simulation and measured by the experiments was still an interesting comparison. It is also noted in passing that previous calculations (Ref. 40) show that heating by the femtosecond laser pulse alone at the low fluence of 0.05 J/cm² used in our experiments makes negligible contributions to anode heating and melting.

Predicted time-varying axisymmetric anode surface temperature distribution for a discharge at applied potential of 30 V is shown in Fig. 15. The solid-liquid transition isotherm is shown on the plots to indicate the relative extents and melting. The extent of the melting isotherm indicates that significant melting of the gold substrate would be expected within a radius of approximately 500 nm of the center of the 30 V discharge. A comparison of predicted and experimentally measured anode melting diameters for discharges formed at various applied potentials is shown in Fig. 16. The predictions are comparable to the measurements, being within one standard deviation of the measured values.

**Constant Current Discharges**

Because the anode heat input from electrical discharges is related to discharge current magnitude, some experiments were done using a series solid-state current-control device known as a current-limiting diode (CLD) to measure the discharge current waveform produced by such a circuit. In contrast to a zener diode, which has an approximately constant voltage drop over a range of series currents, the CLD varies its resistance to maintain an approximately constant series current over a wide range of voltage voltages. Consequently, when inserted in a series with the output of a constant voltage power supply, it converts the constant voltage V-I characteristic to a constant current characteristic. Discharges produced in circuits containing current limiting diodes had similar current waveforms as discharges in circuits with fixed resistors. The current waveforms consisted of a sharp leading edge spike followed by a longer duration, fluctuating current flow with a value that roughly corresponded to the CLD regulation current. Typical current waveforms obtained with a 2-mA CLD and various initial discharge voltages are shown in Fig. 17. Each of the displayed waveforms is the average of several discharges, which were found to be relatively repeatable after adjustment to the same starting time. The maximum current in the leading edge spike was about 2–4 mA, and the duration increased with CLD current limit and varied somewhat with supply voltage. The duration increased from 9 ns at a CLD current limit of 175 µA to 22 ns at a CLD current limit of 2 mA. The data for discharge current regulated by a 2-mA CLD is shown in Fig. 17 while discharge current waveforms for the smaller CLD current limits are not shown. The reader is referred to Ref. 2 for more details. It is interesting to compare these waveforms to those produced with several different series resistances as shown earlier in Fig. 7. The most remarkable difference is that the CLD was able to sustain a small, relatively constant current discharge for a much longer time than the constant-resistance circuits. This difference is presumably due to the variation of series resistance throughout the discharge time that is produced by the self-regulating property of the CLD.

**Conclusions**

Characteristics of and electrode modifications by electrical discharges in submicron and nanoscale gaps between platinum nanotip cathodes and plane gold film anodes were studied. When sufficient voltages were applied to 0.5-µm gaps,
breakdown discharge duration was limited by electrode tip melting at voltages of 40 V. At applied voltages less than or equal to 30 V, discharge currents tended to be brief (approximately 5 ns), low magnitude (< 1 A) pulses. The addition of a series resistance larger than 1.5 kΩ limited the discharge duration to 4 ns, regardless of applied potential. With a series resistance of 1 MΩ, anode surface melt spots diameters decreased from approximately 1.2 µm to slightly smaller than 0.07 µm as the potential was decreased from 80 to 27.5 V. Triggering of discharges in nanotip-plane gaps by femtosecond laser pulses was only effective at intensities that resulted in measurable ablation of nanotips.

In particle-in-cell (PIC) simulations, tip ablation was modeled by the addition of partially ionized electrode material the gap region. When ionized electrode materials were continuously added to the gap region at a sufficient rate, the simulated current pulse duration was directly controlled by the duration material addition. When electrode materials were preloaded into the simulation domain, the current pulses predicted by PIC simulations had comparable peak values but were shorter in duration than experimental values. Consequently, PIC-simulated anode heat input distributions were time-scaled so that transferred charge was equal to experiments. The anode melt spots predicted by these PIC simulations had melt diameters that were comparable to experiments. Control of the spark current with a series-current-limited diode shows promise for providing controllable, adjustable heat inputs from small scale discharges.

References


Iron Man Comic Book, Welding Career DVDs Available for Free

Copies of four unique resource materials, including the Careers In Welding magazine, Iron Man comic book, and Hot Bikes, Fast Cars, Cool Careers DVD, are available for free.

Visit www.CareersInWelding.com, click on the welding publications link, and fill out the form specifying the quantity you need of each item.
Laser Engineered Net Shaping® for Repair and Hydrogen Compatibility

LENS technology seems well suited for repair of overbored reclamation-type materials, but additional process development is required for other types of repairs

BY P. S. KORINKO, T. M. ADAMS, S. H. MALENE, D. GILL, AND J. SMUGERESKY

ABSTRACT

A method to repair mismachined or damaged components using Laser Engineered Net Shaping® (LENS) technology to apply material was investigated for its feasibility for components exposed to hydrogen. The mechanical properties of LENS bulk materials were also tested for hydrogen compatibility. The LENS process was used to repair simulated and actual mismachined components. These sample components were hydrogen charged and burst tested in the as-received, as-damaged, and as-repaired conditions. The testing showed that there was no apparent additional deficiency associated with hydrogen charging compared to the repair technique. The repair techniques resulted in some components meeting the requirements while others did not. Additional procedure/process development is required prior to recommending production use of LENS.

Introduction

Manufacturing processes and quality assurance techniques are being continuously improved; however, human error, equipment malfunction, and wear still occur. To address these problems, methods and approaches are continuously being developed to repair these mismachined and worn parts. It is common practice to add virgin metal to worn and mismachined parts using welding, brazing, thermal spraying, plating, etc. (Refs. 1–13). Repair processes are readily available for many components. There is typically substantial inertia to overcome to implement new processes; however, with reduced budgets and compressed time scales, modern manufacturing facilities must become more agile. This project was conducted to develop an operationally ready capability that is fast, inexpensive, agile, robust, and a repeatable model-based metal component modification and repair system.

The Laser Engineered Net Shaping® (LENS®) technology affords the user two operational modes: 1) complete part/component building or 2) repair/modification of existing parts/components. The focus of this program was on the development and qualification of the LENS technology to repair or modify existing parts and components. This paper provides an overview of the LENS technology and a detailed discussion of the capability of the process to repair mismachined or damaged components. It also demonstrates the hydrogen compatibility of the LENS material in bulk as well as the Savannah River National Laboratory (SRNL) selected repair application.

Process Overview

The LENS process utilizes a laser and powdered metal to form metal parts from computer solid models. The basic system consists of a laser, a powder feeder, a set of motion-controlled axes, a substrate material, an inert atmosphere, and a closed-loop melt pool control system. A 3-D model of the process is shown in Fig. 1. The laser is focused on a metal substrate creating a small molten pool. The powder feeder feeds powdered metal into a flowing argon stream that is directed into the melt pool by four nozzle tips. The powdered metal melts and then the melt pool solidifies as the “axis” moves, via stepper motor, the melt pool to a new location. When moved smoothly along a trajectory, a raised deposit of the desired material is applied. The previously programmed computer-aided design (CAD) model controls the development of the part; the model represents the desired additional material as layers, and each layer is divided into lines. The repair or component fabrication proceeds by depositing material line by line and layer by layer.

Figure 1 also shows several of the most important process parameters that can be varied to change the properties of the part. The laser power has to be balanced so that it is sufficient to melt the powder but not so high as to ablate the material. In many instances, this is controlled by a closed-loop melt pool controller that applies a proportional-integral-differential (PID) controlled feedback loop to maintain a constant area of the melt pool, based on the reflectance of the image, above some chosen intensity value. The powder flow rate is controlled as well. More powder builds taller parts, but excessive powder flow can cool the melt pool to such a point that the metal powder is not fused, resulting in inclusions and pores in the finished part. The layer thickness determines how much of the previous layer is remelted in the current layer. Too large a layer thickness will also cause the laser focus to advance too quickly for the material, ending in a part that does not meet geometric requirements. The hatch width determines the amount of mixing between lines deposited within the same layer. And the axis feed rate determines how fast the melt pool cools in addition to affecting the height of the build by increasing or reducing the amount of time that the melt pool is available to receive powder at a certain position.

Sandia National Laboratory’s (SNL) LENS machine is shown in Fig. 2. The system is composed of five major subsystems: a) a laser subsystem of sufficient size to melt metal and the wavelength determines the laser’s compatibility with specific materials (SNLs system utilizes a 1200-W, continuous wave, Nd-YAG laser); b) a closed-loop melt pool control system that...

KEYWORDS

Laser Engineered Net Shaping (LENS)  
Reclamation Welding  
Hydrogen  
Baseline
works closely with the laser to create consistent, repeatable process conditions; c) a motion control system that uses coordinated movements of a set of axes (the motion must be controlled to create the component in the desired geometry); d) a powder delivery system that typically consists of a stream of pressurized process gas, one or more powder feeders to meter powder into the gas stream, and a powder distribution system; and e) a purified environment (typically argon with <5 ppm oxygen) to ensure the material deposited is as similar as possible to the composition of the metal powder used in the process.

The LENS® process (Refs. 21–25) has been demonstrated for a variety of materials and part configurations. LENS® technology has successfully processed: 1) stainless steels (Types 316, 304L, and 309S); 2) nickel alloys (Inconel® 718, 625, and 690); 3) tool steels (H-13, NU-Die EZ, MM-10, and CPM-10); 4) titanium alloy Ti-6Al-4V; 5) aluminum alloys; 6) gamma titanium-aluminide; 7) tungsten; and 8) metal matrix composites (WC in Co). In this project, we were concerned only with the applicability of the process with 304L stainless steel. With this understanding of the process, one can proceed with the implementation of

### Table 1 — The LENS® Process Parameters Used for Reclamation Base Repairs as Compared to Process Development Parameters Determined for Large Drill Blocks

<table>
<thead>
<tr>
<th>Process Development Block</th>
<th>Reclamation Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powder Flow Rate (gal/min)</td>
<td>23 (400 rpm)</td>
</tr>
<tr>
<td>Laser Power (W)</td>
<td>355–480 W (26–28 A) - 575 W 1st layer</td>
</tr>
<tr>
<td>Filter %</td>
<td>80%</td>
</tr>
<tr>
<td>WP Intensity</td>
<td>400/150</td>
</tr>
<tr>
<td>Fill Area (pix)</td>
<td>750/650</td>
</tr>
<tr>
<td>Border Area (pix)</td>
<td>750/650</td>
</tr>
<tr>
<td>Axis Feed Rate (in./min)</td>
<td>22/20</td>
</tr>
<tr>
<td>Material</td>
<td>304L Drill Blocks</td>
</tr>
</tbody>
</table>
LENS as a repair technology for the SRNL-specific components.

Experimental

Two components were considered for repair development. The first was a hydrogen gas vessel that may be prepared using a solid-state resistance forge weld of a “reclamation” stem into a machined bore. During preparation, it is possible to bore the hole to wrong depth or wrong diameter or to bore the hole eccentrically. These machining errors can be simulated simply by overboring the hole so reclamation test bases were fabricated with bores that were 0.015, 0.030, and 0.045 in. (0.38, 0.76, and 1.14 mm) larger than typically specified. In addition, the largest hole was increased in depth by 0.015 in. (0.38 mm).

The other simulated repair that was of interest was surface anomalies and scratches. The typical depth of the scratches of concern is on the order of a few thousandths of an inch. Due to the difficulty in defining scratch depths of this nature, it was decided to create machined defects that were 0.10, 0.020, and 0.030 in. deep (0.25, 0.51, and 0.76 mm) on gas bottles with a 0.060-in. (1.52-mm) wall.

Mechanical Property Sample

A monolithic block of 304L stainless steel was prepared using the LENS process. This material was deposited using typical 304L stainless steel application processes. The conditions are presented in Table 1.

These conditions are typical of the parameters for Type 304L SS and are based on the extensive knowledge and experience of SNL. This prepared material was used for microstructure and preliminary mechanical property testing.

LENS Repair of Overbored Reclamation Weld Bases

Sample reclamation test weld bases with overbored stem holes were also prepared for LENS® repair. In the actual reclamation process, an old welded stem is removed by milling, the hole is rebored to achieve proper position and size, and a new stem is solid-state resistance welded (RW) into place. The provided bases had sample defect holes that had been overbored such that diameters were too large by 0.015, 0.030, and 0.045 in. (0.38, 0.76, and 1.14 mm). In addition, the very center of the part was bored 0.015 in. (0.38 mm) too deep. The challenge for the process was to add dense, well-bonded material such that the hole could be rebored to the correct diameter, a new stem welded in place, and the sample hydroburst tested. Several of the welds were then sectioned to inspect the interfaces between LENS, base weld, and stem materials.

The bore was filled utilizing a 4th axis unit mounted in the LENS machine with the axis of rotation at an angle of 45 deg from horizontal, as shown in Fig. 3. This approach was used to allow the laser to deposit material on the bottom of the bore as well as the walls. Concentric rings of material with decreasing radii were deposited on the bottom of the bore from the outside to the center. The laser then incremented up one layer and deposited the next layer from the outside to the center again. In this way, the bore was filled. In the initial efforts, the rotational speed of the weld base on the 4th axis was increased as the radius of deposit was decreased such that the apparent feed rate remained constant regardless of radius size. The method presented several challenges, however. As seen in Fig. 4, as the laser approached the center of the bore, the heat built up and caused excess powder to be entrained in the melt pool, thus creating a bump. By the second pass, the bump became tall enough to grow into the beam even when the laser was depositing at the outer edge. This caused the beam to be obscured at the outer edge and caused the bump to grow at a very high rate all the time. To address this issue, the rotational speed of the axis was increased near the center to considerably higher speeds than used previously. In addition, the very center of the part was not filled on the first several passes. This allowed high-quality material to be deposited on the walls of the part without obscuring the center. It did mean that the center material did not adequately fuse with the layer below it. This attribute was not important since the center of the hole is sacrificial material and would be removed as part of the RW preparation of the test bases. In fact, the center material was just provided to allow the hole to be drilled, if desired, rather than helically interpolated with a mill, which is a more time-consuming process.

Figure 5 shows the as-repaired condition of the deposit from a macro standpoint. It is important to note that differences in the appearance and the apparent density and crowning of the fill are not due to the diameter of the oversize bore, but are instead due to process improvements made throughout the repair of these components. The 0.045-in. (1.14-mm) overbore bases were done first and have the least desirable center bump. The 0.030-in. (0.76-mm) overbore bases had the improvement of higher rotational speed near the center of the deposit, and the 0.000- and 0.015-in. (0.38-mm) overbore bases had further improvements in that the center of the hole did not have additive material for the first layers. The zero overbore sample has a slightly improved definition of where the final radius should be for each layer. A difficulty for the process development was that the LENS material deposition team only had two process setup pieces, which was insufficient for optimizing the deposition approach. As shown by Fig. 5, considerable improvement in the appearance of the...
samples is evident from the 0.045-in. (1.14-mm) overbore to the 0.015-in. (0.38-mm) overbore, or from the first to the seventh component (the first of the 0.015-in. overbore repairs). Additionally, as the amount of overbore changed, the diameters of the deposited rings changed, which added another variable to the process development challenges.

In addition to filling the weld base bores, the bases had surface flaws to be repaired. These flaws were developed to be typical of shipping, usage, and handling scratches as might be found on any part that had been through a number of machining processes. The repaired scratches are shown in Fig. 6 with the radial deposit lines showing the location of the scratches. The challenge of repairing these flaws is that the flaws were truly random (created with a hand awl) so process planning was a bit challenging. However, by “blipping” the laser on and off, the end points of straight lines were determined that would cover the flaws.

The process parameters used for the bores are given in Table 1 where they are compared to process parameters determined for large block samples, used for tensile testing, of the same 304L material. In contrast to the description presented earlier, the reclamation weld base repairs were all performed without the closed-loop melt pool controller since the controller was getting false signals from reflections off the walls of the bore.

LENS Repair of Sample Bottle Surface Flaws

The second set of components provided for LENS repair was gouged sample gas bottles. These items represented bottles that are rejected by the customer if there is any visible surface flaw on them, which is typically less than 0.001 in. (0.025 mm) deep. These test sample gouges were milled into each bottle. The gouges were 0.125 in. (2.5 mm) wide and either 0.010 in. (0.25 mm) or 0.020 in. (0.51 mm) deep, and were made by a parallel-sided end mill as shown in Fig. 7. The bottles were positioned in the LENS machine in a V block and toe clamped as shown in Fig. 8. The bottle was positioned against a pin at the end of the V block for positioning and a V-block clamp was used to roll the bottle until the gouge was perpendicular to the laser axis and centered. The toe clamps were then lightly tightened to hold the bottle. The laser, set at low power, traced the edges of the gouge to check alignment. The LENS repair then occurred with the laser depositing two or three layers [for 0.010- and 0.020-in.-(0.25-and 0.51-mm) deep gouges, respectively], as shown in Fig. 9. Due to the limited number of samples prepared and programmatic restraints, neither postrepair metallography nor radiographic examination were conducted. The process parameters for the bottle repair are given in Table 2 for comparison with the process parameters determined for the deposition of the monolithic blocks.

Hydrogen Compatibility Testing

It is widely known that austenitic stainless steels perform better than other types of stainless steel in hydrogen environments. A critical aspect for using repaired components in a hydrogen environment is understanding the interactions between hydrogen and various materials used in process, handling, and storage systems. For this program, 304L was selected as the material of interest for evaluation since it is a major component of various components exposed to hydrogen. To determine the effect of hydrogen on LENS-repaired components, two aspects were studied. The initial effort focused on the evaluation for hydrogen compatibility of baseline materials for LENS processed 304L. Following this initial material properties evaluation, the program considered the repair or modification of representative components using LENS and the subsequent performance of these parts and components following repair or modification in the baseline and hydrogen-charged condition. As was discussed previously, the components selected for repair by
SRNL were gas bottle reclamation weld bores and gas bottle surface defects.

Microstructure and Mechanical Properties of LENS® Processed Material

Microstructure Characterization of 304L LENS Materials. A sample from the 8-cm block of 304L LENS materials fabricated by SNL was sectioned, mounted, polished, and examined using light optical microscopy. The multilayered structure displayed in Fig. 10 is characteristic of LENS-deposited materials and depicts the nature of the multipass deposition technology with very fine grains and interpass and interlayer interfaces. Unfortunately, higher magnification images were not taken so the solidification morphology and primary solidification mode cannot be discerned.

Table 2 — LENS® Process Parameters for Sample Gas Bottle Surface Flaws Compared to Parameters for LENS® Deposit of Large 304L Blocks

<table>
<thead>
<tr>
<th>Process Development</th>
<th>Surface Flaw</th>
</tr>
</thead>
<tbody>
<tr>
<td>Powder Flow Rate (gal/min)</td>
<td>23 (400 rpm)</td>
</tr>
<tr>
<td>Laser Power (W)</td>
<td>350–400 W (26–28 A) – 575 W 1st layer</td>
</tr>
<tr>
<td>Filter %</td>
<td>80%</td>
</tr>
<tr>
<td>WP Intensity</td>
<td>400/150</td>
</tr>
<tr>
<td>Fill Area (pix)</td>
<td>750/650</td>
</tr>
<tr>
<td>Border Area (pix)</td>
<td>750/650</td>
</tr>
<tr>
<td>Axis Feed Rate (in./min)</td>
<td>22/20</td>
</tr>
<tr>
<td>Material</td>
<td>304L Drill Blocks</td>
</tr>
</tbody>
</table>

Mechanical Behavior of LENS Processed Material in Hydrogen. A challenge to the successful qualification and acceptance of LENS-processed materials for service in hydrogen isotope applications is the ability to demonstrate that the mechanical properties are at least comparable to conventional materials. As such, the focus of this task was to evaluate the tensile properties, including yield strength, ultimate tensile strength, and elongation to failure, of LENS materials in both the uncharged and hydrogen-charged conditions. No attempt will be made to compare LENS material properties to the production forged, pedigreed gas transfer bottle materials. Sub-miniature tensile dogbone samples were machined from an 8-cm¹ (3.15-in.) block of 304L LENS materials prepared by SNL — Fig. 11A. The samples were fabricated using electric discharge machining (EDM) at SRNL. Comparison samples were machined from 0.020-in.- (0.51-mm-) thick 304L commercial sheet stock material. The tensile dogbone samples had a 0.3-in. (12-mm) gauge length and an overall sample length of 1.25 in. (31.7 mm). The tests were conducted on samples charged for 5 days at 2500 lb/in.² (17.2 MPa) H₂ at 325°C, which should yield 4.4 cc H₂ per cc metal. Testing was performed at room temperature in air using a screw-driven testing machine with pneumatic grips and a cross-head speed of 0.002 in./min (0.051 mm/min). The load was measured by the load cell on the machine, and the gauge length displacement was measured with a clip gauge attached directly to the sample — Fig. 11B.

In addition to this tensile mechanical

---

**Fig. 8** — Mounting fixture in LENS machine holding bottle for repair.

**Fig. 9** — Repaired gouge in sample gas bottle.

**Fig. 10** — Representative microstructure of as-processed 304L LENS materials (polished and electrolytically etched (10% oxalic acid)).

**Fig. 11** — A — 8-cm block of 304L LENS-processed material and EDM harvested tensile dogbones; B — tensile testing 304L LENS materials.

**Fig. 12** — A — Schematic of small sample punch test; B — SRNL punch test apparatus.
testing, some small sample punch tests were performed to compare the fracture toughness behavior of hydrogen-charged with uncharged LENS-processed 304L material. This technique is amenable to small sample sizes and the experimental setup is rather simple. The arrangement of the technique is shown in Fig. 12A. Tests are conducted on samples approximately 0.118 in. (3 mm) in diameter and 0.008–0.012 in. (0.5–0.75 mm) in thickness. A load is placed on the disk sample via the tensile load frame cross-head pushing on the punch rod of the test apparatus. Typical cross-head speeds of 0.004–0.008 in./min (0.1–0.2 mm/min) are employed. As a relative measure of fracture toughness, several empirical relations have been developed in the literature (Refs. 16–18). Using the original sample thickness and the deflection at sample failure, the biaxial fracture strain is calculated. Using this calculated biaxial fracture strain and an empirically determined relationship between biaxial fracture strain and measured ductile fracture toughness, $J_{IC}$ values can be estimated. Punch test samples were also machined from an 8-cm³ block of 304L LENS materials prepared by SNL—Fig. 11A. The samples were fabricated using EDM similarly to the tensile samples discussed above. The punch samples were approximately 0.118 in. (3 mm) in diameter and 0.010 in. (0.025 cm) in thickness. The tests were conducted on samples charged for 5 days at 2500 lb/in.² (17.2 MPa) H₂ at 325 °C, which should yield 4.4 cc H₂ per cc of metal. Testing was performed at room temperature in air using a screw-driven testing machine with a 1-mm-diameter tungsten carbide ball at a cross-head speed of 0.008 in./min (0.203 mm/min) while recording load and cross-head displacement via a gauge attached to the compression platen.

**Sample Preparation**

Reclamation welds were made using the nominal weld parameters for common production-type test bases fabricated from Type 304L stainless steel, i.e., 2250-lb (5.56-kN) loading force, 11,400-A welding current, and 25 weld cycles based on a 60-Hz weld process current. All of the welds were performed in a manner consistent with the production weld parameter range. Typical reclamation test bases in the as-machined, as-repaired, and as-welded conditions are shown in Fig. 13. There is a small amount of heat banding and some material extrusion around the weld; these features are typical of normal production reclamation welds.

Commercial gas sample bottles, formed by hot spinning and subsequent grinding, were also tested to determine the effect of deep scratches on the burst test characteristics. Sample bottles were prepared for LENS repair by milling a ½-in.-wide notch to a depth of either 0.010 or 0.020 in. deep and LENS repairing the notch. This defect represents a worst-case scenario for small scratches on a reservoir that would result in rejection of the reservoir. The vessels were turned to remove the excess LENS material. The surface condition of the gas sample bottles in the as-milled, as-welded, and as-final-machined conditions is shown in Fig. 14. The vessels were machined to the extent needed to remove the weld reinforcement; no vessel wall material was removed. Since only the minimum material was removed, the entire LENS repair did not clean up. The residual stresses due to the repair process are the most likely cause for the remaining depression in the vessel.

**Hydrogen Charging**

An autoclave engineer’s 1-gal vessel was used to charge the samples. The vessel is rated at 3500 lb/in.² (24.1 MPa) [at 650°F (343°C)] and is made from stainless steel. The vessel is heated by three heater bands that were powered using a PID-controlled power supply. The samples were placed in the vessel with the gas samples on the bottom and the reclamation welded samples on top. The vessel
was approximately 60% filled with hardware. The top cover was installed and argon was used to purge air from the system and internal surfaces of the test articles. After about 20 min, hydrogen at a pressure of 1500 lb/in$^2$ (10.3 MPa) was introduced. The vessel was then heated to 617°F (325°C), the pressure increased to approximately 2500 lb/in$^2$ (17.2 MPa) and held for four days. These conditions are predicted to result in 4.4 cc H$_2$ per cc metal. These test conditions were deemed adequate to achieve greater than 95% hydrogen saturation based on SRNL Diff94 permeation calculations; this program uses a finite difference with published data for solubility and diffusivity to calculate hydrogen concentration profiles. At least one sample of each manufacturing defect and LENS repair condition was tested without hydrogen charging so the effect of hydrogen on the sample could be ascertained. There was some hydrogen pressure decay that is likely due to some leakage as well as hydrogen uptake by the samples, since the vessel did not have an active pressurization control loop, no adjustments for the loss of pressure were made. The samples were cooled under hydrogen pressure, removed from the vessel and tested.

### Table 3 — Estimated Decrease in Fracture Toughness for 304L LENS® Materials Exposed to Hydrogen

<table>
<thead>
<tr>
<th>Material and Condition</th>
<th>$\epsilon_{eq}$</th>
<th>Estimated $J_{IC}$ (kJ/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LENS® 304L Longitudinal — Air</td>
<td>1.250</td>
<td>300</td>
</tr>
<tr>
<td>LENS® 304L Transverse — Air</td>
<td>1.112</td>
<td>261</td>
</tr>
<tr>
<td>LENS® 304L Longitudinal — Hydrogen</td>
<td>0.630</td>
<td>126</td>
</tr>
<tr>
<td>LENS® 304L Transverse — Hydrogen</td>
<td>0.564</td>
<td>108</td>
</tr>
</tbody>
</table>
Results and Discussion

Typical results from the tensile testing and small sample punch testing of 304L LENS samples are shown in Figs. 15 and 16. The tensile curves in Fig. 15 show that for both the longitudinal and transverse sample directions (longitudinal and transverse to the build direction of the 8 cm³ block), there is little difference in the yield strength (YS) and ultimate tensile strength (UTS) comparing identically oriented samples exposed to hydrogen to those not exposed. The largest difference between the unexposed and exposed samples occurs with respect to the percent elongation to failure (%EL). The %EL in both orientations decreased following exposure of the materials to hydrogen. This indicates the reduced ductility from hydrogen embrittlement, which would manifest itself potentially in reduced fracture toughness. Examination of literature data for 304L in both the unexposed and hydrogen-exposed conditions shows a similar trend—little change, to some strengthening—in the tensile properties of YS and UTS with greater change in the %EL upon exposure to hydrogen (Ref. 26). Further analysis of this literature fracture data for samples that exhibited reduced %EL upon exposure to hydrogen has shown a reduction in the ductile fracture toughness on the order of 25–40%.

Analysis of the small sample punch test data in Fig. 16 to estimate the reduction in fracture toughness of the LENS process 304L material upon exposure to hydrogen has been performed. Calculation of the biaxial fracture strain ε_f using Equation 1,

\[ ε_f = 0.15 (b/t_0) \]  

(1)

in both the longitudinal and transverse direction, shows that the estimated strain at fracture for both directions upon exposure to hydrogen decreases on the order of 35%. Estimation of the ductile fracture toughness values using the ε_f and the empirical relationship, Equation 2,

\[ J_{IC} (kJ/m²) = 280 ε_f - 50 \]  

(2)

is given in Table 3. Examination of the trend for the estimated ductile fracture toughness values in Table 3 shows that hydrogen exposure decreases the fracture toughness and that the transverse orientation appears to be more susceptible.

Burst Testing Reclamation Test Bases

The reclamation test samples and bottles are shown in Fig. 20. Similar results for different hydrogen concentrations are shown in Fig. 20, with B — hydrogen charged.

Table 4 — Preparation and Charging Conditions and Test Results for the Reclamation Test Samples and Hydro Burst Results

<table>
<thead>
<tr>
<th>Sample</th>
<th>Charged</th>
<th>Burst Pressure (lb/in.²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LF-7 0.000 3</td>
<td>N</td>
<td>56,172</td>
</tr>
<tr>
<td>LF-7 0.000 2</td>
<td>Y</td>
<td>56,819</td>
</tr>
<tr>
<td>LF-7 0.000 1</td>
<td>Y</td>
<td>57,668</td>
</tr>
<tr>
<td>LF-7 0.015 3</td>
<td>N</td>
<td>61,243</td>
</tr>
<tr>
<td>LF-7 0.015 2</td>
<td>Y</td>
<td>63,180</td>
</tr>
<tr>
<td>LF-7 0.015 1</td>
<td>Y</td>
<td>59,864</td>
</tr>
<tr>
<td>LF-7 0.030 3</td>
<td>N</td>
<td>59,471</td>
</tr>
<tr>
<td>LF-7 0.030 1</td>
<td>Y</td>
<td>62,289</td>
</tr>
<tr>
<td>LF-7 0.030 2</td>
<td>Y</td>
<td>62,113</td>
</tr>
<tr>
<td>LF-7 0.045 1</td>
<td>N</td>
<td>61,752</td>
</tr>
<tr>
<td>LF-7 0.045 2</td>
<td>Y</td>
<td>63,406</td>
</tr>
<tr>
<td>LF-7 0.045 3</td>
<td>Y</td>
<td>62,490</td>
</tr>
</tbody>
</table>
Fig. 23 — A — Metallographic cross section of a burst tested, LENS-repaired 0.045-in. overbore reclamation weld; B — typical Type 304 SS reclamation weld in the as-welded condition (note parallel nature of foot base and reclamation base).

Fig. 24 — Typical area of a LENS-repaired sample that had a 0.020-in.-deep notch machined into it.

Fig. 25 — Burst test sample fractography.

tles were burst tested using hydroburst testing equipment. The samples were connected to the high-pressure fittings and pressurized to failure in about 1 min. The burst tests were videotaped so the burst location could be observed.

All of the reclamation test welds failed in the fill stem tube wall at a pressure of approximately 58 to 62 ksi, which is consistent with the expected material properties of these stems. A graph of the data is shown in Fig. 17 and a photograph of a typical burst tested reclamation test stem is shown in Fig. 18. It can be seen that the tube split and formed a fingernail-type breach. The test results for the reclamation test base samples are listed in Table 4. Failure in the tube wall is expected since the strength of the weld and the length of the effective bond would have to be less than half the wall thickness if the stem were to fail in any other manner, based on a comparison to the thin wall pressure vessel calculations (Ref. 31) where

\[ \sigma_{\text{hoop}} = \frac{\text{pressure} \times \text{radius}}{\text{thickness}} \]  

and

\[ \sigma_{\text{axial}} = \frac{\text{pressure} \times \text{radius}}{2 \times \text{thickness}} \]  

Thus, it is apparent that the axial stress, i.e., the location of the LENS material that is bonded to the test base, will be \( \frac{1}{2} \) that of the hoop stress.

**Burst Test Gas Sampling Bottles**

The sample bottles were sealed on one end with a threaded plug and fitted with a high-pressure fitting on the other end for pressurization. The vessels were filled with water using a hypodermic needle. The bottles were then attached to the system piping and were pressurized to failure in approximately 1 min. The vessels all exhibited a longitudinal tear that apparently initiated near the center of the vessel, which would be at the location of the highest strain. The data for the as-received sample bottle are comparable to the vendor certification data for these vessels (Table 5). The as-notched samples in the uncharged condition exhibited a reduction in both burst pressure and failure ductility. LENS repair for a 0.010-in.-deep notch is able to restore the burst pressure; however, the uniform strain (ductility) is not fully restored — Fig. 19.

The hydrogen-charged samples exhibit interesting results. The baseline data shown in Fig. 19 are repeated in Fig. 20 along with the hydrogen sample data. The hydrogen-charged samples show some strengthening due to hydrogen charging. This phenomenon has been seen in previous tensile test work (Ref. 26). The hydrogen data plotted in Fig. 20 are the average of the two points for each condition indicated in Table 5. As was the case for the baseline samples, the presence of notches reduced the burst pressure for hydrogen-charged samples, although the fractional reduction in burst pressure was less for the hydrogen-charged samples than the baseline. The burst ductility is lower for the hydrogen-charged samples with notches. The sample with the 0.010-in. (0.25-
mm) notch that was LENS repaired demonstrated a slight increase in strength over the baseline condition for hydrogen charging and essentially no loss from the baseline value. Both the 0.020 in. (0.51 mm) notched and 0.020 in. (0.51 mm) notch and LENS-repaired sample exhibit burst pressures and uniform strains of 23 and 20%, respectively, compared to 40% for the baseline sample.

The appearance of the burst tested gas sample bottles exhibited the expected failure with the bottle opening up axially; in addition, all of the samples with notches failed in the notches. There was one exception for the LENS-repaired samples: Sample 0.010 LENS-repaired 1, which failed in the vessel body away from the LENS repair, suggesting an excellent repair and no adverse impact on strength. Macrophotographs of the burst-tested vessels are presented in Fig. 21. The baseline samples are presented in Fig. 21A, and the hydrogen-charged samples are presented in Fig. 21B. The change in sample diameter growth, i.e., direct indication of strain, is apparently lower as the extent of the defect increases.

The fracture surfaces of the LENS repaired surfaces were also examined. The LENS material appears to have cracked axially and some of the samples exhibit a possible delamination. This failure mode may be indicative of the deposition method and deposition direction. The cracking and onset of delamination of sample 0.010 LENS H₂ that did not fail in the LENS repair area is shown in Fig. 22.

The LENS repairs for the sample gas bottles were generally successful with the repaired gouges having an acceptable appearance as shown in Fig. 14. Upon hydrogen charging and burst testing, the bottles all passed the required pressure before bursting, but the bottles did burst along one edge of the gouge. Further analysis and sectioning showed that the LENS material did not quite fill the bottom corner of the gouge in some cases. This bottom corner of the gouge acted as a stress riser causing failure to initiate at the site. To achieve better results in the future, it is suggested that a ball end mill or angled mill be used to make the bottom corner easier to fully fill with LENS material and to reduce the stress riser. It is expected that this modification would make the failure much less likely to occur at the gouge location.

**Metallographic Examination**

Metallographic examination of selected samples was conducted. The samples were cut, polished, and electrolytically etched using a 10% oxalic acid solution. The samples were then examined on an inverted microscope and photographed at suitable magnifications to show the desired attributes.

The reclamation test base that was overbored by 0.0045 in. was selected for metallography after burst testing. A low-magnification view of the sample is shown in Fig. 23A. The fill stem foot is not parallel to the test base due to the burst testing. The edges of the welds may have been separated as well. Due to limited assets, metallographic examination was not conducted prior to testing. However, a typical reclamation weld of a baseline sample is shown in Fig. 23B. The welds generally exhibit 50 to 70% side bonding with a significant amount of extrusion on the top of the sample.

A comparison of the microstructure from a typical Type 304L SS reclamation weld reveals similarities and differences. The flow lines for both the stem foot as well as the base material are apparent. There are perceived differences in the relative amount and location of the material for the LENS-repaired sample compared to the standard base. The presence of flow lines in the LENS material is less apparent than for the fill stem base stock. Note also the presence of fine porosity in the “corner” of the reclamation test base/LENS material. The LENS material seems to have machined well as there is no indication of smearing on the chamfer at the bore centerline.

The sample bottles were also examined metallographically. A typical LENS repaired and machined sample is shown in Fig. 24. This sample exhibits some voids and porosity in the repair area. At least two different sample elevations were examined to verify the presence of these anomalies. The voids appear to be due to incomplete fusion of the laser-sintered powder to the bottle substrate. Higher magnification images clearly indicate that the bond is intermittent. The shape of the voids also indicate incomplete fusion as opposed to gas formation voids. It is surmised that a change in the bottle slot geometry to make the defect more weld repairable would have improved the nature of this repair. It is further expected that radiographic examination of the bottles prior to testing would have revealed these defects and perhaps have enabled a secondary fusion cycle to “heal” the voids. An optimized process certainly would have enabled higher-quality LENS repair techniques and material application to be implemented.

To better understand the nature of the fractures that were observed in the bottle burst tests, the fracture surfaces were examined using the scanning electron microscope. This examination revealed interesting results that support the findings of incomplete fusion that were observed in the optical microscopy. In Fig. 25, the edge of the machined notch can be seen adjacent to the powder fill that still shows sintered particles that retained their spherical geometry.

Ductile rupture was apparent for both the baseline and hydrogen-charged samples. There was no obvious change in the dimple size between the hydrogen-charged samples and the baseline samples. In a well-bonded area of the LENS-repaired sample, there is evidence of ductile rupture with a very fine dimple size.

**Summary**

Reclamation test bases that were overbored for both diameter and depth were successfully repaired using the LENS process. The material was machined and prepared in an acceptable manner for reclamation welding. Weld conditions identical to properly machined produc-
tion-like test bases were successfully used for the LENS-repaired components. Baseline and hydrogen-charged reclamation test weld assemblies were burst tested with failures occurring in the fill stem wall at pressures consistent with expectations. Gas sample bottles were machined to introduce a notch the length of the bottle that was 0.010 or 0.020 in. deep. Gas bottles with the notches were LENS repaired using a nonoptimized method. Gas sample bottles in the as-received, as-notched, and LENS-repaired conditions were hydrogen charged. Both hydrogen-charged and baseline gas sample bottles were hydrous burst tested to failure. Hydrogen-charged samples exhibited slightly higher burst pressures and somewhat lower burst ductilities compared to baseline conditions. The strength of the LENS-repaired 0.010-in.-deep notch samples was slightly higher than the notched sample. With the exception of one sample, all of the LENS-repaired gas bottles failed in the LENS repair. The microstructure of the LENS-repaired material reveal incomplete fusion in a number of the overlay passes. The presence of unmelted particles at the fracture surface confirms inadequate heat. It appears that LENS repair is highly suited for the repair of overbaked reclamation-type materials.

Additional process development is required for weld repair of notched gas sample vessels. This development should include joint preparation in addition to thermal inputs and translation rates.

References


Authors: Submit Research Papers Online

Peer review of research papers is now managed through an online system using Editorial Manager software. Papers can be submitted into the system directly from the Welding Journal page on the AWS Web site (www.aws.org) by clicking on “submit papers.” You can also access the new site directly at www.editorialmanager.com/wj/. Follow the instructions to register or login, and make sure your information is up to date. This online system streamlines the review process, and makes it easier to submit papers and track their progress. By publishing in the Welding Journal, more than 66,000 members will receive the results of your research. Additionally your full paper is posted on the American Welding Society Web site for FREE access around the globe. There are no page charges, and articles are published in full color. By far, the most people, at the least cost, will recognize your research when you publish in the world-respected Welding Journal.
<table>
<thead>
<tr>
<th>Month</th>
<th>Topics</th>
<th>Editorial Deadline</th>
<th>Advertising Deadline</th>
</tr>
</thead>
<tbody>
<tr>
<td>March</td>
<td>Maritime Construction, Do-It-Yourself Projects, Bonus: The American Welder</td>
<td>Jan. 23</td>
<td>Feb. 1</td>
</tr>
<tr>
<td>April</td>
<td>Update on Power Sources, Training for a Welding Career</td>
<td>Feb. 17</td>
<td>March 1</td>
</tr>
<tr>
<td>May</td>
<td>Welding Structural Steel, New Faces in Welding</td>
<td>March 21</td>
<td>April 3</td>
</tr>
<tr>
<td>June</td>
<td>Considerations for Welding Pipe and Tube, Fabricating for Underground Projects, Bonus: The American Welder</td>
<td>April 20</td>
<td>May 1</td>
</tr>
<tr>
<td>July</td>
<td>Welding for the Food Processing Industry, Brazing and Soldering Today</td>
<td>May 23</td>
<td>June 1</td>
</tr>
<tr>
<td>August</td>
<td>Personal Protection and Safety on the Job, Oxyfuel and Plasma Cutting</td>
<td>June 22</td>
<td>July 2</td>
</tr>
<tr>
<td>September</td>
<td>Weld Inspection, Bonus: The American Welder</td>
<td>July 23</td>
<td>Aug. 2</td>
</tr>
<tr>
<td>October</td>
<td>2012 FABTECH Preview</td>
<td>Aug. 21 Bonus Distribution at FABTECH</td>
<td>Sept. 3</td>
</tr>
<tr>
<td>November</td>
<td>Welding Stainless Steel and Other Corrosion-Resistant Alloys, Robotics and Automation</td>
<td>Sept. 21</td>
<td>Oct. 2</td>
</tr>
<tr>
<td>December</td>
<td>Eco-Friendly Manufacturing and Fabricating, Software for Improved Efficiency, Bonus: The American Welder</td>
<td>Oct. 23</td>
<td>Nov. 2</td>
</tr>
</tbody>
</table>
Arcos Electrodes
Meet Exacting Military and Nuclear Standards.

We Can Meet Yours, Too!

When critical welding conditions necessitate performance without compromise, you can depend on Arcos to provide you with a comprehensive line of premium quality high alloy, stainless and nickel electrodes to conform to your stringent requirements.

You can be assured of our commitment to superior welding products because Arcos quality meets or exceeds demanding military and nuclear application specifications. Arcos’ dedication to excellence has earned these prestigious certifications:

- ASME Nuclear Certificate # QSC448
- ISO 9001: Certified
- Mil-I 45208A Inspection
- Navy QPL

To learn more about the many reasons you should insist on Arcos high alloy, stainless and nickel electrodes for your essential welding applications, call us today at 800-233-8460 or visit our website at www.arcos.us.

Arcos Industries, LLC
394 Arcos Drive • Mt. Carmel, PA 17851
Phone: (570) 339-5200 • Fax: (570) 339-5206

For info go to www.aws.org/ad-index
IT’S YOUR CHOICE!

POWER MIG® 140C (K2471-1)
120 Volt Input MIG Welder

$599
After $75 Manufacturer Rebate

OR
VIKING™ Auto-Darkening Helmet - Tribal™ (K3024-1)
A $181 Value!

POWER MIG® 180C (K2473-1)
230 Volt Input MIG Welder

$699
After $75 Manufacturer Rebate

OR
VIKING™ Auto-Darkening Helmet - Tribal™ (K3024-1)
A $181 Value!

POWER MIG® 216 (K2816-1)
216 Amp Output MIG Welder

$1,499
After $125 Manufacturer Rebate

OR
Magnum® 100SG Spool Gun (K2532-1)
A $229 Value!

Square Wave TIG 175 (K1478-5) 175 Amp TIG Welder

$1,699
After $150 Manufacturer Rebate

OR
VIKING™ Auto-Darkening Helmet - Tribal™ (K3024-1)
A $181 Value!

Outback® 145 (K2707-2) Engine-Driven Welder/Generator

$1,799
After $150 Manufacturer Rebate

OR
Canvas Cover (K2804-1) Accessory Kit (K875)
VIKING™ Auto-Darkening Helmet - Tribal™ (K3024-1)
A $405 Value!

To learn more go to www.lincolnelectric.com
(Customer pricing determined by suggested retail price less manufacturer rebate)

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

LINCOLN ELECTRIC
THE WELDING EXPERTS®