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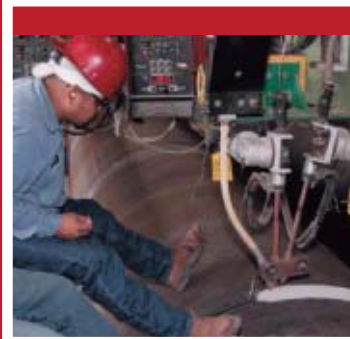
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4 QUESTION SURVEY

WELDING *Journal*

March 2009



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- Reduce Distortion in Ship Panels

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PRESS TIME

NEWS

U.S. Navy Awards General Dynamics \$6 Million for Nuclear Submarine Services

The U.S. Navy recently presented General Dynamics Electric Boat a \$6.3 million modification to a previously awarded contract for management and support of nuclear-maintenance work for submarines homeported at the Naval Submarine Base New London in Groton, Conn. It will continue to operate the Nuclear Regional Maintenance Department (NRMD) at the submarine base through Sept. 30.

In addition, the company will provide project management, planning, training, and radiological control services to support maintenance, modernization, and repairs. A core group of about 25 Electric Boat employees is assigned to the NRMD, with surge groups of up to 100 shipyard employees assigned for short periods.

Northrop Grumman Shipbuilding Aids Gulf Coast Middle Schools with \$25,000 Grants

Northrop Grumman Corp., Pascagoula, Miss., has awarded five gulf coast school districts grants of \$5000 each. These are to be used for specific science, technology, engineering, and math (STEM) projects. Each district will select a middle school within its district to implement and improve necessary STEM resources.

Also, each school district provided details describing its STEM projects. Hancock County seeks to increase measurement knowledge and hands-on work to connect concrete and abstract science in students' minds. Harrison County, with an award to North Gulfport, aims to supplement career discovery classes. Mobile County's grant went to Phillips Preparatory School to update equipment allowing students to load daily news broadcasts to the school's Web site. Moss Point received funds for Magnolia Jr. High, providing alignment with the vocational/technological/scientific programs being offered at high school. Lastly, Pascagoula School District's grant went to Gautier Middle School, which will add to the knowledge that exists in the 2010 Mississippi Science Framework.

If your school wants to participate in the STEM grant program, visit www.northropgrumman.com/corporate-responsibility/corporate-citizenship/contribution-guidelines.html. Information can be obtained there about the company's contributions guidelines and an online application is available. Only one middle school STEM program will be selected for each district. Grant applications must be submitted by Aug. 31 and will be chosen by committee. Applications will be considered in the order received.

Laser Mechanisms Relocates Headquarters

Laser Mechanisms, Inc., a designer and manufacturer of laser beam delivery components and articulated arm systems, has moved its corporate headquarters from Farmington Hills to Novi, Mich. The 22,000-sq-ft facility houses corporate offices, sales, and engineering. Plus, an adjacent 28,000-sq-ft building is being completed for manufacturing and warehousing operations. Together, the two facilities will nearly double the company's previous square footage. This relocation is in response to sustained sales growth and will enable Laser Mechanisms to more effectively serve its expanding customer base.

Airgas National Welders Wins Defense Logistics Agency Performance Award

The Defense Logistics Agency (DLA) has selected Airgas National Welders, Charlotte, N.C., as its Large Business Innovative Performer of the Year for 2008. The company was nominated for the award by the Defense Energy Support Center (DESC) and recently accepted the honor from DLA Director Vice Admiral Alan S. Thompson at the DLA Business Alliance Awards Luncheon in Springfield, Va.

Airgas National Welders was awarded this distinction for its innovation in developing design solutions for safe, high capacity, and high flow cylinder pallet delivery systems. These are known as High Pressure Cylinder Assemblies to DESC's customers. The customized cylinder pallets are capable of transport in a variety of modes as well. The company built, filled, and delivered them for DESC use in overseas deployments.

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EDITORIAL

Making Yourself Recession Proof

The slumping economy is providing new challenges for many of us. In the corporate world, businesses are making tough decisions to trim budgets. At home, we're stretching our paychecks to cover expenses and cutting back spending on nonessentials.

While it is wise to be a prudent consumer, two areas in which you should not cut back are your professional qualifications and professional memberships. Evidence shows that both of these categories actually take on added value during economic downturns.

Professional Qualifications. Many experts believe that during tough economic times technical skills tend to fare better than other abilities. Having spent a considerable part of my career as a welding instructor in the power industry, I agree with this observation.

One reason technical skills gain added luster during tough times is because technical skills drive revenue. For example, workers who have the ability to construct or repair have high worth to employers. Workers with special skills are included among a company's valuable assets.

Another reason technical skills are desirable is that they are transferable. Workers can apply their core skills in many different roles. Even if loss of employment should occur, technical skills are transferable across a wide spectrum of industries. As a result, many individuals today are wisely investing in themselves by updating their skills and developing a wide range of new ones. In the process, these farsighted individuals are making themselves as recession proof as possible.

Professional Membership. The American Welding Society, like other professional associations, is meant to be an agent of change, designed to meet your needs regardless of the economic climate.

One way your membership can provide great benefits is through the grass-roots infrastructure of AWS Sections and Student Chapters located around the world. This fundamental facet of our Society continues to be an amazing asset. This unique global network affords you access to a never-ending wealth of information.

Section meetings allow you to keep up with the latest industry developments. Gold-standard presentations, many times delivered by industry leaders, cover the spectrum of welding industry technology. Do not underestimate the significant role Section meetings play in your obtaining industry knowledge.

In addition, Section meetings provide ample opportunities to cultivate professional relationships. Social networks of friends and associates can prove valuable during times of need. Over the years, I have seen career-defining relationships established at Section meetings.

Meeting attendance produces another intangible benefit. For many, fellowship with others having similar interests provides the moral and emotional support needed during economic turmoil. The need we have to associate does not diminish. We will continue to join together for the common good.

Interestingly, a study recently released by *London Economics* made this conclusion: "Individuals with professional qualifications and membership in a professional association are estimated to achieve higher earnings and are more likely to be employed across a lifetime, in comparison to individuals with no professional qualifications."

As we forge ahead during this time of economic uncertainty, rest assured that your AWS leadership is dedicated to finding ways of adding increased value to your membership. For example, membership benefits now feature health, dental, and disability income insurance. As new benefits continue to be added, it will become increasingly apparent that your AWS membership has deep relevancy to your career.

Experts tell us that economic recessions eventually end. In the meantime, take the opportunities to invest in yourself. Upgrade and expand your skills. Take full advantage of the benefits and opportunities that your AWS membership affords. Make yourself as recession proof as possible. Remember: *The best way to predict the future, is to invent it.* — Alan Kay, American computer scientist.



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“WHEN YOU WELD YOU PUT YOUR OWN SIGNATURE OUT THERE”

Stuart spent 13 years in the welding industry. He developed a passion for the trade while building boats in Louisiana.

Now Stuart teaches at the Southern Arkansas University Tech Career Academy. He became a teacher to help aspiring welders learn the art and craft of welding. “Seeing my students succeed is the most rewarding part of my job,” Stuart says.

AND TO HELP THEM SUCCEED, STUART USES A THERMAL ARC FABRICATOR 140 TO TEACH MIG WELDING. “WE LOOKED AT COMPETITORS’ MODELS, BUT TO ME, THERMAL ARC IS THE CADILLAC OF THE INDUSTRY.”

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“I tell students they can do anything they want with their future. They have no limitations to what they can achieve. “When you weld you put your own signature out there.”

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NEWS OF THE INDUSTRY

Grainger and Discovery Channel's Mike Rowe Join Forces to Support a Skilled Workforce



Grainger President and CEO Jim Ryan (shown right) unveils the company's 2009 catalog. It features Discovery Channel personality Mike Rowe (pictured left) on the cover. Both Grainger and Rowe are committed to raising awareness about the shortage of skilled workers and the growing technical demands of today's workplace.

Grainger, Lake Forest, Ill., has kicked off a partnership with Mike Rowe, creator, executive producer, and host of Discovery Channel's *Dirty Jobs*. As a company spokesperson, he will be featured on the cover of its 2009 catalog and make numerous appearances. In addition, Rowe is partnering with Grainger in raising awareness about the importance of technical education and growing shortage of skilled workers.

Rowe is "a strong advocate of our country's industrial and skilled workforce, and he understands the importance of preparing young people for careers in the trades, especially as baby boomers prepare to retire," said Jim Ryan, Grainger's president and CEO.

Through mikeroweworks.com, Rowe will also create an online information resource about the skilled worker shortage and a destination for those exploring careers in the trades.

Recently, Grainger and Rowe co-hosted a panel discussion in Orlando, Fla., to raise attention to the growing shortage of skilled workers. This brought together local industry experts from organizations such as Orlando's Valencia Community College and the Academy of Construction Technologies. Information on what is currently being done to address the need and how to collectively make an impact going forward were shared and discussed. The dialogue highlighted many aspects, including the need to educate young people and their parents on the career opportunities available in technical fields. Plus, the panel stressed the importance of

businesses and educators partnering on a local level to prepare students of all ages for future jobs.

In other news, the company will be reinforcing its commitment to technical education by more than doubling its Grainger Tools for Tomorrow® scholarship program. This year, Grainger will expand the program to award 100 scholarships to students across the country pursuing careers in areas such as welding, plumbing, and automotive repair.

Northern Michigan Welding Educators Organization Goes International



Darin Kearns, Northern Michigan Welding Educators (NMWE) president, and welding/metal fabrication instructor at Wexford-Missaukee Career Technical Center, Cadillac, Mich., is shown in the welding lab where he teaches. Kearns helped the NMWE members' ideas become a reality.

When a group of eight welding instructors sat down at their annual best practice seminar and discussed what collaborative groups are doing for their required Career and Technical Student Organization (CTSO), the Northern Michigan Welding Educators (NMWE) history began. They asked what would be the most valuable piece of education they could give their students to better prepare them for entering the workforce and learn about welding. The decision was to make a competition commensurate with the official code, simulating a real work experience.

In 2001, Darin Kearns of the Wexford-Missaukee Career Technical Center, Cadillac, Mich., and Chuck Hunt from Traverse Bay Area Intermediate School District Career-Tech Center, Traverse City, Mich., spearheaded this organization to keep it all about the students.

Collectively, the second part of NMWE/CTSO formed: not only expose students to AWS D1.1, *Structural Welding Code — Steel*, and D1.2, *Structural Welding Code — Aluminum*, but also give them an opportunity to take the 3-G 3/8 V-groove test in shielded metal arc, gas metal arc, and gas tungsten arc welding.

Every October, NMWE instructors meet to discuss ways to keep their students on track regarding relevant AWS code tests and address all issues affecting the curriculum. In addition, tours are taken to local welding fabrication-related businesses who are asked for their input. Each year the organization has a different host site, a rotation of its original ten-member team.

In March, students and all instructors are involved in the AWS

codes D1.1 and D1.2 welder qualification procedures. Also, at the March competition students test and compete against each other for the AWS Code Welder Qualification status.

Recently, the organization has grown beyond Northern Michigan. In 2008, it went international and spread to Canada.

As acting president, Kearns does not know what educational challenges 2009 will bring, but the group stands united, keeping it all about the students' education.

New Welding Station at Lincoln Land Community College Benefits Students



Lincoln Land Community College, Springfield, Ill., agriculture fertilizer operations major Zach Meisenheimer performs a gas metal arc weld for a T-weld class assignment. (Photo courtesy of LLCC.)

Not that long ago, Lincoln Land Community College (LLCC) installed a new welding station in the automotive lab on the main campus in Springfield, Ill., for training agriculture and automotive students. It offers them an opportunity to learn the fundamentals of repair and maintenance welding using gas metal arc and shielded metal arc welding.

"We are now better equipped to fill the specific welding training needs of our agriculture and automotive students," said LLCC Automotive Professor Dick Rogers. "The station greatly enhances the students' learning experience with the specialized instruction we can offer them."

In the near future, this station may expand to include use by courses such as art and sculpture. The college further offers a separate welding program and facilities for students wishing to become professional, qualified welders.

Ohio Technical College and Lincoln Electric Team Up in New Welding Program

Ohio Technical College, Cleveland, Ohio, has partnered with The Lincoln Electric Co. to launch a new welding course. This will help meet workforce demand by providing skilled welders.

Enrolled students will receive training at the college's new welding facility outfitted with up-to-date welding equipment and consumables supplied by Lincoln. The 12-month program will



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An Ohio Technical College student practices his welding skills during class. Recently, the college partnered with The Lincoln Electric Co. to launch a 12-month welding program using the latest equipment. (Photo courtesy of Ohio Technical College.)

focus on arc welding skills, processes, techniques, and safety. Students will receive certification following successful course completion. For more information, visit the college's Web site at www.ohiotechnicalcollege.com.

"We're very excited about our partnership with Ohio Technical College because to be successful, it's imperative to the welding market to have a supply of professionally trained welders who understand the safe use of the latest processes and technologies," said Carl Peters, director of training, Lincoln Electric.

Friedman Industries Starts Steel Coil Processing Facility



Friedman Industries, Inc., has opened a steel coil processing plant in Decatur, Ala. It is designed to convert hot-rolled coils received from the adjacent Nucor Steel Co. mill into hot-rolled sheet and plate relieved of distortions commonly associated with coiled steel through the use of temper-passing and leveling equipment. Located on 47.3 acres, the facility began operating in August 2008. It features 48,000 sq ft of plant and warehouse, plus another 2000 sq ft of offices. This plant also follows the Friedman business model of locating next to a major steel mill that translates into reliable supply, higher productivity, and lower production costs.



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First Urban High School to Earn Metalworking Skills Accreditation Honored



Dave Sansone (right), executive director, Precision Metalforming Association Educational Foundation, presents the National Institute for Metalworking Skills accreditation plaque for Max Hayes High School to (from left) Dave Volosin, principal; Israel Burgos, CNC instructor; and Tony Kazel, senior instructor and department head.

Max Hayes High School, Cleveland, Ohio, has recently been recognized by the National Institute for Metalworking Skills (NIMS) as the first urban high school in the country to achieve NIMS educational training program accreditation.

David Sansone, NIMS board and executive committee member and Precision Metalforming Association Educational Founda-

tion executive director, presented school representatives with a plaque denoting this recognition for its CNC machining program. The foundation supported the school's efforts with a small grant, along with many local companies that invested funds, time, and equipment to assist its efforts.

The purpose of the accreditation is to improve the quality of training programs as part of the national endeavor to build and maintain a globally competitive workforce while providing workforce development opportunities for potential and current employees. It involves a three-step process along with credentialing requirements.

Simonds Launches Centralized Bandsaw Blade Welding Center

Simonds International has established its new Central U.S. Weld & Distribution Center, a bandsaw blade welding supercenter, located in Louisville, Ky. The multishift operation offers faster order turnaround, faster order fill rates, and good weld quality. It replaces three current weld center facilities. From here, the company can offer next-day delivery to America's industrial heartland. Additionally, the center focuses on LEAN manufacturing techniques leading to improvements in quality, consistency of the welded bands, and packaging.

Industry Notes

- **TurboSonic Technologies, Inc.**, has received a \$1 million contract to supply a SonicKleen™ wet electrostatic precipitator system for emissions control for a U.S. biofuel producer.

— continued on page 95

TECHNICAL TRAINING

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Visual Inspection
Apr 7-8 • Jun 30-Jul 1 • Nov 23-24

Welding for the Non Welder
Apr 27-30 • Jun 22-25 • Aug 17-20 • Oct 12-15

Arc Welding Inspection & Quality Control
Mar 16-20 • May 4-8 • Jul 27-31 • Oct 19-23

Weldability of Metals, Ferrous & Nonferrous
Mar 23-27 • Apr 20-24 • May 18-22 • Jun 15-19

Liquid Penetrant & Magnetic Particle Inspection
Apr 13-17 • Aug 3-7 • Oct 26-30



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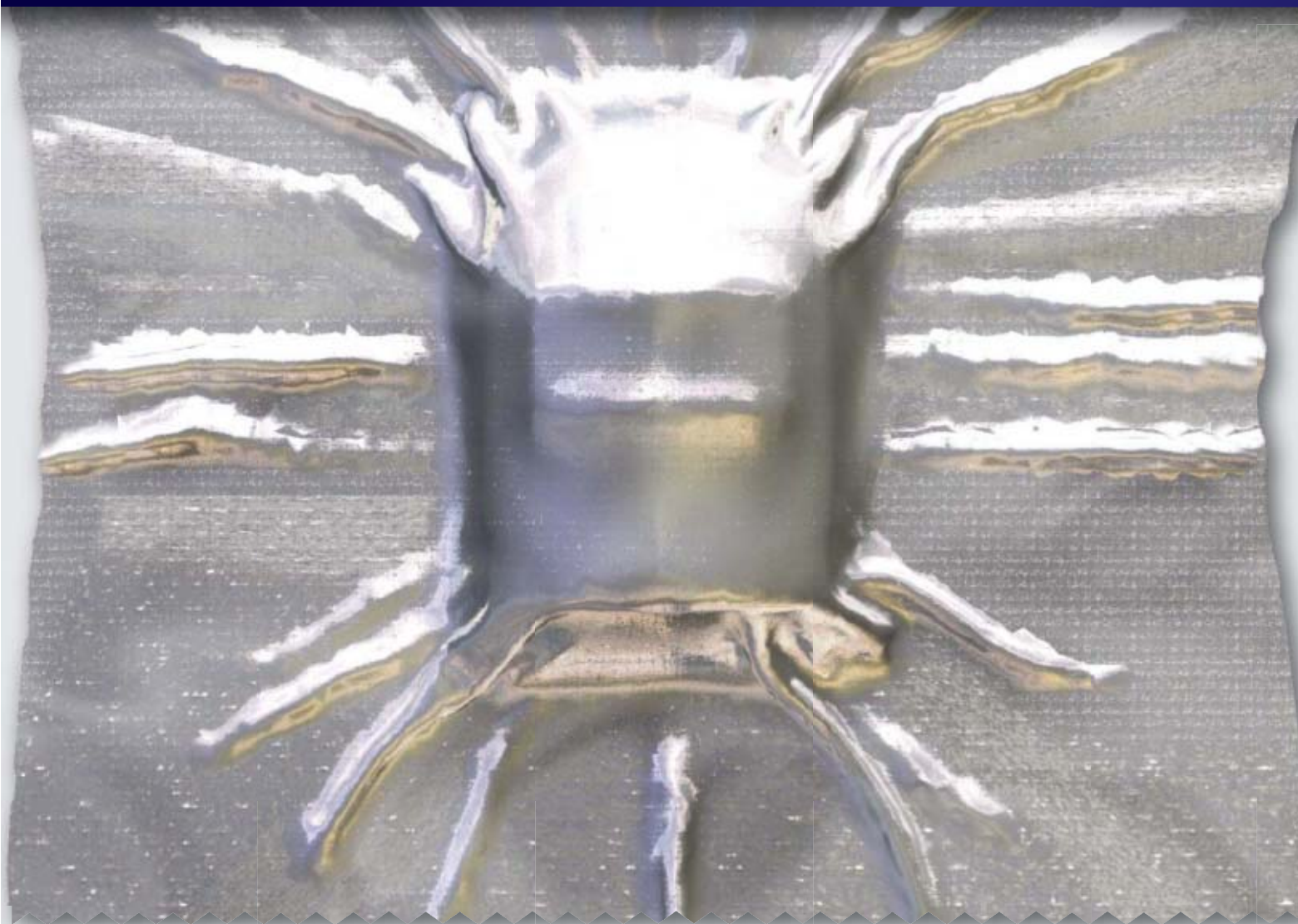
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The **12th Aluminum Welding Conference & Exhibition** will also provide several opportunities for you to network informally with speakers and other participants, as well as to visit an exhibition showcasing products and services available to the aluminum welding industry.

For the latest conference and exhibitor information or to register for the conference, visit our website at www.aws.org/conferences or call 800-443-9353, ext. 455.

To secure tabletop exhibit space or for questions about exhibiting at the conference, please call 800-443-9353, ext. 229.



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Conference Program

Overview of Aluminum Welding

*Tony Anderson
ESAB Welding & Cutting Products
Florence, SC*

The Aluminum Designation System & Characteristics of Aluminum Alloys

*Pete Pollak
The Aluminum Association, Inc.
Arlington, VA*

Aluminum Welding Metallurgy

*Tony Anderson
ESAB Welding & Cutting Products
Florence, SC*

Metal Preparation for Aluminum Welding

*William Christy
Novelis Inc.
Kingston, Ontario, Canada*

Filler Alloy Selection Primary Characteristics

*Tony Anderson
ESAB Welding & Cutting Products
Florence, SC*

Gas Metal Arc Welding of Aluminum Alloys

*Mark Burke
Indalco
Mississauga, Ontario, Canada*

Gas Tungsten Arc Welding and Variable Polarity Plasma Arc Welding of Aluminum

*William Christy
Novelis Inc.
Kingston, Ontario, Canada*

Aluminum Weld Discontinuities: Causes and Cures

*Kyle Williams
Alcoa Technical Center
Alcoa Center, PA*

Design and Performance of Aluminum Welds

*Tony Anderson
ESAB Welding & Cutting Products
Florence, SC*

Application of the AWS D1.2 Structural Welding Code—Aluminum

*Kyle Williams
Alcoa Technical Center
Alcoa Center, PA*

Robotic Applications

*Jay Ginder
ESAB Welding & Cutting Products
Florence, SC*

High Energy Density Beam Welding of Aluminum

*William Christy
Novelis Inc.
Kingston, Ontario, Canada*

Cutting Methods for Aluminum Alloys

*Jay Ginder
ESAB Welding & Cutting Products
Florence, SC*

Overview of Solid State Joining Processes for Aluminum

*Donald J. Spinella
Alcoa Technical Center
Alcoa Center, PA*

Friction Stir Welding Aluminum

*Jay Ginder
ESAB Welding & Cutting Products
Florence, SC*

Resistance Spot Welding of Aluminum

*Donald J. Spinella
Alcoa Technical Center
Alcoa Center, PA*

Question and Answer Sessions

*Bernie Altshuller, Moderator
Rio Tinto Alcan
Kingston, Ontario, Canada*

INTERNATIONAL

UPDATE

Giant Composter Fabricated and Installed for Waste Recovery in Australia



Fig. 1 — Prior to submerged arc welding, 14.5-m-long steel sheets were cut and rolled into cylinders.

RCR Engineering, Welshpool, Australia, recently completed fabrication and delivery of two 65-m-long composters for the Neerabup Resource Recovery Facility, Perth's new \$51.5 million waste management project. Work on the composters began in February 2008.

The two composters were built in halves at the company's facility in Welshpool then transported to the site where RCR Construction and Maintenance assembled, aligned, and welded the sections together. When they go on line this year, the composter drums will each hold more than 420 tons of waste.

The company fabricated the composters from 320 tons of plate and forged materials. The 25–75-mm-thick and 14.5-m-long steel sheets were cut, prepared, and rolled to form the cylinders prior to submerged arc welding — Fig. 1. The welds were ultrasonically tested to check for defects and no failures were recorded.

This first stage of the planned three-stage Resource Recovery Facility will treat up to 100,000 tons of household waste annually and convert about 70% of it into market-quality compost.

Aker Solutions Awarded Contract for Full-Field Development of Kashagan Oilfield

In a joint venture with CB&I UK Ltd. and WorleyParsons Europe Ltd., Aker Solutions has received a front-end engineering and design (FEED) services contract for Phase II of the full-field development of the Kashagan oilfield in Kazakhstan. The contract is valued at \$135 million.

The work in Phase II includes front-end engineering and design of both onshore and offshore facilities and pipelines. The FEED contract includes options for early work, detail engineering, procurement services, technical assistance, and design/system integrity. It also includes provisions for optional FEEDs for other Kazakhstan oilfields, including Aktote, Kairan, and Kalamkas.

Aker Solutions and WorleyParsons are also involved with

Phase I of the Kashagan Project, performing detailed design, fabrication, and hook-up.

Drill Ship Selected as One of Top Ten New Technologies in Korea

A polar drill ship built by Samsung Heavy Industries (SHI) recently received a gold prize and was selected as one of the 2008 Top 10 Technologies in Korea, which was hosted by the Ministry of Knowledge Economy and the Korea Industrial Technology Foundation. The awards honor excellent new technologies and products that have had ripple effects on the entire economy.

The SHI polar drill ship is an oil-drilling unit that can drill oil and gas wells even in deep sea or through rough waves. It can dig up to 11 km below sea level and work at temperatures of –20 deg.

New Vessel Underway to Canada; Set for Service in Late Spring



The Northern Expedition prepares for departure from the Flensburger Shipyard in Germany en route to British Columbia, Canada.

A new cruise ferry built at Germany's Flensburger Shipyard is en route to British Columbia. It is expected to arrive early this month and begin service in late spring.

The *Northern Expedition*, a 150-m-long cruise ferry, includes 55 staterooms and can accommodate 600 passengers and 130 vehicles. It will commence service for BC Ferries Inside Passage route sailing between Port Hardy and Prince Rupert beginning in May.

"FSG Shipyards has produced another fine vessel of quality construction for our customers, which is both on-time and on-budget," said David L. Hahn, BC Ferries president and CEO.

Polysoude Schedules Forums on Narrow Gap Orbital Gas Tungsten Arc Welding

Polysoude, Nantes, France, plans to hold a forum in English during the first half of this year on narrow gap orbital gas tungsten arc welding in the power plant construction industry. Information is available by calling 33-2-40-68-11-74 or by sending an e-mail to info@polysoude.com.

The forum will be similar to two sessions held in the French and German languages in November 2008. More than 100 participants from France, Germany, Austria, Switzerland, Russia, Hungary, and the Czech Republic attended those forums, which were a mix of technical information and demonstrations. In one of the demonstrations, P91 pipes that were 620 mm in diameter and had a wall thickness of 180 mm were joined with orbital GTAW. Today's power plants have higher operating temperatures and therefore more pressure-resistant, thick-walled pipes made from high-temperature steels such as P91 and P92 are required.



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General Office Phone: 859.371.0070 Fax: 859.371.5210 Email: kiswel@kiswelusa.com

**American Welding Society**

Friends and Colleagues:

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

For specifics on the nomination requirements, please contact Wendy Sue Reeve at AWS headquarters in Miami, or simply follow the instructions on the Fellow nomination form in this issue of the *Welding Journal*. Please remember, we all benefit in the honoring of those who have made major contributions to our chosen profession and livelihood. The deadline for submission is July 1, 2009. The Committee looks forward to receiving numerous Fellow nominations for 2010 consideration.

Sincerely,

Nancy C. Cole
Chair, AWS Fellows Selection Committee



CLASS OF 2010
FELLOW NOMINATION FORM

(please type or print in black ink)

DATE _____ NAME OF CANDIDATE _____

AWS MEMBER NO. _____ YEARS OF AWS MEMBERSHIP _____

HOME ADDRESS _____

CITY _____ STATE _____ ZIP CODE _____ PHONE _____

PRESENT COMPANY/INSTITUTION AFFILIATION _____

TITLE/POSITION _____

BUSINESS ADDRESS _____

CITY _____ STATE _____ ZIP CODE _____ PHONE _____

ACADEMIC BACKGROUND, AS APPLICABLE:

INSTITUTION _____

MAJOR & MINOR _____

DEGREES OR CERTIFICATES/YEAR _____

LICENSED PROFESSIONAL ENGINEER: YES _____ NO _____ STATE _____

SIGNIFICANT WORK EXPERIENCE:

COMPANY/CITY/STATE _____

POSITION _____ YEARS _____

COMPANY/CITY/STATE _____

POSITION _____ YEARS _____

SUMMARIZE MAJOR CONTRIBUTIONS IN THESE POSITIONS:

IT IS MANDATORY THAT A CITATION (50 TO 100 WORDS, USE SEPARATE SHEET) INDICATING WHY THE NOMINEE SHOULD BE SELECTED AS AN AWS FELLOW ACCOMPANY NOMINATION PACKET. IF NOMINEE IS SELECTED, THIS STATEMENT MAY BE INCORPORATED WITHIN THE CITATION CERTIFICATE.

SEE GUIDELINES ON REVERSE SIDE

SUBMITTED BY: PROPOSER _____ AWS Member No. _____

Print Name _____

The Proposer will serve as the contact if the Selection Committee requires further information. Signatures on this nominating form, or supporting letters from each nominator, are required from four AWS members in addition to the Proposer. Signatures may be acquired by photocopying the original and transmitting to each nominating member. Once the signatures are secured, the total package should be submitted.

NOMINATING MEMBER: _____ NOMINATING MEMBER: _____

Print Name _____
AWS Member No. _____

Print Name _____
AWS Member No. _____

NOMINATING MEMBER: _____ NOMINATING MEMBER: _____

Print Name _____
AWS Member No. _____

Print Name _____
AWS Member No. _____

SUBMISSION DEADLINE July 1, 2009



Fellow Description

DEFINITION AND HISTORY

The American Welding Society, in 1990, established the honor of Fellow of the Society to recognize members for distinguished contributions to the field of welding science and technology, and for promoting and sustaining the professional stature of the field. Election as a Fellow of the Society is based on the outstanding accomplishments and technical impact of the individual. Such accomplishments will have advanced the science, technology and application of welding, as evidenced by:

- * Sustained service and performance in the advancement of welding science and technology
- * Publication of papers, articles and books which enhance knowledge of welding
- * Innovative development of welding technology
- * Society and chapter contributions
- * Professional recognition

RULES

1. Candidates shall have 10 years of membership in AWS
2. Candidates shall be nominated by any five members of the Society
3. Nominations shall be submitted on the official form available from AWS Headquarters
4. Nominations must be submitted to AWS Headquarters *no later than July 1 of the year prior to that in which the award is to be presented*
5. Nominations will remain valid for three years
6. All information on nominees will be held in strict confidence
7. No more than two posthumous Fellows may be elected each year

NUMBER OF FELLOWS

Maximum of 10 Fellows selected each year.

AWS Fellow Application Guidelines

Nomination packages for AWS Fellow should clearly demonstrate the candidates outstanding contributions to the advancement of welding science and technology. In order for the Fellows Selection Committee to fairly assess the candidates qualifications, the nomination package must list and clearly describe the candidates specific technical accomplishments, how they contributed to the advancement of welding technology, and that these contributions were sustained. Essential in demonstrating the candidates impact are the following (in approximate order of importance).

1. Description of significant technical advancements. This should be a brief summary of the candidates most significant contributions to the advancement of welding science and technology.
2. Publications of books, papers, articles or other significant scholarly works that demonstrate the contributions cited in (1). Where possible, papers and articles should be designated as to whether they were published in peer-reviewed journals.
3. Inventions and patents.
4. Professional recognition including awards and honors from AWS and other professional societies.
5. Meaningful participation in technical committees. Indicate the number of years served on these committees and any leadership roles (chair, vice-chair, subcommittee responsibilities, etc.).
6. Contributions to handbooks and standards.
7. Presentations made at technical conferences and section meetings.
8. Consultancy — particularly as it impacts technology advancement.
9. Leadership at the technical society or corporate level, particularly as it impacts advancement of welding technology.
10. Participation on organizing committees for technical programming.
11. Advocacy — support of the society and its technical advancement through institutional, political or other means.

Note: Application packages that do not support the candidate using the metrics listed above will have a very low probability of success.

Supporting Letters

Letters of support from individuals knowledgeable of the candidate and his/her contributions are encouraged. These letters should address the metrics listed above and provide personal insight into the contributions and stature of the candidate. Letters of support that simply endorse the candidate will have little impact on the selection process.

Return completed Fellow nomination package to:

Wendy S. Reeve
American Welding Society
Senior Manager
Award Programs and Administrative Support
550 N.W. LeJeune Road
Miami, FL 33126

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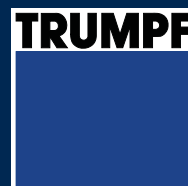
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STAINLESS

Q&A

Q: We are making 1-in.-thick butt joints between 304L stainless steel and ASTM A516-70 carbon steel, using submerged arc welding with ER309L electrode. We use a single U-groove with a ¼-in. root radius, ⅝-in. land, no root opening, and 20-deg included angle. Then we backgouge and finish the joint with FCAW or SMAW. We have a lot of trouble with centerline cracking in the SAW root pass, unless we substitute SMAW with 309L filler metal for the root pass. What can we do to make SAW root passes successfully?

A: The root cause of your root cracking problem is dilution from the carbon steel side causing the root pass to solidify as primary austenite, instead of the desired primary ferrite. The root pass cracks during solidification and it ends up with virtually zero ferrite content. Shielded metal arc welding gets around this problem by reduced dilution as compared to SAW, but its productivity is low.

One way to combat this is by using DCEN polarity for SAW at low wire feed speed (low current) to reduce dilution to levels comparable to those obtained with SMAW. But that is a relatively low productivity approach also, and the DCEN root pass bead shape is often not desirable.

A more robust (forgiving) approach is to design the joint to get away from symmetry. The problem with high dilution in a symmetrical joint, such as a single U-groove, is that the dilution comes approximately equally from the two base metals. It is dilution from the carbon steel side that is responsible for loss of ferrite in the weld metal. Dilution from the 304L side of the joint has a more-or-less negligible effect on root pass ferrite content (or solidification mode). That is because common stainless steels like 304L, 316L, 317L, 321, and 347 are generally designed by the steelmaker to solidify as primary ferrite, just like common stainless steel weld metals like 308L or 309L. This helps them to get a higher yield from hot working of the steel. You can easily establish this for yourself by simply making a GTAW bead-on-plate weld without filler metal on one of these base metals — you will almost certainly find a magnetic response in the weld indicating presence of ferrite, even if the base metal is completely nonmagnetic before welding.

The approach I suggest is to make the joint preparation asymmetrical so that more of the dilution comes from the 304L side of the joint than from the carbon steel side of the joint. This can be done simply by, for example, changing from a single U-

BY DAMIAN J. KOTECKI

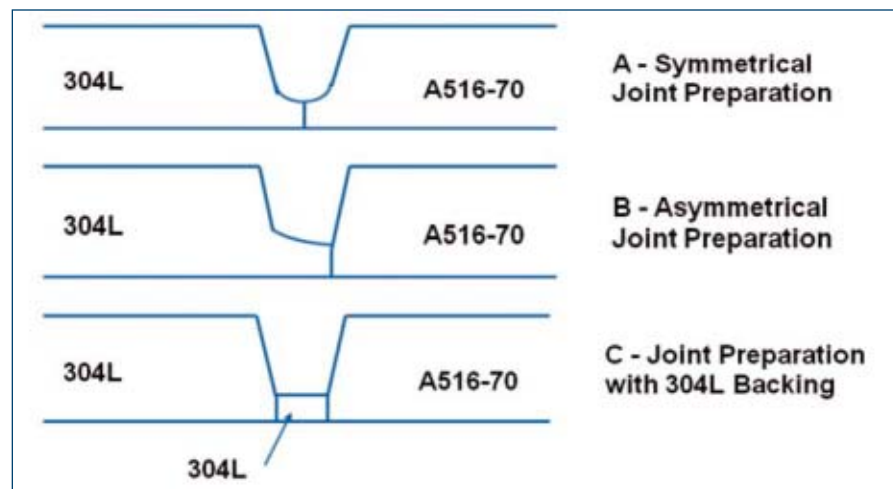


Fig. 1 — Alternate joint preparations for carbon steel to 304L with ER309L filler metal.

groove joint preparation to a compound joint preparation consisting of a single J preparation on the 304L and a single bevel preparation on the A516-70, so that the SAW arc will impinge mostly on the 304L. A second possibility is to insert a 304L stainless steel backing bar into the joint, so that, again, the arc will impinge mostly on the 304L, although in this case it is the backing bar. These two alternatives, as compared to your symmetrical joint preparation, are sketched in Fig. 1. Figure 1A is your symmetrical joint preparation, while Fig. 1B and C are asymmetrical joint preparations as outlined above.

In welding either the joint preparation of Fig. 1B or that of Fig. 1C, you should still align the electrode along the joint preparation centerline, not along the 304L/A516-70 interface. Then the weld bead will wash up onto the carbon steel without a lot of penetration into it. Most of the arc energy will be spent melting 304L base metal (possibly including the backing bar should you choose to use that) and ER309L electrode. Because the joint preparation is asymmetrical, you should find that you will have to backgouge a bit deeper in order to reach sound metal, but that is preferable to cutting out a root pass with a centerline crack as you have been experiencing with the symmetrical single U-groove joint preparation. In fact, this will be evidence that you have achieved lower dilution from the carbon steel.

After a successful root pass, the arc impinges mainly on previously deposited weld metal that contains ferrite, and the low dilution effect from the carbon steel side continues until joint completion.

Once you get the idea of the way this

asymmetrical joint preparation works, I am sure that you can come up with a number of variants on the approach to suit other situations. For example, the backing bar need not be inserted into the root for a single-side joint preparation — a 304L backing bar wider than the root opening could be used underneath the joint preparation with the same effect. In that case, backgouging to remove the backing bar would only have to remove the backing bar and very little of the joint, so that only a very shallow backside weld, if any, would be needed to complete the joint to full penetration.

This approach is not restricted to SAW. It can be used to improve solidification cracking resistance in any situation in which a stainless steel expected to provide a bit of ferrite (316L, for example) is to be joined to carbon steel or even to a stainless steel in which no ferrite would be expected (310 or 320, for example). ♦

DAMIAN J. KOTECKI is president, Damian Kotecki Welding Consultants, Inc. He is a past president of the American Welding Society, currently treasurer and a past vice president of the International Institute of Welding, and a member of the AWS A5D Subcommittee on Stainless Steel Filler Metals, and the AWS D1K Subcommittee on Stainless Steel Structural Welding. He is a member and past chair of the Welding Research Council Subcommittee on Welding Stainless Steels and Nickel-Base Alloys. E-mail your questions to Dr. Kotecki at damian@damiankotecki.com, or send to Damian Kotecki, c/o Welding Journal, 550 NW LeJeune Rd., Miami, FL 33126.

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RWMA

Q&A

Q: What's the current status of electric servo-actuated resistance welding machines?

Forging force, commonly called "weld pressure," is one of the three main variables in the resistance welding process. This variable controls the electrical resistance between the parts being welded. The other two are weld current (amperage) and weld time (the duration of current flow).

A training video available through the Resistance Welding Manufacturing Alliance (RWMA) refers to these three variables as PCT, which stands for pressure, current, and time. To ensure consistently good welds, all these variables must be properly applied and controlled throughout the process.

Since modern digital controls offer absolute accuracy in welding current control and weld duration timing, concern about those two variables has largely been eliminated. In addition, many of the newer welding machine controls have a feature called constant current, which can automatically compensate for changing conditions in the process.

Until recently, however, proper application and control of weld pressure was harder to achieve.

Pneumatic air cylinders, the most common way of applying weld force for the past 50-60 years, were a big improvement over the early days of resistance welding, when force was often applied with a foot- or hand-operated mechanical lever or a motorized cam.

Air cylinders, however, are prone to problems of their own. Moist, dirty plant air supplies often lead to varnishing and corrosion of internal cylinder walls, resulting in weld force being applied inconsistently and welds that are not always properly forged.

Other potential problems with air-operated resistance welding machines include sticky solenoid-operated air valves and worn out cylinder walls and packings, plus plant air supplies that are prone to variations and even starvation when other air-operated machines come on line.

Enter the modern electrically operated servo-actuated force delivery systems that are just now starting to become more common in the world of resistance welding.

Auto manufacturers have used servo-actuated spot welding guns manipulated by robots for several years. However, until recently, most of the standard press-type pedestal welding machines commonly used for resistance spot and projection welding have remained air operated.

BY THOMAS J. SNOW JR.

Since servos prices have dropped, they are now more affordable for many resistance welding applications, especially those requiring the highest level of quality.

Another key development is that software and touch-screen human-machine interface panels available for use with servos have improved to the point that almost anyone can learn to program and set-up a servo-actuated welding machine in a matter of minutes.

Advantages of servo-actuated resistance welding machines include the following:

- High-thrust-force (up to 5000 lb) servo-controlled actuator with quick travel and slow approach
- Slow approach feature improves weld appearance and minimizes electrode wear
- Faster operation than air-operated resistance welding machines
- Weld force is generated instantly (no need to wait while air pressure builds during squeeze time)
- Lower operating cost (expensive compressed air is not needed)
- Weld force repeatability is improved, which produces more consistent welds
- Monitors can be built into the servo control system to verify part stack-up and to monitor electrode wear
- A set-down monitor with programmable limits is ideal for projection welding, especially nuts and studs
- Part stack-up monitor can detect missing or upside down weld nuts
- Retractable stroke, if needed, is available without additional hardware
- Built-in data logging. Welding force and other variables can be viewed and graphed on a color touch screen and transmitted over a plant's network and exported to Microsoft® Office Excel.
- Easy part changeover process.

Since resistance welding is still the strongest and least expensive way to join sheet metal and attach nuts and studs, the value of improvements to the process now being offered by servo-actuated force delivery systems is rapidly being recognized.

Although more expensive than pneu-



Servo-actuated weld force delivery systems are now being adapted to conventional resistance welding machines, including the press-type projection welding machine on the left and the pedestal-type spot welding machine on the right. Advantages include increased welding speeds and improved process quality monitoring.



The addition of a touch screen makes a servo-actuated resistance welding machine much more user-friendly.

matically operated resistance welding machines, servo-actuated machines are being well received by users focused on improving quality and increasing operating speed.◆

THOMAS J. SNOW JR. is CEO of T. J. Snow Co., Chattanooga, Tenn. He is a member of AWS and RWMA. He serves on the RWMA Executive Committee as the Machinery Division representative. In addition, he is vice chair of the RWMA Education Committee. This article was written with the assistance of Josh Garmon and other members of the T. J. Snow team. Thanks also to Roger Hirsch of Unitrol Electronics, RWMA chair, for his input. Comments and questions may be addressed to tomsnow@tjsnow.com, or to Tom Snow, c/o Welding Journal, 550 NW LeJeune Rd., Miami, FL 33126.

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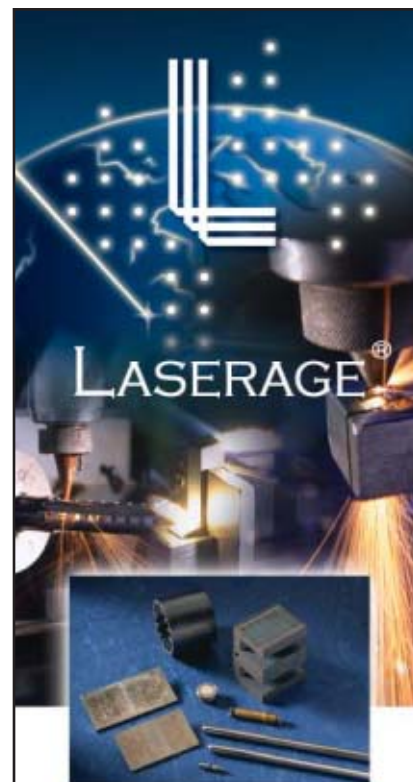
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— continued on page 94



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Laser Welding:

It's Not Just for Metals Anymore

BY STEVEN A. KOCHENY AND BILL MILLER

A number of welding techniques using diode lasers are described to help engineers and designers transition into the expanding field of plastics



Fig. 1 — High-power diode laser stack. (Photo courtesy of Dilas.)

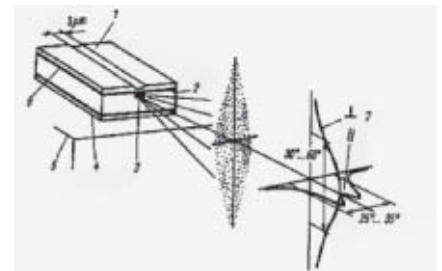


Fig. 2 — Divergence of laser light from diode. Shown is 30 to 60 deg in the perpendicular direction, and 25 to 35 deg in the parallel direction.

Many project engineers associate the term “welding” primarily with metals. In fact, *Merriam-Webster’s Online Dictionary* defines welding as a transitive verb meaning “to unite (metallic parts) by heating and allowing the metals to flow together or by hammering or compressing with or without previous heating” or “to unite (plastics) in a similar manner by heating.” While years of joining metals have formed this association with welding, the ever-increasing use of plastics as a replacement for metals is fostering an increased significance of welding for plastics.

Although welding is the term applied to joining both metals and plastics, the methods used to weld these materials are quite different.

For example, several metals-joining processes employ filler materials to make the weldments, i.e., gas metal arc, submerged arc, and shielded metal arc welding. In contrast, when welding plastics, the use of filler materials is often the exception rather than the rule. Also, the con-

ventional CO₂ and Nd:YAG lasers have been developed into important tools in the metals-joining industry, but their use in the plastic industry is typically limited to cutting and scribing. For plastics, diode lasers are used. Diode lasers are more divergent in how they deliver their energy, have a shorter wavelength, and have output powers that allow them to produce a controlled melt, or welding, of the plastics. This article discusses the use of diode lasers for welding thermoplastics.

Background

In 1962, Robert N. Hall invented the first semiconductor (diode) laser while working for General Electric (Ref. 1). His laser had an output wavelength of 840 nm and could only be operated in the pulsed mode at -196°C (-321°F) (Ref. 2). It wasn’t until 1970 that a diode laser was developed that could operate continuously at room temperature. In 1982, the diode laser used in CD players was developed.

This device has an output of 5 mW with a wavelength of 780 nm. In 1995, DVDs entered the marketplace using a diode laser to emit a light with a wavelength of 635 nm.

Today, materials that generally compose high-powered diode lasers (HPDL) are a mixture of gallium, indium, and aluminum on one side, and phosphorus, arsenic, and antimony on the other side (Ref. 3). Driven by a DC current, the HPDL emits a laser beam with a wavelength in the range of 600 to 1600 nm, depending on the crystal structure of the diode. The HPDLs are composed of diode bars, which are 10 mm wide and 0.1 mm high. Each diode has a power output of 40 to 60 W when operated in the continuous-wave mode. Several bars can be stacked to provide greater output powers — Fig. 1.

These laser diodes are similar to light-emitting diodes (LEDs) in functionality. Operating in the forward bias mode (+ on the P-side), electrons are infused across the P-N junction and into the semicon-

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ductor to create photons. These photons are then emitted in all directions from the plane on the P-N junction. The cleaved surfaces of the laser diode act as mirrors to form the diode laser's resonant cavity (Ref. 4). As laser light emerges from the diode, it diverges in the perpendicular and parallel directions, with more divergence in the perpendicular (30–60 deg) than the parallel (25–35 deg) direction — Fig. 2. This divergent light is generally unusable as emitted from the diode; therefore, it needs to be shaped and collimated according to the needs of the application, i.e., spot or line focus (Ref. 3).

Through-Transmission Infrared Welding (TTIR)

Through-transmission infrared welding of thermoplastics is a process whereby laser light in the range from 800 to 1064 nm wavelength passes through a top (laser transparent) part and is absorbed by either a bottom (laser absorbent) part or a laser absorbent layer between two parts. When the laser light is absorbed, it is transformed into heat. This heat is conducted into both the top and bottom parts where it softens and melts both parts. Through the application of a clamping pressure, the melted regions of both parts are brought into intimate contact. The forces created by the thermal expansion of the materials and the externally applied clamping pressure compel a mixing of the melted areas to take place. Upon rapid cooling, the weld is formed. All of this can occur in a fraction of a second — Fig. 3.

To achieve transmission welding of thermoplastics, the two parts to be welded are chosen so as to have considerably different optical absorption properties at a particular wavelength. The optical characteristics of the top part should be as transmissible to the laser wavelength as possible. Specially pigmented products are available that allow for tinting of the top piece to make it appear visually opaque while still remaining transmissive to the laser beam. Laser absorption of the top part should be kept to a minimum to allow as much energy as possible to reach the weld interface. If excessive laser energy is absorbed by the top part then it may start to degrade before the bottom part has been exposed to sufficient energy to allow for a weld to be created. The optical characteristics of the bottom part should allow a high absorption of the laser wavelength in as thin of a layer as possible. Combining these two optical characteristics ensures that a high amount of the laser energy will be absorbed at the interface between the two parts, and result in a more efficient use of the energy in producing a weld. The reflectivity of both parts should always be kept to a minimum to reduce the loss of laser energy.

The laser energy necessary for welding

can be presented to the parts in the form of either a spot or a line. Each form offers its own advantages, and selection should be based upon each application.

Spot (Contour) Welding

Spot or contour welding refers to the use of a circular spot of laser energy to traverse a preprogrammed contour path and create a weld or bond.

As mentioned previously, as the laser light is emitted from the diode it begins to diverge. Through the use of mirrors and lenses the emitted light can be collimated, shaped, and focused into a circular spot. This focused light can then be transmitted into a fiber-optic, which has a diameter as small as a few 100 μm . The fiber-optic can then convey the light to the work area. As the light exits from the fiber-optic it again begins to diverge, and is once again refocused through a lens and delivered to the area to be welded.

The amount of energy delivered to the work area is governed by the size of the laser spot at the weld interface, travel speed of the laser beam, and the amount of energy supplied by the diode laser module, minus losses for coupling efficiency of the optics.

The input amperage supplied to the diode laser control determines the amount of energy delivered by the diode laser module. A correlation of supplied amperage to delivered power can be determined for each laser module. The operator predetermines what power will be needed for welding and inputs the corresponding amperage into the controller. Most welding of thermoplastics is performed at energy levels of less than 150 W.

The size of the laser spot is set by the distance between the focusing lens and the laser-absorbing part, and is determined by the focal length of the lens. The working distance can be set so that the interface for welding can lie above or below the focal point of the lens, depending on the application. Spot sizes of 1 to 2 mm are recommended for welding, but the spot size can be varied from as small as 0.6 mm to as large as several mm.

The main advantage of spot or contour welding is the flexibility this process offers with virtually any programmable welding path. Each weld path can be saved as a file in a Windows™-based format, and changing between paths is as easy as opening a new file. In addition to the flexibility that

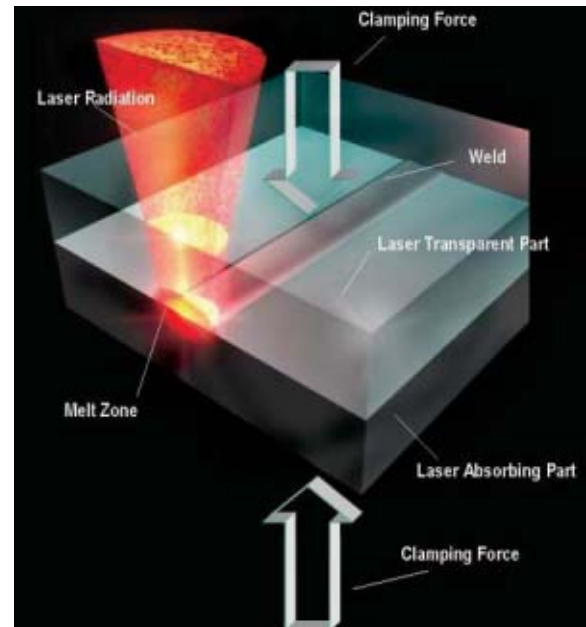


Fig. 3 — Through-transmission infrared (TTIR) welding joint design.

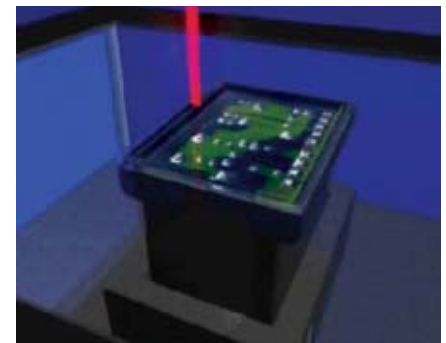


Fig. 4 — Contour welding.

contour welding affords, it also offers the option of temperature feedback control of the weld via closed-loop control of the power and variable weld size through adjustment of the focal distance.

In most contour welding applications, the clamping force necessary to achieve a weld is supplied from an external clamping mechanism. This could be as simple as either pressing up against a piece of glass or using a metal frame to press adjacent to a weld area — Fig. 4. In a variation of the contour technique, the patented Globo technique offered by Leister supplies the clamping force necessary for welding as an integral part of the optic delivery system. For this method, a glass sphere riding on an air bearing in the laser optic head provides the clamping force while allowing the laser energy to pass through the ball lens to the workpiece — Fig. 5.

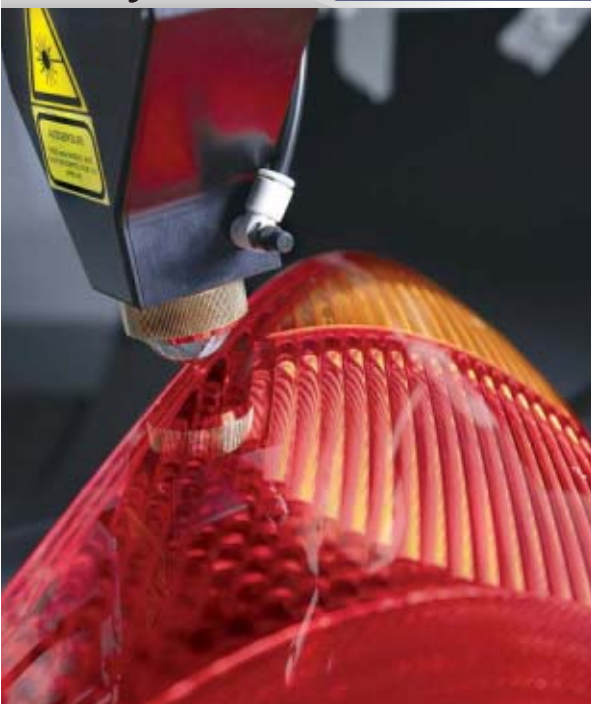


Fig. 5 — Globo welding of a taillight assembly.

Line Welding

Line welding refers to the use of a laser line for welding. Instead of focusing the light emitted from the diode module to a spot, the light is collimated and shaped into a line. Typical weld line dimensions are 1 to 2 mm wide and can vary up to 120 mm in length. This line can then be used to weld as a stationary line (simultaneous) or as a moving line (mask). Line welding uses the same transmission welding principles as spot welding.

Simultaneous Line Welding

Simultaneous welding utilizes one or more laser lines to produce a weld along a part's contour. Each laser diode is turned on at precisely the same time to allow an entire contour to be welded simultaneously. Part geometries for simultaneous welding have been traditionally restricted to square or rectangular shapes. It is now possible, however, to produce circular weld lines by utilizing special optic lenses — Fig. 6. Again, the typical line widths are 1 to 2 mm. The optic lens can be changed to vary the diameter of the circle pattern from 2 to 50 mm.

The main advantage of simultaneous welding lies in the short cycle time required for completing a weld. The part is positioned beneath the laser diode modules, and an external clamping pressure is applied. The diodes are turned on, and the weld is achieved. No movement of the laser light or the parts is required during the weld cycle. Generally, the initial setup required for welding takes longer than the setup of a contour path, and energy densi-

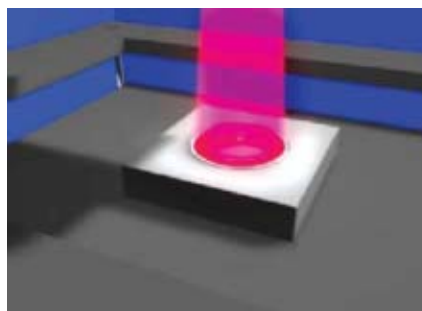


Fig. 6 — Simultaneous welding circle.

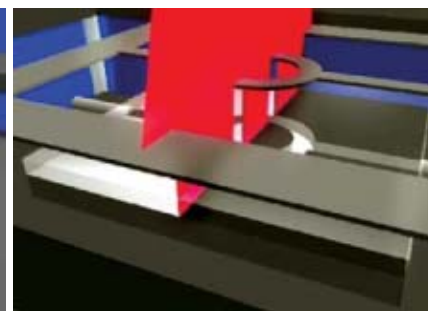


Fig. 7 — Mask welding.

ties tend to be less than for contour welding, but for certain high-volume applications, simultaneous welding may be the answer, especially if multiple programs are not desired.

Mask Welding

Mask welding utilizes the same transmission welding principles as the contour and simultaneous methods. It also requires the same externally applied clamping pressure. Like simultaneous welding, mask welding also uses a laser line to produce a weld. Mask welding differs from the simultaneous process in that it incorporates the use of a mask to block the transmission of the laser line as the line is scanned over the part — Fig. 7. The mask shape determines the pattern of weld produced, and its precision is significant in determining the accuracy of the final weld. A precise mask is produced using photolithographic removal of predetermined portions of a metallic-coated glass, producing a finite pattern. The pattern can be as varied as required by the application.

The mask is accurately positioned over the parts to be welded and the clamping fixture. The laser line is then scanned over the mask. The mask acts to selectively block the laser light from entering into the part. Where the laser light is allowed to enter, welding is achieved. Using the mask welding process it is possible to produce an area of weld instead of just a line of weld.

The main advantage of this process is that it allows for very precise and very fine weld lines. Weld lines as narrow as 100 μm have been successfully made with the mask welding process. In addition, this process allows the possibility of producing welds with elaborate structures or contours. During one weld sequence, it is plausible to weld lines with different widths and shapes, as well as whole areas of the weld (Ref. 3).

The mask process has found a strong foothold in the medical and microfluidic

markets because of its ability to produce very precise weld lines. In addition, mask welding has also found a market where large areas must be welded quickly.

Conclusion

As the benefits and opportunities for using thermoplastics for components and assemblies increase, design and process engineers will be called upon more often to join these materials. Understanding the welding methods used for joining plastics and how these methods compare with metals joining processes will make the transition much easier. ♦

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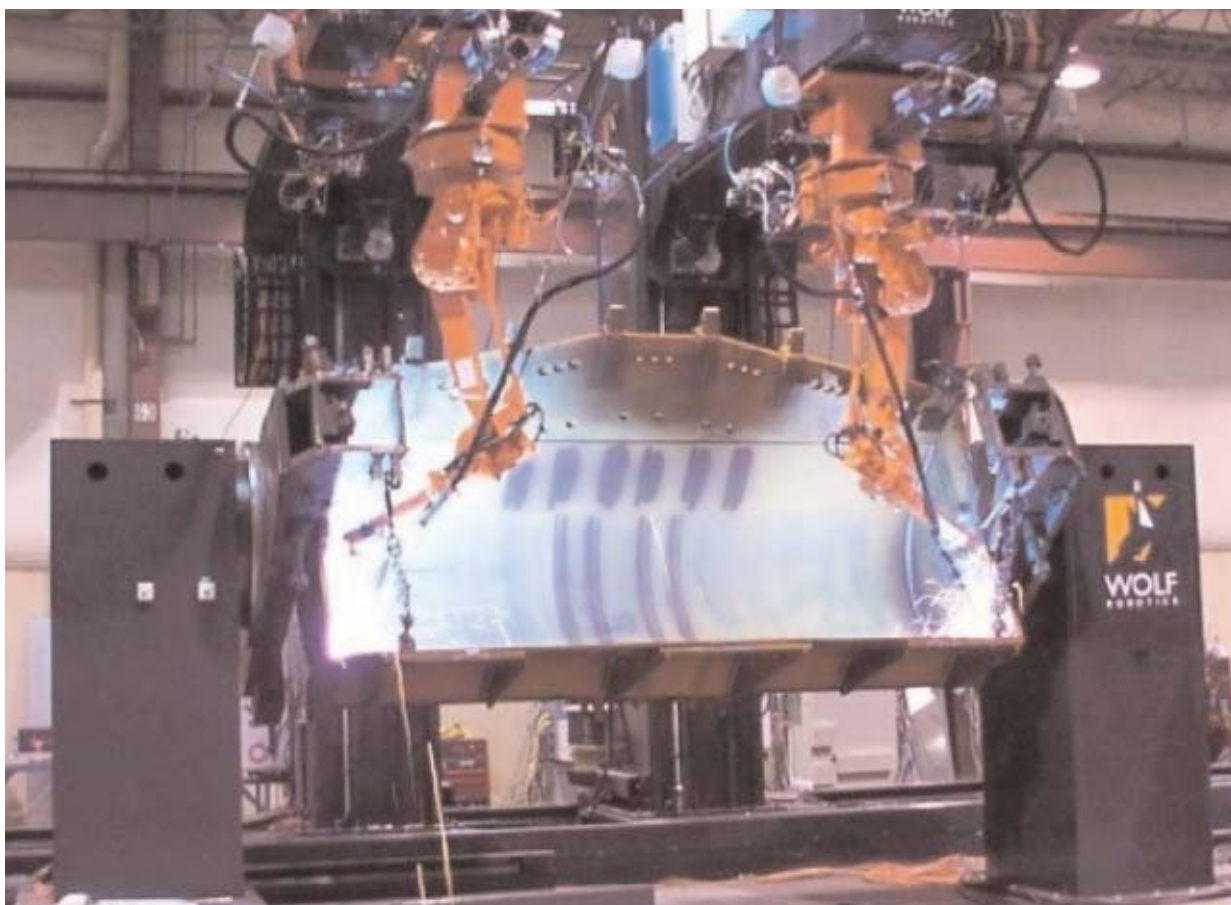
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Using Hybrid Laser-Arc Welding to Reduce Distortion in Ship Panels

Butt joints on production-scale thin-steel panels were successfully made with a hybrid laser-arc process in a shipyard environment

BY S. M. KELLY, S. W. BROWN, J. F. TRESSLER, R. P. MARTUKANITZ, AND M. J. LUDWIG

The use of thin steel (less than 10 mm thick) in shipbuilding has increased significantly in the last 20 years, from less than 10% before 1990 to greater than 90% in 2000 (Ref. 1). The increased use of thin steel is driven by ship designs requiring a reduction in weight, offering performance increases in the final product. At the same time, U.S. shipyards have faced difficulty in dealing with the inherent problems in fabricating large structures with thin material, and, as a result, have experienced significant cost increases due to problems associated with distortion. Currently employed high-heat-input welding processes are responsible for much of this distortion. Moreover, it has been estimated that welding of panel seams leads to significant additional costs during fabrication of major naval platforms. In order to increase affordability of ships built for the U.S. Navy, alternative low-distortion welding processes must be developed, demonstrated, qualified, and implemented.

It has been more than a quarter of a century since researchers first considered combining a conventional welding arc with a laser beam in a hybrid process (Refs. 2, 3), but only recently has commercial laser technology advanced to a point allowing hybrid laser gas metal arc welding (HLAW) has begun to take hold

in industrial applications. Recently, HLAW has begun making inroads in European shipyards as well as U.S. industry (Refs. 4, 5). Coupled with the awareness of HLAW capabilities are significant advances in available fiber-delivered laser technologies. Significant improvements in flexibility, compactness, reduced maintenance, improved electrical efficiency, potential for time-sharing capability, and reduced capital investment per kilowatt of delivered power make HLAW attractive for implementation in the U.S. heavy manufacturing industry (Refs. 6–8).

The hybrid laser arc welding process used in this work and depicted in Fig. 1 employs laser beam welding (LBW) and gas metal arc welding (GMAW) in a combined process that overcomes deficiencies encountered with each individual process. Specifically, laser beam welding provides improved penetration at relatively fast travel speeds; however, difficulties are encountered with the ability to add filler metal and meet joint root opening tolerance requirements experienced in the shipyard production environment. Gas metal arc welding is efficient at adding material resulting in a higher root opening tolerance; however, automated welding speeds and depth of penetration are limited.

Ongoing research by the Applied Re-

search Laboratory at The Pennsylvania State University under commercial- and government-sponsored research and development programs has been directed at the use of HLAW technology for joining thick-section high-strength steel (Ref. 9), steel pipe (Refs. 10, 11), and thin steel panel structures (panel seams, inserts, and stiffeners) (Refs. 12, 13). This article focuses on the welding process improvements measured during a demonstration of HLAW technology conducted at General Dynamics Bath Iron Works.

Conventional Processing

Conventional welding processes such as submerged arc welding (SAW) offer low capital equipment cost and are readily implemented in the production environments of U.S. shipyards. One significant drawback to conventional welding processes is the high level of heat input necessary. Heat input (kJ/in.) to the part has been shown to be proportional to weld distortion. Buckling distortion is especially problematic in thin panel structures since the critical buckling strength is proportional to the thickness squared. For example, the critical buckling strength in 10-mm plate is four times greater than in 5-mm plate, while the welding-induced lon-

S. M. KELLY, S.W. BROWN, J. F. TRESSLER, and R. P. MARTUKANITZ are with Applied Research Laboratory, The Pennsylvania State University, State College, Pa. M. J. LUDWIG currently is with Cianbro Corp., Pittsfield, Maine. He was formerly with General Dynamics Bath Iron Works, Bath, Maine.

gitudinal residual stress levels are relatively constant for this range of thicknesses (Ref. 1). Masubuchi summarized the relationship between heat input and distortion for welding of 0.25-in. steel panels (Ref. 14). The data presented by Masubuchi indicate that a 1% increase in heat input can correspond to a 24.7% increase in out-of-plane distortion in 0.25-in.-thick steel stiffened panel structures.

The current shipyard welding process for butt-joint welding of 5-mm panel seams and inserts, SAW, imparts approximately 5.6 times as much total heat than the hybrid welding process (Ref. 15). The tandem submerged arc welding (TSAW) process, which is receiving considerable interest from shipyards because of its potential for increased productivity, imparts approximately 3.8 times as much heat than a hybrid welding process for 5-mm butt-joint welds (Ref. 16). These relatively high levels of heat input are driven by joint beveling and minimum root opening requirements for conventional arc welding processes, which in turn, increases the amount of filler material and hence energy needed to melt that material. Figure 2 provides a visual comparison of the larger fusion zones associated with SAW compared to HLAW.

Distortion Comparison in Production-Scale Panels

Over a period of three weeks in January 2008, a hybrid laser arc welding demonstration was held at Bath Iron Works Harding Facility in East Brunswick, Maine. The BIW Harding Facility is a primary fabrication plant that produces panels and assemblies that are shipped over road to the main shipyard. The objective was to demonstrate the technical and economic feasibility of the HLAW process within the current shipyard production environment on production-scale panels.

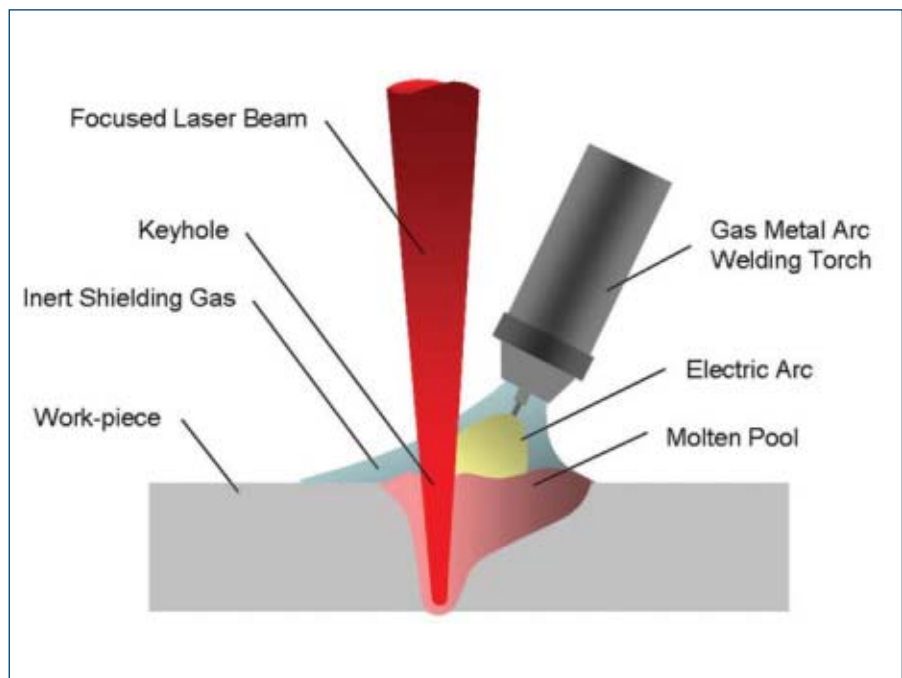


Fig. 1 — Hybrid laser arc welding process (laser leading).

Table 1 — Demonstration Panel Fitup Measured Prior to Welding

Sequence	Type	Length (ft)	Root Opening Range (in.)	
			Hybrid Panel	SAW Panel
1	Butt/Insert	20	0 to 0.030	0 to 0.030
2	Insert	5.5	0.030 to 0.083	0 to 0.040
3	Insert	5.75	0 to 0.030	0 to 0.020
4	Insert	5.75	0 to 0.030	0 to 0.050

The demonstration allowed for direct comparison of HLAW and SAW processes on the basis of welding process characteristics (weld time, heat input, and consumable usage) and welding distortion.

To accomplish the HLAW process demonstration, a portable welding system was required that could provide stable linear motion of the laser beam and arc weld-

ing process while maintaining alignment with the joint (without optical or tactile joint tracking). The system also was required to serve as a Class 1 laser enclosure while providing adequate exhaust gas flow management. Figure 3 shows the system hybrid welding a 20-ft panel joint at BIW. The system resulted in a successful and safe demonstration of hybrid welding tech-

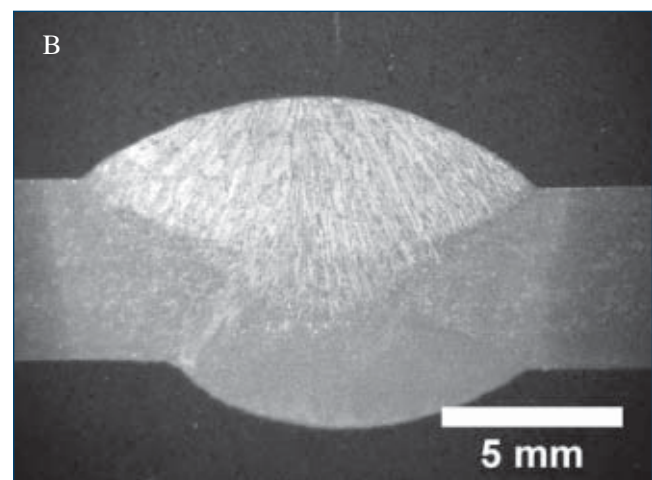
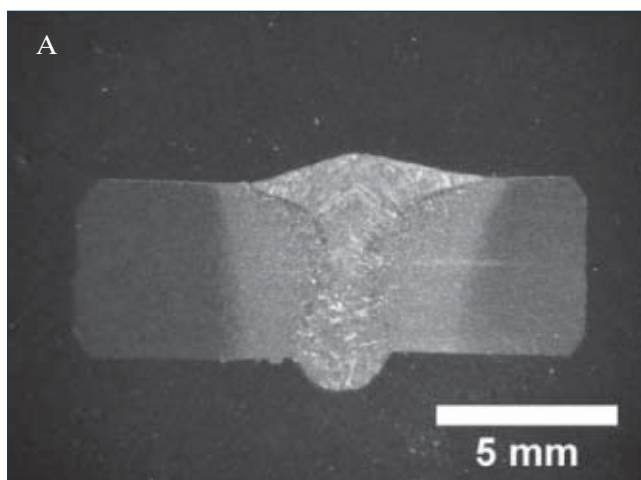


Fig. 2 — Macrographs of weld cross sections in 0.197-in.-thick DH36 steel welded with the following processes: A — Single-pass HLAW; B — double-sided SAW. Both were prepared with a machined square-butt joint with no root opening.



Fig. 3 — Hybrid laser arc welding demonstration system joining two 20-ft panel sections at Bath Iron Works in January 2008.

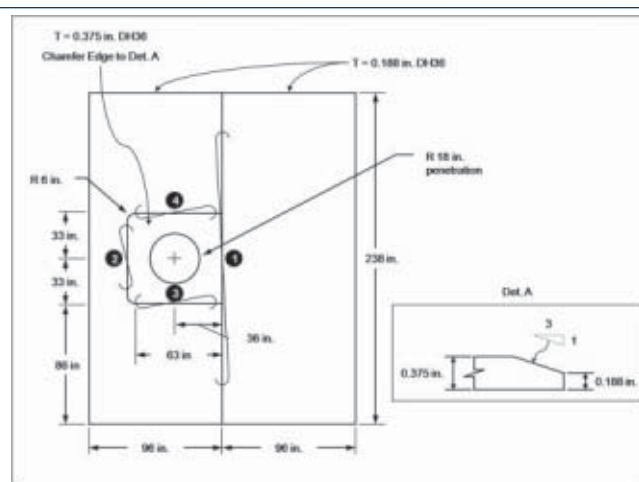


Fig. 4 — Demonstration panel with weld sequence numbered and insert joint prep shown in Detail A.



Fig. 5 — A — HLAW and B — SAW demonstration panels comparing the magnitude of out-of-plane distortion adjacent to the insert after welding. The out-of-plane deflection from a flat position is indicated (the value includes the plate thickness).

nology in the shipyard; however, improvements including the addition of joint tracking and development of a more portable system would be necessary prior to being effectively used in production. It is worth noting that the HLAW process is capable of being implemented in a highly mechanized or fully automated arrangement — with manipulation of the laser focusing optics, GMA torch, and ancillary equipment achieved via mechanized welding tractors or fixed large gantry manipulation.

The demonstration panels, shown schematically in Fig. 4, consisted of a 0.188-in.-thick panel and a 0.375-in.-thick insert. The panel and insert were fabricated of ABS DH36 high-strength structural steel. Edge preparation included high-definition, plasma-cut square-butt joints and grinding away of primer approximately 0.5 in. from the weld joint. The panel was supported above the shop floor using lengths of 3-in.-wide C-channels arranged parallel to the 20-ft panel dimension and spaced nominally 24 in. on center. C-channel was also placed beneath the four welded joints, in a “convex” fashion, to permit complete-joint-penetration hybrid welds. Panels were fit and tacked by shipyard personnel using standard shipyard practice, which included 0.5-in.-diameter manual GMA

spot welds placed approximately 6 to 12 in. apart. The HLAW panel was also autogenously laser tack welded at 12-in. spacing. Run-on/off tabs were manually GMA welded at the start and end of the first weld in the sequence. The fitup of the two panels was measured prior to welding and reported as a range for each weld sequence in Table 1. The panels were not restrained, and the insert radii were not welded in either panel.

The single-pass hybrid laser arc welding process utilized an ytterbium-fiber laser operating continuously at 4500 W of power, and a pulsed GMA process with a mean voltage of 24.2 V and nominal wire feed rate of 330 in./min. The laser led the arc, with the laser beam focal spot and electrode separated by 0.24 in. Welding was conducted at a linear travel speed of 60 in./min. For the second weld in the sequence (having a maximum root opening of 0.083 in.), the laser power was set to 3275 W, and the wire feed speed was increased to 615 in./min along the joint length to provide the required fill (nominal voltage was 30.7 V). The average heat per unit length of weld was 10 kJ/in. for the entire panel. The welding consumables used were ER70S-6, 0.045-in.-diameter electrode and Ar-10CO₂ shield gas flowing at 95 ft³/h.

The SAW process was tractor-driven with a nominal travel speed of 30 in./min, arc voltage of 30 V, and 63 in./min wire feed rate. An 0.125-in.-diameter EM12K electrode and F7A2 flux were used. The joint preparation required the use of a two-sided weld. The first side was welded with an average heat input of 17 kJ/in. while the second side was welded using an average of 23 kJ/in. The total heat input to weld both sides of the panel was approximately 40 kJ/in.

Figure 5 compares postwelding distortion along the longitudinal edge on the insert side of both the HLAW and SAW panels. This region of the panel experienced the greatest out-of-plane (*z*) distortion in both panels due to the increased stiffness associated with the insert. The measured out-of-plane distortion was 0.95 in. and 2.53 in. for the HLAW and SAW processes, respectively.

Out-of-plane distortion was measured before (*z_b*) and after (*z_a*) welding using a laser displacement sensor that was scanned across the plate surface. The displacement sensor is capable of accurately measuring height differences less than 0.005 in. The change in plate shape ($\Delta z = z_a - z_b$) was calculated over a 6-in.-square grid from the obtained data. The resulting change in plate shape for the

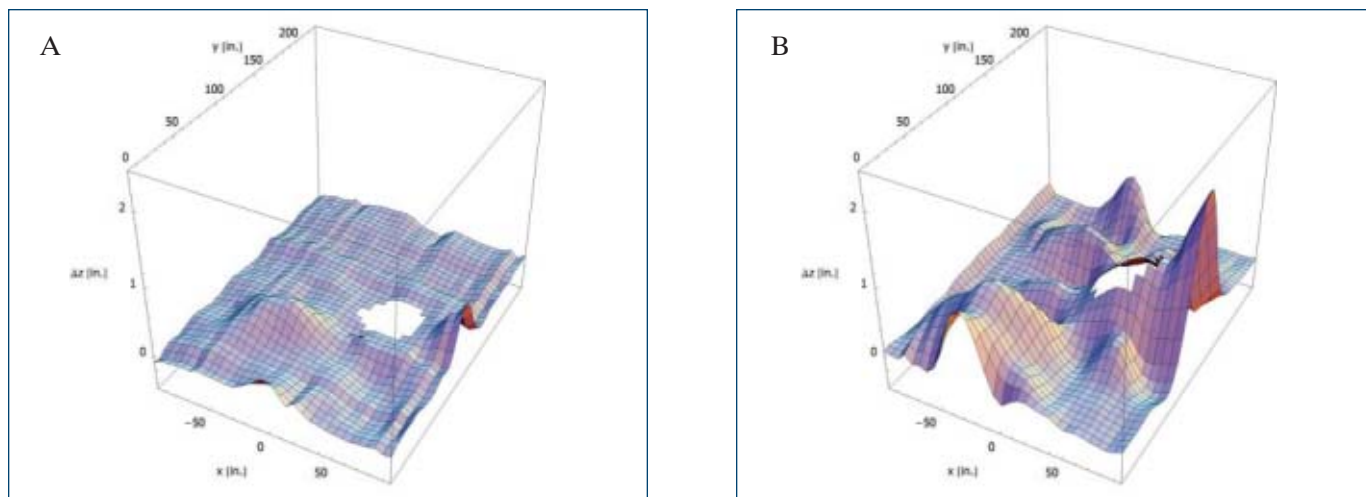


Fig. 6 — Change in demonstration panel shapes following A — HLAW and B — SAW. The Δz axis has been magnified by 230 times (compared to x and y) in both A and B.

HLAW and SAW processes is shown in Fig. 6A and B, respectively. The hybrid welded plate exhibits significantly less weld-induced distortion. The magnitude of distortion is captured quantitatively in Table 2 through the root mean squared (RMS) average and range of the change in plate shape.

Table 2 also shows the percentage of the as-welded plate meeting MIL-STD-1689 fairness requirements for primary hull structure (Ref. 17). The requirement is driven by plate thickness and stiffener spacing (24-in. spacing assumed). While there is no requirement as to when unfairness is measured, it is typically addressed in unit assembly; however, for illustrative purposes herein, the specification is applied after the step of welding the butt joints. After butt-joint welding, the hybrid welded panel was 96% within specification, while the submerged arc welded panel was 75% within specification. It is worth noting that both panels, after fitting and tacking but prior to butt-joint welding, were 98% within specification. Hence, the hybrid welding process contributed only an additional 2% to the panel out of tolerance, whereas the submerged arc process increased the out of tolerance by 23%. These percentages translate to 6 ft² and 74 ft² of distorted (out-of-tolerance) plate in the HLAW and SAW plates, respectively.

Even though the fairness specification was applied prior to the addition of stiffeners, it is likely that overall panel distortion would not be improved when stiffeners are added. Huang et al. reported that the out-of-plane waves induced during the butt-joint welding stage are compressed into shorter period waves of lesser magnitude following stiffener welding (Ref. 1). Given a significantly flatter panel following butt-joint welding, further down-

Table 2 — Quantified Weld Distortion from Demonstration Panels

Measurement	HLAW	SAW
RMS Average Δz	0.101 in.	0.396 in.
Range ($\Delta z_{\max} - \Delta z_{\min}$)	0.874 in.	2.383 in.
Percentage of Plate Meeting MIL-STD-1689 Fairness Requirements for Primary Hull Structure	96%	75%

Table 3 — Demonstrated Performance in 0.188-in.-thick DH36 Steel Production-Scale Panels

Quantity	HLAW	SAW	Compared to HLAW, the SAW process
Productivity (time to weld demo panel)	6.9 min	28.1 min	is 4.0 times slower
Total Heat Input to Panel	10 kJ/in.	40 kJ/in.	adds 4.0 times more heat
Weld Distortion (RMS average change in plate shape)	0.101 in.	0.396 in.	adds 3.9 times more distortion
Weld Metal Deposited (lb/ft)	0.029 lb/ft	0.180 lb/ft	uses 6.2 times more weld metal

stream productivity improvements may be realized by improving the fitup between panel and stiffener and between adjoining units during subsequent unit erection.

Process and Distortion Cost Comparison

A direct comparison of costs between HLAW and conventional SAW was undertaken in order to determine the savings achievable with HLAW. Welding process costs are compared for 0.188-in.-thick steel plate with plasma cut edges. Labor (welding time), filler metal, gas or flux shielding, other laser consumables, and electrical energy consumption were considered in the cost determination. The SAW and HLAW costs are derived from the conditions described above. Figure 7

illustrates the costs associated with each of the aforementioned categories. Hybrid laser arc welding process costs are 2.5 times less than SAW. The welding process cost savings of the hybrid process is driven by reducing weld time and consumable costs. Power consumption costs are minimal due to the high wall-plug efficiency of currently available fiber-delivered lasers. The labor cost for HLAW is based on a laser power of 4.5 kW; however, higher laser powers are commercially available allowing increased travel speeds and reduced welding costs.

Process cost improvements afforded by HLAW are modest in comparison with the potential for reducing costs associated with weld distortion. When the material and application permits, flame straightening is often used to correct distortion problems. Despite its prevalent use, there

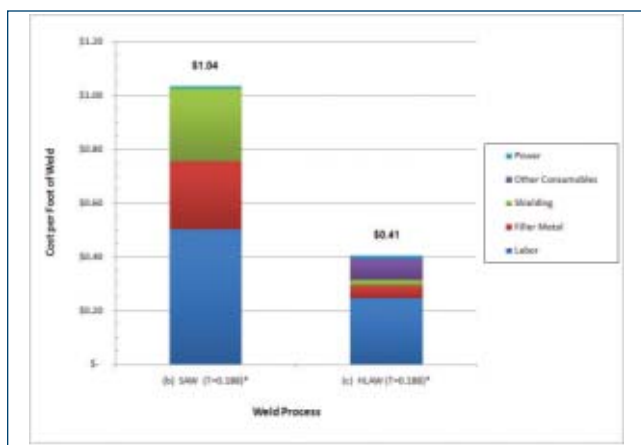


Fig. 7 — Process cost per foot comparison for double-sided SAW and single-sided HLAW in 0.188-in.-thick AB/DH36 steel.

are a wide range of estimates as to the costs associated with flame straightening:

- The cost of correcting distortion in a 0.188-in.-thick panel by flame straightening was reported to be \$1.50/ft² in 1996 (estimated to be \$2.14 in 2008) (Ref. 18).
- In general, distortion rework costs were reported to be approximately \$23.00/ft² in 1996 (estimated to be \$32.79 in 2008) (Ref. 18).
- Pattee et al. reported experimentally determined times to flame straighten shipbuilding steels of thicknesses ranging from 0.375 to 0.75 in. (Ref. 19). Based on these reported times and assuming that flame straightening primarily occurs during the unit fabrication step, the cost for correcting distortion in 0.188-in.-thick steel is estimated to be \$65.33/ft².

The three flame straightening cost estimates and the experimentally determined distorted square footage for HLAW and SAW demonstration panels (6 and 74 ft², respectively) were used to estimate the potential cost savings for a HLAW process. The results indicate that savings due to reduced distortion using the HLAW process could range from \$0.45/ft² to \$13.72/ft².

Ongoing Efforts

Through the supporting Navy Manufacturing Technology program, benchmark welding procedure qualification testing of HLAW 5-mm-thick DH36 has been conducted in accordance with NAVSEA S9074-AQ-GIB-010/248 requirements (Ref. 20). The test matrix included visual inspection, radiographic inspection, and transverse bend and tensile testing required for the base material. In addition, longitudinal bend testing, microhardness,

weld metal tensile, and weld metal Charpy impact testing were conducted for informational purposes. The results indicated that hybrid laser arc welding processes could be qualified to current NAVSEA standards for 5-mm-thick DH36 base material and 70S-6 electrode. The program is currently supporting HLAW process development and initiating weld procedure and performance qualification of DH36 and HSLA-80

steels in 0.188- through 0.5-in. thicknesses.

Summary

Hybrid laser arc butt-joint welding has been successfully demonstrated in a shipyard production environment on production-scale thin-steel panels. The results of the technology demonstration allow for a direct comparison with submerged arc welding. The resulting process performance metrics for productivity, heat input, distortion, and filler metal used are reported in Table 3. The estimated processing cost of hybrid laser arc welding of butt joints is \$0.41/ft and the distortion rework cost savings could range from \$0.45 to \$13.72/ft². The ongoing efforts of the program will continue to mitigate risk associated with weld qualification and cost of implementation. ♦

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One Machine Does It All for Laser Beam Welding and Cutting

This combination system can help you boost flexibility and productivity in sheet metal fabrication

BY DIRK PETRING AND FRANK SCHNEIDER

Three-dimensional laser material processing has benefited in recent years from the developments in high-brightness disk and fiber lasers. The advantages of these lasers are fiber-coupled beam guidance, high beam quality, high laser efficiency, good pulsability, small size, and decreased investment costs. Additionally, the inherent advantages — shortened process chains, high flexibility, and accuracy — of combination processing in which cutting and welding are accomplished with the same processing head make 3-D laser processing ever more attractive (Ref. 1).

What makes brightness relevant for combined cutting and welding is the enlarged operating window allowed for changing head distance. A “slim” focal zone of a bright enough laser allows for cutting narrow kerfs with a small nozzle standoff and for excellent welding conditions with a larger standoff with the same nozzle — even without changing the focal distance relative to the nozzle exit (Ref. 2).

A new combi-head design for machines with integrated beam guidance is presented in this article. The design results in improved features for optimized 3-D processing. Furthermore, a programmable laser modulation control allows a high variation of speeds in 3-D contours and leads to burr-free cuts in the complete speed range of the application.

A typical application of the 3-D combi-head technology is illustrated by means of trimming, aperture cutting, and welding operations on automotive B-pillars.

Added Value by Combi-Processing

The possibility of carrying out laser cutting and welding operations on one machine without changing the process head offers many benefits in laser processing (Refs. 1–4). The combi-head is the

key to this flexible production, allowing the quick change of the processes just by automatically changing the gas type and flow rate, focal and nozzle position, and laser power and speed. The so-called “autonomous nozzle” provides the gas jet for cutting and the shielding gas for welding (Ref. 5). The unique concept of the coaxial nozzle design permits an open space between the optics and nozzle (even during cutting) for the integration of a cross-jet. This jet is essential in order to protect the optics from smoke and spatter during the welding process, when we require only a low volume, smooth gas flow from the coaxial nozzle.

Combi-processing has several economic advantages compared to individual cutting and welding systems. These include short, integrated process chains; high machine utilization; flexible and cost-efficient production of variants; and savings in handling, positioning, and clamping of parts.

Also, the following technological advantages can be listed: identical tool center points (TCP) for both cutting and welding; and the free choice of an optimized sequence of cutting and welding operations with respect to technical and economic criteria. These features enable higher accuracy and shorter tolerance chains. For example, no tracking system is needed for welding because the edges can previously be cut with the combi-head and thus the coordinates of the weld track along these edges are perfectly known by the system. Since the TCP remains the same when welding, the path for the weld joint is precisely defined within the machine coordinates.

The Identical Path Concept

Whenever cutting and welding operations in combi-processing can use an identical path with the same clamping, the precision in repeating the cut/weld contour

is perfect for achieving good and reliable results. Thus, even machines with moderate accuracy such as articulated robots can operate at higher speeds than usual.

Nonlinear tailored blanks processed with the combi-head demonstrate the identical path concept. Figure 1 shows a specimen machined with a 6-axis robot. As shown in the figure from left to right, the edges are first prepared by laser cutting, then put together, and welded along the same path. Finally, cuts in the welded blank are precisely positioned to each other. Even the limited accuracy of a robot at a cutting and welding speed of 8 m/min provides constant good weld joints, because only the reproducibility of the same path is required. Besides tailor-welded blanks, another application of the identical path concept is the processing of coils to produce “endless” coil material by laser trimming the ends of coils and laser welding them together. Figure 2 shows cutting and welding speeds on automotive sheets with 4.0-kW laser power from a fiber laser with a 150- μ m-diameter fiber. With smaller fiber diameters, i.e., higher beam quality, even higher speeds are possible. On the other hand, if an application does not require or cannot handle such high speeds, a laser with lower power can be used, with corresponding cost reductions.

Essentials for 3-D Capability

Those examples show that there are reasonable 2-D applications for combi-processing, but typically the welding in combi-processing is used to manufacture 3-D assemblies from 3-D raw parts such as deep-drawn sheets, blanks, profiles, or tubes. Hence, the following 3-D capabilities from the machine, the processing head, and the process are required:

- Appropriate machine kinematics, pro-

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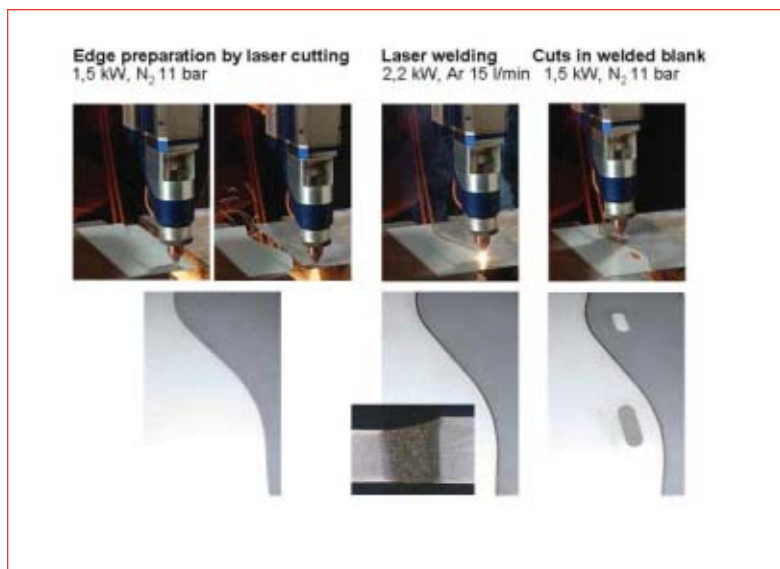


Fig. 1 — Specimen of nonlinear tailor-welded blanks from coated steel (1 mm/1.2 mm), combi-processed with the identical path concept on a 6-axis articulated robot without teaching or joint tracking in a moderate power range of 1.5–2.2 kW and at a processing speed of 8 m/min.

viding the application-oriented requirements in accessibility, speed, acceleration, and accuracy.

- A slim head with a small interfering contour for good accessibility of the workpiece.
- Process parameters that provide good quality over a wide speed range because in 3-D processing, the potential variance in the TCP processing speed is huge due to unavoidable low-speed phases during reorientation of the head, e.g., at bending edges.
- Distance-tolerant process parameters for the cutting process because bended surfaces or lateral material influence the signal of the capacitive distance control and cause higher variation of the nozzle distance than is usual in flat sheet 2-D cutting.

These requirements are met by a machine setup with a new combi-head design for robots with axis-integrated beam guidance and an appropriate choice of the beam parameters.

When following 3-D contours with small radii, the hand axes of the robot can experience rapid changes in orientation of the processing head and produce stresses in the fiber by lashing movements and torsion. This can be avoided by employing an axis-internal beam guidance system that directs the collimated laser beam with mirrors through the last two or three rotational axes of the robot. The latest version of the combi-head F2-X from Laserfact (Fig. 3)

is adapted in this way with a mounting flange coaxial to the last rotational axis of a gantry robot (system RLP16 from Reis), which uses three linear axes with linear direct drives and three rotational axes.

Gantry kinematics profit from short tool lengths when circular paths around the workpiece are required. This is because a short tool reduces compensation movements and improves the dynamics around small radii. The combi-head meets this demand by a short overall length of 305 mm from the flange to the nozzle tip, including the additional z-axis for distance control. High acceleration is achieved by using high dynamic linear drives with 0.7-g acceleration in 3-D movements.

Taking advantage of a modular design, the lower part of the head, containing the protection window, cross-jet, distance sensor and nozzle, is unchanged in comparison to the other combi-head versions, except for an alternative nozzle design: For optimal workpiece accessibility, the cone angle of the nozzle can be reduced from 60 to 40 deg. A small angle also reduces interference of the distance control signal caused by lateral material proximity. Due to the modular head design, the modified nozzles are applicable for all existing combi-head versions.

The upper part of the head, containing the z-axis, the focusing optics with adjustment elements, and all media connections, has been redesigned for a short, compact length and to fit to connection flanges coaxial to the beam entrance aperture.

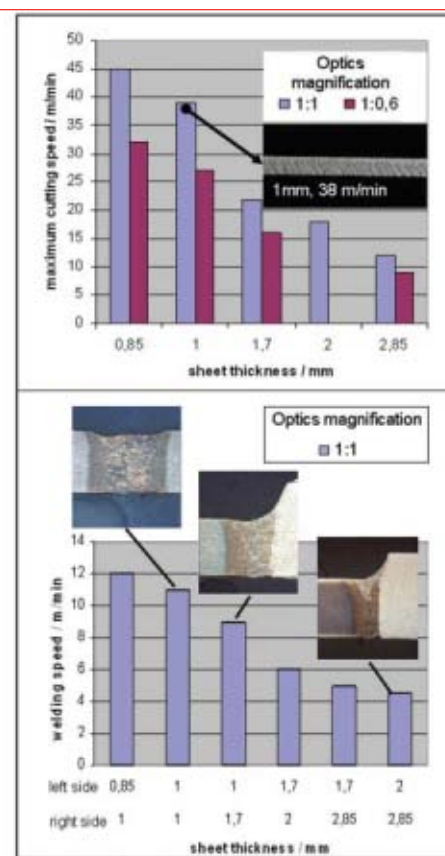


Fig. 2 — Maximum cutting speeds (top), and adapted welding speeds for a sound root formation (bottom). (Laser power: 4 kW; fiber diameter: 150 μ m; material: galvanized steel.)

Switching between Cutting and Welding

In principle, there are no differences between the capabilities and parameters of standard cutting and welding heads and the combi-head. Nevertheless, some details are worth mentioning in order to avoid needless confusion or scepticism. It is sometimes believed that adaptive optics or motorized nozzles for changing nozzle distance and focal position independently are obligatory during switching between cutting and welding. Of course these are possible options, but with the autonomous nozzle for many applications, it turned out to be appropriate to use an identical focal distance from the nozzle tip for both cutting and welding. That means focal position and nozzle distance relative to the workpiece surface are changed simultaneously, simply by lifting the complete head, when switching from cutting to welding. Fewer optical and electrical elements reduce the complexity of the combi-head to the required minimum and ensure maximum robustness. Of course the head distance as well as gas type and flow rate, laser beam power, and processing speed can be adapted auto-

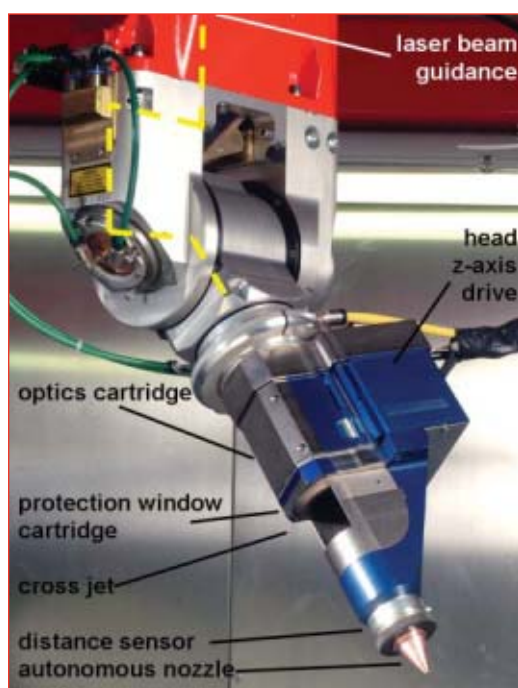


Fig. 3 — Combi-head on a gantry robot with axis-integrated beam guidance.

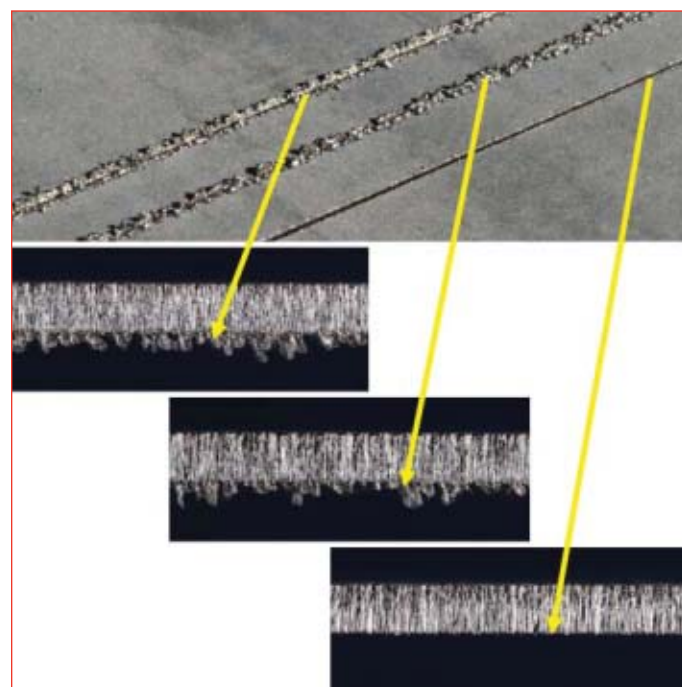


Fig. 4 — Low-speed cutting affects quality: backside of a sheet with three cuts and photos of corresponding cut edges, all cut at a speed of 1 m/min. Top: laser power 2 kW, cw; middle: laser power 0.5 kW, cw; bottom: laser power 0.5 kW (average), peak power 2 kW, pulsed with $f = 250$ Hz, duty cycle 0.25.

matically by the machine control being programmed accordingly. And, of course, the combi-head allows precise manual adjustment of the laser beam focus in lateral and axial direction.

A suitable beam quality and the correct layout of the collimation and focussing optics according to the demands of the combined processes are the crucial boundary conditions to be successful with the above-described concept.

Laser Power Modulation

Depending on the contour involved, the speed of the tool center point (TCP) can vary dramatically in 3-D applications. A factor of 10 or 20 between speeds on straight paths and around small radii is not unusual. Reduced quality occurs in low-speed sections in the form of burrs when cutting and irregular joints during welding. In combi-processing, as in standard cutting or welding, a simple laser power control with respect to speed is an effective answer for some of the problems due to speed variation. However, to achieve a burr-free cut quality over the whole speed range, an adaptive laser power modulation is necessary — Fig. 4. A programmable laser modulation control has been developed that allows us to adapt modulation frequency, duty-cycle, and amplitude of the laser power to the effective speed. By the control of pulse frequency and duty cycle, it is possible to adjust both the average power and spatial

overlapping of pulses individually for each velocity. In addition, by adapting the amplitude, the depth and level of the modulation are tuned according to the required process characteristics.

3-D Applications

The impact of the features that support 3-D performance (high beam quality, an optimized combi-head, and the modulation control) is demonstrated in an automotive application example, namely combi-processing of a B-pillar. Driven by the use of modern hot-formed high-strength steels for crash-relevant car body components, laser trimming and cutting of apertures in these parts is well established because those materials are difficult to cut mechanically. With the availability of combi-processing, it even becomes possible to integrate welding operations into the process chain with the same setup leading to the benefits already discussed.

First, several holes are cut into the B-pillar. Second, the final dimensions are cut. Next, a reinforcing sheet is welded on the pillar and, finally, holes are cut through the reinforcing sheet and the B-pillar — Fig. 5.

All operations are performed in one clamping, thus high positional tolerances between the outer contour and the holes, including those in the weld-on part, are guaranteed.

The processing was done on a gantry

robot (RLP16 from Reis) with a Laserfact combi-head F2-X — Fig. 6. The laser source was an IPG fiber laser YLR4000 SS with a 100- μ m-diameter process fiber. The large contours were cut at 15 m/min, the holes at 3–9 m/min, depending on their diameter and the material thickness. For the smallest radii, the pulsed mode was used. The welding speed was 3 m/min for the lap weld through the reinforcement plate (1.3 mm) and the pillar (1.4 mm). The maximum laser power was 2.5 kW. Depending on the details of the cut contour, the overall processing time for cutting and welding a B-pillar as in Fig. 5 is in the range of 1 min.

Another demonstration of combi-processing capabilities is the possibility of welding a circular joint just before precisely cutting the holes at the edge of the weld joint to produce a gap-free, sealed hole, preventing subsequent crevice corrosion — Fig. 7. The coordinates of the weld are known in the machine and with an identical path plus an offset, a precise position of the cut relative to the weld is possible thanks to the common TCP for cutting and welding. As both processes can be done one after the other, there is no additional positioning. Another option is the welding on of additional functional parts such as nuts, studs, or mounting plates.

In fact, there are many possibilities for intelligent process chains opened up by the integration of laser cutting and welding processes in a flexible manufacturing



Fig. 5 — Combi-processed B-pillar with cross section of the welded reinforcing sheet and details of the cut contours. Maximum laser beam power is 2.5 kW.

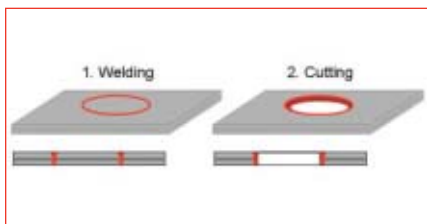


Fig. 7 — Cutting a sealed aperture along a previously welded circular overlap joint through two sheets.

environment. And beside the improvement of existing processes, completely new product designs are also possible and can be cost-efficiently manufactured.

Conclusions

For 3-D combination processing with high-quality results at economically attractive processing times, the following elements are essential:

- A 3-D machine or robot with high dynamic response and accuracy, such as a gantry robot with linear direct drives and integrated beam guidance.
- A laser with a fiber-coupled beam delivery and good beam quality such as a fiber or disk laser.
- A combi-head, featuring optimized 3-D capabilities as a result of its slender design, short length, and fast distance control with a dynamic z-axis.



Fig. 6 — Combi-head at work. Cutting and welding process on the B-pillar with a gantry robot. (Photo courtesy of Laserfact GmbH.)

- A speed-adapted laser power modulation control. ♦

Acknowledgments

The work has been partially funded by the German Federal Ministry of Economics and Technology BMWi in the InnoNet-Program (koLas, 16IN0426). We would like to thank our industrial project partners Reis Robotics, Laserfact, and LBBZ for their cooperation.

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CONFERENCES

International Brazing & Soldering Conference **Orlando, Fla.** **April 26–29**

This three-day conference will provide one of the most comprehensive technical programs available to the brazing and soldering communities. You'll discover the latest trends, products, processes, and techniques available. Join hundreds of other professionals, scientists, and engineers from around the globe who are involved in the research, development, and application of brazing and soldering in valuable networking opportunities, pre-conference educational programs, and exhibits.

12th Aluminum Welding Conference **Toronto, Ont., Canada** **May 5 and 6**

A panel of aluminum industry experts will survey the state of the art in aluminum welding technology and practice. You will also have the opportunity to network with speakers and other participants, as well as to visit an exhibition showcasing products and services available to the aluminum welding industry.

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 of aluminum requires special processes, techniques, and expertise.

Shipbuilding Conference **New Orleans, La.** **June 16 and 17**

Welding is the most vital and fundamental manufacturing process in the construction of ships and metal hull boats. Keeping in tune with the progress of new innovative developments, as well as their potential value and impact to the industry is essential for those in the shipbuilding community. This conference will address the critical importance of welding in the shipbuilding industry by providing current information on new and emerging technologies being developed for shipbuilding applications. The conference will also provide opportunities for you to network informally with experts from academia and industry, as well as with your fellow participants. An exhibition showcasing products and services available to the shipbuilding industry will also be featured.

2009 FABTECH International & AWS Welding **Show Conference Schedule** **Chicago, Ill.**

Weld Cracking: "The Heat-Affected Zone" Conference **November 16**

One of production welding's greatest moments, the construction of the Liberty ships during World War II, was accompanied by a new problem. Weld cracking was observed on some of these ships, and the reason for the cracking was a mystery. The cause has since been determined, but as new metals and alloys have

come into use the problem comes back in different forms to haunt the welding metallurgist. A crack costs money, takes time to repair, and interrupts production. So where does one go for help? The experts will be at Weld Cracking VII. You will obtain answers to your current problems and will be better prepared to solve cracking problems in the future. You can also learn about the latest equipment including induction heating, a wireless heat-treat system, and portable X-ray diffraction equipment. The use of fracture mechanics will be explored. Descriptions will be given on the heat-affected zone and on the many types of cracks that accompany welding. Base materials covered will include various steels, the stainless steels, aluminum, and titanium.

Thermal Spray and Coatings Conference **November 16**

Welding of Chrome-Moly Steels Conference **November 17**

The welding of chrome-moly steel goes back to the days when tubing was oxyacetylene welded to make up the fuselages of the early prealuminum airplanes. It all required outstanding precision on the part of the welder, and even though the methods have changed, the welding of 4130 steel still requires utmost precision. The welding of chrome-moly steels requires great skills on all parties involved, and not just the welding: heat treatment and non-destructive examination are essential to a successful weld. The 2¼ Cr-1 Mo steels are popular materials for boilers and pressure vessels. More recently, the modified 9 Cr-1 Mo steel is now widely specified in the electric utilities and is moving into the oil and gas industry. Conventional welding processes are all used effectively on 4130, 2¼ Cr-1 Mo and modified 9 Cr-1 Mo steels. Newer processes such as hybrid welding have also become popular.

AWS/DVS Electron Beam Welding Conference **November 17 and 18**

This event will include a two-day technical program and a half-day tutorial. Join scientists, engineers, and technical personnel from around the globe who are involved in the research, development, and application of electron beam welding.

Welding the Corrosion-Resistant Alloys Conference **November 18**

Interest in welding corrosion-resistant alloys is extraordinarily high. The reasons include the entry of the duplex stainless steels and other high-performance grades. Another is the unstable prices in nickel, molybdenum, and titanium. When the price of nickel hit the roof, many fabricators switched from 316 to 201 stainless because of the latter grade's lower nickel content. Research is feverish throughout the world in the development of new and cheaper methods of producing titanium. Will a lower-cost titanium make the metal more popular? The overall activity is intense. Cladding and strip overlay processes have become more popular means of protecting parts exposed to heavy corrosion. Duplex stainless is now being welded for over-the-road tankage. New processes, like friction stir welding and thermal stir welding, will be discussed. Keep abreast of this exciting new world in welding where corrosion-resistant alloys have taken center stage.

For more information, please contact the AWS Conferences and Seminars Business Unit at (800) 443-9353, ext. 455. You can also visit the Conference Department at www.aws.org/conferences for upcoming conferences and registration information.

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◆ **Joining Dissimilar Metals Conf.** March 3, 4, Orlando, Fla. Contact American Welding Society, (800/305) 443-9353, ext. 455; visit www.aws.org.

◆ **Laser Additive Manufacturing Workshop.** March 3, 4, Holiday Inn, Riverwalk, San Antonio, Tex. As a cooperating society, AWS members will receive discounted registration fees. Contact Laser Institute of America, www.laserinstitute.org.

Lean for the Supply Chain. March 3–5, Crown Plaza Hotel, San Jose, Calif. Contact Society of Mfg. Engineers, (800) 733-4763, www.sme.org.

◆ **GAWDA, Gases and Welding Distributors Assn., Spring Management Conf.** March 22–24, Sheraton Chicago Hotel & Towers, Chicago, Ill. Visit www.gawda.org.

ILSC® Int'l Laser Safety Conf. March 23–26, John Ascuaga's Nugget Hotel, Reno, Nev. Sponsored by Laser Institute of America, www.laserinstitute.org/conferences/ilsc; or call (407) 380-1553.

Spring Robot Safety Conf. March 23–25, Knoxville Marriott, Knoxville, Tenn. Contact Robotic Industries Assn. at ria@informz.net or ria@robotics.org.

ABB Automation & Power World 2009. March 24–26, Orlando World Center Marriott, Orlando, Fla. Visit www.abb.com/apworld.

Heat Treating of Light Alloys. March 25, 26, Doubletree Hotel, Anaheim, Calif. Visit www.asminternational.org.

WESTEC. March 30–April 2, Los Angeles Convention Center, Los Angeles, Calif. Contact Society of Mfg. Engineers, (800) 733-4763; or visit www.sme.org/westec.

MicroMfg. and NanoMfg. Conf. & Exhibits. March 31–April 1, Sheraton Bloomington Hotel, Minneapolis, Minn. Contact Society of Mfg. Engineers, (800) 733-4763, www.sme.org/micro, www.sme.org/nano.

North American Steel Construction Conf. and AISC Steel Construction Expo. April 1–4, Phoenix, Ariz. Visit www.aisc.org.

2nd Annual Global Marine Renewable Energy Conf. April 15, 16, The Carnegie Institution for Science, Washington, D.C. Contacts (877) 463-3846; info@globalmarinerenewable.com.

The Aluminum Assn. Spring Meeting. April 20–22, Omni La Mansion del Rio, San Antonio, Tex. Visit www.aluminum.org.

◆ **GAWDA Spring Management Conf. 2.** April 21–24, Asheville, N.C. Sponsored by Gases and Welding Distributors Assn. Visit www.gawda.org.

◆ **IBSC, 4th Int'l Brazing and Soldering Conf.** April 26–29, Hilton Hotel in the Walt Disney World Resort, Orlando, Fla. Cosponsored by AWS and ASM International. Contact American Welding Society, (800/305) 443-9353, ext. 229; visit www.aws.org.

JOM-15, 15th Int'l Conf. on the Joining of Materials, and 6th Int'l Conf. on Education in Welding. May 3–6, Helsingør, Denmark. Organized by JOM Institute, supported by Dansk Metal, Danish

Welding Society, DSL.FORCE Technology. Send e-mail inquiries to jom_aws@post10.tele.dk.

AISTech 2009, The Iron & Steel Technology Conf. and Expo and Asia-Pacific Partnership Technology Showcase 2009. May 4–7, St. Louis, Mo. Contact Association for Iron & Steel Technology www.iss.org.

Int'l Thermal Spray Conf. and Expo (ITSC). May 4–7, Flamingo Las Vegas Hotel, Las Vegas, Nev. Sponsored by ASM Int'l Thermal Spray Society, German Welding Society, and Int'l Institute of Welding. Visit www.asminternational.org/itsc.

Offshore Technology Conf. May 4–7, Reliant Center, Houston, Tex. Visit www.otcnet.org/2009.

◆ **12th Aluminum Welding Conf.** May 5, 6, Toronto, Ont., Canada. Contact American Welding Society, (800/305) 443-9353, ext. 229; visit www.aws.org.

◆ **Robotic Arc Welding Conf. and Expo.** May 11–13, Milwaukee Area Technical College, Milwaukee, Wis. Cosponsored by the AWS Milwaukee Section and D16 Committee on Robotic and Automatic Welding. Includes tour of Caterpillar's facility in Aurora, Ill. Contact Karen Gilgenbach at karen.gilgenbach@airgas.com, or call (262) 613-3790.

RAPID 2009. May 12–14, Renaissance Schaumburg Convention Center, Schaumburg, Ill. Contact Society of Mfg. Engineers, (800) 733-4763, www.sme.org/rapid.

Advanced Manuf. Expo. and Plant Maintenance & Design Engineering Show. May 19–21, Place Bonaventure, Montreal, Que., Canada. Contact Society of Mfg. Engineers, (800) 733-4763, www.sme.org.

EASTEC. May 19–21, Eastern States Exposition Grounds, W. Springfield, Mass. Contact Society of Mfg. Engineers, (800) 733-4763; or visit www.sme.org/eastec.

◆ **AWS/Weldmex.** June 2–4, Monterrey, Mexico. Contact American Welding Society, (800/305) 443-9353, ext. 229; or visit www.aws.org.

Beijing-Essen Welding & Cutting Fair. June 2–5, Shanghai, China. Visit www.beijing-essen-welding.de.

AeroMat® 2009 Conf. and Expo. June 7–11, Dayton Convention Center, Dayton, Ohio. Call ASM customer service (800) 336-5152, ext. 0; e-mail customerservice@asminternational.org; or visit <http://asmcommunity.asminternational.org/content/Events/aeromat09/>.

◆ **Weld Cracking VII 'The Heat-Affected Zone' Conf.** June 9, 10, Columbus, Ohio. Contact American Welding Society, (800/305) 443-9353, ext. 229; or visit www.aws.org.

First Int'l Conf. on Welding Technologies. June 11–13, Gazi University, Ankara, Turkey. Visit www.icwet09.org.

◆ **Shipbuilding Conf.** June 16, 17, New Orleans, La. Contact American Welding Society, (800/305) 443-9353, ext. 229; or visit www.aws.org.

Western Manufacturing Technology Show. June 16–18. Northlands Park-AgriCom, Edmonton, Alb., Canada. Contact Society of Manufacturing Engineers, (800) 733-4763; or visit www.sme.org.

7th Int'l Expo on Electric Power Equipment and Technology and 6th Int'l Expo on Electrical Engineering, Electrical Equipment, and Contractors' Supplies. July 8–10. Shanghai Int'l Expo Center, Shanghai, PR, China. Visit www.2456.com/ep.

Essen Welding Fair (Schweissen & Schneiden). Sept. 14–19, Essen, Germany. Visit www.messe-essen.de.

25th ASM Heat Treating Society Conf. and Expo. Sept. 14–17, Indiana Convention Center and RCA Dome, Indianapolis, Ind. Visit www.asminternational.org.

♦ **GAWDA Annual Meeting.** Sept. 20–23, Grand Hyatt Hotel, San Antonio, Tex. Sponsored by Gases and Welding Distributors Assn. Visit www.gawda.org.

SOUTH-TEC. Oct. 6–8, Charlotte Convention Center, Charlotte, N.C. Contact Society of Mfg. Engineers, (800) 733-4763; or visit www.sme.org/southtec.

♦ **Welding of Corrosion-Resistant Alloys Conf.** Oct. 6, 7, New Orleans, La. Contact American Welding Society, (800/305) 443-9353, ext. 229; or visit www.aws.org.

The Aluminum Assn. Annual Meeting. Oct. 25–27, Charleston Place, Charleston, S.C. Visit www.aluminum.org.

National Robot Safety Conf. XXI. Oct. 26–29, Hyatt Regency, Dearborn, Mich. Contact Robotic Industries Assn. at ria@informz.net or ria@robotics.org.

ICALEO, 28th Int'l Congress on Applications of Lasers & Electro-Optics. Nov. 2–5, Hilton in the Walt Disney World Resort®, Orlando, Fla. E-mail Laser Institute of America at conferences@laserinstitute.org; or visit www.icaleo.org.

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♦ **Weld Cracking VII.** Nov. 16, Chicago, Ill. Held during the FABTECH International & AWS Welding Show. Contact American Welding Society, (800/305) 443-9353, ext. 455; or visit www.aws.org.

♦ **Int'l Electron Beam Conf.** Nov. 17, 18, Chicago, Ill. Held during the FABTECH International & AWS Welding Show. Contact American Welding Society, (800/305) 443-9353, ext. 455; or visit www.aws.org.

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♦ **Power-Gen Int'l.** Dec. 8–10, Las Vegas, Nev. Contact American Welding Society, (800/305) 443-9353, ext. 455; or visit www.aws.org.

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

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— continued on page 95



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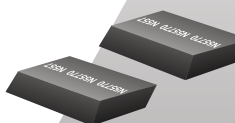
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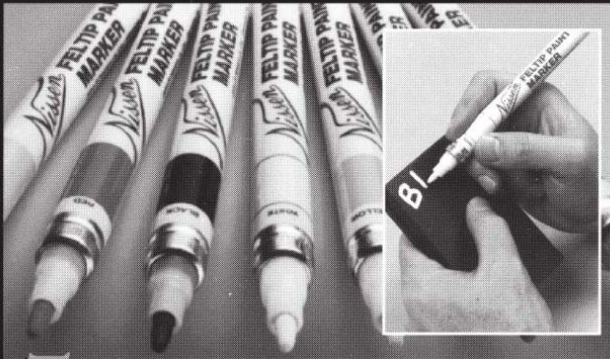


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Certified Welding Inspector (CWI)

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Dallas, TX	Apr. 19-24	Apr. 25
Springfield, MO	Apr. 19-24	Apr. 25
Baton Rouge, LA	Apr. 19-24	Apr. 25
Mobile, AL	EXAM ONLY	Apr. 25
San Francisco, CA	Apr. 26-May 1	May 2
Portland, ME	Apr. 26-May 1	May 2
Las Vegas, NV	Apr. 26-May 1	May 2
Waco, TX	EXAM ONLY	May 2
Miami, FL	EXAM ONLY	May 14
Nashville, TN	May 10-15	May 16
Jacksonville, FL	May 10-15	May 16
Baltimore, MD	May 10-15	May 16
Long Beach, CA	EXAM ONLY	May 30
Detroit, MI	May 31-Jun. 5	Jun. 6
Miami, FL	May 31-Jun. 5	Jun. 6
Albuquerque, NM	May 31-Jun. 5	Jun. 6
Spokane, WA	Jun. 7-12	Jun. 13
Oklahoma City, OK	Jun. 7-12	Jun. 13
Birmingham, AL	Jun. 7-12	Jun. 13
Hartford, CT	Jun. 14-19	Jun. 20
Pittsburgh, PA	Jun. 14-19	Jun. 20
Beaumont, TX	Jun. 14-19	Jun. 20
Corpus Christi, TX	EXAM ONLY	Jun. 20
Kansas City, MO	Jun. 21-26	Jun. 27
Miami, FL	EXAM ONLY	Jul. 16
Fargo, ND	Jul. 12-17	Jul. 18
New Orleans, LA	Jul. 12-17	Jul. 18
Sacramento, CA	Jul. 12-17	Jul. 18
Phoenix, AZ	Jul. 19-24	Jul. 25
Orlando, FL	Jul. 19-24	Jul. 25
Milwaukee, WI	Jul. 19-24	Jul. 25
Cleveland, OH	Jul. 26-31	Aug. 1
Los Angeles, CA	Jul. 26-31	Aug. 1
Louisville, KY	Jul. 26-31	Aug. 1
Denver, CO	Aug. 2-7	Aug. 8
Philadelphia, PA	Aug. 2-7	Aug. 8
San Diego, CA	Aug. 9-14	Aug. 15
Miami, FL	Aug. 9-14	Aug. 15
Charlotte, NC	Aug. 16-21	Aug. 22
San Antonio, TX	Aug. 16-21	Aug. 22
Bakersfield, CA	Aug. 16-21	Aug. 22
Rochester, NY	EXAM ONLY	Aug. 22
Portland, ME	Aug. 23-28	Aug. 29
Salt Lake City, UT	Aug. 23-28	Aug. 29
Seattle, WA	Aug. 23-28	Aug. 29
Corpus Christi, TX	EXAM ONLY	Aug. 29
Pittsburgh, PA	Aug. 30-Sept. 4	Sept. 5
Houston, TX	Aug. 30-Sept. 4	Sept. 5
Minneapolis, MN	Aug. 30-Sept. 4	Sept. 5
St. Louis, MO	Sept. 20-25	Sept. 26
Miami, FL	Sept. 20-25	Sept. 26
New Orleans, LA	Sept. 20-25	Sept. 26
Anchorage, AK	EXAM ONLY	Sept. 26

9-Year Recertification Seminar for CWI/SCWI

LOCATION	SEMINAR DATES	EXAM DATE
Dallas, TX	Mar. 30-Apr. 4	NO EXAM
Sacramento, CA	May 4-9	NO EXAM
Pittsburgh, PA	Jun. 1-6	NO EXAM
San Diego, CA	Jul. 13-18	NO EXAM
Orlando, FL	Aug. 24-29	NO EXAM
Dallas, TX	Oct. 5-10	NO EXAM
Miami, FL	Nov. 30-Dec. 5	NO EXAM

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

Certified Welding Supervisor (CWS)

LOCATION	SEMINAR DATES	EXAM DATE
New Orleans, LA	Apr. 20-24	Apr. 25
Columbus, OH	Jun. 1-5	Jun. 6
Minneapolis, MN	Jul. 20-24	Jul. 25
Philadelphia, PA	Aug. 31- Sep. 4	Sep. 5
Tulsa, OK	Oct. 5-9	Oct. 10
Long Beach, CA	Nov. 30-Dec. 4	Dec. 5

CWS exams are also given at all CWI exam sites.

Certified Radiographic Interpreter (CRI)

LOCATION	SEMINAR DATES	EXAM DATE
Indianapolis, IN	Apr. 20-24	Apr. 25
Miami, FL	Jun. 22-26	Jun. 27
Houston, TX	Jul. 27-31	Aug. 1
Miami, FL	Oct. 19-23	Oct. 24

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

Certified Welding Educator (CWE)

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

Senior Certified Welding Inspector (SCWI)

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

Code Clinics & Individual Prep Courses

The following workshops are offered at all sites where the CWI seminar is offered (code books not included with individual prep courses): Welding Inspection Technology (general knowledge and prep course for CWI Exam-Part A); Visual Inspection Workshop (prep course for CWI Exam-Part B); and D1.1 and API-1104 Code Clinics (prep courses for CWI Exam-Part C).

On-site Training and Examination

On-site training is available for larger groups or for programs customized to meet specific needs of a company. Call ext. 455 for more information.

International CWI Courses and Exams

AWS training and certification for CWI and other programs are offered in many countries. For international certification program schedules and contact information, please visit http://www.aws.org/certification/inter_contact.html

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

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American Welding Society®

The most complete event on weld cracking

Learn different types... Understand the causes... Discover solutions.

The most perplexing problem in the welding industry has to be weld cracking. Back by popular demand, this one-day conference is for those who want or need to get a handle on any weld cracking situation. The 2009 conference will also provide networking opportunities where you can talk to welding cracking experts and others in the industry who face the challenges of weld cracking.

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NOVEMBER 16, 2009 - CHICAGO

WELD CRACKING

"THE HEAT AFFECTED ZONE"

CONFERENCE



American Welding Society

Friends and Colleagues:

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

To be eligible for appointment, an individual shall have demonstrated his or her leadership in the welding industry by one or more of the following:

- Leadership of or within an organization that has made a substantial contribution to the welding industry. The individual's organization shall have shown an ongoing commitment to the industry, as evidenced by support of participation of its employees in industry activities.
- Leadership of or within an organization that has made a substantial contribution to training and vocational education in the welding industry. The individual's organization shall have shown an ongoing commitment to the industry, as evidenced by support of participation of its employee in industry activities.

For specifics on the nomination requirements, please contact Wendy Sue Reeve at AWS headquarters in Miami, or simply follow the instructions on the Counselor nomination form in this issue of the *Welding Journal*. The deadline for submission is July 1, 2009. The committee looks forward to receiving these nominations for 2010 consideration.

Sincerely,

Alfred F. Fleury
Chair, Counselor Selection Committee



CLASS OF 2010 COUNSELOR NOMINATION FORM

(please type or print in black ink)

DATE _____ NAME OF CANDIDATE _____

AWS MEMBER NO. _____ YEARS OF AWS MEMBERSHIP _____

HOME ADDRESS _____

CITY _____ STATE _____ ZIP CODE _____ PHONE _____

PRESENT COMPANY/INSTITUTION AFFILIATION _____

TITLE/POSITION _____

BUSINESS ADDRESS _____

CITY _____ STATE _____ ZIP CODE _____ PHONE _____

ACADEMIC BACKGROUND, AS APPLICABLE:

INSTITUTION _____

MAJOR & MINOR _____

DEGREES OR CERTIFICATES/YEAR _____

LICENSED PROFESSIONAL ENGINEER: YES _____ NO _____ STATE _____

SIGNIFICANT WORK EXPERIENCE:

COMPANY/CITY/STATE _____

POSITION _____ YEARS _____

COMPANY/CITY/STATE _____

POSITION _____ YEARS _____

SUMMARIZE MAJOR CONTRIBUTIONS IN THESE POSITIONS:

IT IS MANDATORY THAT A CITATION (50 TO 100 WORDS, USE SEPARATE SHEET) INDICATING WHY THE NOMINEE SHOULD BE SELECTED AS AN AWS COUNSELOR ACCOMPANY THE NOMINATION PACKET. IF NOMINEE IS SELECTED, THIS STATEMENT MAY BE INCORPORATED WITHIN THE CITATION CERTIFICATE.

****MOST IMPORTANT****

The Counselor Selection Committee criteria are strongly based on and extracted from the categories identified below. All information and support material provided by the candidate's Counselor Proposer, Nominating Members and peers are considered.

SUBMITTED BY:

PROPOSER _____

AWS Member No. _____

The proposer will serve as the contact if the Selection Committee requires further information. The proposer is encouraged to include a detailed biography of the candidate and letters of recommendation from individuals describing the specific accomplishments of the candidate. Signatures on this nominating form, or supporting letters from each nominator, are required from four AWS members in addition to the proposer. Signatures may be acquired by photocopying the original and transmitting to each nominating member. Once the signatures are secured, the total package should be submitted.

NOMINATING MEMBER: _____ Print Name _____

AWS Member No. _____

NOMINATING MEMBER: _____ Print Name _____

AWS Member No. _____

NOMINATING MEMBER: _____ Print Name _____

AWS Member No. _____

NOMINATING MEMBER: _____ Print Name _____

AWS Member No. _____

SUBMISSION DEADLINE JULY 1, 2009



American Welding Society

Nomination of AWS Counselor

I. HISTORY AND BACKGROUND

In 1999, the American Welding Society established the honor of Counselor to recognize individual members for a career of distinguished organizational leadership that has enhanced the image and impact of the welding industry. Election as a Counselor shall be based on an individual's career of outstanding accomplishment.

To be eligible for appointment, an individual shall have demonstrated his or her leadership in the welding industry by one or more of the following:

- Leadership of or within an organization that has made a substantial contribution to the welding industry. (The individual's organization shall have shown an ongoing commitment to the industry, as evidenced by support of participation of its employees in industry activities such as AWS, IIW, WRC, SkillsUSA, NEMA, NSRP SP7 or other similar groups.)
- Leadership of or within an organization that has made substantial contribution to training and vocational education in the welding industry. (The individual's organization shall have shown an ongoing commitment to the industry, as evidenced by support of participation of its employees in industry activities such as AWS, IIW, WRC, SkillsUSA, NEMA, NSRP SP7 or other similar groups.)

II. RULES

- A. Candidates for Counselor shall have at least 10 years of membership in AWS.
- B. Each candidate for Counselor shall be nominated by at least five members of the Society.
- C. Nominations shall be submitted on the official form available from AWS headquarters.
- D. Nominations must be submitted to AWS headquarters no later than July 1 of the year prior to that in which the award is to be presented.
- E. Nominations shall remain valid for three years.
- F. All information on nominees will be held in strict confidence.
- G. Candidates who have been elected as Fellows of AWS shall not be eligible for election as Counselors. Candidates may not be nominated for both of these awards at the same time.

III. NUMBER OF COUNSELORS TO BE SELECTED

Maximum of 10 Counselors selected each year.

Return completed Counselor nomination package to:

Wendy S. Reeve
American Welding Society
Senior Manager
Award Programs and Administrative Support
550 N.W. Lejeune Road
Miami, FL 33126
Telephone: 800-443-9353, extension 293

SUBMISSION DEADLINE: July 1, 2009

PROFESSIONAL PROGRAM ABSTRACT SUBMITTAL

Annual FABTECH International & AWS Welding Show

Chicago, IL – November 15-18, 2009

Submission Deadline: March 13, 2009

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

Primary Author (Full Name):						
Affiliation:						
Mailing Address:						
City:	State/Province	Zip/Mail Code	Country:			
Email:						
Co-Author(s):						
Name (Full Name):		Name (Full Name):				
Affiliation:		Affiliation:				
Address:		Address:				
City:		City:				
State/Province:		State/Province:				
Zip/Mail Code:		Zip/Mail Code:				
Country:		Country:				
E-Mail:		E-Mail:				
Name (Full Name):		Name (Full Name):				
Affiliation:		Affiliation:				
Address:		Address:				
City:		City:				
State/Province:		State/Province:				
Zip/Mail Code:		Zip/Mail Code:				
Country:		Country:				
E-Mail:		E-Mail:				
Answer the following about this paper Original submittal? Yes ☐ No ☐ Progress report? Yes ☐ No ☐ Review paper? Yes ☐ No ☐ Tutorial? Yes ☐ No ☐ What are the welding/Joining processes used? What are the materials used? What is the main emphasis of this paper? Process Oriented ☐ Materials Oriented ☐ Modeling ☐ To what industry segments is this paper most applicable? Has material in this paper ever been published or presented previously? Yes ☐ No ☐ If "Yes", when and where? Is this a graduate study related research? Yes ☐ No ☐ If accepted, will the author(s) present this paper in person? Yes ☐ Maybe ☐ No ☐						
Keywords: Please indicate the top keywords associated with your research below 						
Guidelines for abstract submittal and selection criteria: - Only those abstracts submitted on this form will be considered. Follow the guidelines and word limits indicated. - Complete this form using MSWord. Submit electronically via email to techpapers@aws.org <table style="width: 100%;"> <tr> <td style="vertical-align: top; width: 33%;"> Technical/Research Oriented - New science or research. - Selection based on technical merit. - Emphasis is on previously unpublished work in science or engineering relevant to welding, joining and allied processes. - Preference will be given to submittals with clearly communicated benefit to the welding industry. </td> <td style="vertical-align: top; width: 33%;"> Applied Technology - New or unique applications. - Selection based on technical merit. - Emphasis is on previously unpublished work that applies known principles of joining science or engineering in unique ways. - Preference will be given to submittals with clearly communicated benefit to the welding industry. </td> <td style="vertical-align: top; width: 33%;"> Education - Innovation in welding education at all levels. - Emphasis is on education/training methods and their successes. </td> </tr> </table> ☒ Check the category that best applies: ☐ Technical/Research Oriented ☐ Applied Technology ☐ Education				Technical/Research Oriented - New science or research. - Selection based on technical merit. - Emphasis is on previously unpublished work in science or engineering relevant to welding, joining and allied processes. - Preference will be given to submittals with clearly communicated benefit to the welding industry.	Applied Technology - New or unique applications. - Selection based on technical merit. - Emphasis is on previously unpublished work that applies known principles of joining science or engineering in unique ways. - Preference will be given to submittals with clearly communicated benefit to the welding industry.	Education - Innovation in welding education at all levels. - Emphasis is on education/training methods and their successes.
Technical/Research Oriented - New science or research. - Selection based on technical merit. - Emphasis is on previously unpublished work in science or engineering relevant to welding, joining and allied processes. - Preference will be given to submittals with clearly communicated benefit to the welding industry.	Applied Technology - New or unique applications. - Selection based on technical merit. - Emphasis is on previously unpublished work that applies known principles of joining science or engineering in unique ways. - Preference will be given to submittals with clearly communicated benefit to the welding industry.	Education - Innovation in welding education at all levels. - Emphasis is on education/training methods and their successes.				

Proposed Title (max. 50 characters):

Proposed Subtitle (max. 50 characters):

Abstract:

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

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

Results/Discussion (300 words max.) – For technical papers, summarize the results with emphasis on why the results are new or original, why the results are of value to further advance the welding science, engineering and applications. For applied technology and education papers, elaborate on why this paper is of value to the welding community, describe key aspects of the work developed and how this work benefits the welding industry and education.

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

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

Note: The Technical Program is not the venue for commercial promotions of a company or a product. All presentations should avoid the use of product trade names. The Welding Show provides ample opportunities for companies to showcase and advertise their processes and products.

Return this form, completed on both sides, to

AWS Education Services
Professional Program 2009
550 NW LeJeune Road
Miami FL 33126
FAX 305-648-1655

MUST BE RECEIVED NO LATER THAN MARCH 13, 2009

POSTER ABSTRACT SUBMITTAL

Annual FABTECH International & AWS Welding Show

Chicago, IL – November 15-18, 2009

(Complete a separate submittal for each poster.)

Primary Author (Full Name):							
School/Company:							
Mailing Address:							
City:	State/Province:	Zip/Mail Code:	Country:				
Email:							
Poster Title (max. 50 characters):							
Poster Subtitle (max. 50 characters):							
Co-Author(s):							
Name (Full Name): Affiliation: Address: City: State/Province: Zip/Mail Code: Country:		Name (Full Name): Affiliation: Address: City: State/Province: Zip/Mail Code: Country:					
Email:		Email:					
Poster Requirements and Selection Criteria: - Only those abstracts submitted on this form will be considered. Follow the guidelines and word limits indicated. Complete this form using MSWord. Submit electronically via email to techpapers@aws.org or print and mail. - Maximum size – 44 inches tall x 30 inches wide. (Vertical format, please). - Must be legible from a distance of 6 feet. A minimum font size of 14 pt. is suggested. - Posters must be submitted to AWS as a single flat printed medium (e.g. laminated print or foam core board mount). - Any technical topic relevant to the welding industry is acceptable (e.g. welding processes & controls, welding procedures, welding design, structural integrity related to welding, weld inspection, welding metallurgy, etc.). - Submittals that are incomplete and that do not satisfy these basic guidelines will not be considered for competition. Posters accepted for competition will be judged based on technical content, clarity of communication, novelty/relevance of the subject & ideas conveyed and overall aesthetic impression. Criteria by category as follows: <table style="width: 100%;"> <tr> <td style="vertical-align: top; width: 25%;"> (A) Student - Students enrolled in 2 yr. college and/or certificate programs at time of submittal. - Presentation need not represent actual experimental work. Rather, emphasis is placed on demonstrating a clear understanding of technical concepts and subject matter. - Practical application is important and should be demonstrated. </td> <td style="vertical-align: top; width: 25%;"> (B) Student - For students enrolled in baccalaureate engineering or engineering technology programs at the time of submittal. - Poster should represent the student's own experimental work. Emphasis is place on demonstrating a clear understanding of technical concepts and subject matter. - Practical application and/or potential relevance to the welding industry is important and should be demonstrated. </td> <td style="vertical-align: top; width: 25%;"> (C) Student - For students enrolled in graduate degree programs in engineering or engineering technology at time of submittal. - Poster should represent the student's own experimental work. Poster must demonstrate technical or scientific concepts. Emphasis is placed on originality and novelty of ideas presented. - Potential relevance to the welding industry is important and should be demonstrated. </td> <td style="vertical-align: top; width: 25%;"> (D) Professional - For anyone working in the welding industry or related field. - Poster must demonstrate technical or scientific concepts. Emphasis is placed on original contributions and the novelty of the presentation. - Potential relevance to the welding industry is important and should be demonstrated. </td> </tr> </table>				(A) Student - Students enrolled in 2 yr. college and/or certificate programs at time of submittal. - Presentation need not represent actual experimental work. Rather, emphasis is placed on demonstrating a clear understanding of technical concepts and subject matter. - Practical application is important and should be demonstrated.	(B) Student - For students enrolled in baccalaureate engineering or engineering technology programs at the time of submittal. - Poster should represent the student's own experimental work. Emphasis is place on demonstrating a clear understanding of technical concepts and subject matter. - Practical application and/or potential relevance to the welding industry is important and should be demonstrated.	(C) Student - For students enrolled in graduate degree programs in engineering or engineering technology at time of submittal. - Poster should represent the student's own experimental work. Poster must demonstrate technical or scientific concepts. Emphasis is placed on originality and novelty of ideas presented. - Potential relevance to the welding industry is important and should be demonstrated.	(D) Professional - For anyone working in the welding industry or related field. - Poster must demonstrate technical or scientific concepts. Emphasis is placed on original contributions and the novelty of the presentation. - Potential relevance to the welding industry is important and should be demonstrated.
(A) Student - Students enrolled in 2 yr. college and/or certificate programs at time of submittal. - Presentation need not represent actual experimental work. Rather, emphasis is placed on demonstrating a clear understanding of technical concepts and subject matter. - Practical application is important and should be demonstrated.	(B) Student - For students enrolled in baccalaureate engineering or engineering technology programs at the time of submittal. - Poster should represent the student's own experimental work. Emphasis is place on demonstrating a clear understanding of technical concepts and subject matter. - Practical application and/or potential relevance to the welding industry is important and should be demonstrated.	(C) Student - For students enrolled in graduate degree programs in engineering or engineering technology at time of submittal. - Poster should represent the student's own experimental work. Poster must demonstrate technical or scientific concepts. Emphasis is placed on originality and novelty of ideas presented. - Potential relevance to the welding industry is important and should be demonstrated.	(D) Professional - For anyone working in the welding industry or related field. - Poster must demonstrate technical or scientific concepts. Emphasis is placed on original contributions and the novelty of the presentation. - Potential relevance to the welding industry is important and should be demonstrated.				
(E) High School - Junior or Senior high school students enrolled in a welding concentration at the time of submittal. - Presentation should represent technical concepts and application to the welding industry. - Practical application and creativity are important and should be demonstrated.							

Check the category that applies:

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

Poster Title (max. 50 characters):

Poster Subtitle (max. 50 characters):

Abstract:

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

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

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

Return this form, completed on both sides, via email to techpapers@aws.org
MUST BE RECEIVED NO LATER THAN April 3, 2009

SOCIETY NEWS

BY HOWARD M. WOODWARD

Student Chapter Supports Its Community

Led by President **Will Ross**, a welding engineering technology senior, the AWS Ferris State University (FSU) Student Chapter has actively supported its Big Rapids, Mich., community in a variety of activities that have allowed significant interaction between the students and community members. "As members of the Ferris community it is important that we are involved with local needs," stated Ross.

Jeffrey Carney, chair and associate professor, FSU Department of Welding Engineering Technology, and Student Chapter advisor, said, "The Chapter generates funds to support local projects as well as student field trips and picnics. This year, since the beginning of school in September, the Student Chapter has donated time and funds to many local organizations including Project Starburst, WISE, Salvation Army, Angel Tree and Bell Ringing, and United Way. The group is also active in the Big Rapids River Walk project and the Michigan D.O.T. Adopt-a-Highway program."

Carney said, "The Chapter members raise money from the sale of FSU welding program clothing, welding equipment,



Will Ross, FSUSC president, presents a \$300 donation to Connie Brower, Project Starburst representative, December 11, to help provide emergency aid to needy persons in the area.

plus an annual fund-raiser. For the past five years we have hosted the FSU Welding Alumni Golf Outing, where about 50 golfers participated last year."

Last December, the Chapter donated \$300 to Project Starburst, to provide emergency aid and food for needy persons in the Big Rapids area.

AWS Weldmex Building for a Grand Opening in June



This year, AWS Weldmex will include FABTECH Mexico and Metalform Mexico to create the largest welding, metalworking, and fabrication show in Latin America. The 60,000-sq-ft show will take place June 2-4 in Monterrey, Mexico. Nearly 100 of the top metalworking suppliers and service companies have already signed up to exhibit at the show.

Ray Shook, AWS executive director, said, "We expect more than 8000 attendees to take advantage of this convenient

show that will bring metalworking managers, suppliers, engineers, and purchasing agents together in one location. Having all the latest metalworking products, services, and information in one place at one time and communicated in the Spanish language is a value for companies and metalworking professionals throughout Latin America."

AWS Weldmex will include brazing, punching, bending/folding, resistance welding, coil processing, robotics, con-

trols, roll forming, cutting, safety equipment, finishing, saws, handling equipment, shears, industrial gases, testing equipment, laser beam cutting and welding, plate/structural fabrication, tubing and piping, metalworking equipment, welding consumables, plasma cutting, power sources, soldering, pressworking/stamping, and welding equipment and accessories. For more information, visit the new AWS Weldmex Web site at www.aws weldmex.com.

Tech Topics

Interpretations D1.1 Structural Welding Code — Steel

Subject 1: Table 4.2 Note d and Fillet Size

Code Edition: D1.1:2006

Code Provision: Tables 4.2 and 4.4

AWS Log: D1.1-06-109

Inquiry:

If groove welds are used to qualify fillet welds, in accordance with Table 4.2 Note d, what is the maximum single-pass fillet and the minimum multiple-pass fillet size qualified?

Response:

If groove welds are used to qualify fillet welds, in accordance with Table 4.2 Note d, the maximum single-pass fillet and the minimum multiple-pass fillet size qualified are unlimited, except as limited by Clause 2 and Clause 5.

Subject 2: WPS Qualification using ASTM A 514

Code Edition: D1.1:2006

Code Provision: Tables 4.8 and 4.9

AWS Log: D1.1-06-103

Inquiry:

1. If I qualify a WPS using ASTM A 514 (2 inches) to itself, can I substitute ASTM A 514 (3 inches) to itself in this WPS without requalification?

2. If I qualify a WPS using ASTM A 514 (3 inches) to itself, can I substitute ASTM A 514 (2 inches) to itself in this WPS without requalification?

3. If I qualify a WPS using ASTM A 514 (2 inches) to ASTM A 514 (3 inches), can I substitute ASTM A 514 (3 inches) to itself in this WPS without requalification?

4. If I qualify a WPS using ASTM A 514 (2 in.) to ASTM A 514 (3 in.), can I substitute ASTM A 514 (2 in.) to itself in this WPS without requalification?

Response:

1. Yes, provided there is no change in grade or increase in specified minimum yield strength. See Table 4.8.

2. No. This results in an increase in specified minimum yield strength. See Table 4.8.

3. Yes, provided there is no change in grade or increase in specified minimum yield strength. See Table 4.8.

4. No. This results in an increase in specified minimum yield strength. See Table 4.8.

Errata D1.1:2008 Structural Welding Code — Steel

The following errata have been identified and incorporated into the current reprint of this document.

Page 67, Table 3.1, Filler Metal Requirements: Remove the hyphen from “E9018-M” under Electrode Classification column from Group IV so it reads “E9018M”.

Page 105, Figure 3.4, Joint Designation C-U2a-GF. Under “Notes” column: “Note 1” should read “Note a”.

Pages 136–153, Header: Change from “Clause 4. Prequalification” to “Clause 4. Qualification” on all the designated pages.

Page 146, Table 4.9, Filler Metal Requirements: Remove hyphen from “E11018-M” in the Electrode Classification column under “Matching Strength Filler Metals” so it reads “E11018M”.

Page 150, Table 4.11, Welder and Welding Operator Qualification — Number and Type of Specimens and Range of Thickness and Diameter Qualified (Dimensions in Millimeters) — For Production Fillet Welds (T-joint and Skewed), under “Number of Specimens” column for side bend tests: “Note 3” should read “Note c”.

Standards for ANSI Public Review

C4.2/C4.2M:200X, *Recommended Practices for Safe Oxyfuel Gas Cutting Torch Operation*. Revised standard — \$25. Review expires 3/16/2009.

D1.7/D1.7M:200X, *Guide for Strengthening and Repairing Existing Structures*. New standard — \$30. Review expires 3/9/2009.

AWS was approved as an accredited standards-preparing organization by the American National Standards Institute (ANSI) in 1979. AWS rules, as approved by ANSI, require that all standards be open to public review for comment during the approval process. The above two standards are open for public review until the dates shown. Draft copies may be obtained from R. O'Neill, ext. 451, roneill@aws.org.

Technical Committee Meetings

March 10–12, D14 Committee on Machinery and Equipment. Burr Ridge, Ill. Contact: M. Rubin, ext. 215.

March 17–20, D1 Committee on Structural Welding. Tucson, Ariz. Contact: S. Morales, ext. 313.

March 30, 31, A5 Committee on Filler Metals and Allied Materials. Orlando, Fla. Contact: R. Gupta, ext. 301.

April 1, A5M Subcommittee on Carbon and Low-Alloy Steel Electrodes for Flux Cored Arc Welding. Orlando, Fla. Contact: R. Gupta, ext. 301.

April 9, D3 Committee on Welding in Marine Construction. Hanover, Pa. Contact: B. McGrath, ext. 311.

April 29, A5H Subcommittee on Filler Metals and Fluxes for Brazing. Orlando, Fla. Contact: S. Borrero, ext. 334.

April 30, C3 Committee and Subcommittees on Brazing and Soldering. Orlando, Fla. Contact: S. Borrero, ext. 334.

May 11–13, Robotics Conf. and Expo. Milwaukee, Wis. Sponsored by the D16 Committee. Contact: M. Rubin, ext. 215.

Prof. Masubuchi Award Nominees Sought

November 2 is the deadline for submitting nominations for the 2010 Prof. Koichi Masubuchi Award, sponsored by the Dept. of Ocean Engineering at Massachusetts Institute of Technology. This award includes an honorarium of \$5000. It is presented each year to one person who has made significant contributions to the advancement of materials joining through research and development.

The candidate must be 40 years old or younger, may live anywhere in the world, and need not be an AWS member. The nomination package should be prepared

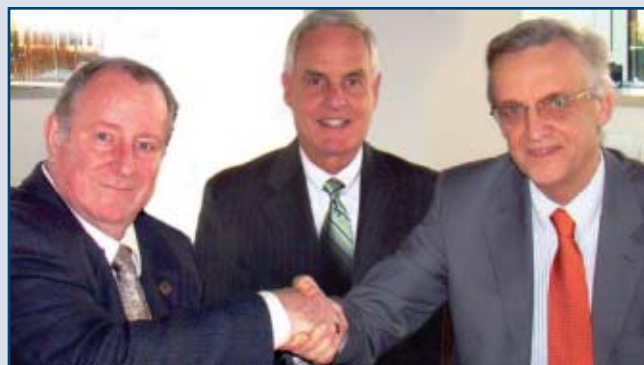
by someone familiar with the research background of the candidate. It should include the candidate's résumé listing background, experience, publications, honors, and awards, plus at least three letters of recommendation from fellow researchers.

This award was established to recognize Prof. Koichi Masubuchi for his numerous contributions to the advancement of the science and technology of welding, especially in the fields of fabricating marine and outer space structures.

E-mail your nominations to Prof. John DuPont at jnd1@lehigh.edu.



Shown during the January IIW meeting in Paris, France, are (from left) Ernest Levert, past AWS president; Ray Shook, AWS executive director; Klaus Middeldorf, chief executive officer of the German Welding Society; and Kazutoshi Nishimoto, president, Japan Welding Society. The group had just signed an agreement for the first International Electron Beam Welding Conference to be held Nov. 17, 18, 2009, during the FABTECH International & AWS Welding Show.



AWS President Victor Matthews (left) and AWS Executive Director Ray Shook (center) recently signed a Professional Cooperation Agreement with Alain Houdart, president of the Institut de Soudure (French Welding Institute) in Villepinte, France. The agreement creates an avenue for cooperation between the two societies in areas related to membership eligibility, technical activities, exhibitions, and publications.

Member-Get-A-Member Campaign

Listed are the Jan. 21 tallies. For rules and prize list see page 69 of this *Welding Journal* or visit www.aws.org/mgm. Call the Membership Dept., (800) 443-9353, ext. 480, regarding your proposer point status.

Winner's Circle

Sponsored 20+ new members.

The superscript indicates the number of times the member has achieved Winner's Circle status since June 1, 1999.

J. Compton, San Fernando Valley⁷
E. Ezell, Mobile⁶
J. Merzthal, Peru²
G. Taylor, Pascagoula²
L. Taylor, Pascagoula²
B. Mikeska, Houston¹
R. Peaslee, Detroit¹
W. Shreve, Fox Valley¹
M. Karagoulis, Detroit¹
S. McGill, NE Tennessee¹
T. Weaver, Johnstown/Altoona¹
G. Woomer, Johnstown/Altoona¹
R. Wray, Nebraska¹
M. Haggard, Inland Empire¹

President's Roundtable

Sponsored 9-19 new members.

E. Ezell, Mobile — 16
P. Betts, Mobile — 12

President's Club

Sponsored 3-8 new members.

L. Contreras, South Florida — 8
R. Ellenbecker, Fox Valley — 6
J. Compton, San Fernando Valley — 5
C. Daon, Israel — 5
W. Rice, Tri-State — 5
D. Wright, Kansas City — 5
M. Hackl, Cuautitlan Izcalli — 4
R. Newman, Maine — 4
B. Vernyi, Cleveland — 4
C. Becker, Northwest — 3
B. Franklin, Mobile — 3
L. Moss, Sangamon Valley — 3
P. Newhouse, British Columbia — 3
M. Rahn, Iowa — 3
M. Wheat, Western Carolina — 3

President's Honor Roll

C. Alfaro, San Diego — 2
M. Boggs, Stark Central — 2
M. Boyer, Detroit — 2
R. Boyer, Nevada — 2

B. Donaldson, British Columbia — 2
E. Dupree, Tidewater — 2
F. Hendrix, New Jersey — 2
R. Johnson, Detroit — 2
T. Johnson, Pittsburgh — 2
G. Lawrence, N. Central Florida — 2
J. Livesay, Nashville — 2
J. Padilla, Cuautitlan Izcalli — 2
S. Luke, Acadiana — 2
J. Nash, Atlanta — 2
R. Pitt, Tidewater — 2
J. Polson, L.A./Inland Empire — 2
J. Rule, Cleveland — 2
J. Sisson, Niagara Frontier — 2
K. Smith, North Texas — 2
A. Stute, Madison-Beloit — 2
D. Thomason, Chicago — 2
B. Whatley, Albuquerque — 2
M. Yung, Portland — 2
P. Zammit, Spokane — 2

Student Member Sponsors

Sponsored 4 or more students.

D. Berger, New Orleans — 110
B. Benyon, Pittsburgh — 41
A. Baughman, Stark Central — 36
M. Boggs, Stark Central — 36
R. Jones, Puget Sound — 36
A. Rowe, Philadelphia — 36
A. Zinn, Eastern Iowa — 34
T. Moore, New Orleans — 32
J. Carney, Western Michigan — 26
E. Norman, Ozark — 26
S. Siviski, Maine — 26
T. Geisler, Pittsburgh — 24
J. Kline, Northern New York — 24
D. Newman, Ozark — 2
R. Newman, Maine — 24
R. Cook, Utah — 23
D. Howard, Johnstown-Altoona — 23
B. Suckow, Northern Plains — 23
L. Clark, Milwaukee — 22
H. Hughes, Mahoning Valley — 22
D. Schnalzer, Lehigh Valley — 22
J. Rule, Cleveland — 21
R. Munns, Utah — 20
A. Duron, New Orleans — 19
J. Fox, Northwest Ohio — 19
D. Pickering, Central Arkansas — 18
R. Schmidt, Philadelphia — 18
J. Boyer, Lancaster — 17

T. Strickland, Arizona — 17
B. Hallila, New Orleans — 16
C. Donnell, Northwest Ohio — 15
M. Arand, Louisville — 14
W. Harris, Pascagoula — 14
R. Hutchinson, Long Bch./Or. Cty. — 14
J. Roberts, Sacramento — 14
G. Smith, Lehigh Valley — 14
A. Mattox, Lexington — 13
R. Rummel, Central Texas — 13
D. Saunders, Lakeshore — 13
A. Stute, Madison-Beloit — 13
D. Taylor, Kern — 13
J. Daugherty, Louisville — 12
J. Marshall, Siouxland — 12
R. Evans, Siouxland — 11
J. Theberge, Boston — 11
C. Kipp, Lehigh Valley — 10
D. Vranich, N. Florida — 10
D. Zabel, Southeast Nebraska — 10
C. Abram, Columbus — 9
A. Badeaux, Washington, D.C. — 9
S. Colton, San Diego — 9
D. Kowalski, Pittsburgh — 9
R. Ledford Jr., Birmingham — 9
R. Norris, Maine — 9
V. Facchiano, Lehigh Valley — 9
M. Rabo, Sacramento — 8
G. Saari, Inland Empire — 8
N. Carlson, Idaho/Montana — 7
W. Galvery Jr., Long Bch./Or. Cty. — 7
J. Geesey, Pittsburgh — 7
S. MacKenzie, Northern Michigan — 7
C. Schiner, Wyoming — 6
K. Caliva, New Orleans — 5
D. Kearns, Northern Michigan — 5
R. Olesky, Pittsburgh — 5
J. Reed, Ozark — 5
H. Evans, Portland — 4
W. Geiger, N. Central Florida — 4
C. Hobson, Olympic Section — 4
S. Robeson, Cumberland Valley — 4
G. Rolla, L.A./Inland Empire — 4
J. Ciaramitaro, N. Central Florida — 3
D. Hamilton, Chattanooga — 3
J. Hayes, Oklahoma City — 3
T. Hopper, Mobile — 3
D. Saunders, Holston — 3
M. Shelton, Sabine — 3
S. Tennant, Fox Valley — 3

AWS Makes Big Plans with Arkansas Weld Expo



Angela Harrison, chairman and CEO of WELSCO, Inc., North Little Rock, Ark., is shown with **Sam Gentry** (left), executive director, AWS Foundation; and **Ray Shook**, AWS executive director, at the Arkansas Welding Expo. More than 1700 welding enthusiasts attended the event that showcased the products of more than 35 suppliers. Shook and Gentry met with Harrison and **Charles Ross**, vice president of purchasing, to determine how the Society can work with the company to make next year's show even better. Ross said, "Welsco holds the Expo every December and makes an effort to invite students and instructors. We look forward to having the students attend, they are the future of our industry." WELSCO is the largest woman-owned gas and welding supply distributor in the United States. More information on the Expo can be found at www.welsco.com.

New AWS Supporters

Sustaining Companies

Ciramar Shipyards

International Trading Co., Ltd.

Jose A. Brea Peña No. 112
Ens. Evaristo Morales, Santo Domingo
Dominican Republic
(809) 332-6940; FAX (809) 562-7635
www.ciramar.com

Representative: Fereshteh Hajihassani

Ciramar Shipyards, centrally located in the Caribbean, works under strict safety rules, regulations, and procedures. Its expertise and competitive pricing are offered for vessel engineering, construction, and repairing, as well as offering vessel leasing. The company's motto is, "Our services to your ships will keep your ships in service."

Columbia Machine Works, Inc.

1940 Oakland Pkwy.; PO Box 1018
Columbia, TN 38402
(932) 338-6202; FAX (931) 388-8128
www.columbiamachineworks.com

Representative: James D. Langsdon

Since 1927, Columbia Machine Works has offered precision large-capacity services and technical expertise to provide cost-efficient, high-quality machinery and fabrications. Its services include contract machining, welding, machine rebuilding, repair, and maintenance.

Affiliate Companies

Advantage Steel, Inc.

5101 24th Ave. S.
Tampa, FL 33619

Dust Control Inc.

2107A N. Hwy. 14-16
Gillette, WY 82716

EDYCE S.A.

Algarrobo 159
Talcahuano Concepcion
9261542, Chile

Mokats Welding & Fabrication

PO Box 661, Lydia, LA 70569

Peak Steel, LLC

1610 N. Salem St.
Apex, NC 27523

Premier Precision Group

260 Plymouth Ave. N.
Minneapolis, MN 55411

PWS

5290 Orcutt Rd.
San Luis Obispo, CA 93401

Welding Solutions International Inc.

2301 Dundas St.
Burlington, ON L7R 3X4, Canada

Supporting Companies

Manufactura y Suministros

Industriales S.A. de C.V.

Laguna de Mayr'an 1020 Col. La Salle
25240 Saltillo, Coahuila, Mexico

Metalmasters, Inc.

704 N. Fayetteville Ave.
Dunn, NC 28334

Mettler-Toledo, Inc.

6600 Huntley Rd.
Columbus, OH 43229

Warrior Mfg., LLC

1145 5th Ave. SE, PO Box 8
Hutchinson, MN 55350

Educational Institutions

Denison Job Corps Center

10 Opportunity Dr.
Denison, IA 51442

Los Angeles Trade-Technical College

400 W. Washington Blvd.
Los Angeles, CA 90015

Academy of Welding and Consultancy Services

10 Corporate Ave., Sonawala Rd.
Goregaon (E), Mumbai
Maharashtra, 400063, India

Capital District Educational Opportunity Center

145 Congress St.
Troy, NY 12180

Gamma Rad

#13 Arghavan Gharbi St.
Farahzadi Blvd., Shahrak Gharb
Tehran 1468995311, Iran

Penobscot Job Corps

1375 Union St.
Bangor, ME 04401

Tucson High Magnet School

400 N. 2nd Ave.
Tucson, AZ 85705

Welding Distributor

Scott-Gross Co., Inc.

664 Magnolia Ave.
Lexington, KY 40505

Membership Counts

Member Grades	As of 2/01/09
Sustaining.....	518
Supporting.....	312
Educational.....	496
Affiliate.....	464
Welding distributor.....	49
Total corporate members.....	1,839
Individual members.....	50,010
Student + transitional members.....	5,408
Total members.....	55,418

SECTION NEWS

District 1

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District 2

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PHILADELPHIA

JANUARY 14

Activity: The Section members toured the UA Local 420 training facility to see demonstrations of Liburdi Dimetrics P-300 with a Model F weld head orbital pipe welding system and some Wachs pipe prep equipment. Apprenticeship Training Director **Steve Sweeny** and **Don Brown**, precision welding applications manager, conducted the tour.



Presenter Don Brown (left) is shown with Chairman Gary Atherton at the Philadelphia Section program.

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District 5

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FLORIDA WEST COAST

JANUARY 14

Speaker: **Edward M. Beck, P.E.**
Affiliation: Mactech Engineering and Consulting Inc.
Topic: How NDT can get you into trouble and how logic can get you out
Activity: A gift certificate for Walden Lakes Country Club was raffled to raise funds for the Section scholarship fund. The program was held at Frontier Steak House in Tampa, Fla.



Florida West Coast Section members are shown at the January 14 program.

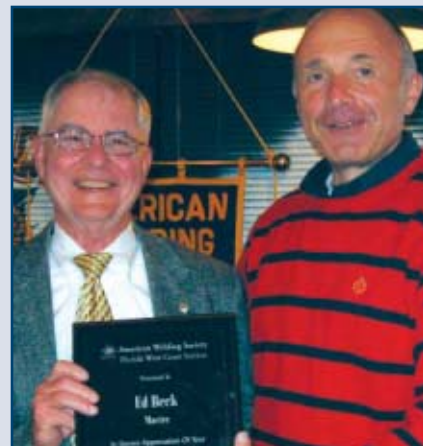
District 6

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k.phy@holtec.com

NORTHERN NEW YORK

DECEMBER 2

Speakers: **Mike Todd** and **Chris Lanese**, welding instructors
Affiliation: Capital Region Board of Co-operative Educational Services (BOCES)
Topic: The welding program presented at Capital Region BOCES, Albany, N.Y.
Activity: **Warren Alexander** made a presentation on his techniques for performing uphill submerged arc welding. The program was held at Mill Road Restaurant and Tavern in Lantham, N.Y.



Edward Beck (left) receives a speaker appreciation plaque from Al Sedory, Florida West Coast Section chairman.



The speakers at the Northern New York Section meeting were (from left) Mike Todd, Chris Lanese, and Warren Alexander.



Speaker Kevin Summers (right) is shown with Steve Whitney, Dayton Section chair.



Mobile Section Chair Joshua Sanders (left) presents a speaker gift to Ken Haga.

District 7

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

DAYTON

JANUARY 13

Speaker: **Kevin Summers**, robotics and automation strategy manager
Affiliation: Miller Electric Co.
Topic: Welding cost containment
Activity: The program was held at Amber Rose Restaurant in Dayton, Ohio.



Story-teller Grady Bauer held everyone's attention at the Mobile Section meeting.

District 8

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District 9

George D. Fairbanks Jr., director
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fits@bellsouth.net

MOBILE

JANUARY 8

Speaker: **Ken Haga**, territory manager
Affiliation: Industrial Air Quality
Topic: Welding fume abatement
Activity: **Grady Bauer**, the Section's veteran jokester, entertained with a selection of funny stories.

District 10

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(440) 338-5921
richaharris@alltel.net

MAHONING VALLEY

JANUARY 15

Activity: The Section held an executive committee meeting at Harry & Jean's Restaurant in Canfield, Ohio. Discussed were plans for the upcoming season. Thanked for their continued support of the Section's activities were Air Gas Great Lakes, Akron Testing Lab and Welding School, Boardman Steel, Brilex Tech Services, Cedar Steel, City Machine Technologies, Northeast Fabricators, Columbiana Boiler Co., Converse All Metal Services, Diamond Steel Construction, Falcon Foundry Co., Northeast Fabricators, and Youngstown Oxygen and Welding Supply.

District 11

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ft.siradakis@airgas.com

DETROIT

JANUARY 8

Activity: The Section members toured the Industrial Automation facility in Orion Township, Mich. **Bethany Duncan**, senior applications engineer, made a presentation, then conducted demonstrations of various materials-handling and tool-changing issues often encountered in the welding industry plus some tips on methods for improving workplace productivity. Assisting was **Catherine Morris**, senior account manager.

NORTHWEST OHIO

DECEMBER 18

Activity: **Jim Czywocki**, welding instructor, conducted the members on a tour of the Local 50 UA Piping Industry Training Center in Northwood, Ohio. The facility specializes in training for DOT gas pipeline certification, valve repairs, and welding and brazing certifications as part of a five-year apprentice training program and advanced training for journeymen who want to specialize.

District 12

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

LAKESHORE

JANUARY 8

Activity: The Section members toured the AZCO plant in Appleton, Wis., to study the company's equipment and methods for welding angle box structures and tubing. **Dave Jansen**, project manager, conducted the program. Following the tour, a dinner meeting was held at the Main Event in Little Chute, Wis., where a question and answer session was conducted regarding the tour.

MILWAUKEE SECTION

COMING EVENT
MAY 11-13, 2009

Robotic Arc Welding Conf. and Expo, Milwaukee Area Technical College, Milwaukee, Wis. Co-hosted by the Milwaukee Section and the D16 Committee on Robotic and Automatic Welding. Theme: Expanding the use of robots in arc welding beyond traditional applications. Includes a full-day tour of the Caterpillar facility in Aurora, Ill. E-mail karen.gilgenbach@airgas.com; or call (262) 613-3790; or visit http://sections.aws.org/milwaukee/Links/AWS_RAWC2009.pdf.



Northern Plains Section members and welding students posed for a group shot at Northland College.



Dave Jansen (left) is shown with Nick Freiberg, Lakeshore Section chairman.

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District 14

Tully C. Parker, director
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tparke@millerwelds.com

District 15

Mace V. Harris, director
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NORTHERN PLAINS

NOVEMBER 18

Activity: The Section members met with welding students at the Northland College welding shop in East Grand Forks, Minn., to see demonstrations of Smith Equipment welding products by **Dale Johnson** and Lincoln Electric machines by **Paul Hewitt**. Following the program, the group traveled to Rydell Toy Shop, a custom hot rod shop in Grand Forks, N.Dak. **Doug Peterson** discussed several projects in various stages of completion including the Grand Master, a joint project with Chip Foose of Foose Design.



Shown at the Detroit Section program are (from left) presenters Bethany Duncan and Catherine Morris with Section Chair John Bohr.



Doug Peterson demonstrates metal shaping for Northern Plains members at Rydell Toy Shop.



East Texas Section members and guests are shown at Norris Cylinder in Longview, Tex.



Paul Hewitt demonstrated the latest Lincoln products for the Northern Plains Section members.



Speaker Les Jointer (left) is shown with Jamie Pearson, Tulsa Section chairman.

District 19

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

ALASKA

JANUARY 16

Speaker: **Steve Stuart**, underwater welder

Affiliation: American Marine

Topic: Underwater welding in Alaska

Activity: **Peter Millar** received his Life Membership Certificate Award for 35 years of service to the Society. **Louis Alvord** was presented the Silver Membership Certificate Award for 25 years of service. The program was held at Peggy's Restaurant in Anchorage, Alaska.

BRITISH COLUMBIA

NOVEMBER 25

Activity: In a private presentation, **Avaral Rao** of Powertech received his Silver Membership Certificate Award for 25 years of service to the Society.

District 16

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dlandon@vermeermfg.com

District 17

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jjones@thermadyne.com

EAST TEXAS

NOVEMBER 18

Activity: **Sally Mitchell** conducted the Section members on a tour of the Norris Cylinder facility in Longview, Tex., to study the manufacture of cylinders used for welding and cutting applications. Representatives from four schools attended: **Dan Bricker**, Caddo Career & Technology Center; **Bryan Baker**, Tyler Jr. College; **Harris Williams**, Welding Institute in Shreveport, La.; and **Bill Kielhorn**, LeTourneau University.

TULSA

NOVEMBER 19

Speaker: **Les Jointer**, director

Affiliation: Ocean Corp.

Topic: Underwater welding and inspection

District 18

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District 20

William A. Komlos, director
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bkoz@arctechllc.com

COLORADO

DECEMBER 11

Speaker: **Conor Tracy**, CWI

Affiliation: Front Range Community College, welding instructor

Topic: The college's course offerings

Activity: This students' night program, held at the college, was sponsored by General Air, a local welding supply company. Section Chair **James Corbin** encouraged the students to continue their studies to earn an associate degree in the welding program. **Dave Murphy** of DMD Torch was presented the Section Meritorious Award.

IDAHO/MONTANA

JANUARY 16

Activity: The Section members toured Diversified Metal Products in Idaho Falls, Idaho. Featured were the operations in its shops for processing carbon steel and stainless steel projects. The company is involved in projects for renewable energy, nuclear waste management, and commuter trains. Conducting the tour were **Nathan McMasters**, president, and **Maria McCosh**, quality assurance manager. McCosh owes her success in part to receiving an AWS scholarship. Read her Member Milestone story on page 76 of this *Welding Journal*. **Paul Tremblay** unveiled the banner presented



Front Range Community College students attended the Colorado Section students' night program.



Idaho/Montana Section members are shown during their Diversified Metal Products tour.



Avaral Rao, British Columbia Section, received his 25-year membership award.

by the AWS Foundation to commemorate the Idaho/Montana Section's endowment of the Paul O'Leary Memorial Named Scholarship. The banner was presented at the recent FABTECH International & AWS Welding Show during the Awards Luncheon.



Shown at the Colorado Section program are (from left) speaker Conor Tracy, Chair James Corbin, and award winner Dave Murphy.

UTAH

DECEMBER 18

Activity: The Section members held their winter social event at Hunt Mystery Theater. **Jeff Taniguchi** received the District Educator Award. **Brian Stephenson** and **Greg Bugni** received the Section Meritorious Award. The Section CWI Award was presented to **Terri Pinkney, Kris Kirkland, Rex Harrison, and Dave Lund.**



Peter Millar (right) receives his Life Membership Certificate from Peter Macksey, Alaska Section chair.



Alaska Section Chair Peter Macksey (left) presents Louis Alvord his Silver Membership Certificate.



The Utah Section members are shown at Hunt Mystery Theater.



Speaker Steve Kent (left) is shown with Brad Bosworth, Fresno Section chairman.



Shown during the Idaho/Montana Section tour are (from left) President Nathan McMasters, Brad Carver, QA Manager Maria McCosh, Dan Payne, and Randy Williams. Read Maria McCosh's Member Milestone story on page 76 of this Welding Journal.



Paul Tremblay displays the Idaho/Montana Section banner presented by the AWS Foundation.



Shown at the Fresno Section open house are (from left) Tom Smeltzer, Chair Brad Bosworth, District 22 Director Dale Flood, speaker Steve Kent, and Kent Baucher.



Simon Engel is shown with Liisa Pine, San Francisco Section chair.

District 21

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(702) 429-5017
Nan07@aol.com

District 22

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

FRESNO

JANUARY 15

Speaker: **Steve Kent**, owner
Affiliation: Kent Performance Center
Topic: Race car fabrication and welding
4130 chrome-moly tubing using gas tungsten arc process

Activity: The Section hosted an open house event at Kent Performance Center in Fresno, Calif. Welding educators from Fresno City College, Reedley College, and California State University at-

tended the event. District 22 Director **Dale Flood** and **Kent Baucher**, a past District 22 director, attended the program.

SAN FRANCISCO

JANUARY 7

Speaker: **Simon L. Engel**, president
Affiliation: HDE Technologies, Inc.
Topic: Laser beam welding
Activity: The program was held at Spenger's Restaurant in Berkeley, Calif.

Guide to AWS Services

American Welding Society
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www.aws.org; (800/305) 443-9353; FAX (305) 443-7559
(Staff telephone extensions are shown in parentheses.)

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INT'L INSTITUTE of WELDING

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Webster, Chamberlain & Bean, Washington, D.C., (202) 785-9500; FAX (202) 835-0243. Identifies funding sources for welding education, research, and development. Monitors legislative and regulatory issues of importance to the welding industry.

CONVENTION and EXPOSITIONS

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Joe Krall.. jkrall@aws.org(297)
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RWMA — Resistance Welding Manufacturing Alliance

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

WEMCO — Welding Equipment Manufacturers Committee

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

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Welding Handbook

Welding Handbook Editor
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Publishes the Society's monthly magazine, *Welding Journal*, which provides information on the state of the welding industry, its technology, and Society activities. Publishes *Inspection Trends*, the *Welding Handbook*, and books on general welding subjects.

MARKETING COMMUNICATIONS

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Director, Int'l Business & Certification Programs
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EDUCATION SERVICES

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Technical Publications
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Stephen Borrero.. sborrero@aws.org(334)
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Note: Official interpretations of AWS standards may be obtained only by sending a request in writing to the Managing Director, Technical Services. Oral opinions on AWS standards may be rendered. However, such opinions represent only the personal opinions of the particular individuals giving them. These individuals do not speak on behalf of AWS, nor do these oral opinions constitute official or unofficial opinions or interpretations of AWS. In addition, oral opinions are informal and should not be used as a substitute for an official interpretation.

Nominees for National Office

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

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

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

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

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

Treasurer: To be eligible to hold the

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

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

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

E-mail the letter to Gricelda Manalich, gricelda@aws.org, c/o Gene Lawson, chair, National Nominating Committee.

The next meeting of the National Nominating Committee is scheduled for November 2009. The terms of office for candidates nominated at this meeting will commence January 1, 2011.

Honorary Meritorious Awards

The Honorary Meritorious Awards Committee makes recommendations for the nominees presented to receive the Honorary Membership, National Meritorious Certificate, William Irrgang Memorial, and the George E. Willis Awards. These honors are presented during the FABTECH International & AWS

Welding Show held each fall. The deadline for submissions is December 31 prior to the year of the awards presentations. Send candidate materials to Wendy Sue Reeve, secretary, Honorary Meritorious Awards Committee, wreeve@aws.org; 550 NW LeJeune Rd., Miami, FL 33126. Descriptions of these awards follow.

William Irrgang Memorial Award

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

George E. Willis Award

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

Honorary Membership Award

The honor is presented to a person of acknowledged eminence in the welding

profession, or to one who is accredited with exceptional accomplishments in the development of the welding art, upon whom the Society deems fit to confer an honorary distinction. Honorary Members have full rights of membership.

National Meritorious Certificate Award

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

International Meritorious Certificate Award

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

AWS Publications Sales

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

Welding Journal Reprints

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

Custom reprints of *Welding Journal* articles, in quantities of 100 or more, may be purchased from

FosteReprints

Claudia Stachowiak
Reprint Marketing Manager
866-879-9144, ext. 121
claudia@fostereprints.com

AWS Foundation

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

Chairman, Board of Trustees
Gerald D. Uttrachi

Executive Director, AWS
Ray Shook, ext. 210, rshook@aws.org

Executive Director, Foundation
Sam Gentry, ext. 331, sgentry@aws.org

Corporate Director, Solutions Opportunity Squad
Monica Pfarr, ext. 461, mpfarr@aws.org

Director, Solutions Opportunity Squad
Connie Bowling, ext. 308, cbowling@aws.org

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

AWS Mission Statement

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

It is the intent of the American Welding Society to build AWS to the highest quality standards. Your suggestions are welcome. Please contact any staff member or AWS President Victor Y. Matthews, as listed on the previous page.



AWS IS ON A MISSION

Win Great Prizes in the **2007-2008 AWS Member-Get-A-Member Campaign***

MISSION: 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 2007-2008 Member-Get-A-Member Campaign. By recruiting new members to AWS, you're adding to the resources necessary to expand your benefits as an AWS Member. Year round, you'll have the opportunity to recruit new members and be eligible to win special contests and prizes. Referrals are our most successful member recruitment tool. Our Members know first-hand how useful AWS Membership is, and with your help, AWS will continue to be the leading organization in the materials joining industry.



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

PRIZE CATEGORIES

President's Honor Roll: Recruit 1-2 new Individual Members and receive an AWS key chain.

President's Club: Recruit 3-8 new Individual Members and receive an American Welder™ camouflage hat and an AWS key chain.

President's Roundtable: Recruit 9-19 new Individual Members and receive an American Welder™ camouflage t-shirt, hat and an AWS key chain.

President's Guild: Recruit 20 or more new Individual Members and receive a Timex camouflage watch, an American Welder™ camouflage hat, a one-year free AWS Membership, the "Shelton Ritter Member Proposer Award" Certificate and membership in the Winner's Circle.

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

SPECIAL PRIZES

Participants will also be eligible to win prizes in specialized categories. Prizes will be awarded at the close of the campaign (June 2008).

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 2008 FABTECH International & AWS Welding 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 key chain.

The AWS Member who sponsors the most Student Members will receive a free, one-year AWS Membership, an American Welder™ camouflage t-shirt, hat and an AWS key chain.

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

LUCK OF THE DRAW

For every new member you sponsor, your name is entered into a quarterly drawing. The more new members you sponsor, the greater your chances of winning. Prizes will be awarded in November 2007, as well as in February and June 2008.

Prizes Include:

- ★ Complimentary AWS Membership renewal
- ★ American Welder™ camouflage t-shirt
- ★ American Welder™ camouflage hat

SUPER SECTION CHALLENGE

The AWS Section in each District that achieves the highest net percentage increase in new Individual Members before the June 2008 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.

*The 2007-2008 MGM Campaign runs from June 1, 2007 to May 31, 2008. Prizes are awarded at the close of the campaign.



American Welding Society

Visit www.aws.org

SPECIAL OFFER FOR NEW AWS INDIVIDUAL MEMBERS – TWO YEARS FOR \$135 (a \$25 savings)

★ PLUS... Get a popular welding publication for only \$25 (\$192 value)

AWS MEMBERSHIP APPLICATION

4 Easy Ways to Join or Renew:

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

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

Last Name _____

First Name _____ M.I. _____

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.

- ① Who pays your dues?: ☐ Company ☐ Self-paid ② Sex: ☐ Male ☐ Female
- ③ 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\$ _____

Domestic Members add \$25 for book selection (\$192 value), and save up to 87%†.....\$ _____ (Optional)

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

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

TOTAL PAYMENT\$ _____

AWS STUDENT MEMBERSHIP†††

☐ Domestic (Canada & Mexico incl.).....\$15

☐ International\$50

TOTAL PAYMENT\$ _____

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

\$4.00 of membership dues goes to support the AWS Foundation.

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

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

Your Account Number _____ Expiration Date (mm/yy) _____

Signature of Applicant: _____ Application Date: _____

Office Use Only

Check # _____ Account # _____

Source Code **WJ** Date _____ Amount _____



American Welding Society

P.O. Box 440367
Miami, FL 33144-0367
Telephone (800) 443-9353
FAX (305) 443-5647
Visit our website: www.aws.org

Member Services Revised 5/4/06

†Two-year Individual Membership Special Offer: applies only to new AWS Individual Members. ††Discount Publication Offer: applies only to new AWS Individual Members. Select one of the four listed publications for an additional \$25; International Members add \$75 (\$25 for book selection and \$50 for international shipping); Multi-Year Discount: First year is \$80, each additional year is \$75. No limit on years (not available to Student Members). †††Student Member: Any individual who attends a recognized college, university, technical, vocational school or high school is eligible. Domestic Members are those students residing in North America (incl. Canada & Mexico). This membership includes the *Welding Journal* magazine. Student Memberships do not include a discounted publication. **Airmail Postage Option:** International Members may receive their magazines via Airmail by adding \$99 to the annual dues amount.

BOOK/CD-ROM SELECTION

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

NOTE: Only **New Individual Members** are eligible for this selection. Be sure to add \$25 to your total payment. **ONLY ONE SELECTION PLEASE.**

- ☐ **Jefferson's Welding Encyclopedia (CD-ROM only)**
- ☐ **Design and Planning Manual for Cost-Effective Welding**
- ☐ **Welding Metallurgy**
- ☐ **Welding Handbook (9th Ed., Vol. 2)**

☐ **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)

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

Job Classification (Check ONE only)

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

Technical Interests (Check all that apply)

- A ☐ Ferrous metals
- B ☐ Aluminum
- C ☐ Nonferrous metals except aluminum
- D ☐ Advanced materials/Intermetallics
- E ☐ Ceramics
- F ☐ High energy beam processes
- G ☐ Arc welding
- H ☐ Brazing and soldering
- I ☐ Resistance welding
- J ☐ Thermal spray
- K ☐ Cutting
- L ☐ NDT
- M ☐ Safety and health
- N ☐ Bending and shearing
- O ☐ Roll forming
- P ☐ Stamping and punching
- Q ☐ Aerospace
- R ☐ Automotive
- S ☐ Machinery
- T ☐ Marine
- U ☐ Piping and tubing
- V ☐ Pressure vessels and tanks
- W ☐ Sheet metal
- X ☐ Structures
- Y ☐ Other
- Z ☐ Automation
- 1 ☐ Robotics
- 2 ☐ Computerization of Welding

RWMA is looking for nominations for the Elihu Thomson Resistance Welding Award for 2010.



The **Elihu Thomson Resistance Welding Award** is awarded annually by the **RWMA** Committee to a living individual who has made an outstanding contribution to the technology and application of resistance welding, as evidenced by one or more of the following:*

- Authored one or more technical papers on a resistance welding subject published in the *AWS Welding Journal* or any other industry-recognized publication.
- Developed innovations in resistance welding equipment or technology.
- Made a unique application of resistance welding in a production environment.
- Other contributions as the **RWMA** Governance Committee shall deem worthy of recognition.

Deadline for nominations is March 27, 2009

*Nominees may not be posthumously selected for recognition by this award. However, once selected, the award can be made posthumously.



RWMA is currently taking nominations for the **2010 Elihu Thomson Resistance Welding Award**.

Complete the nomination form at www.aws.org/rwma/awards/eliu.html and fax it back to **RWMA Headquarters** at 305-442-7451 or e-mail the completed form to rwma@aws.org.

The Award will be presented at the **FABTECH International** and **AWS Welding Show Award Ceremony** in Atlanta, Georgia, on November 2, 2010. This award consists of a plaque and honorarium (\$1,000), which maybe presented in cash or designated as a scholarship, at the recipient's option.



WHO WAS ELIHU THOMSON? Elihu Thomson, born in Manchester, England on March 29, 1853, was an engineer and inventor who was instrumental in the founding of major electrical companies in the United States, the United Kingdom and France. His family moved to Philadelphia in 1858. By 1880 he established, with Edwin J. Houston, the Thomson-Houston Electric Company. In 1892, this merged with the Edison General Electric Company to become the General Electric Company. Thomson's name is further commemorated by the British Thomson-Houston Company (BTH), and the French companies Thomson and Alstom. His early companies are also involved in the history of The General Electric Company Limited (GEC) in Britain and the Compagnie Generale d'Electricite' in France.

Thomson was a prolific inventor, being awarded over 700 patents. For example, he invented the induction wattmeter mechanism used in electric meters. He was the first recipient of the American Institute of Electrical Engineers AIEE (now Institute of Electrical and Electronics Engineers (IEEE) Edison Medal, bestowed upon him in 1909 "for meritorious achievement in electrical science, engineering and arts as exemplified in his contributions thereto during the past thirty years." Ironically, Thomson and Houston had been involved in a very public and acrimonious dispute with Edison in 1877-78 over etheric force. He was a founder member, as well as the second president, of the International Electrotechnical Commission. He served as acting president of MIT during 1920-1923. Thomson died in his estate in Swampscott, Massachusetts, on March 13, 1937.

We are looking for 2010 Nominees Now...Nominate Someone Now!

Please take the time to nominate someone who you feel would be worthy of this prestigious award.

You can nominate them by completing the form, and faxing it directly to

RWMA Headquarters at 305-442-7451 or e-mail it to rwma@aws.org.

You may also go to www.aws.org/rwma/awards/eliu.html and click on "Nominate Someone Now."

NEW

LITERATURE

Industrial Skills Training DVDs Detailed in Catalog

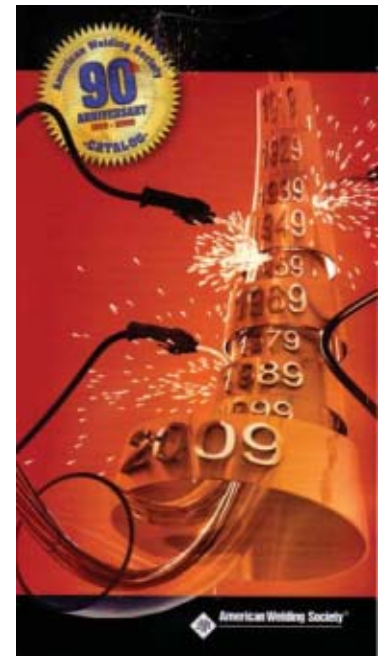


principles of metallurgy, joint design and symbols, general techniques and safety practices, oxyfuel gas cutting, brazing and braze welding, shielded metal arc (SMA) welding principles, SMA structural and pipe welding, principles of gas tungsten arc (GTA) welding, GTA structural and pipe welding, principles and techniques of gas metal arc welding, causes and corrections of weld defects, and plasma arc cutting. Other general topics offered include hydraulic systems, maintenance management, training the trainer, electrical maintenance and safety, plus many other titles. The catalog and more detailed course information can be downloaded from the Web site.

ITC Learning
www.itclearning.com
(800) 638-3757

Catalog Celebrates AWS 90th Anniversary

The Society's *90th Anniversary Catalog* is a compact 36-page, full-color, easy-to-



A two-page catalog lists industrial skills training DVDs and videotapes on a wide range of topics. Welding DVDs include

use compilation of standards, pocket handbooks, standard welding procedures specifications, and manuals on all aspects of materials joining. Look here for documents on industrial safety; welder qualification, training, and certification; weld testing and inspection; structural and sheet metal; base metal weldability; resistance welding; thermal spraying; joining plastics; all welding and cutting processes; standard welding procedure specifications; brazing and soldering; pipe and tubing; food-processing systems; and filler metal specifications. The booklet belongs on the bookshelf of everyone involved in industrial design or purchasing in the automotive, marine, aerospace, railroad, construction, machinery, and general manufacturing industries. Visit the Web site to order or download the PDF.

American Welding Society
www.aws.org
(800/305) 443-9353

Hexavalent Chromium White Paper Offered

Hexavalent Chromium: What You Need to Know has been released for industrial manufacturers involved in welding, stainless steel fabrication, and thermal spray coatings. It discusses the control and capture of hexavalent chromium to comply with OSHA's permissible exposure level requirements. The white paper was writ-

— continued on page 74

www.BlackStallion.com

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See sparks fly

Be part of the 45th SkillsUSA Championships, where since 1969, industry experts have been choosing the top student welders in the United States.

Don't miss your chance to be part of this year's event
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See the top high school and college/postsecondary student welders compete, and don't miss the trials to select the 2009 SkillsUSA WorldTeam member who will represent the United States in the WorldSkills Competition in Calgary this September.

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or call: 703-737-0624

To learn more about SkillsUSA, visit:
www.skillsusa.org

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

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ten by Jeff Abelson, technical applications manager for the company's line of dust, fume, and mist collection and filtration systems. It addresses the questions most manufacturers face on how to meet the new requirements. It defines what is hexavalent chromium, how workers can be exposed to it, and how hexavalent chromium can be captured and controlled. The document may be requested by phone or read online.

Donaldson Torit
www.donaldsontorit.com. Printed
(800) 365-1331

Certified Safety Products Pictured in New Catalog

A recently released 32-page, full-color catalog features more than 60 styles of safety eyewear, hearing, respiratory, head, and face protection products. Included is the safety certification information for each product, including ANSI, CSA, UV-A and UV-B, Underwriters Laboratories certifications for eye and face protection, and independently tested noise-reduction ratings for the hearing-protection products. The pictured eyewear products feature polycarbonate lenses with antiscratch



and antifog coatings designed to make workers want to wear them on the job.

Gateway Safety, Inc.
www.gateway-safety.com
(800) 822-5347

New Brochures Feature Welding Products

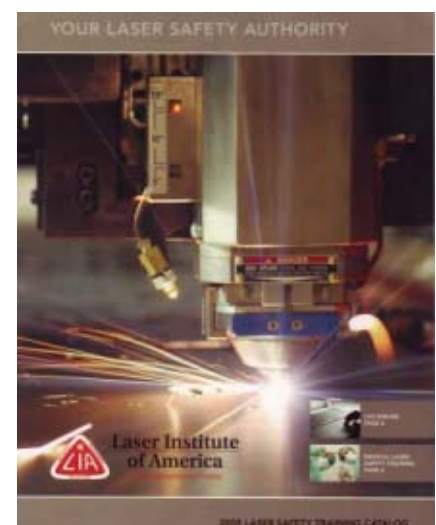
The company offers a number of new



catalogs on a variety of welding-related topics. The 27-page, full-color joining catalog features a wide range of alloyed and nonalloyed wires for use in severe environments in the nuclear, offshore, LNG, and transport industries. Other brochure titles include cored wires for hardfacing; continuous casting, advanced roll cladding solutions; MultiSurfacers™ custom-designed automated welding equipment; Hardlite™ ultrathin composite wear plate; and hardfacing, cladding, and thermal arc spraying. Call to request electronic or hard copies.

Welding Alloys USA, Inc.
www.welding-alloys.com/usa
(859) 525-0165

Laser Safety Training Updated for 2009



The 2009 *Laser Safety Training Catalog* details the company's complete course offerings for the year. Included are course

— continued on page 94

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



THE AWS WELDER MEMBERSHIP

EXCLUSIVELY FOR WELDERS

***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

PERSONNEL

Hobart Institute Adds Staff



Jonathan Brittingham



David Strasfeld



Sally Church

Hobart Institute of Welding Technology, Troy, Ohio, has hired additional staff to accommodate increased student enrollments. **Jonathan Brittingham** and **David Strasfeld**, both graduates of the Institute's structural and pipe welding program, have joined the welding skill instructor staff. **Sally Church**, with experience in a college office environment, has been appointed student services assistant. Brittingham brings five years of fabrication and manufacturing welding experience to the job. Strasfeld previously served as a U.S. Navy hull technician, a pipefitter, and teacher of vocational education in the Peace Corps.

Member Milestone

Maria McCosh



Maria McCosh

Maria McCosh recently was promoted to quality assurance manager at Diversified Metal Products, Inc., Idaho Falls, Idaho, where she has worked since January 2000. Her successful career began when she accepted a District 20 scholarship to help finance her two-year associate's degree in welding at Ricks College, in Rexburg, Idaho, currently named Brigham Young University — Idaho. Since graduating, she qualified for AWS Certified Welding Inspector (CWI), Penetrant Test PT Level II, and NQA-1 auditor. Along the way she has acquired nine years of quality assurance and quality control experience in the nuclear industry, technical, documentation, specification verification, procedure and code compliance, and vendor surveillances and audits.

Upon joining Diversified Metal Products, she wrote welding procedures and welder qualifications in accordance with AWS and ASME standards. She reviewed contract documents and drawings, performed audits, approved vendors' lists, assured quality assurance programs met the requirements of NQA-1, provided training of personnel, and assured the proper implementation of QA programs. Her new position at Diversified Metal Products expands her responsibilities to include supervision of Quality Department personnel, monitoring subcontractors' work through source verification, performance history, and audits, and to provide training as required to assure that the QA programs are properly implemented.

Since 1997, McCosh has been an active member of the AWS Idaho/Montana Section. Since 2001 she has served as a member of the Welding Advisory Committee providing assistance with welding programs presented at local high schools. She also serves as a team captain for the American Cancer Society's Relay for Life of Bonneville County.

PFERD Names National Accounts Manager



Robert Mumm

PFERD Inc., Leominster, Mass., has appointed **Robert Mumm** to the newly created position of national accounts manager. Prior to joining the company, Mumm worked six years as director of sales at WMH Tool Group of Elgin, Ill.

Kaman Industrial Promotes Two to Key Posts

Kaman Industrial Technologies, Windsor, Conn., has announced the promotions of **Ron Hittel** and **Sam Cooper** to district managers. Hittel, with the company for 34

years, will serve as district manager for the Great Lakes district. He most recently served as a strategic accounts manager for the central and southeast regions. Cooper, previously a branch manager in Columbus, Ohio, will serve as district manager for the Ohio Valley district.

Oxygen Products Firm Names Marketing Manager



Sara Lippold

Responsive Respiratory, St. Louis, Mo., a supplier of high-pressure oxygen products, has named **Sara Lippold** marketing manager. Prior to joining the company, Lippold served in various marketing and product management positions for a safety products company.

ASTM Chair Announced

Paul K. Whitcraft has been elected 2009 chair of ASTM International, West Conshohocken, Pa. Whitcraft is director of quality, safety, and engineering at Rolled Alloys, Temperance, Mich.

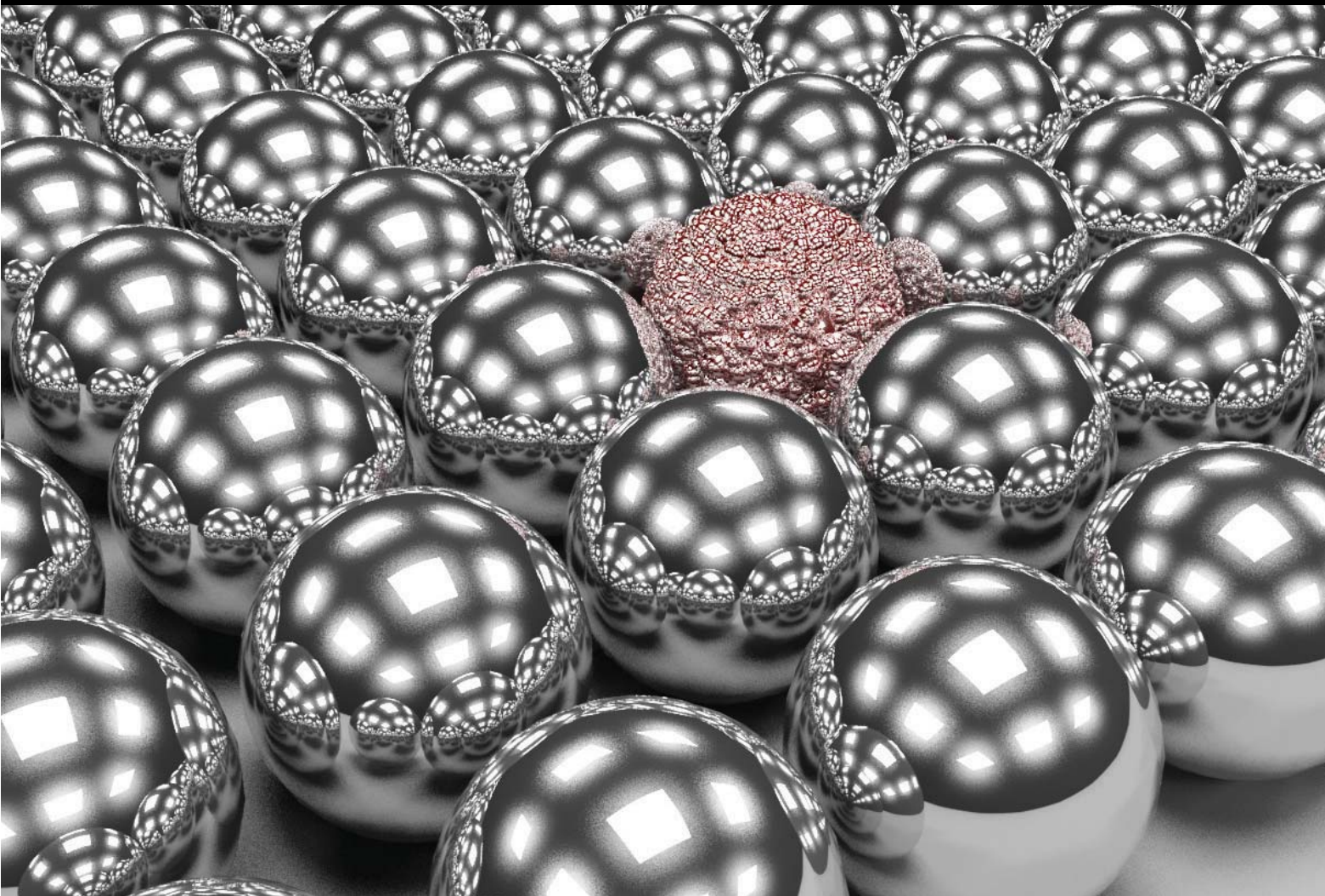
RathGibson Names CEO and CFO

RathGibson, Lincolnshire, Ill., a manufacturer of welded, drawn, and seamless stainless steel, nickel, and titanium tubing, has appointed **Michael Schwartz** chief executive officer and a member of its board of directors. **Jon Smith**, formerly with the Engine and Transmission Components group of Magna Powertrain, was appointed chief financial officer. Schwartz joined the company in April 2008 as pres-

— continued on page 78

Welding Corrosion Resistant Alloys Conference

Chicago, November 18th, 2009



Welding Corrosion Resistant Alloys Takes Center Stage. Find answers to the unknown and discover new processes.

The interest level is extraordinarily high when it comes to the welding of corrosion-resistant alloys. There are many reasons for this. One is the entry of the duplex stainless steels and other high-performance grades. Another is the unstable prices in nickel, molybdenum and titanium. When the price of nickel hit the roof, many fabricators switched from 316 to 201 stainless because of the latter grade's lower nickel content. Research is feverish throughout the world in the development of new and cheaper methods of producing titanium. Will a lower cost titanium make the metal more popular?

The overall activity is immense. Cladding and strip overlay processes have become more popular means of protecting parts exposed to heavy corrosion. Duplex stainless is now being welded for over-the-road tankage. New processes, like friction stir welding and the more

advanced thermal stir welding out of NASA will be discussed as well. Also, improvements in weld properties are being realized by increasing the weld interpass temperatures for conventional austenitic stainless steels.

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— continued from page 76

ident and chief operations officer. Previously he served as president and chief executive officer of Airoom, Inc.

Oxford Alloys Designates Export Sales Director

Oxford Alloys, Inc., Baton Rouge, La., has named **John A. Robinson** director of export sales. Before joining the company, Robinson worked with Techalloy, Central Wire Group, a producer of stainless steel and nickel wire.

Sales Director Appointed at NanoSteel®

The NanoSteel® Co., Providence, R.I., has appointed **Mike Place** sales director for the company's portfolio of Super Hard Steel® coating, overlay, and wear plate solutions. Previously, Place worked for Liquid Metal Coating Solutions as national sales director and field operations manager.

Multiquip Names President



Mike Howlett

Multiquip, Carson, Calif., has appointed **Mike Howlett** president of its General Construction Equipment internal division. Most recently, Howlett served as vice president of operations.

Hypertherm Adds Sales Support for Canada

Jamie Lowrie has joined **Vince Tucker** as a district sales manager for the western Canadian provinces to support the significant business growth in the region. Lowrie, formerly a consumable sales manager for Hypertherm, will support distributors in the Manitoba, Saskatchewan, and Northern Alberta provinces. Tucker will work with distributors in Southern Alberta and British Columbia.

TRUMPF Names VP

TRUMPF Inc. has appointed **Christian Schmitz** vice president, lasers, based at the company's North American headquarters in Farmington, Conn. Previously,

Schmitz was responsible for managing the Disk Laser Group and overseeing the development of a new diode-pumped solid laser system at the TRUMPF Laser GmbH facility in Schramberg, Germany.

Rockford Toolcraft Taps Sales Manager

Rockford Toolcraft Inc., Rockford, Ill., a tool and die builder and metal stamping firm, has named **Doug Kosch** sales manager. With the company for 18 years, Kosch most recently worked as die estimating engineer since 2001.

Aluminum Association President Joins ITAC

Steve Larkin, president of The Aluminum Association, Arlington, Va., has joined the Industry Trade Advisory Committee (ITAC). The committee, operating under the U.S. Department of Commerce International Trade Administration, is missioned to strengthen the nation's negotiating position by enabling the U.S. government and private industry to display a united front when negotiating trade agreements with other nations.

Obituaries

William T. DeLong



William T. DeLong

William (Bill) T. DeLong, 87, died Dec. 30 in York, Pa. An AWS Life Member, he served as AWS president (1981–1982) and

was named an AWS Fellow (1991).

DeLong graduated from Lehigh University in 1943 with a degree in metallurgical engineering. During WW II, he served in the Chemical Warfare Branch of the U.S. Army. He worked for Teledyne-McKay in welding research from 1950 to 1984 when he retired as vice president of corporate development. During his career, he was granted 15 patents for his work and authored numerous technical papers published widely in industry journals. He led the effort for international standardization of magnetic measurement of ferrite. DeLong, named an ASM International Fellow in 1977, was active in the International Institute of Welding, Welding Research Council, chaired the AWS A5 Committee on Filler Metals and the Technical Activities Committee, and served on the AWS Safety and Health Committee and its subcommittees, the Project Committee on Ni and Cr⁺⁶ hazards, and the Task Group on Health Hazards. He also was a member of the NEMA Task Group that developed OSHA Material Safety Data Sheets and product warning labels. His many awards include the Comfort A. Adams Lecture Award (1974), R. D. Thomas Memorial Award (1974), National Meritorious Award (1985), and Honorary Membership Award (1986). He was a founding member of the Unitarian Society of York, and remained active until his death. He loved gardening, working outside, and discussing the latest breakthroughs in many fields of science. DeLong is survived by his wife, Bernadean (Bunny); her live-in caretaker, Connie; sons John, Thomas, and James; and six grandchildren.

Jan-Eric Nelson

Jan-Eric Nelson, 56, died Dec. 29. An AWS member 1984 to 2005, he was a resident of Pahrum, Nev., where he lived for ten years after leaving Los Angeles, where he had lived since 1957. Prior to his professional career position as a specialty construction inspector in structural steel welding, concrete, masonry, and seismic projects, he was a journeyman welder through the Ironworkers Union Local 433. He worked both as self-employed and employed as a construction inspector with the IUOE Local 12, Twining Labs, Converse Consultants, City of Los Angeles-Con Ad, and the Los Angeles County Sanitation Districts and OSHPD. He held memberships in ICC/ICBO, MCIA, SEIU, and ACIA. He enjoyed gardening, reading, and taking many continuing education classes pertaining to his work. Nelson is survived by his wife, Terri; daughters Cinthia Nelson and Suzi Lighten; mother, Hanna Nelson; and two grandchildren.

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Welded Sculptures Pay Tribute to Fallen Heroes

A retired firefighter devotes his time and energy creating various figures for a new memorial in remembrance of 9/11

BY KRISTIN CAMPBELL



Felix Gonzalez, sitting next to his masterful three-dimensional steel New York firefighter, shows power in a humble way with this sculpture. "I want people to remember he represented the firefighters who died, but beyond that, he also represents humanity," Gonzalez said.

KRISTIN CAMPBELL
(kcampbell@aws.org) is associate editor of the Welding Journal.

Felix Gonzalez spent seventeen months making what he believes is the world's first three-dimensional steel sculpture of a New York firefighter. The piece represents the pillar of strength shown by those courageous and brave firefighters who went into the burning World Trade Center (WTC) buildings on 9/11/2001. "This is from my heart and soul," Gonzalez said. "There's a lot of emotion behind it — that's what I love."

As a veteran firefighter himself, serving Miami-Dade, Fla., for 28 years, he could not have been a better choice to create the tribute. During Gonzalez's career he learned gas metal arc welding (GMAW), gas tungsten arc welding (GTAW), and how to use an oxyacetylene torch; he even taught himself more about these subjects by reading. Now retired, he enjoys making art with mixed materials, has participated in local shows, and paints.

In 2006, Gonzalez gladly accepted the City of Pembroke Pines, Fla., commission to design and sculpt a memorial to the survivors of 9/11. He has been given a lot of freedom and flexibility to bring his ideas to fruition. The city commission also awarded him a \$20,000 honorarium funded by revenues generated from the city's annual art festival.

His workspace in Pembroke Pines could be called the 9/11 memorial fire station/studio. "We basically took a fire station and converted it into a shop," Gonzalez said. Cabinets, tools and machines, a new compressor, fans, and accordion gates were added to enhance the garage.

Gonzalez spends his days busily working to finish this collection in time for the tenth anniversary of the 9/11 attacks in 2011. The steel for making these items

was donated by local sources including Doug Record of Recs Wrecks Inc.; two demolition companies; and the city.

Dean Combs, Parks & Recreation director for the City of Pembroke Pines, has helped meet Gonzalez's needs. This project runs under his division. "They're behind me 100%," Gonzalez added of Pembroke Pines Mayor Frank Ortis and city commissioners. He appreciates all the support received.

According to Combs, a decision has not been made by the city commission as to where the 9/11 sculptures will be exhibited, but they will be displayed indoors either at Pembroke Pines planned new City Hill at City Center or at the current City Hall.

"We are very fortunate and grateful that Felix volunteered to create a one-of-a-kind sculpture, a sculpture that will be a memorial to a day that shall never be forgotten," Combs said. "It's a work in progress, but every time I visit his studio, I am in awe of his passion for this project. Wherever this 9/11 exhibit is eventually placed, it will become a 'destination piece of art.' People will visit with the sole purpose of viewing this majestic memorial display."

Forming a Firefighter

The three-dimensional steel New York firefighter evokes power, courage, and empathy. This hollow sculpture weighs 2½ tons and stands 8½ ft tall. "The strength is on the inside," Gonzalez said. He applied the second application of clear coat, high-gloss urethane as a finishing touch recently — Fig. 1.

In the firefighter's construction, Gonzalez used techniques learned making art with wood and applied them to tai-



THE AMERICAN WELDER



Fig. 1 — The unique firefighter, built using pieces of steel, looks ready to rescue someone with its complete gear in tow. “He’s pretty spectacular, and I’m really happy with my results,” Gonzalez said.

lored cut sections of ¼-in. steel. “Each piece had to be perfect,” Gonzalez said. He used gas metal arc welding with flux cored wire to individually weld these parts placed in different angles. Two plasma cutting devices helped achieve the correct proportions and flows.

The sculpture has two textures — from the boots to the waist and from the waist to the helmet. “I started from the bottom and worked my way up,” Gonzalez said. With a general idea in mind, this figure came together by slowly building upward.

The firefighter’s special details include the following:

- Helmet with a shield that reads F.D.N.Y. 343 to honor the number of firefighters lost on 9/11
- Universal face anyone could identify with
- Traditional firefighter jacket, pants, and shoes worn
- A large pike pole, used to look for fire, held in the left hand and a pike axe held in the right hand
- Big fists on both sides representing strength



Fig. 2 — Long sections of twisted steel comprise this original rendition honoring the WTC. A — Tower 1 with four wings on its top and 9-11-01 marked on one of its beams; B — the sculpture of Tower 2; and C — ashes coming out of the dust design shown in Tower 2.



THE AMERICAN WELDER



Fig. 3 — Awaiting use, donated steel rests on a grassy patch for more sculptures to be made with it.



Fig. 4 — Gonzalez performs gas metal arc welding on another work of art, a little girl modeled after his granddaughter.



Fig. 5 — Benoit Menasche, an impressionist, stands next to a side of his marble carving. The stone came from Italy.

- Axe and helmet slightly bigger to represent the power of firefighters
- Pressure gauge, which tells the firefighter how much air is left in the tank, on right side
- Air tank on its back with a pressure gauge on this showing a time of 8:46 to represent the first WTC strike

- Flashlight on the back left side
- Small pouch for storing a mask
- A plaque at the bottom that reads September 11, 2001, F.D.N.Y. - W.T.C., by Felix D. Gonzalez, July 30, 2008.

When displayed, Gonzalez would like this firefighter placed upon a granite pedestal with the idea to overpower peo-

ple and a 9/11 documentary playing in the background. "I'm really proud of it. I can't believe I pulled it off," he said.

Putting Together the Twin Towers

Numerous beams representing the WTC's two buildings have also been made with donated steel. Gonzalez wanted to remind people of the wreckage but not in an overdone way. "I call it simple elegance," he said. They took three months to complete.

Tower 1 rises 16 ft tall with an 11-in. base, features four wings on its top to symbolize the four hijacked airplanes, and has 9-11-01 carved out on a beam — Fig. 2A. Tower 2 looms 14 ft high, contains a 9-in. base, and includes a design of ashes rising from dust — Fig. 2B, C.

Each sculpture weighs about one ton. Plasma cutting tools, GMAW, and GTAW were used in their construction. A commemorative plaque is going to be made for the towers, and they will receive a urethane coating.

Steve Albertson, a maintenance worker for the city's Parks & Recreation Dept., assisted Gonzalez by building the converted fire station's infrastructure. Plus, he helped assemble Tower 1. "The hardest part was lifting pieces," Albertson said of the beams; in general, these weighed 300–500 lb. He performed tack welds and GTAW, too. "Some of the welds took forty-five minutes to an hour to put together," Albertson said. He also



THE AMERICAN WELDER

made its bottom base with 1/4-in. steel.

All together, these two towers along with the other sculptures will provide a statement about the events of 9/11 and as a nation what is represented. "The whole idea is to make you feel like you were there," Gonzalez said.

Sources of Inspiration

Working on this project became challenging at times. Gonzalez compared the creation process to a game of chess. "The hardest part is how you're going to present the artwork," he said. As pieces get put together, details come, and then it turns into movement and shapes.

Getting welds tight and clean required tedious attention. "My welding had to be accurate," he said.

Despite all this, the reward of making sculptures for many to view outweighs any difficulties. "I like monumental art, creating big pieces," Gonzalez said, because everybody sees different things. Also, when he thinks of those who passed away on 9/11, this drives him to do the best he can.

Gonzalez finds it gratifying to create something totally different from other items. "I never make the same things twice. If you're not extending yourself, how are you going to grow?" he said.

Upcoming Works of Art

Steel stays in the station's yard ready for service — Fig. 3. A chain-link fence keeps it safe from intruders. Gonzalez plans on using this, along with other metal he will receive, for constructing additional pieces. "I'm really much into shapes — the texture, maybe the age of the material," Gonzalez said.

Not that long ago, he started working on a frail-looking girl figure — Fig. 4. She will be solid with no hollow parts, on her knees, have lots of hair, and stand 4 1/2 ft high. Gonzalez's granddaughter, Natalia, served as the model for this design.

Additionally, he will create sculptures of a woman (conveying sympathy and softness just like the girl) and a police officer with a search dog. "I want them to be slightly different yet the same," Gonzalez said of this group.

Making Images out of Marble

Part of the 9/11 exhibit will include a 9.5-ton, 4-ft-tall marble sculpture by Benoit Menasche, the City of Pembroke Pines art curator — Fig. 5. Gonzalez said Menasche

is the sole inspiration behind this memorial, has a positive can-and-will-do spirit, and credits him with making it all possible. Menasche further provided motivation and encouragement to Gonzalez.

This four-sided figure shows the following types of grief: shock, realization, acceptance, and rebuilding. Each side displays a different image. "It's a story," Menasche said, representing what happened to somebody who lost something and the stages of trying to understand.

A steel girder donated from New York's WTC remains will go on top of this piece. "I'm putting this girder onto something white," Menasche said, adding he did not want the marble base to overpower the girder but did want to show a concept of dark vs. light. For the viewer, the whole figure will be at eye level; its base will be 8 in.

Various tools used for the carving include air compressors, hammers and chisels, grinders, die grinders, and diamond bits. "It's very, very hard marble," Menasche said. He works on the images when time permits and shares the converted fire station with Gonzalez. It is expected to be done later this year.

Bright Outlook

"I think I want people to be moved, but also get a sense of our humanity, how close we are to one another," Gonzalez said of the whole memorial. He wants individuals to fully understand it and ask questions like what the artist conveyed and the meaning of that day.

He further hopes others will be inspired to accomplish their dreams and goals after viewing the display. "I want it to be a total experience," he added.

After all, when Gonzalez set out to make his firefighter he was told it could not be done with steel, yet he pushed ahead anyway with this transformation. "I like creating the impossible," he said.

In the future, he would like to continue using his welding and artistic skills for a good cause. "I want to do this the rest of my life," he said.

Eventually, Gonzalez would like to create sculptures in honor of the Holocaust survivors as well as for Cubans because his father served as a tank captain/soldier in the Bay of Pigs Invasion. "I like public art," he said, noting its incredible ability to touch so many lives. ♦

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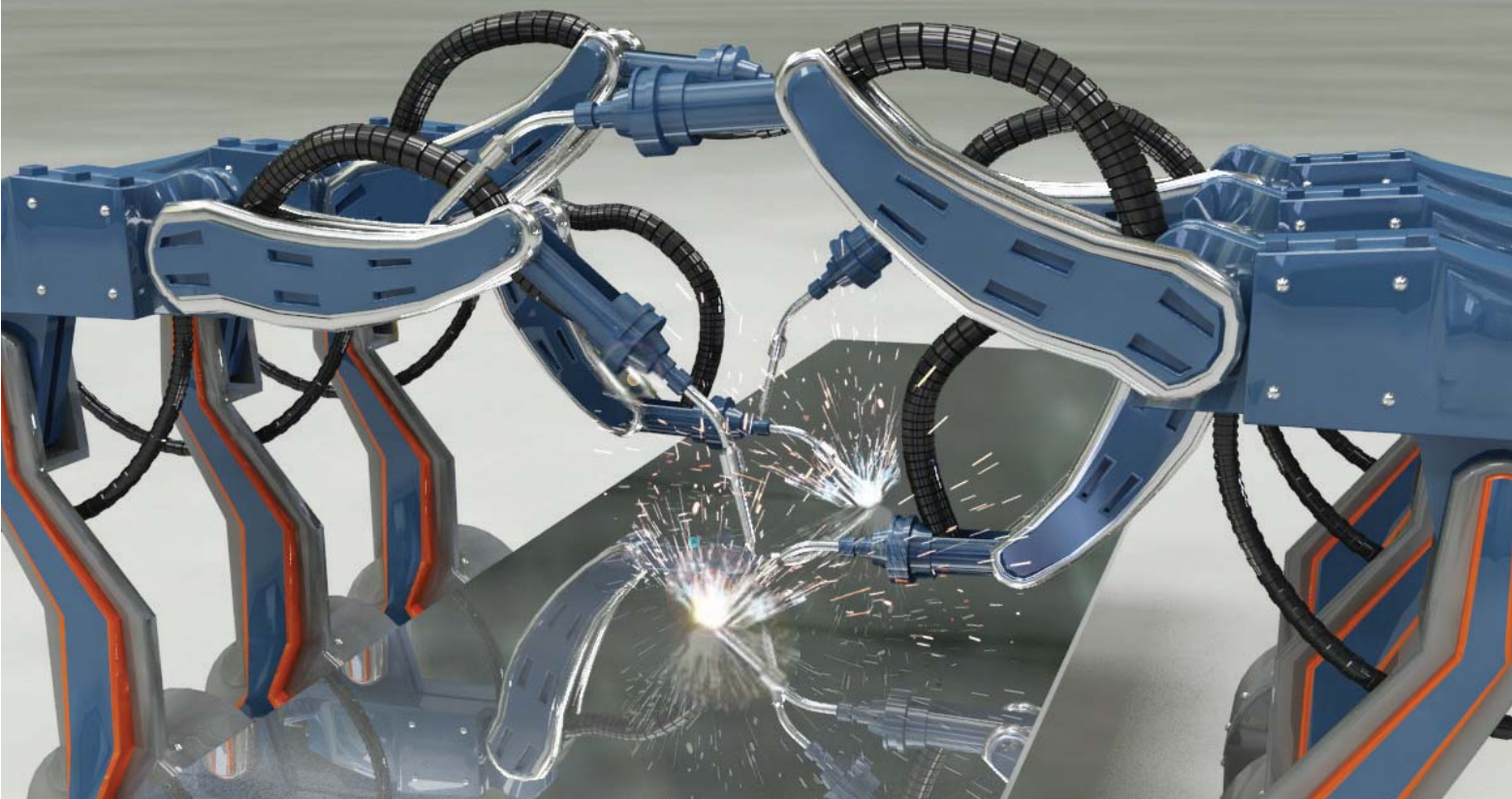
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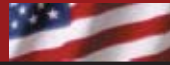
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Optimizing Tungsten Electrode Performance

Proper preparation can lead to an increase in electrode life and better welds

BY MIKE FLETCHER

It can be argued that the electrode is the weakest link in the drive for gas tungsten arc weld quality. Poor electrode choice and preparation invariably lead to defective joints.

While hand grinding can be tolerated in some circumstances, producing welds for safety-critical applications and where weld properties must meet stringent inspection criteria needs a more controlled approach. Following are some tips for optimizing electrode preparation, which can lead to a significant increase in electrode life.

1. Choose the right diameter.

Table 1 can be used to determine the electrode diameter best suited to the welding current you are using. This guide to the optimum diameter is based on decades of welding practice.

2. Choose a reputable supplier.

Superficially, electrodes from different companies look much the same, but do consider that, in general, cost means quality. The better electrodes have been manufactured to ensure a small grain structure that allows for better migration of oxides to the tip, easier arc starting, improved arc time, and better weld quality with minimized contamination.

3. Choose the best electrode composition.

For many years, manufacturers have been adding residual compounds to offer improved performance. Additions of stable oxides such as thoria, ceria, and lanthana provide the same level of emission as pure tungsten at lower temperatures, while improving arc time and stability.

Pure tungsten has a high work function, i.e., it takes a great deal of energy to operate. This makes it difficult to start and maintain a stable arc. It also has a high burn-off rate and thus a shorter service life.

Thoria stabilized. It is now clear that thoria, although promoting better welding, is low-level radioactive and many manufacturers and welders have stopped using it because of the health concerns (Refs. 1, 2).

Zirconia stabilized. Zirconia is used for radiographic-quality welding where tungsten contamination must be minimized. It balls up easily in AC applica-

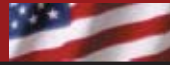


Fig. 1 — Precision mechanized tungsten grinder with dust extraction. (Photo courtesy of Huntingdon Fusion Techniques Ltd., UK.)

MIKE FLETCHER is with
Delta Consultants, UK.

Table 1 — Recommended Current Levels for Different Electrode Diameters

	Current Range (Amp)	Current Range (Amp)	Current Range (Amp)
	DCEN	DCEP	AC Balanced Wave
Electrode Diameter (mm)			
0.5	5–20	uncommon	5–20
1.0	15–80	uncommon	20–60
1.6	70–150	10–20	60–120
2.4	150–250	15–30	100–180
3.2	250–400	25–40	160–250
4.0	400–500	40–45	200–320



tions, but has good arc starting and current-carrying capacity.

Ceria stabilized. Ceria electrodes are good for low-current, DC, orbital tube, pipe, and thin-sheet applications. This formula has low current capacity but offers low arc ignition and good arc stability.

Lanthana stabilized. These electrodes are a nontoxic alternative to thorium-stabilized products. They offer excellent ignition and re-ignition properties and good service life.

Combination stabilized. Some companies manufacture electrodes with complex oxide stabilization. These advanced nonradioactive formulas combine three oxides with tungsten to produce excellent all-purpose electrodes. They offer long life, repeatable performance, and reliable arc starting even after numerous ignitions (Ref. 3). An example of this type of electrode is Multi-Strike™ from Huntingdon Fusion Techniques.

Color coding is used on some electrodes but this practice is not standardized for all mixes and varieties from Europe, Japan, and the United States. See AWS standard A5.12/A5.12M, *Specification for Tungsten and Tungsten-Alloy Electrodes for Arc Welding and Cutting* for U.S. designations.

Classification is undertaken on the basis of chemical compositions, as follows:

- E: Electrode
- W: Tungsten
- P: Pure tungsten
- Zr: Zirconia stabilized
- Th: Thorium stabilized
- Ce: Ceria stabilized
- La: Lanthana stabilized
- G: Unspecified oxide stabilization.

The numbers on electrodes specify the nominal alloying composition (in wt-%). For instance, EWTh-2 is a thorium-stabilized tungsten electrode that contains 2% thorium.

4. Choose the best electrode grinder.

A standard bench grinder just isn't good enough. Cross contamination from other operations to the electrode surface can introduce impurities, which materially affect the welding process. Furthermore, an uneven wheel will pro-

duce a poorly shaped electrode tip.

Choose a grinding machine that has been designed specifically for electrode preparation and use it only for this purpose — Fig. 1. Select one with robust performance to cover the entire range of diameters to be used. A diamond wheel is preferred and the operation should ensure that any grinding marks are parallel to the length: electrons flow along a surface and become erratic if they encounter cross-grinding marks — Fig. 2. Ensure that an angle-setting jig is provided (0–90 deg) and extraction facilities are available to remove any radioactive dust safely.

Repeatability is a must if consistency of weld deposition is to be realized and this is where the advantages of employing a tungsten tip grinding machine start to be appreciated. The alternative of manual preparation by the welder brings with it the probability not only of inconsistent geometry from electrode to electrode but the introduction of significant deviations from the optimum. Table 2 compares machine grinding to manual grinding.

5. Choose the proper tip grinding procedure.

The geometry and surface finish of the electrode point are crucial to good welding — Fig. 3.

Taper. Only experience — taking into consideration the arc current, welding power supply, welding torch, material to be welded and its thickness, and joint preparation — will define the truly optimum electrode configuration, but Table 3

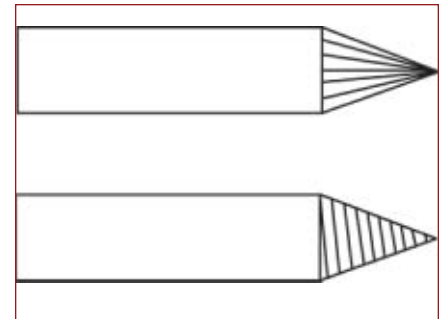


Fig. 2 — Grinding should be done so that grinding marks run along the electrode length and not normal to it.

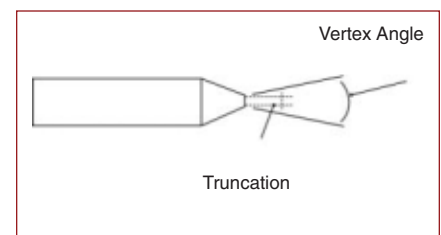


Fig. 3 — Geometry of electrode tip showing vertex angle and truncation.

for DC polarity can be used as a valuable guide.

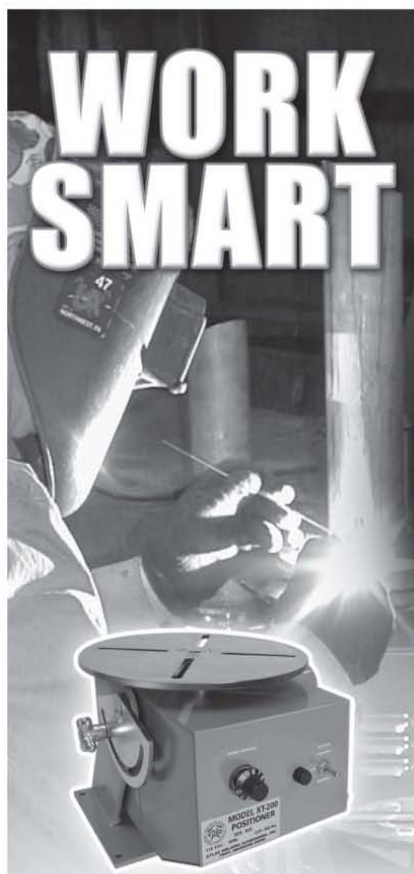
In general, larger angles offer longer life, better penetration, a narrower arc, and the capability to sustain more current without erosion. Smaller angles result in less tendency for arc wander, give a wider

Table 2 — Recommended Vertex Angle for Different Electrode Diameters and Currents

Diameter (mm)	Current (Amp)	Vertex Angle (Deg)
0.5	5–20	10
1.0	15–80	10
1.6	70–150	15
2.4	150–250	30
3.2	250–400	40
4.0	400–500	45

Table 3 — Comparison of Machine and Manual Grinding

Machine Grinding (Advantages)	Manual Grinding (Disadvantages)
Surface finish consistent and of high quality	Surface finish poor and inconsistent
Collet loading ensures security	Electrodes can fracture during grinding
Lengths down to 12 mm can be handled	Short lengths cannot be handled
Dust extraction incorporated	Health hazard with dust
No risk of hand injury	Operator hand injuries likely
Low skill level	High level of skill required



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and more stable arc, and can be used at lower currents.

Electrode tip finish. Current transfer takes place predominantly through the flow of electrons along the electrode surface and is influenced by the surface finish. Free flow of electrons is inhibited by scratches or grinding marks that do not run parallel to the axis, and for this reason, it is important that grinding should be longitudinal and concentric. For optimum operation, a typical surface finish of 0.5 Ra is essential. Electrodes that have been ground normal to the axis or that have a surface finish much coarser than 0.5 Ra will produce instability in current flow. This may result in the following: arc initiation away from the tip, arc wander, thermal shock at the tip, and reduced electrode life.

Truncation. For some specific applications, the use of a truncated tip is beneficial. A truncated cone of specified included angle, obtained by grinding, is often preferred for DCEN. Table 4 shows recommended truncation dimensions for different electrode diameters. ♦

Table 4 — Recommended Truncation Dimensions for Different Electrode Diameters

Electrode Diameter (mm)	Recommended Truncation
0.5	0.1
1.0	0.5
1.5	0.75
2.5	0.85
3	1
4	1.25
4.75	1.5
6	1.75

References

1. Thoriated tungsten electrodes studied for effects on welders' health. 1994. *Welding Journal* 73(5): 88, 89.
2. Statement of Commission VIII on health aspects in the use of thoriated tungsten electrodes. 1994. *Soudage dans le Monde* 33(4): 276.
3. Performance of TIG Electrodes. June 1993. Welding Institute Ref 220177/1/93.

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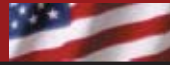
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How to Choose Ergonomic Hand Tools

These tips will tell you what makes a hand tool ergonomic, and help you choose the right one for your body and the job

BY PAUL HOLSTEIN

Drop into any hardware store, home improvement center, or welding distributor and you're likely to find aisles full of tools labeled "ergonomic."



Fig. 1 —Tools such as these screwdrivers, which feature a cushioned handle, provide a firmer grip, cut down on slippage, and are more comfortable for longer periods of time.

But what exactly does that mean for consumers? Simply put, ergonomics is the science of designing and producing tools, furniture, and other work-related implements that improve a worker's efficiency while reducing discomfort, fatigue, and risk of injury.

Ergonomically enhanced tools can include helpful features like angled handles, padded handgrips, and nonslip coatings. However, no matter how impressive a tool's design is, it's almost impossible for it to be universally ergonomic since human physiques and project applications vary greatly from one to the next.

Whether you're shopping for ergonomic tools or just trying to select the right one for the job from an existing collection, the key things to consider are whether or not the tool fits your hand, how well it suits the job being done, and whether or not it eases your work and prevents you from straining in ways that could lead to injury. Regardless of how user-friendly a tool is built to be, the most important factor in what makes a tool ergonomic is, ultimately, you.

To make the decision process a little easier, here are some guidelines for choosing the right ergonomic hand tool for your body type and the job at hand.

- Because finger size and placement differs from person to person, avoid using tools whose handles have built-in finger grooves. When fingers don't naturally align with grooves, excessive pressure

from the raised groove edges can cause discomfort and injury.

- Choose tools with handles that are covered in a soft material, like foam or flexible plastic. Cushioned handles are not only comfortable for long hours of use, but they provide a much firmer grip and cut down on slippage — Fig. 1. Hard-handled tools can be quickly and inexpensively converted by adding a sleeve.

- Ensure tool handles are free from sharp edges and seams that might irritate or cut the hands.

- When selecting double-handed gripping and cutting tools, opt for ones with spring-loaded handles that will automatically return to the open position.

- If you need to forcefully pinch or grip an object for an extended amount of time, prevent muscle strain by switching from standard pliers to a clamp or grip.

- Only use tools that allow you to work with your wrist in a straight position.

- For tasks that require force, such as torquing screws and nuts, hammering, and heavy chiseling, choose single-handle tools with handle diameters that range from 1¼ to 2 in. Larger handles allow fingers to wrap comfortably around the tool in a power grip, which prevents slippage and reduces stress and impact on hands, fingers, and wrists.

- For tasks that call for more precision and delicacy (like fine chiseling and driving miniature screws), opt for single-

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handle tools whose grips fall within the ¼–½-in. range. The smaller-diameter handles make it easy to comfortably grip tools between the fingertips without overexerting fingers, knuckle joints, or hand muscles.

- Just as grip diameter affects work with single-handle tools, the grip span of pliers, snips, cable cutters, and other double-handled tools can either make your job easier or cause you hand fatigue. For maximum comfort and efficiency for tasks that require more force (like gripping with large pliers, cutting wires, or snipping through sheet metal), choose tools with a maximum “open” grip span of 3½ in., and a “closed” grip span no less than 2 in. across.

- Detailed jobs that involve grasping small parts and components with pincers, tweezers, or tongs are best done with double-handled tools whose grip spans range from no less than 1 in. (closed) to no more than 3 in. (open).

- When a work space is tight but the task at hand requires a good deal of force,

opt for “power grip” tools (with handle diameters from 1¼ to 2 in.) that are grasped with the entire hand instead of just pinched between the fingertips. This type of grip lets you finish the job in far less time, with far less physical stress.

- Tool length should also be matched to space constraints. Excessively long tools can force you to assume awkward work postures and wrist positions when you’re trying to reach components in cramped areas. Instead, choose short-handled tools that give you the freedom to meet the target work area directly, while keeping your wrist straight.

- The palms of your hands are full of pressure-sensitive nerves and blood vessels, and in order to avoid damaging these during high-force tasks, it’s important to make sure that the handles of your tools are long enough that their ends won’t press into your palms. To measure, hold your hand palm up, with fingers together and thumb against the side of your hand. As long as the tool’s handle is longer than the widest part of your hand (the span

from the outer edge of your pinkie to the outer edge of your thumb), it’s safe to use. ♦

Do You Have Some News to Tell Us?

If you have a news item that might interest the readers of the *Welding Journal*, send it to the following address:

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Items can also be sent via FAX to (305) 443-7404 or by e-mail to mjohnsen@aws.org.



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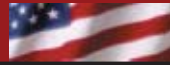
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Understanding Edge Shapes

Edge shape refers to the shape of the edge of the joint member. The figure shows the seven edge shapes and the types of welds for which they are applicable. With a **square edge shape** (Fig. 1A), the prepared surface lies perpendicular to the material surface.

A **single-bevel edge shape** (Fig. 1B) is

a type of bevel edge shape that has one prepared surface, while a **double-bevel edge shape** (Fig. 1C) has two prepared surfaces adjacent to opposite sides of the material. Figure 1D shows a **single-J edge shape**, a type of J-edge shape that has one prepared surface; Fig. 1E shows a **double-J edge shape**, a type of edge

shape that has two prepared surfaces adjacent to opposite sides of the material. A **flanged edge shape**, such as shown in Fig. 1F, is produced by forming the member, and a **round edge shape** (Fig. 1G) is one in which the surface is curved.

	(A) SQUARE EDGE SHAPE	APPLICABLE WELDS DOUBLE-BEVEL-GROOVE GROOVE DOUBLE-BEVEL-FLARE-GROOVE DOUBLE-J-GROOVE SINGLE-BEVEL-GROOVE SINGLE-FLARE-BEVEL-GROOVE SINGLE-J-GROOVE SQUARE-GROOVE EDGE FILLET BRAZE
	(B) SINGLE-BEVEL EDGE SHAPE	APPLICABLE WELDS SINGLE-BEVEL-GROOVE SINGLE-V-GROOVE BRAZE
	(C) DOUBLE-BEVEL EDGE SHAPE	APPLICABLE WELDS DOUBLE-BEVEL-GROOVE DOUBLE-V-GROOVE
	(D) SINGLE-J EDGE SHAPE	APPLICABLE WELDS SINGLE-J-GROOVE SINGLE-U-GROOVE
	(E) DOUBLE-J EDGE SHAPE	APPLICABLE WELDS DOUBLE-J-GROOVE DOUBLE-U-GROOVE
	(F) FLANGED EDGE SHAPE	APPLICABLE WELDS SINGLE-FLARE-BEVEL-GROOVE SINGLE-FLARE-V-GROOVE EDGE FILLET PROJECTION SEAM SPOT BRAZE
	(G) ROUND EDGE SHAPE	APPLICABLE WELDS DOUBLE-FLARE-BEVEL GROOVE DOUBLE-FLARE-V-GROOVE BRAZE

Fig. 1 — Edge shapes.

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

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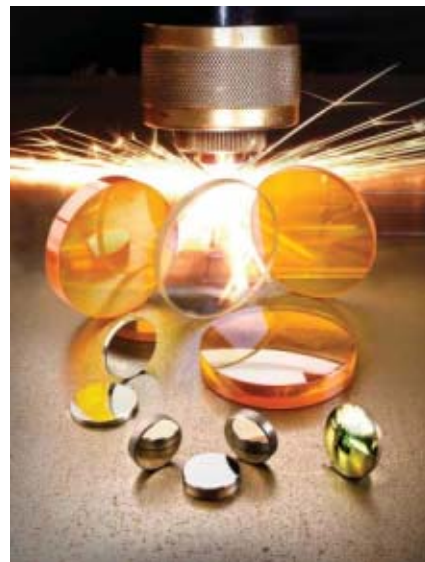
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NEW LITERATURE

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overviews, instructors' names and qualifications, student prerequisites, registration fees, and training location details. The courses presented in the 16-page, full-color brochure are laser safety officer (LSO), LSO with hazard analysis, advanced LSO, medical LSO, and advanced medical LSO. The online courses described are LSO, industrial laser safety, medical LSO, and laser safety for physicians. Also described are courses available for presentation at the customer's facility, and laser safety audit services.

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NEWS OF THE INDUSTRY

— continued from page 11

- Craig P. Eddy, past chairman of **The Aluminum Association**, represented the organization's board of directors at the 2008 China Aluminum Forum.
- **Western Enterprises**, Westlake, Ohio, partnered with Lorain County Community College as the supplier of shielding gas regulators, flashback arrestors, and hose quick disconnects for the new National Center for Welding Education and Training.
- The acquisition of Gordon Woods Industrial Welding Supply, Inc., Accu Air Gases & Equipment, LP, Summit Gas & Gear, LP, and Great Lakes Oxygen has been completed by **Airgas, Inc.**, Radnor, Pa.
- A new Web site unveiled by **Weldcraft**, Appleton, Wis., at www.weldcraft.com displays convenient product selection information as well as valuable educational resources.
- At the recent **Rend Lake College**, Ina, Ill., board of trustees meeting, a \$35,389.48 bid from ILMO Products Co., Mt. Vernon, Ill., was accepted for 14 welding machines and accessories.
- The Texas Workforce Commission chose **Lauren Engineers Constructors**, Abilene, Tex., as the 2008 Current Workforce Award recipient.
- **Smith Equipment**, Watertown, S.Dak., received an Overall Performance Achievement Award from Goodrich Corp.'s Sensors and Integrated Systems business.
- **FARO**, Lake Mary, Fla., a provider of portable 3-D measurement and imaging technology, won the Defense Manufacturing Excellence Award from the National Center for Advanced Technologies.
- The welding program offered at **Northeast Community College**, Norfolk, Neb., will also be given by the school in South Sioux City. The 36-credit-hour program will begin this fall.
- **Rockford Toolcraft Inc.**, Rockford, Ill., has been recognized by Daimler Trucks North America, Portland, Ore., as a Masters of Quality Supplier.
- A FocalSpot FSX-075, high definition X-ray system has been added to the Selective Soldering Process Development Lab at **ACE Production Technologies, Inc.**, Spokane Valley, Wash.
- **Hypertherm**, Hanover, N.H., has acquired the core assets of MTC Software, Lockport, N.Y., a developer of computer-aided manufacturing software.
- Affiliated Distributors, Wayne, Pa., recently named **PFERD Advance**, Leominster, Mass., as its Supplier of the Year.
- **Hobart Institute of Welding Technology**, Troy, Ohio, launched a revised Web site at www.welding.org with features including drop-down menus, training information, and promotional materials ordering, its library collection, and job bank for its students.
- An OPTIMO 3-D laser cutting system has been delivered by **PRIMA North America, Inc.**, Chicopee, Mass., to Northern Manufacturing Co., Oak Harbor, Ohio.
- The hand-held line of Niton® XL3t Series XRF analyzers from **Thermo Fisher Scientific Inc.**, Billerica, Mass., has been recognized with a GOOD DESIGN™ Award by the Chicago Athenaeum Museum.

COMING EVENTS

— continued from page 47

Motorsports Welding School Advanced Materials Courses. Cleveland, Ohio. April 27–May 1, June 15–19, Sept. 14–18, Oct. 12–16, Dec. 7–11. Contact The Lincoln Electric Co., www.lincolnelectric.com.

Motorsports Welding School Basic Materials Courses. Cleveland, Ohio. March 9–13, April 20–24, May 11–15, June 8–12, July 27–31, Sept. 8–11, Sept. 21–25, Oct. 5–9, Nov. 9–13, Nov. 30–Dec. 4. Contact The Lincoln Electric Co., www.lincolnelectric.com.

NACE Int'l Training and Certification Courses. Contact National Assoc. of Corrosion Engineers, (281) 228-6223, www.nace.org.

NDE and CWI/CWE Courses and Exams. Allentown, Pa., and at customers' locations. Contact Welder Training and Testing Institute, (800) 223-9884, www.wtti.edu.

Pipe Welding. Cleveland, Ohio. Three-week-long courses beginning March 30, May 11, June 22, Aug. 3, Sept. 14, and Oct. 26. Contact The Lincoln Electric Co., www.lincolnelectric.com.

Plastics Welding School. A two-day, hands-on course for certification to European DVS-approved plastics welding standards for hot gas and extrusion techniques. Contact Malcom Hot Air Systems, www.plasticweldingtools.com.

Shielded Metal Arc Welding of 2-in. Pipe in the 6G Position — Uphill. Troy, Ohio. Contact Hobart Institute of Welding Technology, (800) 332-9448, www.welding.org.

Structural Welding: Design and Specification Seminars and AWS D1.1, Structural Welding Code — Steel. Contact Steel Structures Technology Center, www.steelstructures.com, (248) 893-0132.

Tool and Die Welding Courses. Troy, Ohio. Contact Hobart Institute of Welding Technology, (800) 332-9448, www.welding.org.

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Welding Gun Inclination Detection and Curved Fillet Weld Joint Tracking

An investigation was conducted to detect the welding gun deviation and inclination simultaneously based on the welding current for the control of a mobile robot to track curved fillet welds

BY Y. F. GAO, H. ZHANG, AND Z. W. MAO

ABSTRACT

It is important to adjust the welding gun's inclination during automatic curved-joint tracking of arc welding. In this paper, a novel method is proposed to detect the deviation and inclination of the welding gun based on the arc currents acquired by a high-speed rotational arc sensor. It uses a least-squares method to fit the arc currents to a plane in three dimensions. The deviation and inclination of the welding gun are projected to two orthogonal planes so that they can be decoupled and thus can be calculated separately. A mobile welding robotic system was developed, which consists of a differential driving vehicle and a cross-slider manipulator. A fuzzy controller was designed to control the robot wheels and the horizontal slider in the curved fillet weld tracking. Experiment results show that the detection errors of welding gun inclination and deviation are approximately ± 7.85 deg and ± 0.42 mm, respectively.

Introduction

Real-time joint tracking is very important in robotic arc welding. Devices such as arc and vision sensors have been employed to detect the precise position of the joint (Refs. 1–4). In rotational arc sensing, the welding electrode rotates as it moves along a V-joint or a fillet weld. Because the variations of the contact tip-to-workpiece

distance (CTWD) cause variations in the arc currents, these arc current variations can be used to detect the welding gun deviation. Due to its compact structure, resistance to arc light disturbance, and real-time capabilities, rotational arc sensing is widely employed in automatic joint tracking (Refs. 5, 6). In the manufacturing of large ships and oil containers, there are many curved and broken-lined joints that need to be welded. Since these workpieces are usually not welded in a workshop, the welding paths are not easily preprogrammed. When these joints are tracked automatically in robotic welding, the inclination errors of the welding gun are probably very great. Therefore, it is essential to adjust the inclination of the welding gun dynamically in order to achieve high-quality welding.

Kim and Na (Ref. 7) established a mathematical model for gas metal arc welding with rotational arc sensors, and Yoo and Na (Ref. 8) improved the model for joint tracking and endpoint detection. Shi and Yoo (Ref. 9) proposed a signal pattern for joint tracking and endpoint detection after E. Halmoy (Ref. 10) simulated the joint tracking signals from a high-speed, rotating electrode in gas metal arc welding of carbon steels. Their experiments were very close to the results of other researchers.

In this research, a novel method was

developed that fits the arc currents to a plane in three dimensions using a least-squares fitting method. The deviation of the welding gun was obtained through calculating the intersection line slope of the fitting plane with the Y-Z plane, and the inclination was calculated through the intersection line slope of the fitting plane with the X-Z plane.

A wheeled mobile robot consisting of a differential driving vehicle and a cross-slider manipulator was developed. A rotational arc sensor was used for measuring the deviation and inclination of the welding gun. A fuzzy controller was designed to control the robot path and to extend the horizontal slider based on the measurements.

Dynamic Model of the Rotational Arc Sensor

Figure 1 shows the equivalent circuit of a gas metal arc welding (GMAW) system. The output voltage of the welding power source can be calculated by

$$U(t) = U_e(t) + U_a(t) \quad (1)$$

where U_e and U_a are the voltages of the wire extension and the welding arc, respectively. The arc voltage can be expressed as

$$U_a(t) = k_a H_a(t) + k_p I(t) + U_c \quad (2)$$

where k_a is the potential gradient across the arc column, k_p is the equivalent resistance of the cathode and anode spots, and U_c is a constant in the welding model.

The voltage of the wire extension $U_e(t)$ can be written as

$$U_e(t) = k_e H_e(t) I(t) \quad (3)$$

where k_e is the electrical resistance per unit length of the wire extension, and

KEYWORDS

Fuzzy Control
Gas Metal Arc Welding
Mobile Robot
Rotational Arc Sensor
Weld Joint Tracking
Curved Fillet Weld

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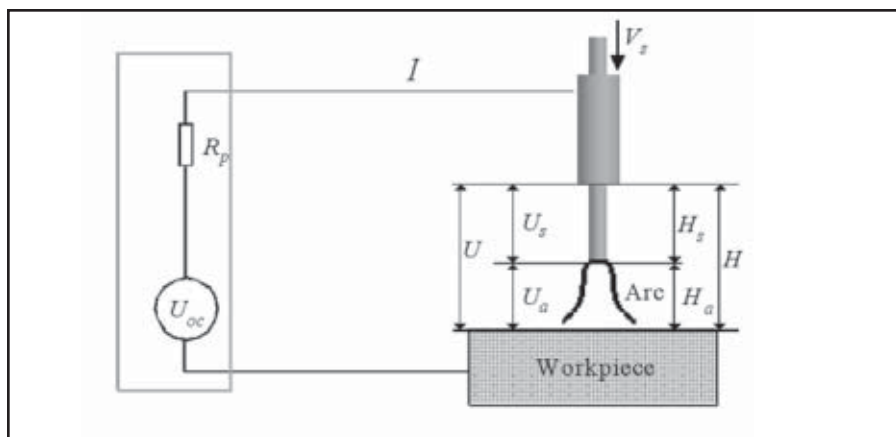


Fig. 1 — Equivalent circuit of gas metal arc welding (GMAW) system.

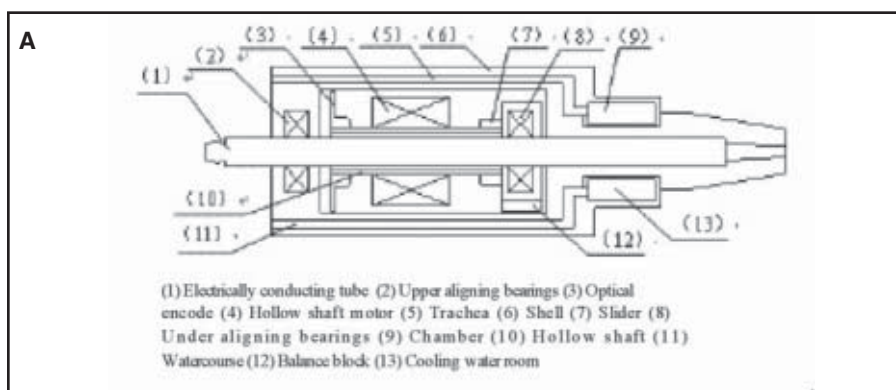


Fig. 2 — The construction of rotational arc sensor. A — Cutaway view of rotational sensor; B — the encoder of the rotational sensor.

$H_e(t)$ is the length of the wire extension.

For GMAW, a melting model was developed by Lesnewich (Ref. 11) in which the wire-melting rate is

$$V_m(t) = k_m I(t) + k_{\eta} H_e(t) P(t) + C_m \quad (4)$$

where k_{η} can be regarded as the influence of resistance heating on the melting rate, k_m is the influence of arc heating on the melting rate, and C_m is a constant. If we assume that the working range of the arc

sensor is within a small area around the quiescent point, the small-signal theory is justifiable for analysis, and $H_e(t)I(t)$ and $H_e(t)P(t)$ can be linearized according to a first-order Taylor series. Based on the assumption, Equations 3 and 4 can be linearized as

$$U_e(t) = k_l I(t) + k_i H_e(t) + C_1 \quad (5)$$

$$V_m(t) = k_c I(t) + k_r H_e(t) + C_2 \quad (6)$$

Assuming $I(t)$ in the quiescent point is I_0 and $H_e(t)$ is H_{e0} , we have $k_l = k_e H_{e0}$, $k_i = k_e I_0$, $k_c = k_m + 2k_{\eta} H_{e0}$, and $k_r = k_{\eta} I_0$. C_1 and C_2 are constants.

The relationship of wire feed rate and the wire-melting rate is

$$\frac{dH(t)}{dt} + V_m(t) - V_f(t) = \frac{dH_a(t)}{dt} \quad (7)$$

where $V_f(t)$ is the wire feed rate.

From Equations 1, 2, 5, and 6, we can get

$$\frac{dU(t)}{dt} = \frac{dU_e(t)}{dt} + \frac{dU_a(t)}{dt} \quad (8)$$

$$\frac{dU_a(t)}{dt} = k_a \frac{dH_a(t)}{dt} + k_p \frac{dI(t)}{dt} \quad (9)$$

$$\frac{dU_e(t)}{dt} = k_l \frac{dI(t)}{dt} + k_i \frac{dH_e(t)}{dt} \quad (10)$$

$$\frac{dV_m(t)}{dt} = k_m \frac{dI(t)}{dt} + k_r \frac{dH_e(t)}{dt} \quad (11)$$

Using Laplace transform for Equations 7–11, we have

$$U(s) = U_s(s) + U_a(s) \quad (12)$$

$$U_a(s) = k_a H_a(s) + k_p I(s) \quad (13)$$

$$U_e(s) = k_l I(s) + k_i H_e(s) \quad (14)$$

$$V_m(s) = k_c I(s) + k_r H_e(s) \quad (15)$$

$$sH(s) + V_m(s) - V_s(s) = sH_a(s) \quad (16)$$

$P(s)$ denotes the dynamic model of the welding power source and is written as

$$P(s) = \frac{I(s)}{U(s)} \quad (17)$$

Based on Equations 12–17, Pan (Ref. 12) developed the transfer function from $H(s)$ to $I(s)$ as

$$G(s) = \frac{I(s)}{H(s)} = \frac{k_a(s + k_r)P(s)}{(1 - k_N P(s))s + k_q P(s) + k_r} \quad (18)$$

where $k_N = k_p k_l$, $k_q = k_i k_c - k_r k_N - k_a k_N k_m$. When the welding power source has the hard output characteristic, its transform function can be written as

$$P(s) = P_0 \quad (19)$$

So the transfer function of the arc sensor becomes a first-order model and can be written as

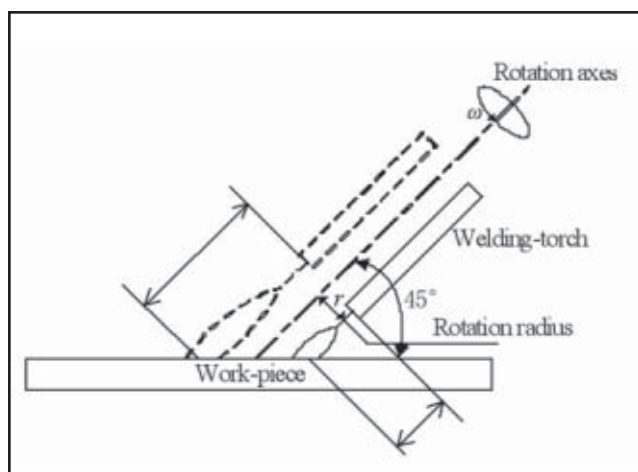


Fig. 3 — Dynamic character identification experiments.

$$G(s) = k \frac{1 + T_1 s}{1 + T_2 s} \quad (20)$$

$$\text{where } k = \frac{k_a k_r P_0}{k_q P_0 + k_r}, T_1 = \frac{1}{k_r}, T_2 = \frac{1 - k_N P_0}{k_q P_0 + k_r}$$

Rotational Arc Sensor Structure and Identification of the Arc Sensor System

The construction of the rotational arc sensor is shown in Fig. 2. A hollow shaft motor is used as the main body of the rotational welding gun, and the electrically conducting tube is inserted with a tilt through the hollow shaft. The upper self-aligning bearing is used as a hinge for the electrically conducting tube, which is fixed on the upper end of the shell. The balance block is installed in the lower part of the electrically conducting tube. The eccentricity of the bottom of the electrically conducting tube can be adjusted by changing the position of the balance block. Thus, the welding electrode rotates on the line that generates a cone when the armature of the motor rotates. An optical encoder is mounted to the end of the motor. On the optical encoder circumference, there are 64 shallow slots and one deep slot. Two photocouplers that are fixed in the upper part of the arc sensor shell correspond to shallow slots and deep slot, respectively. The signal from the deep slot is used to detect the start point of each rotation cycle, and the signal from the shallow slot is used as a trig source for the out-trigger of DAQ, so there are 64 discrete sampled current values in one rotation cycle. The welding current is measured by a Hall-effect current sensor and acquired by a plug-in DAQ board.

From the above descriptions, we know

that the dynamic model for the rotational arc sensors can be regarded as a first-order model, but we do not know the actual numerical value of the parameters, which is important for calculating the deviation and inclination of the welding gun. So it is necessary to identify the arc sensor system. Because the ratio of the output and input amplitudes and the phase difference between them change with the change of the input-signal frequency when a sinusoidal exciting signal is fed into a system, the rule by which these parameters change represents the dynamic properties of the system. To get the dynamic characteristic of the rotational arc sensor system, an experiment was designed as shown in Fig. 3. The welding gun was installed with its axis inclined 45 deg to the horizontal steel plate. Then the welding gun height varies according to a sinusoidal waveform while the gun rotates.

Suppose that the arc rotation frequency is ω , the rotation radius is r , then the contact tip-to-workpiece distance H can be computed as

$$H = r \sin(\omega t + \beta_0) + H_0 \quad (21)$$

where β_0 is the welding gun angle position when $t = 0$, and H_0 is the average height of the welding gun. The parameters for welding experiments are shown in Table 1. The experimental results are shown in Table 2, which indicates the change of the welding gun height.

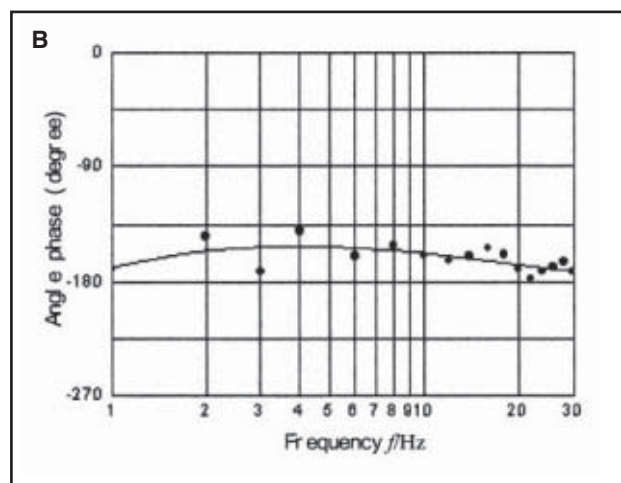
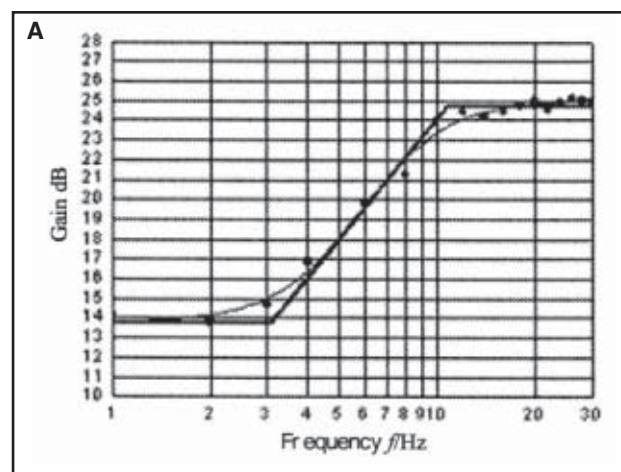


Fig. 4 — The Bode diagram of rotational arc sensor system. A — The amplitude frequency characteristics; B — the phase frequency characteristics.

Based on the experimental results from Table 2, the Bode diagram of the sensor system is plotted as Fig. 4.

From Fig. 4A, it can be seen that the zero frequency is $f_1 = 3.2$ Hz, the pole frequency is $f_2 = 11.35$ Hz, and the gain is $k = -\text{ant} \log(13.8/24.8) = -3.60$, where the gain is negative since the angular phase differences are about 180 deg from Fig. 4B. So the first-order transfer function of the sensor system is

$$G(s) = -3.60 \frac{1 + 0.0497s}{1 + 0.014s} \quad (22)$$

Filtering of Welding Current Signals

Because the welding current signals are often disturbed by outside noises, a hybrid filtering method is proposed in this paper. The flow chart of this filtering method is shown as Fig. 5. First, the welding current is filtered by the mean filtering method.

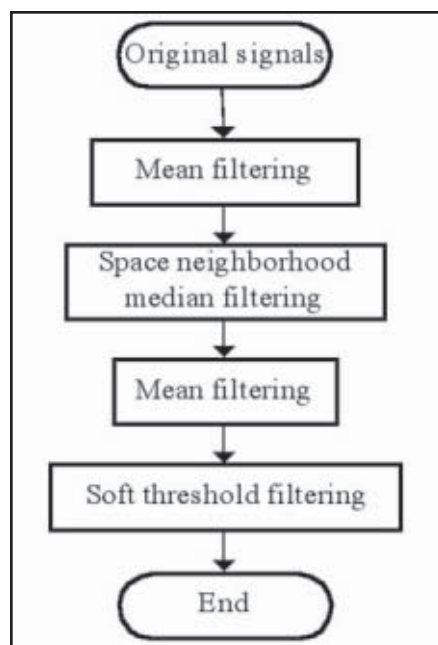


Fig. 5 — Filtering flow chart of rotational arc signals.

Then it is filtered by the space neighborhood median filtering method and the mean filtering method in turn. Finally, the last signal is obtained by use of the soft threshold wavelet filtering method. The wavelet used in this paper is four order Daubechies wavelet. The principle of the space neighborhood median filtering method is shown as Fig. 6.

Every row of data in Fig. 6 is the data sampled in one revolution of the arc (64 points per revolution). In each column, the data were sampled during different rotations of the arc, but they are at the same position of the arc in relation to the groove. Region B is the neighborhood in space, and region C is the neighborhood in time. The effect of filtering depends on the number of data in the neighborhood. If it takes more points to filter in the direction of the row, it would result in a large phase delay. Because the welding gun is moving in the course of welding, the contact tip-to-workpiece distance is not the same at the same angular position in different cycles. It would cause a large error if it takes more points to filter in the direction of the column. So nine points were taken as a neighborhood window, and the value of the window's center was calculated as

$$a'(i,j) = \text{Median}(a(i,j)) \quad (23)$$

A

where A is the neighborhood window, and Median denotes the median filtering method.

To validate the hybrid filtering method, a series of experiments were done. The parameters for the welding experiments are also shown in Table 1, and the arc rota-

Table 1 — Welding Conditions for Experiments

Items	Parameters
Welding machine	Miller DeltaWeld 450
Shielding gas	85%Ar + 15%CO ₂
Welding wire	Real core wire, 1.2-mm diameter
Welding speed	36 cm/min
Welding voltage	28 V
Rotational radius	3 mm
Welding wire feed rate	200 mm/s
Gas flow rate	15 L/min

Table 2 — Experimental Results of Dynamic Character Identification

$f(\text{Hz})$	$ I (\text{A})$	$ H (\text{mm})$	$ I/H $	I (deg)
1	30.7843	6	5.1307	-170.535
2	29.4755	6	4.9126	-144.901
3	32.5259	6	5.4210	-172.053
4	42.0366	6	7.0061	-140.065
6	58.4183	6	9.7364	-159.706
8	69.3201	6	11.5534	-151.628
10	95.6106	6	15.9351	-158.927
12	99.9301	6	16.6550	-163.562
14	96.8024	6	16.1337	-159.667
16	99.9000	6	16.6500	-153.971
18	103.5972	6	17.2662	-158.755
20	106.9184	6	17.8197	-169.573
22	101.5930	6	16.9322	-177.502
24	106.0734	6	17.6789	-172.071
26	108.3966	6	18.0661	-168.639
28	106.5992	6	17.7665	-163.843
30	106.5470	6	17.7578	-172.180

tional frequency was 20 Hz. Because the welding gun inclines 45 deg to the workpiece, the contact-to-workpiece distance changed as a sinusoidal waveform. Based on the dynamic model of the rotational arc sensor, the welding current signals would also change as a sinusoidal waveform. The experimental results are shown in Fig. 7.

From Fig. 7, we can see that the original signal has many short-circuiting currents that appear as sharp pikes, which are regarded as interference. After being filtered by the proposed method, the short-circuiting current was suppressed completely. The waveform of the signal is approximately sinusoidal.

Mathematical Model of Welding Gun Height when Tracking a V-Groove

As shown in Fig. 8, the angle θ between the axis of the welding gun and the normal of the workpiece is known as the inclination angle. Along the direction of welding, the inclination is a backward incline when the top is behind the end of welding gun (as the θ shown in Fig. 8), otherwise, it is a forward incline. The error between welding gun and the symmetrical line of weld

groove is known as deviation and recorded as e . Suppose the angle between weld groove and horizontal plane is β , the arc rotation radius is r , the rotation period is $2T$, the rotation angle speed is ω , $\phi = \arcsin(e/r)$, and the arc is in the left of the groove when $t = 0$. Then in one rotational cycle, the welding gun height can be computed as Equation 24.

$$H(t) = \begin{cases} H - r \cdot \sin \omega t \cdot \sin \theta - \left(\cos \omega t - \sin \phi \right) r \\ \cdot \tan \beta & 0 \leq t < \frac{T}{2} - \frac{\pi/2 - \phi}{\omega} \\ H - r \cdot \sin \omega t \cdot \sin \theta + \left(\cos \omega t - \sin \phi \right) r \\ \cdot \tan \beta & \frac{T}{2} - \frac{\pi/2 - \phi}{\omega} \leq t < \frac{3T}{2} + \frac{\phi}{\omega} \\ H - r \cdot \sin \omega t \cdot \sin \theta - \left(\cos \omega t - \sin \phi \right) r \\ \cdot \tan \beta & \frac{3T}{2} + \frac{\phi}{\omega} \leq t \leq 2T \end{cases} \quad (24)$$

Suppose $\beta = 45$ deg, $r = 3$ mm, and $H = 25$ mm, $H(t)$ can be shown as in Fig. 9.

Based on Equation 24, we can get the heights of the welding gun from welding currents acquired from the rotational arc sensor. From Fig. 9, it can be seen that the heights both in interval $[0, 32]$ and $[0, 64]$ are symmetrical when $e = 0$ and $\theta = 0$.

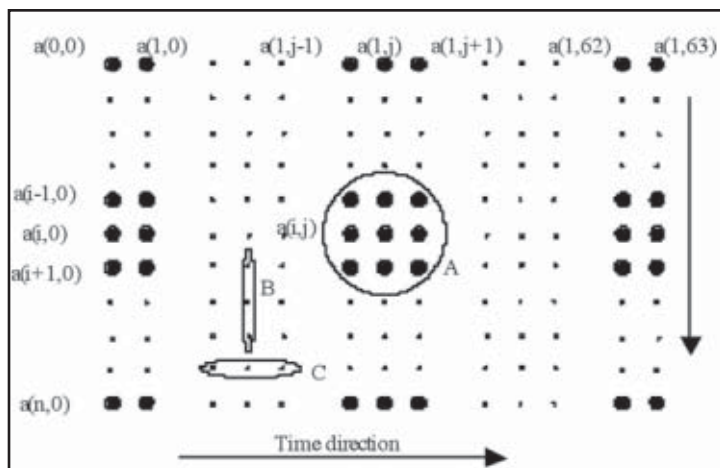


Fig. 6 — The principle of the space neighborhood median filtering method.

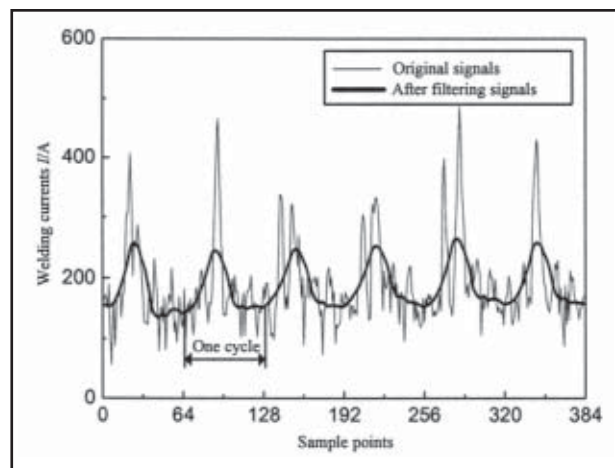


Fig. 7 — Welding current signals acquired by rotational arc sensor.

While the heights in interval $[0, 32]$ are not symmetrical when $e = -1.5$ and $\theta = 0$, but the heights in $[0, 64]$ are symmetrical. So the symmetry of heights in interval $[0, 32]$ reflects the deviation of the welding gun and the symmetry of heights in interval $[0, 64]$ reflects the inclination. This method is called the interval integral method.

Although the interval integral method is simple and easy, the symmetry of heights is destroyed when both $e \neq 0$ and $\theta \neq 0$ due to the coupling of welding gun deviations and inclinations (such as Fig. 9D), so it cannot detect the deviation and inclination simultaneously.

Welding Gun Deviations and Inclinations Detection Method

The Construct of Character Plane

Taking the welding of a V-groove as an example, a Cartesian frame as shown in Fig. 10 is constructed. The frame $[X Y Z O]$ is linked to the welding gun, and the coordinate origin is the center of the arc rotation, the Z axis is parallel with the axis of the welding gun, and the X axis is parallel with the direction of welding.

Because the welding velocity is far less than the arc rotation velocity, the height of welding gun $H(t)$ can be computed as Equation 24 in one rotation cycle, and $X(t)$ and $Y(t)$ can be written as

$$\begin{cases} x(t) = r \cos(\omega t + \pi/2) \\ y(t) = r \sin(\omega t + \pi/2) \end{cases} \quad (25)$$

Based on Equations 24 and 25, the graph of heights in one rotation cycle is plotted in three dimensions in Fig. 11.

From Fig. 11, it can be seen that the heights of the welding gun show different three-dimensional characteristics in space with the change of deviations and inclinations. If we use the least-squares method

to fit the heights into a plane, the plane will reflect the deviation and inclination of the welding gun. For the sake of clarity, the graph of Fig. 11B and Fig. 11C is projected into the X-Z and the Y-Z surfaces, and shown as Fig. 12.

The lines aa and $a'a'$ in Fig. 12 are the intersection lines of the fitting plane with the X-Z plane, and the lines bb and $b'b'$ are the intersection lines of the fitting plane with the Y-Z plane. It can be seen that the slopes of lines aa and $a'a'$ are only related to the deviations, and the slopes of lines bb and $b'b'$ are only related to the inclinations. By

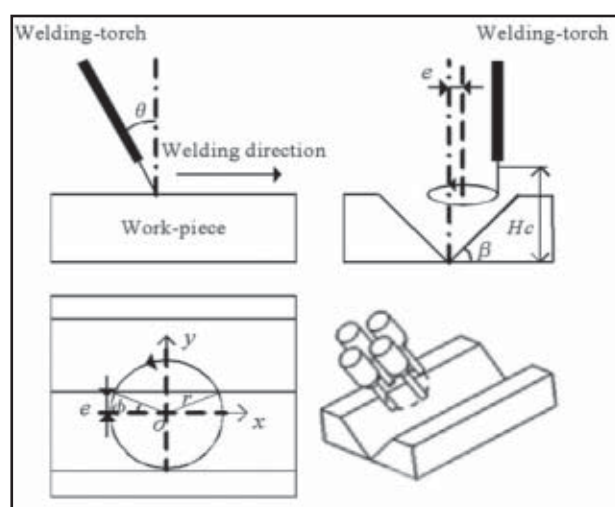


Fig. 8 — Welding gun space attitude sketch.

Table 3 — Experimental Results of Welding Gun Inclination Detection

Actual values (deg)	Detection values (radian)	Variances (radian)
-45	-0.9079	0.1027
-34	-0.6215	0.1219
-22	-0.4416	0.1217
-11	-0.3136	0.1637
0	0.0136	0.1860
11	0.0930	0.1243
22	0.3601	0.1085
34	0.4701	0.1122
45	0.6046	0.1105

Table 4 — Experimental Results of Welding Gun Deviation Detection

Actual values (mm)	Detection values	Variances
3 mm	0.7733	0.0843
0 mm	0.0515	0.1670
-3 mm	-0.7812	0.0723

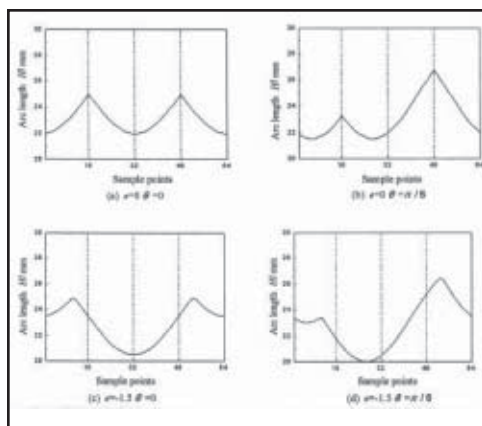


Fig. 9 — Welding gun heights in different deviations and inclinations.

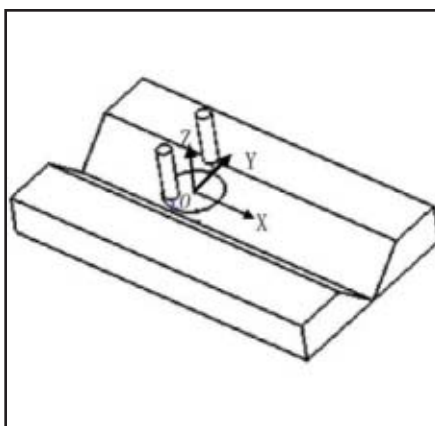


Fig. 10 — Coordinate frame of character plane.

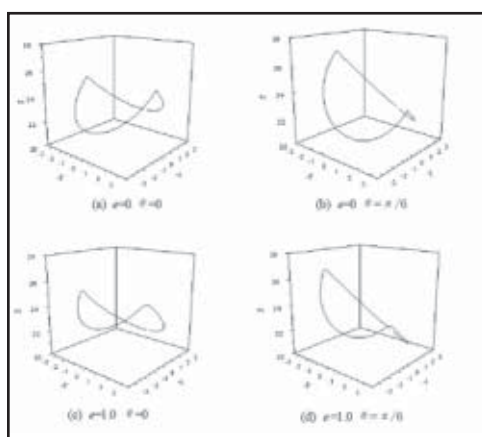


Fig. 11 — The welding gun heights in three dimensional space.

projecting the deviations and inclinations to two orthogonal planes, they can be decoupled and calculated.

The Mathematical Method for Solving Fitting Plane

Suppose H_i , x_i , and y_i are the discrete points of $H(t)$, $x(t)$, and $y(t)$, respectively. Based on the analytic geometry theory, a space plane equation can be shown as

$$Z = Ax + By + C \quad (26)$$

In order to facilitate discussion, Equation 26 is changed to

$$Z = \beta_0 + \beta_1 x_1 + \beta_2 x_2 \quad (27)$$

Vector and matrix marks are introduced

$$\beta = (\beta_0 \ \beta_1 \ \beta_2)^T$$

$$X = \begin{bmatrix} 1 & x_{11} & x_{12} \\ 1 & x_{21} & x_{22} \\ \vdots & \vdots & \vdots \\ 1 & x_{n1} & x_{n2} \end{bmatrix}$$

(28)

For fitting the welding gun heights into one plane, β must meet the following conditions.

$$\begin{aligned} & \sum_{i=1}^n \left(H_i - \sum_{j=0}^2 x_{ij} \beta_j \right)^2 \\ &= \min \sum_{i=1}^n \left(H_i - \sum_{j=0}^2 x_{ij} \beta_j \right)^2 \end{aligned} \quad (29)$$

Using the differential method to solve Equation 29, we have

$$\sum_{i=1}^n \left(H_i - \sum_{j=0}^2 x_{ij} \beta_j \right) x_{ik} = 0 \quad (k=0,1,2) \quad (30)$$

Changing Equation 30 to

$$\begin{aligned} \sum_{i=1}^n H_i x_{ik} &= \sum_{i=1}^n \sum_{j=0}^2 x_{ij} x_{ik} \beta_j \\ &= \sum_{j=0}^2 \left(\sum_{i=1}^n x_{ij} x_{ik} \right) \beta_j \end{aligned} \quad (31)$$

Expressed by matrix, the above equation can be written as

$$X^T H = (X^T X) \beta \quad (32)$$

By analyzing, we know that the matrix $X^T X$ is a positive matrix, therefore it has an inverse matrix $(X^T X)^{-1}$. So β can be computed as

$$\beta = (X^T X)^{-1} X^T H \quad (33)$$

Experimental Study

To verify the performance of the proposed method in detection deviation and inclination of the welding gun, numerous experiments were performed. In the experiments the inclination of the gun was set at -45° , -34° , -22° , -11° , 0° , 11° , 22° , 34° , and 45° , respectively. The negatives denote backward inclination, and the positives denote forward inclination. The deviations of the gun were set at -3 mm, 0 mm, and 3 mm, respectively. The experimental results are shown in Tables 3 and 4.

For achieving welding gun inclination detection, the data of Table 3 were fit into a second-order polynomial, and plotted, as shown in Fig. 13.

From Fig. 13, it is seen that the detection values correspond to the actual values, and their relationship is shown as

$$y = 2.7576 + 61.0594x + 9.2245x^2 \quad (34)$$

where y is the actual value of inclination, and x is the detection value.

Similarly, the relationship of deviations can be fitted into a one-order polynomial and is shown as

$$y = -0.0560 + 3.8532x \quad (35)$$

From Equations 34, 35, and Tables 3 and 4, we can get the average variance of inclination and deviation as $\pm 7.85^\circ$ and ± 0.42 mm, respectively.

To further verify the proposed algorithm, an experimental method was designed, as shown in Fig. 14. Keeping the welding speed unchanged, the deviation of the gun changes from ($e > 0$) to ($e = 0$) and ($e < 0$). Because the shape of the welded fillet joint is in an arc, the inclination of the gun changes from forward incline to backward incline. Thus, the detection results representing the deviation and inclination will be a time-variable function. The detection results are shown in Fig. 15.

From Fig. 15, we can see that the detection results of deviation and inclination are in accord with the actual ones, which verifies that the proposed method can correctly detect the deviation and inclination of the welding gun simultaneously.

Curved Fillet Joint Tracking by Mobile Robot

Design of Mobile Welding Robot

Figure 16 shows the mobile welding robot. The robotic welding system consists of a main controller, a robot body, driving actuator parts, and a rotational arc sensor. An industrial computer is used as the main controller. The welding current is measured by a Hall-effect current sensor and is acquired by a plug-in DAQ board (Ad-

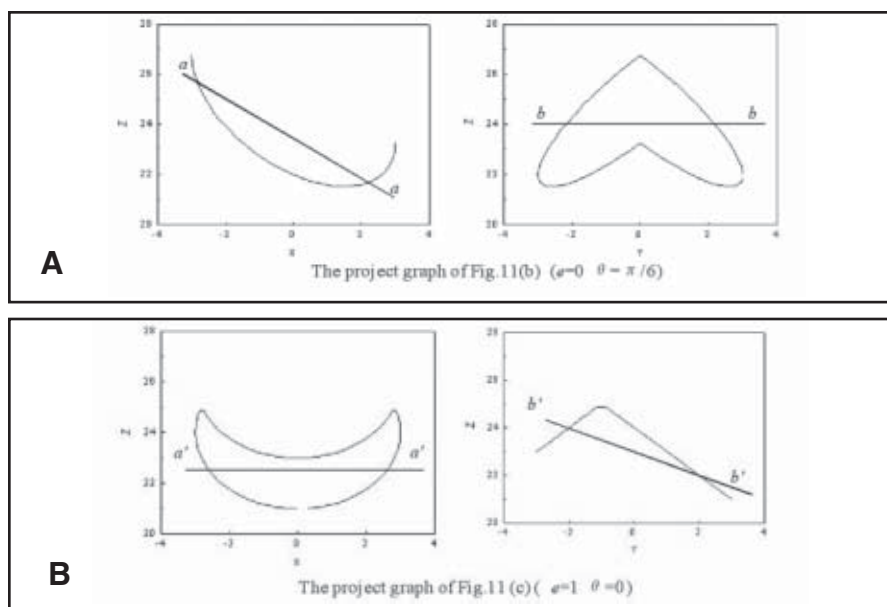


Fig. 12 — The project graph of welding gun heights.



Fig. 14 — The experiment of curved fillet welding.

ventech PCI-1713). The control value is sent to driving actuator parts by a plug-in data output card (Adventech PCI-1723). The robot body consists of a differential driving vehicle and a cross-slider manipulator. The right and left wheels are driving wheels and the front and back wheels are omnidirectional. The mass center of the mobile robot is in the middle of the axis of the driving wheels, and the cross-slider is over the axis of the driving wheels and can move horizontally and vertically. In order to avoid skidding, four magnets are attached in four corners under the body. The driving part is composed of four Maxon RE35 DC servo motors, and they drive two wheels and the cross-slider, respectively. The rotational arc sensor is attached to the cross-slider to detect the deviation and inclination, and it is used as a welding gun as well.

The Design of the Controller for Tracking Curved Fillet Welds

For the curved fillet joint tracking, as shown in Fig. 17, v_c and ω_c are the robot's current center linear velocity and angular velocity, respectively. Suppose v_t is the lin-

ear velocity of the welding gun's front-end point, and v_r is the reference linear velocity. We then know that the angular error is α . The inclination of the welding gun detected by the rotational arc sensor is θ , and apparently θ is equal to α . So the control process is described as follows: when tracking the curved fillet joints, the deviations are used to control horizontal slider extension, and the inclination is used to control the wheels moving and turning along the joints.

The fuzzy controller used to control the welding gun was described in Hu (Ref. 13), Wang (Ref. 14), and Liang (Ref. 15). In this project, a fuzzy controller was developed to deal with the disturbance of the welding processing and the dynamic uncertainties of mobile robots. The control scheme is shown in Fig. 18.

It is composed of two fuzzy controllers. One is a multisegment controller that is used to control horizontal slider extension, for eliminating the deviations, and the other is a traditional fuzzy controller that is used to control the moving and turning wheels, for the elimination of inclinations. The control cycle of the two controllers is equal.

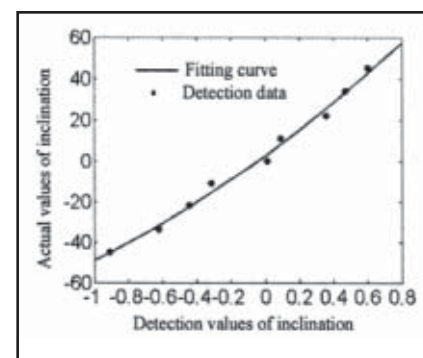


Fig. 13 — The relationship between real values and measured values of welding gun inclination.

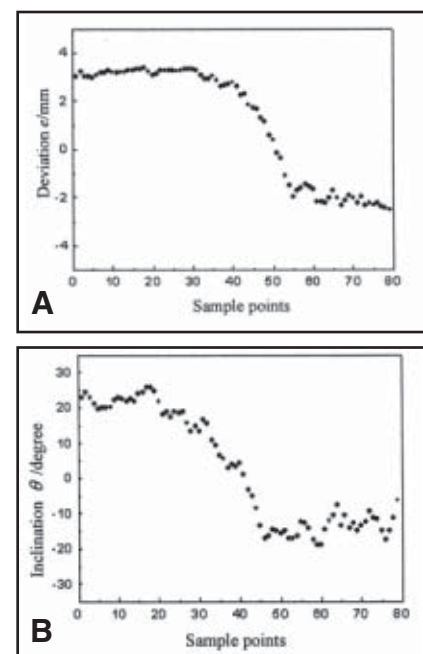


Fig. 15 — The measured results of curved fillet welding. A — Detection results of deviations; B — detection results of inclinations.

The Design of Multisegment Controller

For controlling the horizontal slider, a multisegment controller was proposed and the key idea is shown in Fig. 19. The controller is composed of a proportion controller and a fuzzy controller. When the deviation is large, the proportion controller will be used to quickly reduce the deviation, otherwise the fuzzy controller will be used to avoid overshoot and achieve smooth tracking. In view of that, a fuzzy controller cannot eliminate static errors. An integral operation was introduced, and its principle is described as follows: the deviation change rate is used as a switch threshold, and when it is small, the deviations will be integrated and then are put into the fuzzy controller, otherwise the deviations will not be integrated.

The two inputs of the fuzzy controller are the welding gun deviations e and its

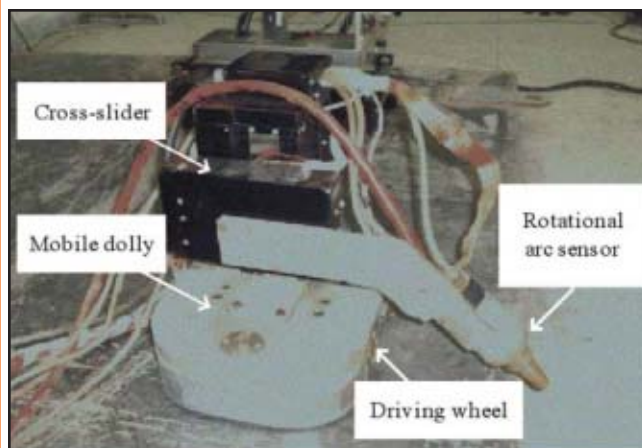


Fig. 16 — Structure of mobile welding robot.

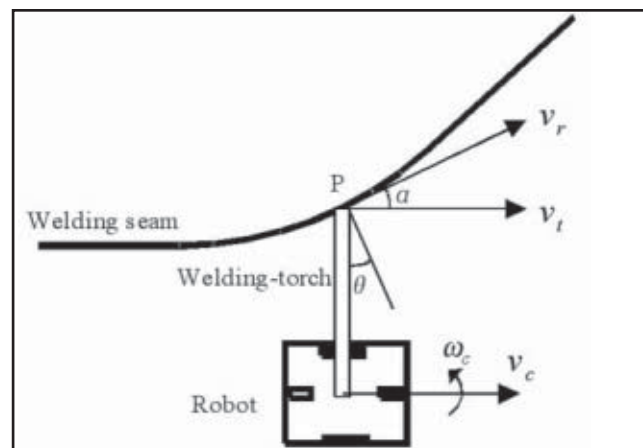


Fig. 17 — The sketch of curved fillet weld joint tracking.

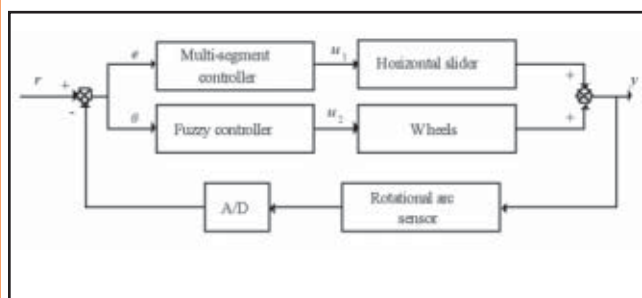


Fig. 18 — Controller frame of tracking curved fillet welds.

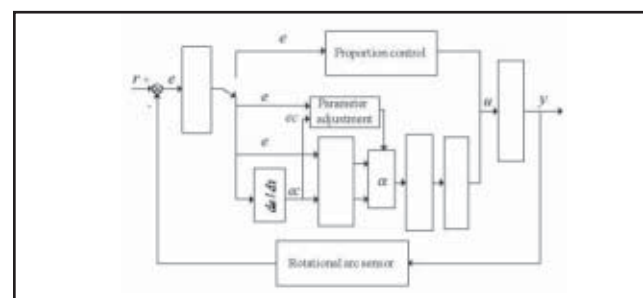


Fig. 19 — The principle frame of horizontal slider.

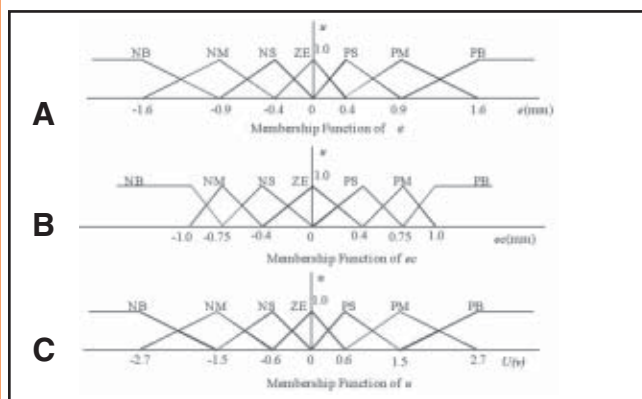


Fig. 20 — Membership function of fuzzy controller for horizontal slider.

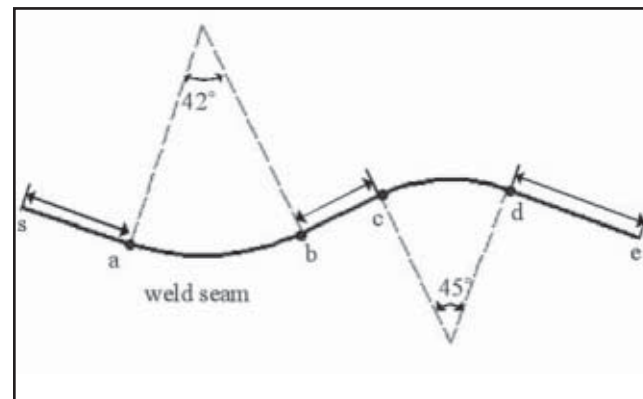


Fig. 21 — The tracked curved weld joint shape.

Table 5 — Measuring Results of Tracking Errors

Number	L1 (mm)	L2 (mm)	e (mm)
Section 1	6.3	6.5	0.141
Section 2	6.5	6.3	-0.141
Section 3	6.7	6.0	-0.495
Section 4	6.6	6.1	-0.354
Section 5	6.2	6.5	0.212

change rates ec , and the output is the control value u of the horizon slider. In order to keep the number of fuzzy rules at a reasonable level, we defined the fuzzy sets of inputs and outputs as the same as {PB

(Positive Big), PM(Positive Middle), PS (Positive Small), ZE (Zero), NS (Negative Small), NM (Negative Middle), NB (Negative Big)}. The membership functions of inputs and output are shown in Fig. 20.

For fuzzy control, the mathematical model of adjusting the modifying gene can be written as

$$\underline{u} = (\alpha e + (1 - \alpha) e_{\varepsilon}) \quad (36)$$

where e , e_{ε} , and $\underline{u}$ are the fuzzy values of e , e_{ε} , and $\underline{u}$, respectively, and α is the modify gene.

From Equation 36 we can see that α re-

flects the different weights of e and e_{ε} , so the parameters of the fuzzy controller can be changed by adjusting α . Usually e should be eliminated when it is big, so α should be augmented. On the contrast, α should be reduced. In view of the real-time application of welding joint tracking, a function is used to modify α and it is written as

$$\alpha = 2 \left(\frac{1}{1 + \exp(-|e|)} - 0.5 \right) \quad (37)$$

Curved Fillet Joint Tracking Experiments

The welding parameters used in experiments were Miller DeltaWeld 450 welding machine, 85% Ar+15%CO₂ shielding gas, 17 L/min gas flow rate, 24 cm/min welding speed, 25 V, 11 m/min wire feed speed, 6-mm diameter of arc rotation, 20-Hz frequency of arc rotation, 0.4-s sample time, and 20-mm average CTWD.

The shape of the weld joint is shown in Fig. 21, where s is the start point, e is the end point, and the robot is right of the joint.

Figure 22 shows the deviations y_e detected by the rotational arc sensor. From the figure, we can see that the deviations are $-2.50 \sim +2.50$ mm. Figure 23 shows the welding gun inclination θ_e and it reflects the orientation change of the mobile robot in tracking a curved joint. The actual tracking result is shown in Fig. 24. It is important to note that the deviations shown in Fig. 22 are detected by the rotational arc sensor, but not the actual tracking errors. For getting the actual tracking errors, the welded joint is cut into six sections of equal length. Figure 25 is a sectional view of the welding joint, in which L_1 is the length of the weld toe horizontally, L_2 is the length of the weld toe vertically, OC is the angle bisector of AOB , M is the midpoint of AB , MD is parallel to OC , and e is the tracking error, which is negative when MD is under OC , otherwise it is positive. The measurement of e is shown in Table 5. From Table 5 we can see that the maximal tracking error is -0.495 mm, so the joint tracking quality meets the production requirement.

Conclusion

A dynamic model of a rotational arc sensor was established, and the parameters of the model were identified by experiments. The transfer function from CTWD to the welding current shows that the sensing system is linear. By constructing the fitting plane in three dimensions, the deviation and inclination of the welding gun were projected to two orthogonal planes, so they are decoupled and can be calculated simultaneously. Compared with other approaches, the developed method can work in real time and shows a high degree of detection accuracy. For the curved welding joint tracking, a fuzzy controller was developed to control the wheels and horizontal slider of the welding robot based on the measurements of deviation and inclination. The experimental results demonstrated the feasibility and advantages of the fuzzy controller on the curved fillet joint tracking.

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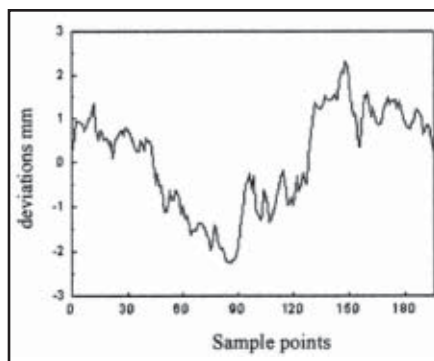


Fig. 22 — Welding gun deviations in tracking.

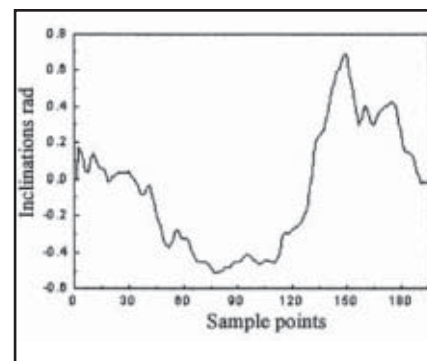


Fig. 23 — Welding gun inclinations in tracking



Fig. 24 — Result of tracking a curved weld joint.

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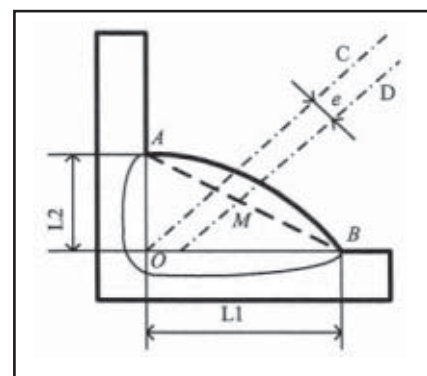


Fig. 25 — The sectional view of weld joint.

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Heat Transfer and Fluid Flow during Electron Beam Welding of 304L Stainless Steel Alloy

Models were used to calculate the three-dimensional temperature field and fluid velocities for electron beam welding of 304L stainless steel

BY R. RAI, T. A. PALMER, J. W. ELMER, AND T. DEBROY

ABSTRACT

A numerical model for three-dimensional heat transfer and fluid flow in keyhole mode electron beam welding was developed and applied to 304L stainless steel welds made at different power density distributions achieved by varying the focal spot radius at a fixed input power. The model first calculates keyhole geometry based on energy balance on keyhole walls and then solves the three-dimensional temperature field and fluid velocities in the workpiece. Since the energy balance and, consequently, the keyhole penetration are affected by the keyhole wall temperatures, the variation of the keyhole wall temperature with depth has been considered. A modified turbulence model based on Prandtl's mixing length hypothesis was used to calculate the spatially variable effective values of thermal conductivity and viscosity to account for enhanced heat and mass transfer due to turbulence in the weld pool. Unlike models available in literature, the model proposed in this work considers the physical processes like variations of keyhole wall temperatures with depth and the resulting influence on calculation of keyhole depth and fluid velocities along the keyhole wall, and three-dimensional heat and mass transport. Thus, the model can be applied to materials with a range of thermophysical properties. The model was used to study the fluid flow patterns in the weld pool and their effects on the calculated weld geometry. The calculated weld dimensions agreed reasonably well with the measured values. Peclet number calculation showed that convective heat transfer was very

significant. The influence of convection was illustrated by comparing the calculated weld pool geometries in the presence and absence of convection. The vapor pressures and wall temperatures in the keyhole increased with increase in the peak power density.

Introduction

High-energy-density electron beams are often used to join a wide range of materials with an equally wide range of thicknesses for applications where a high aspect ratio (depth/width) and narrow heat-affected zone are needed. Due to the very high intensity of electron beams, the workpiece material undergoes strong localized evaporation, resulting in the formation of a narrow and deep vapor cavity or "keyhole" (Refs. 1, 2). A pressure gradient forms along the keyhole depth because of the flow of metal vapor resulting in a variation in the equilibrium temperatures of the keyhole walls with weld depth. Temperatures at the top and the bottom of the keyhole can differ by several hundred degrees (Ref. 3), which results in the flow of liquid metal in the vertical direction under the influence of the surface-tension gradient along the keyhole walls.

While many numerical models for heat transfer and fluid flow have been developed for keyhole mode laser welding (Refs. 4–23), comprehensive heat transfer

and fluid flow models for electron beam welding are not available in the literature. Klemens (Ref. 7) performed pressure balance at the keyhole walls to calculate the keyhole radius. Mazumder and Steen (Ref. 8) proposed a 3-D heat conduction model for the calculation of temperature profiles in the workpiece. Kaplan (Ref. 12) and Zhao (Ref. 19) calculated the asymmetric keyhole profile at high welding speeds by considering energy balance at the keyhole walls. Sudnik et al. (Ref. 13) approximated the 3-D fluid flow in the weld pool by 2-D flows in horizontal and vertical planes. Ki et al. (Refs. 17, 18) calculated the transient evolution of the keyhole and the weld pool during laser welding using the level set method to track the liquid-vapor interface. Rai et al. (Refs. 20–23) calculated the asymmetric keyhole profile through energy balance at keyhole walls considering multiple reflections of the laser beam within the keyhole, and the 3-D heat transfer and fluid flow in the weld pool. Elmer et al. (Ref. 24) proposed three heat conduction models for electron beam welding based on distributed, point, or line heat sources, depending on the power densities and compared calculated and measured weld geometries. Wei and Giedt (Ref. 25) proposed a two-dimensional heat transfer and fluid flow model and computed the free surface temperature, liquid layer thickness, and tangential free surface fluid velocities assuming the surface tension gradient to be the main driving force for the fluid flow. Wei and Chow (Ref. 26) studied the effect of beam focusing and alloying elements on the shape of the electron beam keyhole. Assuming the vapor cavity to be a paraboloid of revolution, Wei and Shian (Ref. 27) calculated penetration depth and surface temperatures using an analytical three-dimensional heat conduction model.

Here we propose a three-dimensional phenomenological model for heat transfer and fluid flow in electron beam welding that considers keyhole formation and the variation of keyhole wall temperature as a function of depth. A very important parameter in the electron beam welding

KEYWORDS

Electron Beam Welding
Keyhole
Heat Transfer
Fluid Flow
Stainless Steel
Weld Process Simulation
Three-Dimensional
Phenomenological Model

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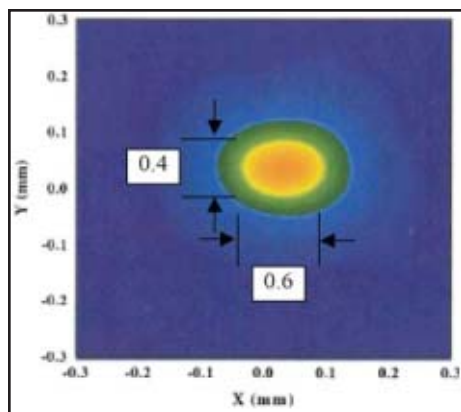


Fig. 1 — Beam shape for 0.17-mm beam radius produced at sharp focus settings for 1000-W power at a work distance of 229 mm.

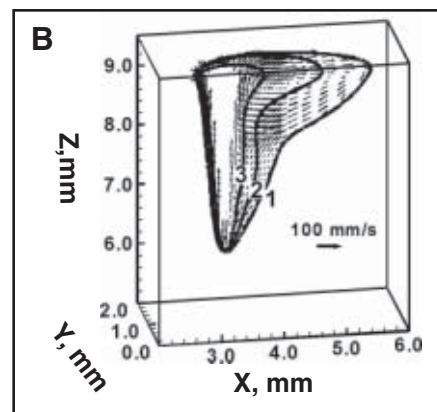
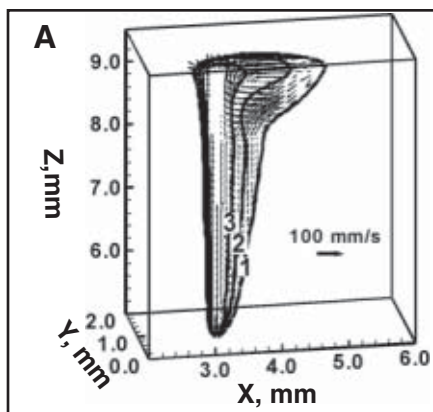


Fig. 2 — Fluid flow pattern in electron beam weld for focal spot radius of the following: A — 0.13 mm; B — 0.28 mm. Labels 1, 2, and 3 represent 1697, 1900, and 2200 K, respectively.

process is the power density distribution. In this work, the model was applied to welds made on 304L stainless steel with fixed input power and welding speed but different power density distributions. The power density distribution was varied by changing the work distance and then refocusing the electron beam to a sharp spot on the workpiece surface. The increase in the focal spot diameter with increasing work distance also affects the geometry of the weld pool shape (Ref. 28). The calculated and the experimental weld geometries were compared for each case and the effect of variation of power density distribution on the weld geometry was investigated. The resulting fluid flow circulation patterns in the 304L stainless steel electron beam weld pools were studied. The nail-head-shaped weld cross section of electron beam welds observed in this study was explained in terms of the fluid flow and resulting convective heat transfer.

Experiments

Autogenous electron beam welds were made on 9.5-mm-thick 304L stainless steel samples with a power of 1000 W (100 kV, 10 mA) and a welding speed of 17 mm/s.

The stainless steel workpiece had a composition of 18.2%Cr, 8.16%Ni, 1.71%Mn, 0.02%C, 0.082%N, 0.47%Mo, 0.44%Si, 0.14%Co, 0.35%Cu, 0.0004%S, 0.03%P, and balance Fe. Six welds were made using a sharply focused beam at different work distances (Table 1). The resulting weld pool cross sections were polished and etched with electrolytic oxalic acid solution to provide the outline of the fusion zone boundary. Image Pro, Version 4.1 was then used to measure the weld dimensions (Ref. 28).

The sharp focus condition was determined by using an enhanced modified Faraday cup (EMFC) device to ensure a more consistent and quantified beam focus than is manually possible (Ref. 28). The EMFC device samples the electron beam through 17 linear slits placed radially around a tungsten slit disk and converts them into voltage drops across the known resistor. A computer-assisted tomographic (CT) imaging algorithm is then used to reconstruct the power density distribution of the beam using the data from the 17 linear slits. From the reconstructed beam, the peak power density, full width of the beam at half of its peak intensity (FWHM), and the full width of the beam

at $1/e^2$ of the peak intensity (FWe2) are measured. The beam radius was taken to be $1/2$ of the FWe2 value measured by the EMFC. Figure 1 shows the beam shape for the case of a 0.17-mm focal spot radius, from EB welding machine model number SN/175 manufactured by Hamilton Standard at a 229-mm work distance (Ref. 28). Since the beam has an elliptical shape, the effective value of the beam radius was taken as the radius of a circle with an area equal to the actual beam spot (Ref. 28). The beam shape and radius may vary with distance from the focal plane, which can affect the weld geometry. However, due to a lack of data on the divergence of the beam near the focal plane, its effect has been neglected in this work.

Mathematical Model

Calculation of Keyhole Profile

Quasi-steady state and flat top surface outside the keyhole region are assumed. The fluctuations of the keyhole shape and size have been neglected. Energy balance is performed on the liquid-vapor interface to calculate the keyhole geometry using a model that is available in literature (Refs.

Table 1 — Experimental and Calculated Weld Dimensions for Welds Made at 1000-W Input Power and 17 mm/s Welding Speed Using Electron Beam Welding Machine S/N 175

WD mm	R _f mm	PPD kW/mm ²	d _m mm	d _c mm	% error	w _m mm	w _c mm	% error	MA mm ²	AR
127	0.131	34.9	4.46	4.20	-6.19	1.27	1.38	7.97	2.40	3.52
184	0.166	21.6	4.21	3.87	-8.79	1.29	1.52	15.13	2.55	3.27
229	0.173	20.0	3.97	3.80	-4.47	1.48	1.58	6.33	2.63	2.65
305	0.207	14.1	3.69	3.56	-3.65	1.48	1.68	11.90	2.58	2.49
381	0.243	10.2	3.39	3.33	-1.80	1.55	1.76	11.93	2.56	2.19
457	0.279	7.79	2.96	2.97	0.34	1.71	1.90	10.00	2.62	1.73

WD: work-distance, R_f: radius of focal spot; PPD: peak power density; d: depth; w: width; subscripts m and c stand for measured and calculated; MA: melted cross-sectional area; AR: aspect ratio.

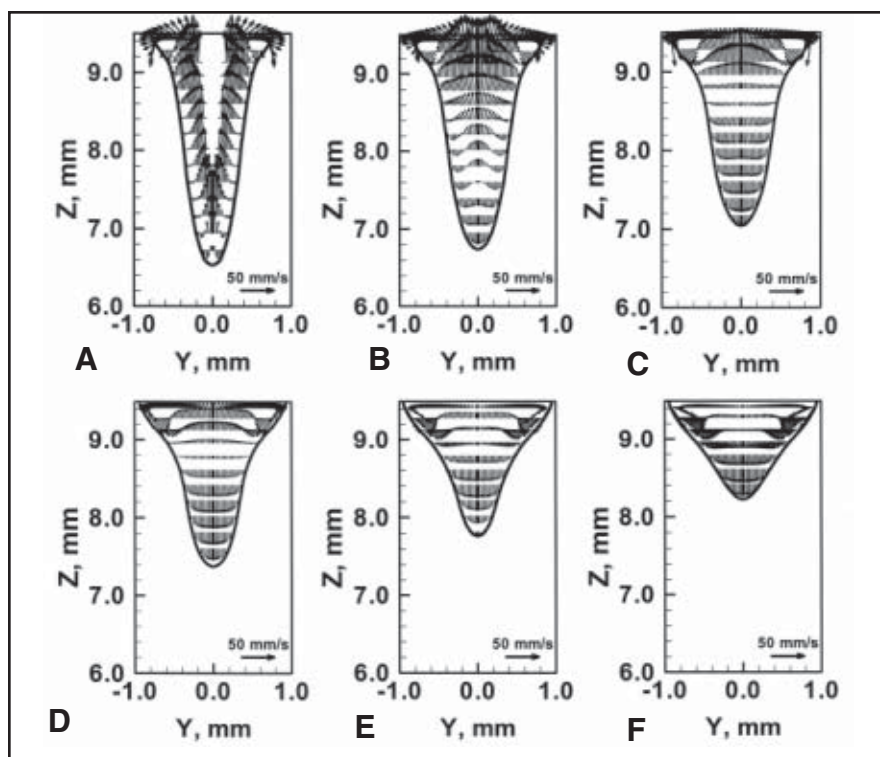


Fig. 3 — Fluid flow in the weld made with 0.28-mm beam radius in transverse planes at the following locations behind the electron beam: A — 0.11 mm; B — 0.28 mm; C — 0.45 mm; D — 0.62 mm; E — 0.78 mm; and F — 0.95 mm. Only the top 3.5 mm of the total plate thickness of 9.5 mm is shown.

12, 19–23). The temperature gradient in the vertical direction is small compared to that along any direction in the horizontal plane. Therefore, the heat transfer takes place mainly along horizontal planes. However, the temperature gradient on the keyhole walls along the vertical direction is still sufficient to generate surface tension driven flow along the keyhole walls in the vertical direction.

The keyhole is kept open by a balance between the surface tension force $\gamma/r(z)$, the hydrostatic force due to the liquid head ρgz , and the vapor pressure inside the keyhole p through the following relationship:

$$p = \rho gz + \gamma(T)/r(z) \quad (1)$$

where ρ is the density, g is the acceleration due to gravity, $\gamma(T)$ is the surface tension at temperature T , and $r(z)$ is the keyhole radius at distance z from the top surface. The decrease in $r(z)$ with increasing depth in the keyhole results in an increase in the surface tension force. As a result, the vapor pressure required to keep the keyhole open increases with depth. Thus, the vapor pressure at various depths in the keyhole can be calculated from the above equation.

The temperature at the keyhole wall at any depth can then be calculated from the

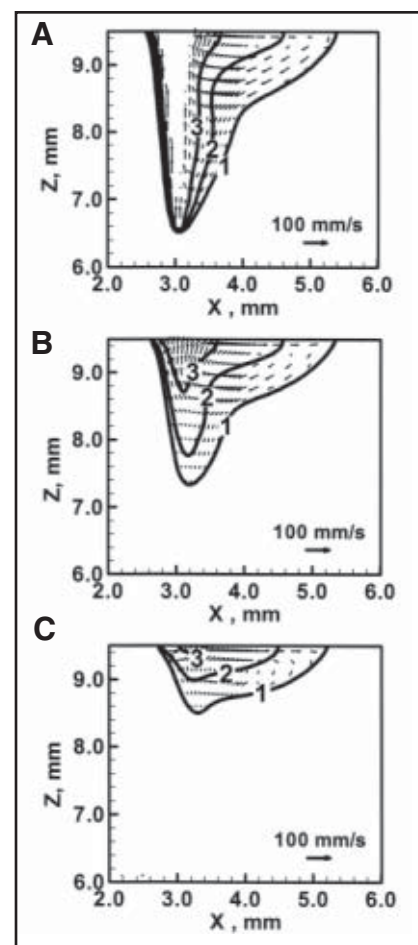


Fig. 4 — Fluid flow in the weld made with 0.28-mm beam radius in longitudinal planes at the following locations from the centerline: A — 0 mm; B — 0.28 mm; and C — 0.45 mm. Labels 1, 2, and 3 represent 1697, 1900, and 2200 K, respectively. Only the top 3.5 mm of the total plate thickness of 9.5 mm is shown.

equilibrium temperature vs. pressure relation for the alloy-vapor interface assuming ideal solution behavior (Ref. 29). The keyhole geometry is iteratively calculated first by assuming a constant temperature equal to the normal boiling point of the alloy at 1 atmosphere on the keyhole walls. The calculation of the energy balance at the keyhole walls is described elsewhere (Refs. 12, 19–23). The wall temperature is modified in subsequent iterations by first calculating the vapor pressure required to balance the surface tension and the hydrostatic force at the keyhole wall. Using this calculated vapor pressure, the wall temperature is then determined through equilibrium temperature vs. pressure relation, changing the keyhole depth and radius. Thus, the wall temperatures are corrected with each iteration, and the calculations continue until the change in keyhole depth with each additional iteration becomes less than 10^{-4} mm, at which point the calculations are assumed to con-

Table 2 — Data Used for Calculations

Physical Property	Value
Solidus temperature, (K) [Refs. 23, 48]	1697
Liquidus temperature, (K) [Refs. 23, 48]	1727
Density of liquid (kg/m ³) [Ref. 23]	7000
Specific heat of solid, (J/kg K) [Ref. 23]	712
Specific heat of liquid, (J/kg K) [Ref. 23]	800
Viscosity, (Pa-s) [Ref. 23]	0.007
Coefficient of thermal expansion, (1/K) [Ref. 23]	1.96×10^{-5}
Temperature coefficient of surface tension, (N/m K) [Ref. 48]	-0.43×10^{-3}
Enthalpy of solid at melting point, (J/kg) [Refs. 23, 48]	1.20×10^6
Enthalpy of liquid at melting point, (J/kg) [Refs. 23, 48]	1.26×10^6
Emissivity	0.3
Heat transfer coefficient, W/m ² -K	210
Plasma attenuation coefficient, (m ⁻¹)	10
Absorption coefficient	0.2

Values are estimated based on the data available in the reference.

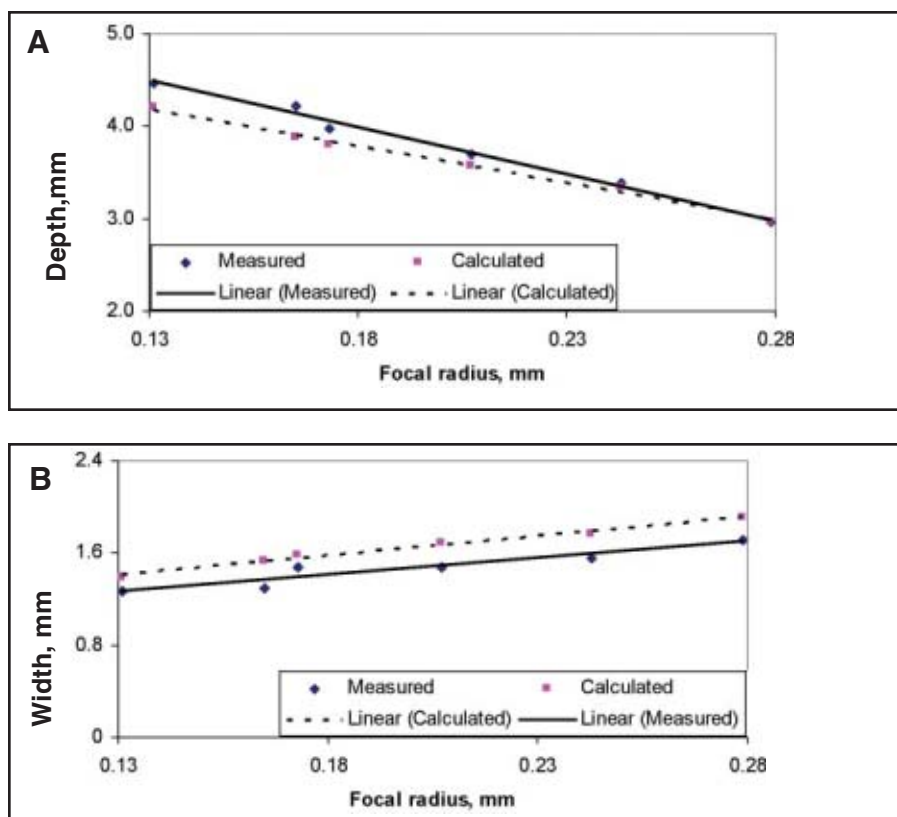


Fig. 5 — A — Variation of weld depth with spot radius; B — variation of weld width with spot radius.

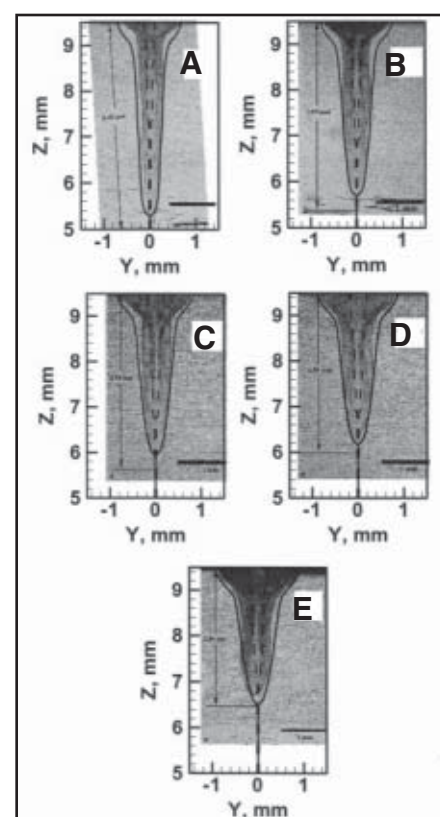


Fig. 6 — Comparison of experimental and calculated weld geometries for focal spot radii: A — 0.131 mm; B — 0.173 mm; C — 0.207 mm; D — 0.243 mm; E — 0.279 mm. Input power: 1000 W. Welding speed: 17 mm/s.

verge. During calculation of the asymmetric keyhole geometry, all temperatures inside the keyhole were assigned the wall temperature at that depth, for the identification of the keyhole. At each horizontal xy plane, where x is the direction of welding, the keyhole boundary was identified by both minimum and maximum x values for any given y value.

The attenuation of the beam due to absorption and scattering, as it traverses a unit distance in the plasma, is estimated by using attenuation coefficients (Ref. 12). The beam attenuation affects the amount of electron beam energy incident on keyhole walls below the workpiece surface. It is assumed that the energy loss due to large angle backscattering of electrons by the plasma in a deep, narrow keyhole is small (Ref. 30). Consequently, a small value of attenuation coefficient has been assumed here for the attenuation of the electron beam. With a plasma attenuation coefficient value of 10/m used for electron beam plasma here, 99% and 96% of the electron beam passes through lengths of 1 and 4 mm, respectively, through the plasma. Table 2 lists the values of material properties and process parameters used for the calculations. Thermal conductivity

values for the solid phase were temperature dependent and the thermal conductivity data were available up to a temperature of 1273 K. Approximate thermal conductivity values above this temperature were estimated based on linear extrapolation of the experimental data for 304L stainless steel (Ref. 31). Thermal conductivity for liquid was calculated based on the Wiedemann-Franz relation, which states that the ratio of thermal conductivity to the product of temperature and electrical conductivity is a constant (Ref. 32). The electrical conductivity of liquid stainless steel was taken as the electrical conductivity of liquid iron at its theoretical melting point, which was close to the value obtained by extrapolating the data for electrical resistivity of 18Cr-8Ni steel between 300 and 1273 K to the liquidus temperature (Ref. 29).

Heat Transfer and Fluid Flow in the Weld Pool

After calculating the keyhole profile, the fluid flow and heat transfer in the weld pool are modeled by solving the equations of conservation of mass, momentum, and energy in three dimensions. The liquid

metal flow in the weld pool can be represented by the following momentum conservation equation (Refs. 33, 34):

$$\rho \frac{\partial u_j}{\partial t} + \rho \frac{\partial (u_i u_j)}{\partial x_i} = \frac{\partial}{\partial x_i} \left(\mu \frac{\partial u_j}{\partial x_i} \right) + S_j \quad (2)$$

where ρ is the density, t is the time, x_i is the distance along the i^{th} ($i = 1, 2, \text{ and } 3$) orthogonal direction, u_j is the velocity component along the j direction, μ is the effective viscosity, and S_j is the source term for the j^{th} momentum equation and is given as

$$S_j = -\frac{\partial p}{\partial x_j} + \frac{\partial}{\partial x_i} \left(\mu \frac{\partial u_i}{\partial x_j} \right) - C \left(\frac{(1-f_L)^2}{f_L^3 + B} \right) u_j + \rho g_j \beta (T - T_{ref}) - \rho U \frac{\partial u_j}{\partial x_1} \quad (3)$$

where p represents pressure, U is the weld-

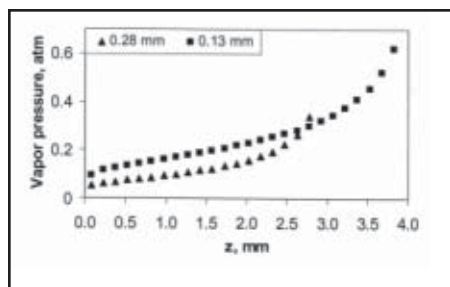


Fig. 7 — Variation of vapor pressure in the keyhole with depth for radius of 0.13 and 0.28 mm. $z = 0$ at the surface of the workpiece.

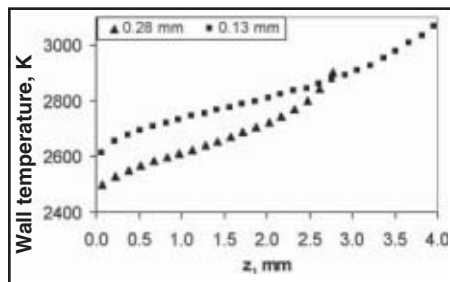


Fig. 8 — Variation of keyhole wall temperature with depth for radius of 0.13 and 0.28 mm. $z = 0$ at the surface of the workpiece.

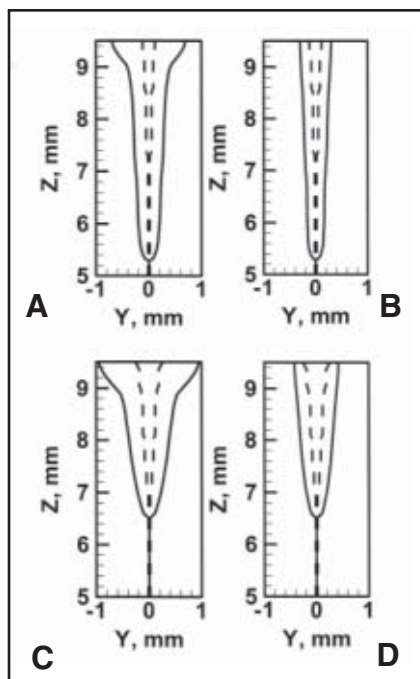


Fig. 9 — Weld pool cross sections for focal spot radius of 0.13 mm: A — With convection and B — without convection; and 0.28 mm: C — with convection and D — without convection. Input power: 1000 W, welding speed: 17 mm/s.

ing velocity, β is the coefficient of volume expansion, and T_{ref} is a reference temperature taken here as the solidus temperature. The third term represents the frictional dissipation in the mushy zone according to the Carman-Kozeny equation for flow through a porous media (Refs. 35, 36), where f_L is the liquid fraction, B is a very small computational constant introduced to avoid division by zero, and C is a constant accounting for the mushy zone morphology (a value of 1.6×10^4 was used in the present study) (Ref. 36). The fourth term is the buoyancy source term (Refs. 37–41). The last term accounts for the relative motion between the electron beam and the workpiece (Ref. 37).

The following continuity equation is solved in conjunction with the momentum equation to obtain the pressure field.

$$\frac{\partial(\rho u_i)}{\partial x_i} = 0 \quad (4)$$

In order to trace the weld pool liquid/solid interface, i.e., the phase change, the total enthalpy H is represented by a sum of sensible heat h and latent heat content ΔH , i.e., $H = h + \Delta H$ (Ref. 37). The sensible heat ' h ' is expressed as $h = \int C_p dT$, where C_p is the specific heat, and T is the temperature. The latent heat content ΔH is given as $\Delta H = f_L L$, where L is the latent

heat of fusion. The liquid fraction f_L is assumed to vary linearly with temperature for simplicity (Ref. 37):

$$f_L = \begin{cases} 1 & T > T_L \\ \frac{T - T_S}{T_L - T_S} & T_S \leq T \leq T_L \\ 0 & T < T_S \end{cases} \quad (5)$$

where T_L and T_S are the liquidus and solidus temperatures, respectively. Thus, the transport of thermal energy in the weld workpiece can be expressed by the following modified energy equation:

$$\rho \frac{\partial h}{\partial t} + \rho \frac{\partial(u_i h)}{\partial x_i} = \frac{\partial}{\partial x_i} \left(\frac{k}{C_p} \frac{\partial h}{\partial x_i} \right) + S_h \quad (6)$$

where k is the thermal conductivity. The source term S_h is due to the latent heat content and is given as

$$S_h = -\rho \frac{\partial(\Delta H)}{\partial t} - \rho \frac{\partial(u_i \Delta H)}{\partial x_i} - \rho U \frac{\partial h}{\partial x_1} - \rho U \frac{\partial \Delta H}{\partial x_1} \quad (7)$$

The heat transfer and fluid flow equa-

tions were solved for the complete workpiece. For the region inside the keyhole, the coefficients and source terms in the discretized algebraic equations were adjusted to obtain zero fluid velocities and temperature equal to the wall temperature at that depth. The methodology for the implementation of known values of variables in any specified location of the solution domain is well documented in the literature (Ref. 34).

Boundary Conditions

A 3-D Cartesian coordinate system is used in the calculation, and only half of the workpiece is considered since the weld is symmetrical about the weld centerline. The boundary conditions are discussed as follows.

Top Surface

Outside the region of vapor cavity, the weld top surface is assumed to be flat. The velocity boundary conditions are given as (Refs. 40–43)

$$\begin{aligned} \mu \frac{\partial u}{\partial z} &= f_L \frac{d\gamma}{dT} \frac{\partial \gamma}{\partial x} \\ \mu \frac{\partial v}{\partial z} &= f_L \frac{d\gamma}{dT} \frac{\partial \gamma}{\partial y} \\ w &= 0 \end{aligned} \quad (8)$$

where u , v , and w are the velocity components along the x , y , and z directions, respectively, and $d\gamma/dT$ is the temperature coefficient of surface tension. As shown in this equation, the u and v velocities are determined from the Marangoni effect (Refs. 40–43). The w velocity is equal to zero since the outward flow at the top surface is assumed to be negligible.

The heat flux at the top surface is given as

$$\begin{aligned} k \frac{\partial T}{\partial z} \Big|_{top} &= \frac{fQ\eta}{\pi r_b^2} \exp \left(-\frac{f(x^2 + y^2)}{r_b^2} \right) \\ &\quad - \sigma \epsilon (T^4 - T_a^4) - h_c (T - T_a) \\ &\quad - \sum_{i=1} h_{v,i} J_{v,i} \end{aligned} \quad (9)$$

where r_b is the beam radius, f ($=3.0$) is the power distribution factor, Q is the total power, η is the absorption coefficient, σ is the Stefan-Boltzmann constant, ϵ is the emissivity, h_c is the heat transfer coefficient, $h_{v,i}$ is the heat of evaporation for the i^{th} element, $J_{v,i}$ is the evaporation flux for the i^{th} element calculated using the Langmuir equation (Ref. 1), and T_a is the ambient temperature. In Equation 9, the first term on the right-hand side is the heat input from the Gaussian heat source. The

second, third, and fourth terms represent the heat loss by radiation, convection, and vaporization, respectively.

Symmetric Plane

The boundary conditions are defined as zero flux across the symmetric surface, i.e., the vertical plane defined by the welding direction, as

$$\frac{\partial u}{\partial y} = 0, \quad v = 0, \quad \frac{\partial w}{\partial y} = 0 \quad (10)$$

$$\frac{\partial h}{\partial y} = 0 \quad (11)$$

Keyhole Surface

$$h = h_w \quad (12)$$

where h_w is the sensible heat of the material at the local wall temperature. The velocity component perpendicular to the keyhole surface is assigned zero to represent no mass flux due to convection. Along the keyhole walls, the temperature gradient in the vertical direction results in the surface tension gradient. As a result, Marangoni convection currents are formed in the vertical direction along the surface of the keyhole. The w-velocity boundary condition along the keyhole walls is therefore given as

$$\mu \frac{\partial w}{\partial n} = f_L \frac{d\gamma}{dT} \frac{\partial T}{\partial z} \quad (13)$$

where n is the direction vector normal to the keyhole surface.

Solid Surfaces

At all solid surfaces far away from the heat source, a convective heat transfer boundary condition is given and the velocities are set to be zero.

Turbulence Model

The presence of fluctuating velocities during welding often enhances the rates of transport of heat, mass, and momentum in the weld pool. An appropriate turbulence model that provides a systematic framework for calculating effective viscosity and thermal conductivity (Refs. 41, 42) is used to account for the fluctuating velocities. The values of these properties vary with the location in the weld pool and depend on the local characteristics of the fluid flow. In this work, a turbulence model based on Prandtl's mixing length hypothesis is used to estimate the turbulent viscosity (Ref. 45)

$$\mu_t = \rho l_m^2 v_t \quad (14)$$

where μ_t is the turbulent viscosity, l_m is the mixing length, and v_t is the turbulence velocity. The mixing length at any location within the weld pool is the distance traveled by an eddy before its decay and is often taken as the distance from the nearest wall (Ref. 45). The extent of computed turbulent kinetic energy was found to be about 10% of the mean kinetic energy, in a controlled numerical study of recirculating flows in a small square cavity (Ref. 46). Yang and DebRoy (Ref. 47) computed mean velocity and turbulent energy fields during GMA welding of HSLA 100 steel using a two equation k-ε model. Their results also show that there is a 10% contribution of the turbulent kinetic energy to the mean kinetic energy. The turbulent velocity v_t can therefore be expressed as

$$v_t = \sqrt{0.1v^2} \quad (15)$$

By coupling Equations 14 and 15, the turbulent viscosity can be expressed as

$$\mu_t = 0.3\rho l_m^2 v \quad (16)$$

The effective viscosity at a particular point can be expressed as the sum of the turbulent (μ_t) and laminar (μ_l) viscosities, i.e., $\mu = \mu_t + \mu_l$. The corresponding local turbulent thermal conductivities are calculated by using the turbulent Prandtl number, which is defined in the following relationship:

$$Pr = \frac{\mu_t c_p}{k_t} \quad (17)$$

where k_t is the turbulent thermal conductivity. For the calculations described here, the turbulent thermal conductivity is calculated by assuming a Prandtl number of 0.9, based on previous modeling work (Refs. 44, 46).

Calculation Methodology

The calculation of heat transfer and fluid flow in the workpiece was done in the following steps:

1. The keyhole geometry is calculated based on a heat balance model available in the literature (Ref. 17) and boiling point temperature at all locations on the keyhole wall.
2. The vapor pressure in the keyhole is calculated at all depths through a force balance between the vapor pressure, surface tension, and hydrostatic force.
3. Wall temperatures are calculated for all depths from the equilibrium pressure-temperature relations for the given alloy.
4. Keyhole geometry is calculated assuming new values of wall temperatures at different depths.

5. Steps 2–4 are repeated until the variation of keyhole depth with further iteration becomes less than 10^{-4} mm.

6. The keyhole geometry is mapped onto a coarser mesh for 3-D heat transfer and fluid flow calculations. Temperatures are assigned on the keyhole wall from the values calculated during keyhole geometry calculation based on equilibrium pressure-temperature relations for the alloy.

7. The momentum and energy balance equations are solved keeping fixed temperatures on the keyhole wall, and assuming no mass flux across the wall boundary. Convergence was assumed when residuals of enthalpy and u, v, and w velocities are less than 1%.

8. A turbulence model is used to update the viscosities and thermal conductivities in the liquid phase.

Results and Discussion

Figure 2 shows the computed weld geometry and the 3-D fluid flow within the weld pool for the welds made with the highest (0.28 mm) and the lowest (0.13 mm) beam radii at input power of 1000 W and welding speed of 17 mm/s. The flow of molten metal is driven by the surface tension gradient along the keyhole walls and on the top surface of the weld pool. A negative temperature coefficient of surface tension drives fluid flow at the top surface from the high-temperature region near the keyhole to the low-temperature region near the solid-liquid boundary, resulting in enhanced heat transfer at the top surface.

Within the keyhole, temperatures are highest at the bottom and lowest near the top surface. This temperature gradient along the keyhole surface drives fluid flow from the hot keyhole bottom to the top, resulting in a fluid flow pattern in the weld pool where hot fluid moves along the keyhole walls to the top, moving outward from there, and finally coming back inward and down along the solid-liquid boundary. A distinct nail-head shape results from this type of fluid flow pattern.

Figure 3 shows the fluid flow in transverse planes perpendicular to the welding direction at selected distances from the heat source. Plane 'a' is the closest to the electron beam location (0.11 mm) and plane 'f' is the farthest behind the electron beam (0.95 mm). The keyhole region, which is characterized by the absence of velocity vectors at the center of the weld pool, is present only in Fig. 3A. Under the influence of surface-tension gradients at the vapor-liquid interface, the fluid near the keyhole wall moves from the bottom to the top. The magnitude of fluid velocities in the vertical direction is highest near the vapor-liquid interface and decreases to zero at the solid-liquid boundary. As the

distance of the transverse section from the heat source increases, fluid gradually starts to come downward and the reversal of the direction of fluid velocity from upward to downward happens at shorter distances from the top surface.

In the longitudinal sections shown in Fig. 4, the fluid moves upward near the heat source location and circulates backward near the top surface resulting in enhanced heat transfer toward the rear of the weld pool and an elongated weld pool. The circulation pattern is similar in all of the longitudinal sections shown in Fig. 4 located at different distances from the weld centerline.

As shown in Table 1, an increase in work distance from 127 to 457 mm resulted in more than a twofold increase in the beam focal spot radius (R_f). With a larger focal spot radius, the beam is more diffuse and the peak power density is lower, decreasing from 34.9 kW/mm² for 127-mm work distance (focal radius = 0.13 mm) to 7.79 kW/mm² for 457-mm work distance (focal radius = 0.28 mm) (Ref. 28). As a result, the weld characteristics are likely to be strongly affected by the variation in beam radius. Figure 5A, B shows the variation of weld pool depth and width at the top surface, respectively, with the variation in the focal spot radius. The calculated weld width and depth display trends similar to the measured values. With an increase in beam radius, the input energy distribution is more diffuse and the peak power density decreases, thus decreasing the weld penetration. However, a larger focal spot radius increases melting on the top surface, resulting in a wider weld pool. Thus, the ratio of weld pool depth to width decreases with increasing beam radii, as shown in Table 1. The area of calculated weld cross section is nearly constant with variation in the beam radius.

Figure 6 shows the comparison of calculated and experimental weld cross sections for different focal spot radii. The dashed lines show the calculated keyhole profile. The calculated keyhole radius at the top surface of the weld is closely related to the electron beam radius. The calculated weld cross sections are similar to the experimentally observed weld cross sections. The experimentally observed nail-head shape of the weld cross section is predicted by calculations as well. Even though the beam divergence may contribute to the nail-head shape, this characteristic shape of electron beam welds can also be explained in terms of Marangoni convection.

The keyhole and weld geometry depends on the keyhole wall temperatures, which in turn depend on the vapor pressure in the keyhole. Figure 7 shows the variation of vapor pressure with depth for beam radii of 0.13 and 0.28 mm. For the welds shown in Fig. 6, the keyhole be-

comes narrower and deeper as the beam radius is decreased. The narrower keyhole for lower focal spot radius requires a larger vapor pressure to balance the surface tension force that tends to close the keyhole. Therefore, vapor pressures are higher for the higher peak power densities obtained with the smaller focal spot radii. In accordance with higher vapor pressures in the keyhole for the smaller beam radius, equilibrium wall temperatures at the keyhole walls are higher for the beam radius of 0.13 mm as compared to the larger beam radius of 0.28 mm as shown in Fig. 8. The higher keyhole wall temperatures calculated for the smaller focal spot radius are consistent with more intense heating. The average temperature gradient in the perpendicular-to-welding direction was always significantly higher than that along the keyhole wall in the vertical direction. For example, for the weld made with the beam radius of 0.28 mm, the average temperature gradient in the weld pool at mid-height of the keyhole in the horizontal direction was about 26 times that in the vertical direction. Thus, the assumption that the temperature gradient in the vertical direction is small compared to that in the horizontal plane is justified. Since the variation of vapor pressure from the bottom to the top of the keyhole results in less than a 15% variation in the wall temperature, any errors in vapor pressure calculation are likely to result in much smaller errors in the computed wall temperatures.

The significance of convective heat transfer relative to conductive heat transfer is given by the Peclet number, $Pe = \rho u C_p (w/2) / k$, where ρ is the density, u is the characteristic velocity, C_p is the specific heat, w is the weld pool width, and k is the thermal conductivity. Using $\rho = 7000$ kg/m³, $u = 0.1$ m/s (the value of reference velocity vector in Fig. 2), $C_p = 800$ J/kg-K, $w/2 = 8.0 \times 10^{-4}$ m, and $k = 30$ W/m-K, $Pe = 14.9$. Therefore, convective heat transfer is very important for the welding conditions studied here.

To further illustrate the significance of convection on the weld pool geometry, the temperature field in the workpiece was calculated by considering only conductive heat transfer and ignoring fluid flow. Figure 9A, C shows the calculated weld pool cross sections for the case of 0.13- and 0.28-mm focal spot radius, respectively, with convection, and Fig. 9B, D shows the corresponding weld cross sections in the absence of any convection. In the absence of convection, heat transfer is significantly reduced, which results in much narrower weld pools. The calculated weld pool in absence of convection also lacks the nail head shape usually observed in experiments because of the absence of enhanced outward heat transfer

at the top surface of the workpiece. The differences in shape and size of the calculated weld pools in absence of and in the presence of convection indicate the significance of convective heat transfer under the conditions considered.

Summary and Conclusions

The geometry of the keyhole formed during electron beam welding was calculated through an energy balance at the keyhole walls considering the variation of vapor pressure and keyhole wall temperature with depth. A numerical heat transfer and fluid flow model was used to calculate the three-dimensional temperature field and fluid velocities for electron beam welding of 304L stainless steel. A turbulence model based on Prandtl's mixing length hypothesis was used to estimate the effective viscosities and thermal conductivities in the weld pool. The vapor pressure in the keyhole was calculated through a force balance on the keyhole wall considering the surface tension force, the hydrostatic force, and the force due to vapor pressure. The wall temperatures were calculated from equilibrium temperature-pressure relations for the alloy.

The calculated weld pool depth and width were compared with experimentally observed values for a set of experiments where the power density distribution was varied by changing the focal spot radius at a fixed input power. As the focal spot size increased and the power distribution became progressively diffuse, the penetration depth decreased and the weld width increased proportionally in order to maintain the total weld cross-sectional area for the fixed input power. Higher peak power density with the same input power resulted in higher peak temperature and vapor pressure at the keyhole bottom. Fluid circulation in the weld pool was studied for transverse sections located at different distances from the electron beam. Convective heat transfer was very significant in determining the weld geometry, as shown by Peclet number calculations. In the absence of convection, the calculated nail head shape of the weld pool was not obtained. The reduced heat transfer near the top surface in the absence of convection resulted in a much narrower calculated weld pool, further illustrating the significance of convective heat transfer for the conditions of welding considered.

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Metallurgical Investigation into Ductility Dip Cracking in Ni-Based Alloys: Part II

Microstructural and microchemical development is characterized during simulated weld reheat thermal cycle and correlated to ductility dip cracking susceptibility

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ABSTRACT

In this second of two papers, the microstructural and microchemical evolution of Alloy 600 (A600), Alloy 690 (A690), Filler Metal 82H (FM82H), and Filler Metal 52 (FM52) during the weld thermal cycle was investigated and compared to the hot ductility data presented in the first paper (Ref. 1). The Gleeble® hot ductility test was used to subject these four alloys to a simulated weld thermal cycle. Water quenching was conducted at select temperatures so that the elevated temperature microstructure could be subsequently characterized. Microstructural and microchemical characterization was carried out using scanning electron microscopy, transmission electron microscopy, and analytical electron microscopy techniques. Complete dissolution of intergranular carbides was observed in A690 and FM52 at ~2400°F (1316°C), both of which exhibit an on-cooling ductility minimum at 1600°F (871°C). Of all four alloys, the greatest resistance to ductility dip cracking (DDC) was observed in A600 and A690 during on-heating, which had coarse, homogeneously distributed intergranular carbides. FM82H, which formed NbC intergranular carbides, had the most stable intergranular microstructure and serrated grain boundaries, which corresponded to the best overall DDC resistance. Modifications to the thermal cycle that resulted in increased intergranular carbide coverage in FM82H and FM52 also reduced DDC susceptibility. AEM analysis did not

reveal any sulfur or phosphorous segregation in FM52 at 1600°F (871°C) on-heating, on-cooling, or after a 60-s hold. Samples with microstructures that consisted of coarsened carbides and/or serrated grain boundaries, which are expected to decrease grain boundary sliding, were found to be resistant to DDC. Based on the results of this work and the results previously presented in Paper I (Ref. 1), grain boundary sliding contributes to DDC. Conversely, sulfur and phosphorous embrittlement do not play a role in DDC of FM52 at the concentrations investigated. The dynamic precipitation of partially coherent intergranular $M_{23}C_6$ carbides at intermediate temperatures may exacerbate DDC in A690 and FM52, but requires further investigation.

Introduction

In the first paper of this two part series the Gleeble® hot ductility test was used to evaluate the DDC susceptibility of wrought A600 and A690, along with their companion filler metals, FM82H and FM52, throughout the heating and cooling portions of a simulated weld thermal cycle. Both macroscopic mechanical measures (ductility and ultimate tensile strength (UTS)), and microscopic measures (normalized crack length) of DDC were quantified and compared. The macroscopic measures of DDC were found to have reasonable agreement with normalized crack

length. The hot ductility curves for all four alloys are presented in Fig. 1.

Of all four alloys, the greatest resistance to DDC was observed in A600 and A690 during heating, where no ductility dip cracks formed even when the samples were strained to fracture. Both A690 and FM52 were found to form an intermediate on-cooling dip in ductility and ultimate tensile strength (UTS), which corresponded to an increase in the amount of intergranular ductility dip crack length normalized per grain boundary length. The normalized crack length decreased in both FM52 and FM82H when the thermal cycle was modified to promote precipitation/coarsening of intergranular carbides. The precipitation/coarsening of intergranular carbides can act to decrease grain boundary sliding (GBS), and may also act by reducing strain at the partially coherent $M_{23}C_6$ precipitate/matrix interface by decreasing lattice/precipitate misfit. In these tests FM82H has the best overall (on-heating and on-cooling) resistance to DDC due to its serrated grain boundaries and presence of MC-type grain boundary carbides, which are very effective at reducing DDC susceptibility.

Recently, a significant amount of research has been performed to identify the mechanism(s) of DDC. There are three prevailing hypotheses that will be briefly reviewed: impurity element (sulfur and phosphorous) embrittlement, precipitation-induced cracking, and grain boundary sliding. Grain boundary sliding (GBS) was first proposed by Rhines and Wray based on their observations of tensile deformation behavior at intermediate temperatures in brass, 70%Ni-30%Cu, and Monel (Ref. 2). Typical time to fracture during their testing was approximately 10 s. They proposed that DDC was a creep-like phenomena, where the ductility decreases with decreasing strain rate (Ref. 2). This strain rate sensitivity was also seen in Invar, where GBS increased with decreasing stroke rate at intermediate temperatures, which resulted in a larger intermediate temperature ductility dip (Ref. 3). Decreasing strain rate has also been

KEYWORDS

Alloy 600 (A600)
Alloy 690 (A690)
Filler Metal 82H (FM82H)
Filler Metal 52 (FM52)
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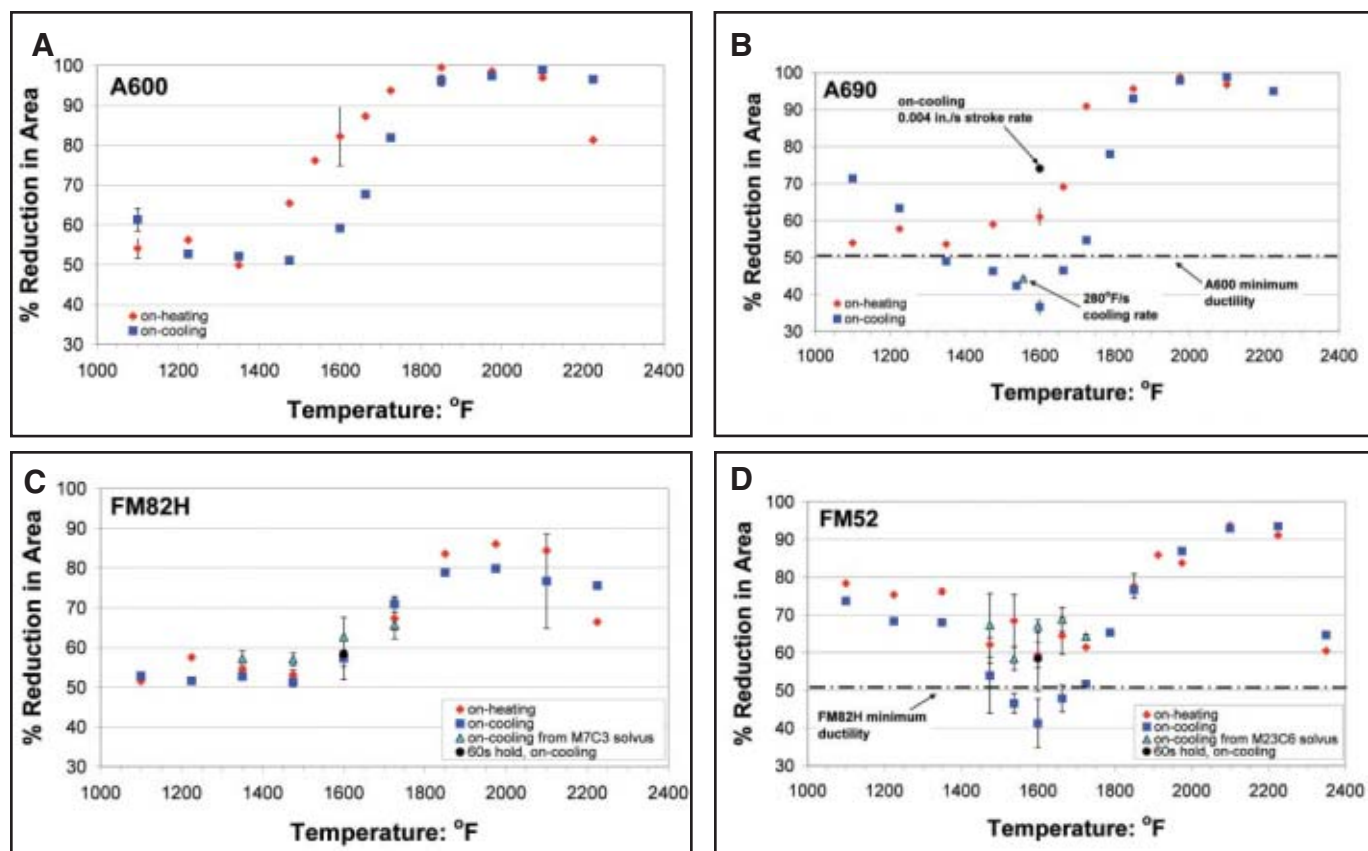


Fig. 1 — On-heating and on-cooling hot ductility curves for the following: A — A600; B — A690; C — FM82H; and D — FM52. FM82H and FM52 hot ductility curves also include on-cooling data from their respective carbide solvus temperatures.

shown to increase DDC susceptibility in 310 stainless steel (Ref. 4). However, recent testing performed on A690 has shown just the opposite effect, where decreasing the strain rate significantly improved the intermediate temperature ductility (Ref. 1). However, this difference may be the result of intergranular precipitation that was promoted by the increased time allotted by the slower strain rate. It has been shown that intergranular particles decrease grain boundary sliding (Refs. 5, 6), and both A690 and FM52 are strong intergranular $M_{23}C_6$ formers.

The second DDC hypothesis is impurity element embrittlement. Of all impurity elements, sulfur has the most detrimental effect in Ni and Ni-based alloys (Ref. 7). Nominal sulfur concentrations as low as 0.002 wt-% have been shown to have a dramatic effect on the ductility of

Ni over a wide range of temperature spanning from 20° to 1200°C (Ref. 8). Sulfur and phosphorous have also been implicated in the DDC of Invar (Refs. 9–11) and FM52 (Refs. 12, 13). The intergranular concentration of sulfur that will result in embrittlement of Ni has been found to be approximately 5 wt-% (9 at-%) (Refs. 14, 15). Other investigators have utilized auger electron spectroscopy to identify sulfur at grain boundaries in multipass welds of FM52 that were fractured in a high vacuum environment (Refs. 12, 16). However, since this analysis was performed on a multipass weld, it is impossible to know during which thermal cycle sulfur segregated to the grain boundaries (Ref. 12) or whether the segregation occurred after the ductility dip crack formed (Ref. 16). It has yet to be shown that sulfur is present at grain boundaries of FM52

at the point in the thermal cycle where ductility dip cracks form.

Intergranular precipitates are the third proposed mechanism for DDC. Intergranular MnS, MnO, AlN, and Al_2O_3 have all been found on DDC fracture surfaces in Invar (Ref. 17). Intergranular chromium-rich precipitates have also been observed on DDC fracture surfaces of 304 stainless steel (Ref. 18), FM82H (Ref. 19), and FM52 (Refs. 16, 19). It has been proposed that alloys that form $M_{23}C_6$ carbides, like FM52 and A690, are more prone to DDC (Refs. 16, 20). This is thought to be the result of localized interfacial stresses associated with the partially coherent $M_{23}C_6$ carbide. In contrast, alloys that form incoherent precipitates such as Ti(C,N), NbC, and M_7C_3 are generally not thought to exhibit DDC in multipass welds (Refs. 16, 20) because significant interfacial strains

Table 1 — Alloy Compositions (in wt-%)

	Ni	Cr	Fe	C	Mn	S	Si	Cu	Nb	Ti	Al	Ti + Al	P	Mo	Other
A600	75.67	14.87	8.22	0.079	0.36	0.001	0.25	0.01	—	—	—	—	—	—	—
FM82H	71.52	20.38	2.26	0.049	2.99	0.002	0.06	0.01	2.28	0.3	0.04	0.34	0.002	—	<0.5
A690	60.75	29.28	9.12	0.025	0.17	<0.001	0.08	0.01	<0.01	0.3	0.22	0.52	0.005	0.01	—
FM52	59.12	29.12	10.08	0.027	0.25	<0.001	0.13	0.01	<0.01	0.51	0.71	1.22	0.003	0.01	<0.5

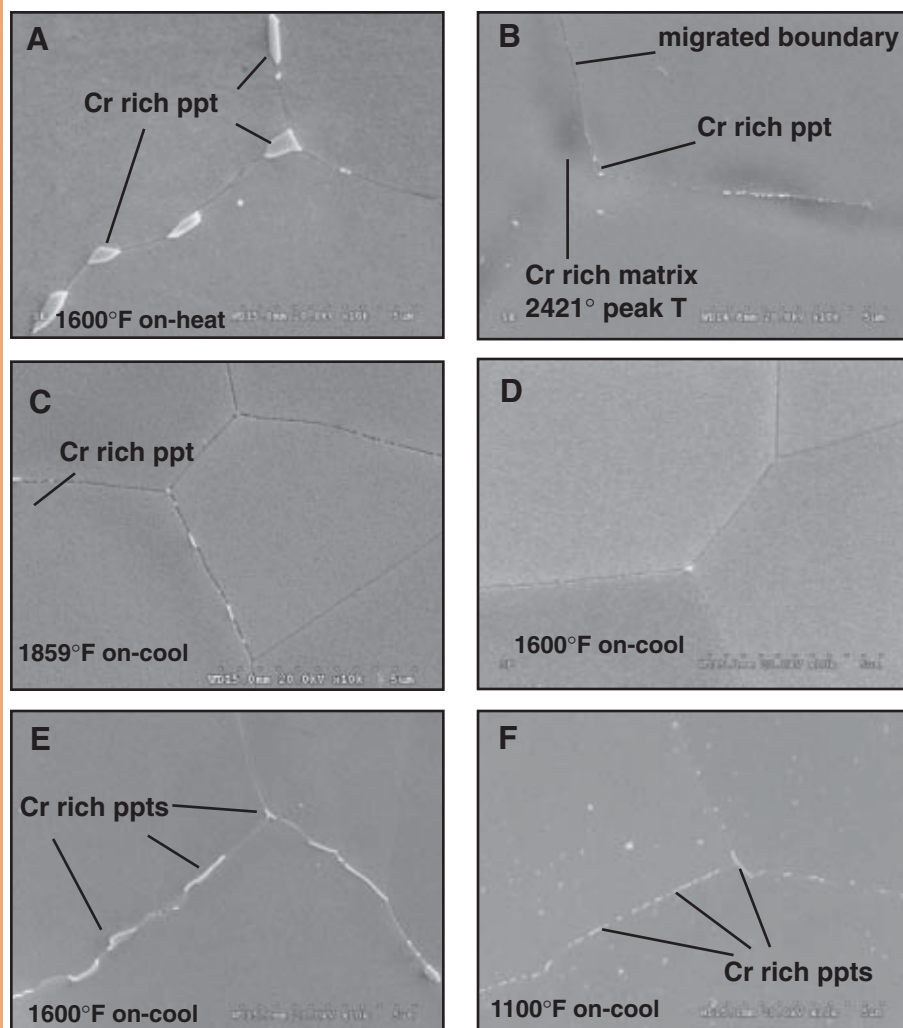


Fig. 2 — A600 water-quenched SEM micrographs. A — 1600°F on-heating; B — 2421°F peak temperature; C — 1859°F on-cooling; D and E — 1600°F on-cooling; and F — 1100°F on-cooling. EDS used to identify composition of various regions and precipitates indicated on micrographs.

are not expected. The exact role of intergranular precipitates on DDC remains unclear. Specifically, $M_{23}C_6$ may be the cause of DDC, contribute to it, or be merely coincidental.

Previous investigations into DDC have had several limitations in their experimental approach. Multipass weld mock-ups have been used to assess the DDC susceptibility of candidate filler metals (Refs. 20–22). However, these samples experience complex and multiple thermal-mechanical cycles that prevent accurate determination of microstructures, and/or microsegregants that cause ductility dip cracks to form. This problem can be resolved by using a hot tensile/Gleeble®-based test that exposes single-pass samples in the as-solidified condition to a simulated weld thermal cycle. Gleeble®-based testing has been used by several investigators, but only the heating or cooling portion of the weld thermal cycle has been investigated (Refs. 4, 19, 23–26). This is the sec-

ond limiting factor in previous work since reheated weld metal experiences both heating and cooling. To determine when the reheated weld metal is metallurgically most susceptible to form DDC, both the heating and cooling portions of the thermal cycle must be evaluated. There is a potential limitation of performing microstructural characterization on Gleeble specimens that are allowed to ‘free cool’ in the Gleeble vacuum jaws from their testing temperature. Preliminary testing showed that this method of cooling would result in cooling rates as low as 15°F/s in the sample design used for this work. This may allow enough time for diffusive processes to occur that can change segregation profiles and/or form secondary phases that may not have been present at the elevated temperature where the cracking susceptibility of the alloy was determined. Therefore, to minimize the potential for diffusional microstructural changes (e.g., precipitation, Sulfur segregation) that may occur during

‘free-cooling’ in the Gleeble, select samples were rapidly quenched from their test temperature for subsequent microstructural and microchemical characterization.

The objective of this work is to characterize the microstructural and microchemical development of A600, A690, FM82H, and FM52 during both heating and cooling portions of a simulated weld thermal cycle, and to correlate these microstructural changes to DDC susceptibility. As a first step, the majority of this characterization work was carried out on samples that were exposed to the weld thermal cycle, but without being strained. This approach captures the microstructure present immediately before strain was applied in the form of a Gleeble® hot ductility test as described in the first paper. The microstructural evolution in these unstrained samples will be compared to the DDC susceptibility of the alloys, which was determined in previous work (Ref. 1.) This work will provide further insight into the metallurgical mechanism(s) of DDC.

Experimental Procedure

Sample Preparation

A total of four alloys were investigated as part of this work: A600 (UNS: N06600), A690 (UNS: N06690), FM82H (AWS: ER-NiCr-3), and FM52 (AWS: ERNiCrFe-7). A600 and A690 were the two wrought alloys. FM82H and FM52 are the companion weld filler metals for A600 and A690, respectively. Nominal compositions for each alloy are given in Table 1. A600 and A690 form the base metal material in multipass weldments of many industrial applications and were therefore tested in the wrought condition as part of this work. The weld filler metals were tested in the as-solidified condition, which allowed the DDC susceptibility and microstructural evolution during the first weld thermal cycle to be studied. Details of the specimen design are presented elsewhere (Ref. 1).

Testing Parameters and Design

The heating rate for the on-heating tests was 200°F/s (111°C/s), while the cooling rate for all on-cooling tests was 90°F/s (50°C/s). He gas quench was used to augment the cooling rate in the “on-cooling” samples because the maximum “free cool” cooling rate that could be obtained in the Gleeble® was so low (15°F/s). The heating and cooling rates were based upon thermocouple measurements taken from a standard weld joint during typical multipass welding conditions. Samples were hot ductility tested at 125°F (51°C) intervals between 1100°F (593°C) and the peak temperature for each alloy. Smaller tem-

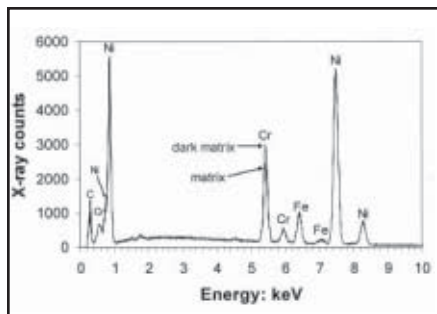


Fig. 3 — Two EDS spectra from A600 2421°F peak temperature superimposed on one another. The “dark matrix” refers to the “Cr-rich matrix” region in Fig. 2B. Sample was water quenched.

perature intervals of 62.5°F (17°C) were used in some cases to provide more detail within temperature ranges of interest. The details of the testing parameters are presented elsewhere (Ref. 1).

To better understand how microstructure and microchemistry affected DDC susceptibility, several samples from each alloy were water quenched at select temperatures along the weld thermal cycle. These temperatures were based upon the results of hot ductility testing. In an actual multipass weld, the weld metal experiences a complex combination of thermal and mechanical influences. As a first step, only the thermal influences on microstructural evolution were investigated with the majority of samples in this work. These samples were not strained when they were water quenched at the temperatures of interest. The cooling rates obtained using the water quench were in excess of 3000°F/s. The combined effect of thermal and mechanical influences was examined with a limited number of samples that were water

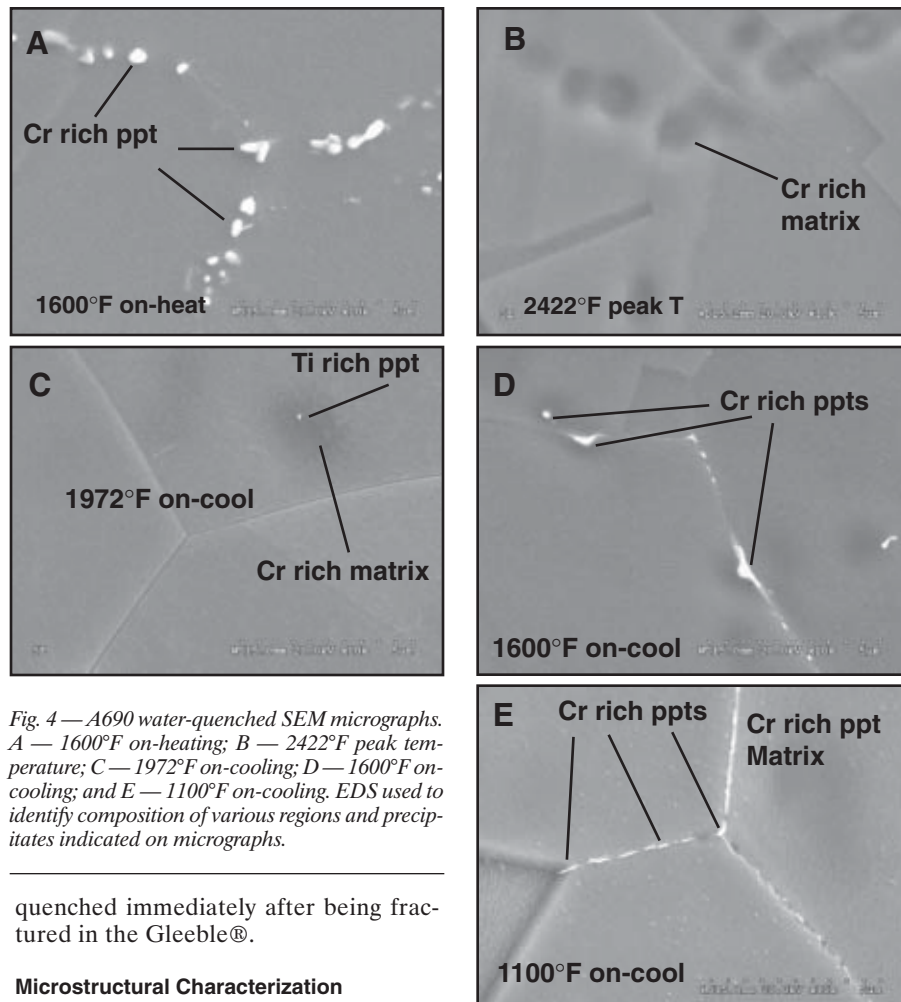


Fig. 4 — A690 water-quenched SEM micrographs. A — 1600°F on-heating; B — 2422°F peak temperature; C — 1972°F on-cooling; D — 1600°F on-cooling; and E — 1100°F on-cooling. EDS used to identify composition of various regions and precipitates indicated on micrographs.

quenched immediately after being fractured in the Gleeble®.

Microstructural Characterization

Samples were sectioned and mounted in thermosetting epoxy so that the following surface could be viewed: longitudinal-transverse orientation for the base metal and parallel to the welding direction-transverse for the weld metal samples.

Standard metallographic techniques were used to prepare the samples to a 0.05- μ m colloidal silica finish. After final polishing, the samples were ultrasonically cleaned in ethanol, followed by distilled water. This step was found to be effective at removing

Table 2 — Grain diameter data as a function of temperature along first reheat thermal cycle.

Temp (°F)	A600 Grain diam. (μm)	Std. dev. (μm)	Temp (°F)	A690 Grain diam. (μm)	Std. dev. (μm)
BM	41	7	BM	29	7
1100 on-heat	41	5	1100 on-heat	30	2
1600 on-heat	42	7	1600 on-heat	25	3
1859 on-heat	41	4	1972 on-heat	35	20
2422 peak T	50	8	2422 peak T	52	10
1859 on-cool	57	8	1972 on-cool	86	11
1600 on-cool	98	27	1600 on-cool	93	13
1100 on-cool	196	54	1100 on-cool	101	11

Table 2 — (continued)

Temp (°F)	EN82H Grain diam. (μm)	Std. dev. (μm)	Temp (°F)	EN52 Grain diam. (μm)	Std. dev. (μm)
As-solidified	153	36	As-Solidified	294	40
1600 on-cool from 1967	158	38	1600 on-cool from 2077	269	51
1600 on-cool	142	34	1600 on-cool	263	50
1600 on-cool	158	38	1600 on-cool 2077	269	51
60-s hold @ 1600	144	38	60-s hold @ 1600	293	50

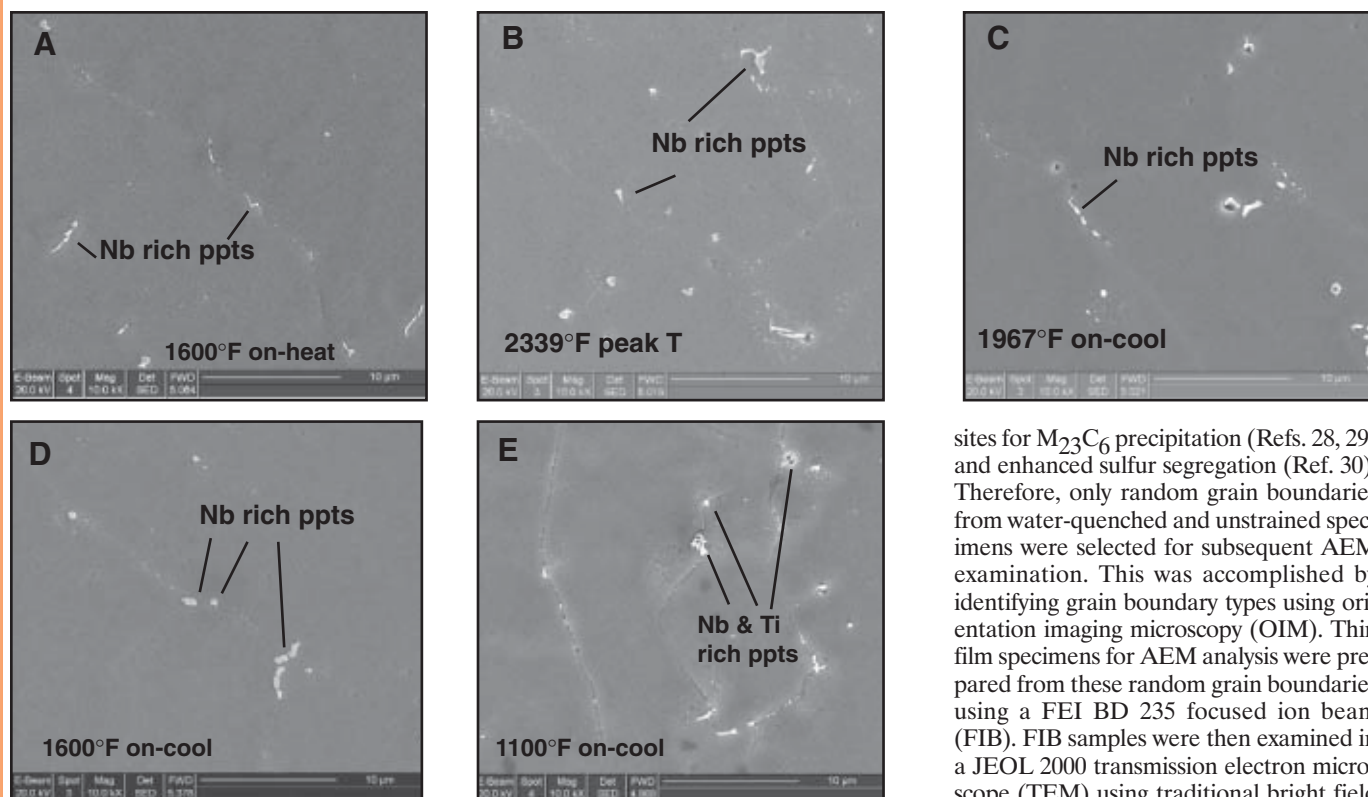


Fig. 5 — FM82H water-quenched SEM micrographs. A — 1600°F on-heating; B — 2339°F peak temperature; C — 1967°F on-cooling; D — 1600°F on-cooling; and E — 1100°F on-cooling. EDS used to identify composition of various regions and precipitates indicated on micrographs.

polishing media from intergranular crack surfaces while preserving their microstructure. The samples were then electrolytically etched at 2–3 V for 3–10 s in a solution containing equal parts by volume of water and sulfuric and phosphoric acid. Grain size measurements were carried out on water-quenched specimens using the Abrams Three-Circle procedure as detailed in ASTM E112 (Ref. 27). This method compensates for nonequiaxed grain shapes, which is to be expected in the weld metal samples.

The general microstructure and chemistry of second phases was characterized using either an FEI DB 235 or Hitachi 4300 Schottky field emission gun scanning electron microscope (FEG-SEM) with an energy-dispersive spectrometer (EDS).

All operation was performed using 20-keV accelerating voltage. An Everhart-Thornley detector, commonly known as a secondary electron detector (SED), was used for all SEM images. The scale markers differ for the two microscopes. Images captured using the Hitachi 4300 use a 10-dot marker with the scale indicated on the lower right corner of the image. Samples mounted in epoxy were lightly coated with carbon to prevent charging. These FEG-SEMs and operating conditions enabled particles as small as 20 nm in size to be resolved.

Previous research has shown that grain boundaries with random orientations are the most susceptible to ductility dip cracks (Ref. 24). It has also been shown that these same random boundaries are preferential

sites for $M_{23}C_6$ precipitation (Refs. 28, 29) and enhanced sulfur segregation (Ref. 30). Therefore, only random grain boundaries from water-quenched and unstrained specimens were selected for subsequent AEM examination. This was accomplished by identifying grain boundary types using orientation imaging microscopy (OIM). Thin film specimens for AEM analysis were prepared from these random grain boundaries using a FEI BD 235 focused ion beam (FIB). FIB samples were then examined in a JEOL 2000 transmission electron microscope (TEM) using traditional bright field and dark field imaging techniques. The grain boundary chemistry of the thin films were examined in a VG 603 dedicated scanning transmission analytical electron microscopy (AEM), operated at 300 kV and fitted with a Nion spherical aberration corrector.

The VG 603 was used to generate compositional maps, line scans, and point analyses using EDS, and capture dark field images using a high-angle annular dark field detector (HAADF). The compositional maps were 128×128 pixels in size and collected using a 200-ms dwell time at each pixel. An EDS spectrum file was generated for each map. Background subtracted compositional maps were generated for each element of interest using the computer software program Digital Micrograph version 1.6.1 by integrating the number of counts in the K_{α} peak of each element of interest and subtracting that by a background window. The point analyses and line scans were collected using 120 s of live time per point, which did not result in any specimen contamination or discernable damage. The composition of Fe, Ni, and Cr were quantified using the Cliff-Lorimer technique (Ref. 31), and integrated K_{α} peak intensities that were background subtracted for each element. The measurement error of each AEM data point was calculated using the quadrature sum technique (Ref. 32). Experimentally determined Cliff-Lorimer sensitivity factors or “k-factors” were generated from an FM52 sample that was homogenized by isothermal hold for 10 min at 2350°F (1288°C) in the Gleeble®, then water quenched.

Table 3 — JMatPro Calculated Carbide Solvus Temperatures for the Predominant Carbides in Each Alloy and the Time above Calculated Carbide Solvus Temperatures during Simulated Weld Reheat Thermal Cycle

Alloy	Intergranular Carbide	Calculated Carbide Solvus (°F)	Time above Calculated Carbide Solvus (s)
A600	M_7C_3	1859	9.1
FM82H	MC	2196	2.3
FM82H	M_7C_3	1967	6.0
A690	$M_{23}C_6$	1972	7.3
FM52	$M_{23}C_6$	2077	5.3

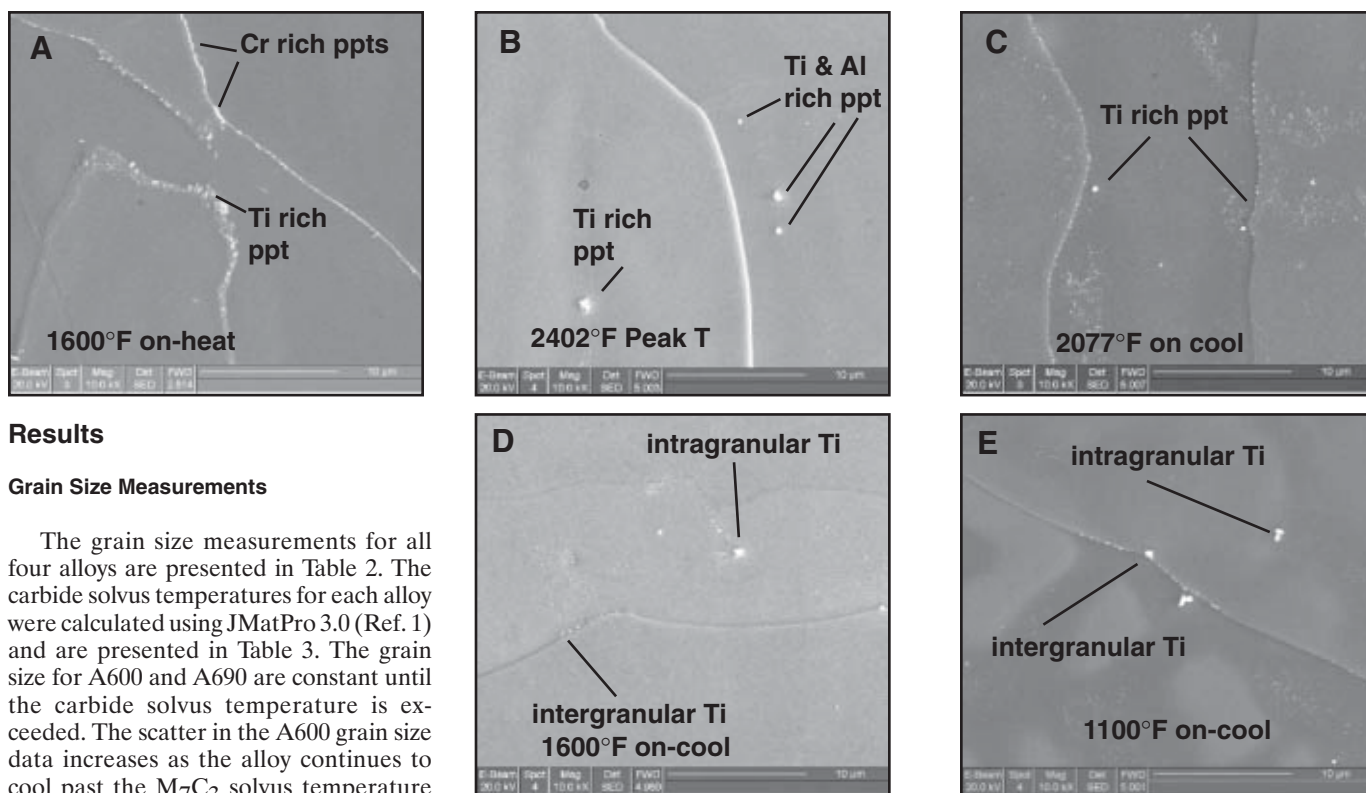


Fig. 6 — FM52 water-quenched SEM micrographs. A — 1600°F on-heating; B — 2402°F peak temperature; C — 2077°F on-cooling; D — 1600°F on-cooling; and E — 1100°F on-cooling. EDS used to identify composition of various regions and precipitates indicated on micrographs.

Results

Grain Size Measurements

The grain size measurements for all four alloys are presented in Table 2. The carbide solvus temperatures for each alloy were calculated using JMatPro 3.0 (Ref. 1) and are presented in Table 3. The grain size for A600 and A690 are constant until the carbide solvus temperature is exceeded. The scatter in the A600 grain size data increases as the alloy continues to cool past the M_7C_3 solvus temperature (1859°F (1015°C)). There is less scatter in the grain size data of A690. The average grain size of FM82H and FM52 remains stable, even though the standard deviation is larger than that observed for the two wrought alloys.

Microstructural Characterization: SEM

The thermal effects on the microstructural evolution of the four alloys during the first thermal cycle are shown in Figs. 2 through 6. The microstructures at five key temperatures are displayed for each alloy. The first micrograph is for 1600°F (871°C) on-heating. In all four alloys there was no microstructural change observed between the starting condition (wrought or as-solidified) up to the carbide solvus temperature on-heating. Therefore, the 1600°F (871°C) on-heating micrograph is representative over this range of temperatures. The grain boundaries of all alloys were decorated with carbides in their starting condition and up to their respective carbide solvus temperatures. In A600 the grain boundaries are decorated with globular chromium-rich precipitates, which have previously been shown to be M_7C_3 carbides (Refs. 33, 34). In A690 chromium-rich $M_{23}C_6$ carbides are predominant (Refs. 28, 35). Both intra and intergranular Nb-rich MC carbides are present in FM82H (Ref. 36). FM52 contains both titanium- and chromium-rich second phases. The titanium-rich phase is a carbo-nitride and occurs both intra and intergranularly, while the chromium-rich phase is $M_{23}C_6$, and is only found inter-

granularly (Ref. 36). Because the phases formed in each alloy are well known, only EDS was used to qualitatively confirm the types of the second-phase particles.

The second micrograph is for the peak temperature of each alloy, which corresponds to the nil strength temperature (NST) -25°F. At this temperature the microstructural development differs for each alloy. In A600 there was partial dissolution of intergranular carbides. Additionally, a small degree of grain boundary migration was observed in grain boundaries that were no longer pinned by carbides. The carbide dissolution produced dark regions in the matrix as seen in Fig. 2B. The composition of these dark regions was ana-

lyzed using EDS and compared to the matrix, as seen in Fig. 3. The integrated x-ray counts in the chromium K_{α} peak of the dark region were found to be 9% greater than in the matrix, confirming that the dark region was enriched in chromium. These EDS results are corroborated by the atomic number contrast exhibited between the chromium-rich region and the matrix. Increasing chromium concentration will decrease the average atomic number, which causes these regions to appear darker.

At the peak temperature in A690 and FM52 (Figs. 4B and 6B), there was complete dissolution of chromium-rich carbides. Chromium-rich regions in the A690

Table 4 — AEM Point Data for FM52 Specimens from Various Thermal Conditions. Absolute Error for Each Element in wt-% is as Follows: Ni $\pm$ 0.9, Cr $\pm$ 1.2, Fe $\pm$ 1.2

Condition	Location	Ni	Cr	Fe
1600°F on-heating	Grain boundary	66.3	21.4	10.5
	Matrix	58.9	29.8	9.6
	Precipitate	13	81.5	3.8
1600°F on-cooling	Grain boundary	57.9	30.4	9.9
	Matrix	58.3	30.2	9.7
	Precipitate	no Cr- rich precipitates		
60-s hold at 1600°F on-cooling	Grain boundary	65.9	21.2	11.2
	Matrix	58.7	29.6	9.9
	Precipitate	11.4	83.1	3.5

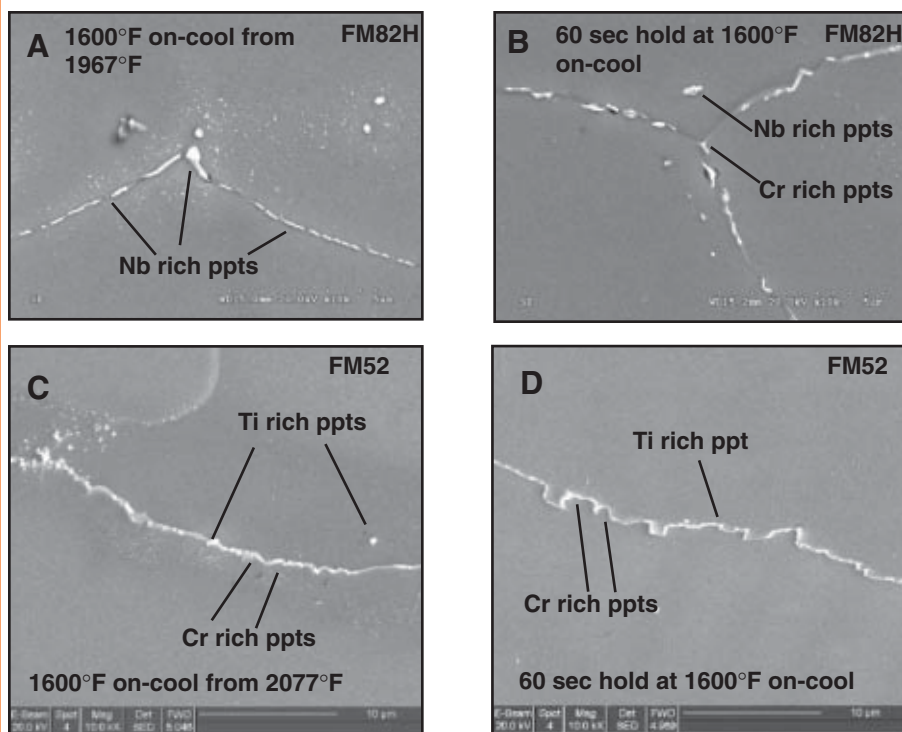


Fig. 7 — SEM micrographs of FM82H (A and B) and FM52 (C and D) that were water quenched at 1600°F on-cooling from the carbide solvus temperature (A and C), and water quenched after a 60-s hold at 1600°F on-cooling from NST-25°F.

matrix remained where intergranular carbides were once located, similar to A600. These chromium-rich regions traced out the former location of grain boundaries, which had all migrated away from their original locations. The only second phases existent at the peak temperature of both A690 and FM52 were Ti(C,N). There is no discernable microstructural change in A690 and FM52 at the on-cooling $M_{23}C_6$ solvus temperature (Figs. 4C and 6C), which is 1972°F (1078°C) and 2077°F (1136°C), respectively. Extensive interrogation of precipitates using EDS revealed that only Ti(C,N) precipitates remain over this temperature range. For example, all the second phases present in Fig. 6C contain titanium, thereby precluding them from being $M_{23}C_6$. However, at 1600°F (871°C) on-cooling there are intergranular chromium-rich carbides in A690 that are not present in FM52 at the same temperature. These chromium-rich intergranular precipitates are found to be inhomogeneously precipitated on A690 grain boundaries that intersect the chromium-rich regions of the matrix that remain after the dissolution of blocky $M_{23}C_6$ intergranular carbides. Figure 4D shows a region where the grain boundary carbide coverage is relatively high for this alloy and temperature; however, much of the grain boundary length was free of chromium-rich carbides. In both A600 and A690 the intergranular carbide cover-

age is much greater on-heating than it is on-cooling.

The carbide dissolution behavior in A600 is distinctly different than in A690 and FM52. In A600 there are regions of grain boundaries where the intergranular carbides never fully dissolve during the super solvus portion of the thermal cycle. This is shown in Fig. 2C, which is taken on-cooling at the M_7C_3 solvus for A600 (1859°F (1015°C)). As the alloy cools these carbides coarsen, as shown in Fig. 2D, which is taken at 1600°F (871°C) on-cooling. The carbide content may also increase due to precipitation below the carbide solvus temperature. However, this intergranular carbide coverage is not uniform, as some boundaries contain very few precipitates, as seen in Fig. 2E, which is at 1600°F (871°C) on-cooling. In this region the carbides fully dissolved and have yet to reprecipitate. Additionally, both the intergranular carbide morphology and grain boundary carbide coverage for both A600 and A690 at 1600°F (871°C) on-cooling is significantly different than at 1600°F on-heating. The micrographs shown in Figs. 2D and 4D represent the greatest amount of intergranular precipitation observed in both A600 and A690 at 1600°F on-cooling.

There were three different levels of intergranular carbide dissolution observed with the four alloys. A690 and FM52 experienced complete intergranular chromium-carbide dissolution, while the

chromium-carbide dissolution in A600 was incomplete. In FM82H there was no discernable dissolution of the NbC precipitates throughout the thermal cycle. Qualitatively, it appeared that there may be a slight increase in intergranular NbC precipitates at the peak temperature as seen in Fig. 5B. The FM82H microstructure remains very stable, as can be seen in the micrographs at 1600°F (871°C) and 1100°F (593°C) on-cooling.

The microstructural results from modifying the thermal cycle in FM82H and FM52 are shown in Fig. 7. Increased intergranular carbide coverage was observed when the peak temperature was lowered to the respective carbide solvus for each alloy. The time at the solvus temperature was short (less than 0.25 s) and insufficient to cause any carbide dissolution. An isothermal hold at the on-cooling ductility minimum temperature (1600°F (871°C)) for 60 s also produces increased intergranular carbides in both alloys. Additionally, some of the grain boundaries in FM52 become more serrated as a result of the isothermal hold.

Microstructural and Microchemical Characterization: AEM

The experimentally determined Cliff-Lorimer sensitivity factors and associated standard deviation were found to be $k_{FeNi} = 0.913 \pm 0.0068$ and $k_{CrNi} = 0.861 \pm 0.0044$. The thin foils prepared using the FIB technique were first examined using a TEM to determine that they were suitable for subsequent analysis. This examination involved using electron diffraction to confirm the location of grain boundaries prior to analysis in the AEM. All of the boundaries are oriented vertically in the following AEM maps. Figure 8 displays the AEM results from an FM52 1600°F on-heating. The dotted line in the HAADF image denotes the grain boundary. Chromium-rich precipitates are observed adjacent to a titanium-rich precipitate. No sulfur or phosphorous were detected in the AEM maps collected from this condition, nor were they detected in any spot analysis performed on the boundary or in the matrix. Table 4 contains quantified point analyses data collected from the grain boundaries and matrix. It was found that the grain boundaries in FM52 at 1600°F on-heating were depleted in Cr (21.4 vs. 29.8 wt-%) and enriched in Ni (66.3 vs. 58.9 wt-%) as compared to the matrix, while there was no difference in Fe concentration (~10 wt-%) given the experimental error.

The AEM mapping results for FM52 1600°F (871°C) on-cooling from the NST-25°F temperature are presented in Fig. 9. The dotted line in the HAADF image denotes the grain boundary. No chromium-

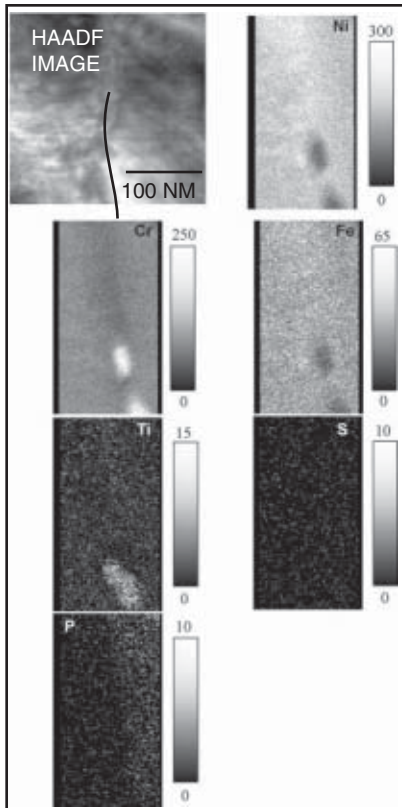


Fig. 8—AEM results from FM52 1600°F on-heating, water-quenched sample. Dotted line in HAADF image delineates grain boundary. Grayscale bar indicates number of integrated x-ray peak counts above background.

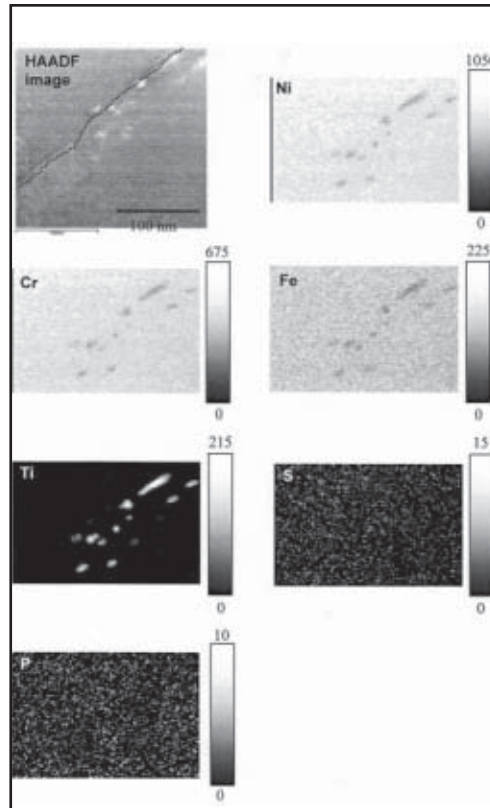


Fig. 9—AEM results from FM52 1600°F on-cooling from NST-25°F, water-quenched sample. Dotted line in HAADF image delineates grain boundary. Grayscale bar indicates number of integrated x-ray peak counts above background.

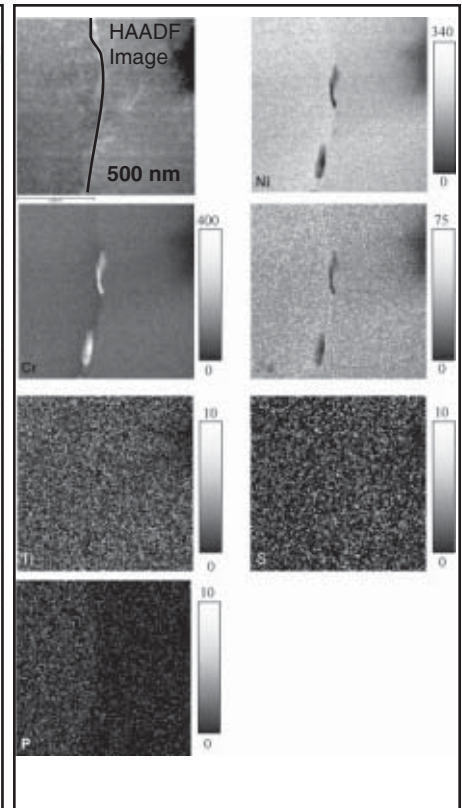


Fig. 10—AEM results from FM52 60-s hold at 1600°F on-cooling from NST-25°F, water-quenched sample. Dotted line in HAADF image delineates grain boundary. Grayscale bar indicates number of integrated x-ray peak counts above background.

rich precipitates were observed in this condition; however, titanium precipitates are observed along the grain boundary. The smallest precipitate that was resolved in all of the AEM work was a seven-nm-diameter titanium precipitate in this thermal condition. The concentrations of iron, nickel, and chromium along the grain boundary in the composition maps are indistinguishable from those in the matrix. This similarity is quantified by use of spot measurements, which are recorded in Table 4. This shows that not only did the peak temperature portion of the thermal cycle dissolve the chromium-rich carbides, but it homogenized the near grain boundary concentration profiles of nickel and chromium that were existent at 1600°F (871°C) on-heating.

Figure 10 shows the results for FM52 after a 60-s hold at 1600°F (871°C) on-cooling from the NST-25°F temperature. Larger chromium-rich intergranular precipitates are observed in this condition, which necessitated that the compositional map displayed in Fig. 10 be collected at a lower magnification than for the 1600°F on-heating and 1600°F on-cooling conditions. Like these other two conditions, no sulfur or phosphorous was detected in any

AEM map, nor in any point analysis in the 60-s hold condition. Like the 1600°F on-heating condition, there is chromium depletion (21.2 vs. 29.6 wt-%) and nickel enrichment (65.9 vs. 58.7 wt-%) along the grain boundaries as compared to the matrix. The chromium concentration adjacent to the precipitate-matrix interface is different on each side of the precipitate, as seen in Fig. 11. The interface that the precipitate has with the grain on the right exhibits no chromium depletion (~29.5 wt-% Cr), while the chromium concentration at the interface the same precipitate has with the other grain is only approximately 24 wt-% on one side of the precipitate.

The detectability of any element using EDS is a function of collection live time (Ref. 37). Therefore, to improve the detectability of sulfur and phosphorous, EDS spectra collected from multiple AEM maps and point analyses were summed. This was performed for data collected from FM52 specimens quenched at the ductility minimum temperature, 1600°F (871°C) on-cooling from NST-25°F. EDS data from nearly 23,000 pixels located near grain boundary region of 13 different boundaries were added, which resulted in the EDS spectrum in Fig. 12A.

This summed EDS spectrum had a total live time of 76 min. No sulfur or phosphorous were detected. Similarly, EDS spectra from multiple 120-s live time point analyses were summed to produce Fig. 12B, which had a total live time of 16 min. Once again, there was no evidence of sulfur or phosphorous.

Fractography

A ductility dip crack from an FM52 specimen tested at 1600°F on-cooling that was water quenched immediately after fracture is shown in Fig. 13. The fracture surface contains both dimpled and wavy regions. The wavy regions are the dominant fracture surface appearance in ductility dip crack of all four alloys. The fracture surface is decorated with chromium-rich precipitates, as determined by EDS, that are 200–300 nm in width (Fig. 13B). Intergranular precipitates with similar size, morphology, and chemistry (chromium rich) are observed on the grain boundary adjacent to ductility dip crack (Fig. 13C and D). Intergranular cavities are found adjacent to these precipitates, as seen in Fig. 13D.

For the purpose of comparison, Fig. 14

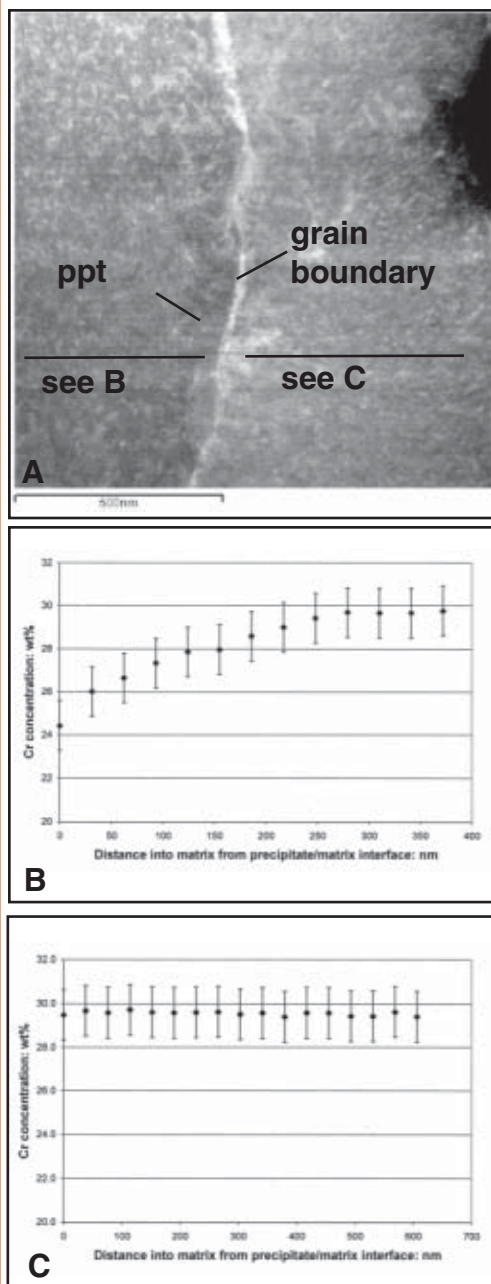


Fig. 11 — AEM chromium concentration profiles as a function of distance from precipitate matrix interface in the FM52 60-s hold at 1600°F on-cooling water quenched sample. HAADF image in A is the same as that in Fig. 10; B and C are the chromium concentration profiles to the left and right of the precipitate, respectively.

is a SEM fractograph of a ductility dip crack taken from a multipass weld of FM52 that was fabricated as part of previous work (Refs. 22, 20). The fracture surface of the multipass weld is quite similar to the DDC fracture surface in the Gleeble® hot ductility specimen (Fig. 13). Each fracture surface exhibits a wavy appearance and is decorated with chromium-rich carbides that are approximately 200–300 nm in size.

Figure 15 is the fracture surface from an FM52 specimen held at 1600°F (871°C) for 60 s before being hot ductility tested. The

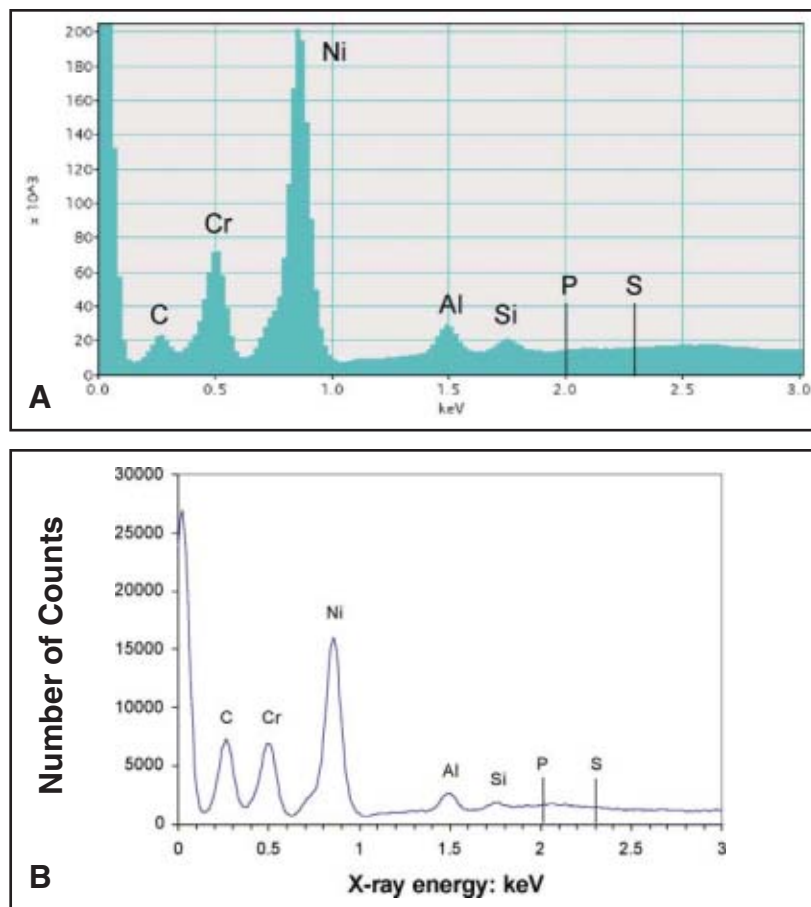


Fig. 12 — EDS spectra from FM52 water quenched at 1600°F on-cooling from NST-25°F grain boundary regions. A — Sum from compositional maps; B — sum from point analyses.

tensile axis is oriented in the horizontal direction. This crack shares some similar features with those observed in the specimen fractured at 1600°F without any hold (Fig. 13). Additionally, in both conditions the samples have intergranular cavities along the grain boundary adjacent to the ductility dip crack. The difference is that the precipitates in the 60-s hold specimen are significantly larger and have a disc shape (Fig. 15B and C) compared to those observed in the sample without the hold. The interprecipitate cavities are also clearly seen between the precipitate discs on the fracture surface in Fig. 15D.

Discussion

Influence of Microstructure on Grain Size Evolution

The changes in grain size throughout the thermal cycle are a function of the precipitate dissolution behavior. In A600 and A690 the grain size remains stable on-heating up the respective carbide solvus temperature. This is the result of intergranular carbides pinning the boundaries

and preventing them from migrating. Other investigators have reported similar findings for A690 (Refs. 38–40). At temperatures above the carbide solvus the grain size of A690 begins to increase considerably while that of A600 only changes slightly. This is the result of the complete dissolution of intergranular carbides in A690 and incomplete dissolution in A600. As the temperature continues to decrease on-cooling the grain size in A690 stabilizes due to the formation of intergranular precipitates at locations where the boundary intersects chromium-rich regions in the matrix that are remnants of previously dissolved intergranular carbides. In A600 the grain boundaries that contain carbides remain pinned, while those that do not contain carbides continue to migrate even as the temperature drops to 1100°F (593°C) on-cooling. It is for these reasons that the grain size standard deviation for A600 at 1600°F (871°C) and 1100°F on-cooling is so large.

While the grain size varies with temperature in the wrought alloys it is essentially constant in both of the weld metal alloys, FM82H and FM52. The stable average grain size for the two weld metals can be at-

tributed to two factors. First, the driving force for grain growth is inversely proportional to grain size. The as-solidified grain size in FM52 is nearly 10 times greater than that in A690; therefore, there is much less driving force for grain growth in FM52 than in A690. The second cause for the stable average grain size is shown in Figs. 5 and 6. There are intergranular Nb- and Ti-rich precipitates in FM82H and FM52, respectively, which never fully dissolve during the peak temperature portion of the thermal cycle. The NbC second phases are not expected to dissolve before liquation would occur because they are a terminal solidification product. These precipitates pin the grain boundaries and prevent grain growth in just the same way as was seen for A600 and A690 on-heating. There is a larger standard deviation about the average grain size in both the weld alloys as compared to the wrought alloys. This variation is not the result of abnormal grain growth since there was no evidence of large scale grain boundary migration. This variation can be attributed to the competitive grain growth that occurs during solidification of the weld metal. Grains that have their easy growth direction ($\langle 100 \rangle$ in face-centered cubic) oriented in the direction of the maximum heat extraction (temperature gradient) will grow the fastest, resulting in the largest grains in the solidified weld metal. These fast growing grains will crowd out the growth of grains where the easy growth direction is not as favorably oriented to the direction of heat flow.

Although the grain size for FM52 ranges from 3 to 10 times larger than that of A690, they both exhibit a very similar ductility minimum ($\sim 38\%$ RA) and increase in ductility dip cracking at 1600°F (871°C) on-cooling. The grain sizes of A600 and A690 at 1600°F are similar, yet at this same temperature A690 has a significantly lower ductility and higher normalized ductility dip crack length (Ref. 1). Thus, the observed differences in DDC susceptibility cannot be explained by grain size.

Microstructural and Microchemical Characterization: AEM

The FEG-SEM combines good resolving power with the ability to examine a comparatively large surface area (compared to the TEM), which was approximately $10^6 \mu\text{m}^2$ in the case of the samples examined in this work. However, its analytical resolution is limited to approximately $1 \mu\text{m}^3$ due to incident electron-specimen interactions that occur in bulk specimens. Conversely, the analytical resolution of FEG analytical electron microscope (FEG-AEM) permits detection

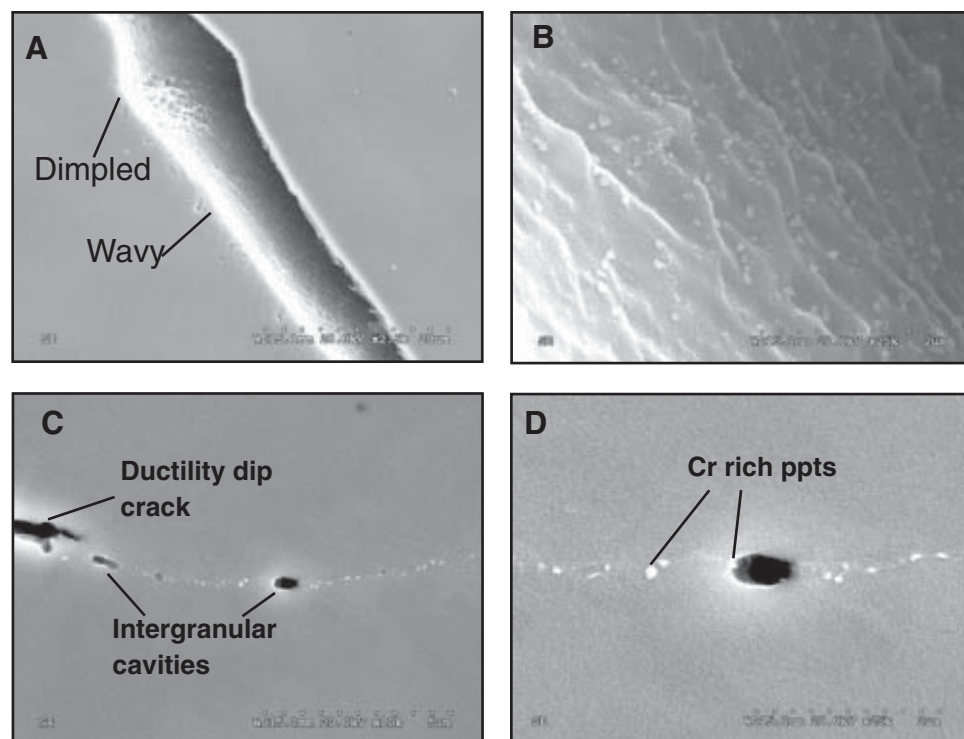


Fig. 13 — SEM micrographs of ductility dip crack in FM52 1600°F on-cooling hot ductility sample, immediately water quenched after fracture. A — Ductility dip crack with both dimpled and wavy regions; B — precipitates on the fracture surface in wavy region of A; C and D — precipitates along grain boundary adjacent to ductility dip crack in A and B.

down to $10^{-5} \mu\text{m}^3$ (Ref. 37), but the total sample surface area that can be examined is limited to approximately $100 \mu\text{m}^2$.

For the above reasons, specimens to be examined using AEM must be carefully selected so that they are representative. It has been shown that DDC is most likely to form on grain boundaries that have a random coincident site lattice (CSL) orientation (Ref. 24). Random boundaries have also been shown to be more prone to form M_{23}C_6 precipitates in A690 (Ref. 28) and 304 stainless steel (Ref. 29) due to the greater surface energy associated with random boundaries. In grain boundary segregation studies performed using high purity nickel doped with sulfur, random boundaries were found to have the greatest degree of sulfur segregation (Ref. 30). Therefore, of all grain boundaries that could be examined in the AEM, random grain boundaries are the most important since they are most susceptible to ductility dip cracking, forming precipitates, and having impurity elements segregate to them. In this work only random boundaries were examined in the TEM and AEM.

The AEM maps were performed at magnifications ranging from 100,000 to 1,000,000 $\times$. Each pixel ranged from 9.1 to 0.91 nm in size. The AEM results corroborate the SEM observations that intergranular chromium-rich precipitates were present in FM52 when the DDC resist-

ance at 1600°F (871°C) was high: at both 1600°F on-heating and after a 60-s hold at 1600°F on-cooling. At the ductility minimum temperature in FM52 (1600°F on-cooling) there were no chromium-rich carbides observed in the FEG-SEM or AEM. Only precipitates containing titanium were observed in the water quenched, unstrained samples examined in the FEG-SEM or AEM. The smallest second phase resolved in the AEM work was 7-nm-diameter titanium-rich precipitate; therefore, if chromium-rich precipitates are present at 1600°F on-cooling in FM52, they must be smaller than 7 nm in size. This effective resolution limit would correspond to approximately seven M_{23}C_6 unit cells and the clustering of approximately 580 chromium atoms given the crystallography (Ref. 41) and typical composition of M_{23}C_6 (Ref. 42).

The composition of the chromium carbides along the grain boundaries in FM52 (Table 4) are in good agreement with similar compositional measurements of M_{23}C_6 made by others (Refs. 42, 43). However, this compositional data actually provides an overestimate of the metallic content (Fe, Ni, and Cr) of the precipitate. This is because the Cliff-Lorimer technique collectively groups the concentration of all elements other than Fe, Ni, and Cr into a remainder term. For the bulk composition of FM52 that remainder is $\sim 1.74 \text{ wt}\%$. However, in the M_{23}C_6 car-

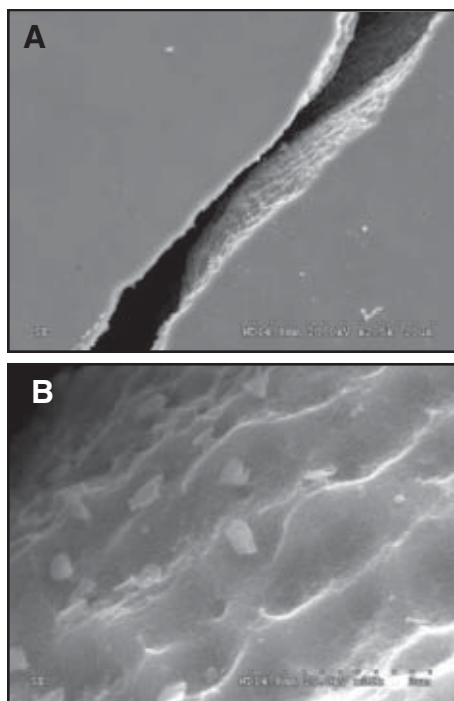


Fig. 14 — SEM fractographs taken from ductility dip crack in FM52 multipass weldment. A — Lower magnification revealing intergranular nature of crack; B — higher magnification that shows chromium-rich carbides on a wavy fracture surface.

bide the remainder term is actually ~ 5.7 wt-%. This leads to an overestimation of the metallic concentration in the carbide.

Approximately the same degree of chromium depletion is observed along the grain boundary, 25 nm away from the precipitate (21.3 ± 1.15 wt-%), as is observed directly adjacent to the precipitate at the precipitate-matrix interface (24.4 ± 1.15 wt-%) at 1600°F (871°C) on-heating, and after a 60-s hold at 1600°F on-cooling. AEM maps reveal that the grain boundary chromium depletion exists along the entire length of the boundary as seen in Figs. 8 and 10. This is a result of the nearly five order of magnitude greater chromium diffusivity along the grain boundary as compared to the matrix at 1600°F (Ref. 44). The grain boundary acts as a fast diffusion pathway for chromium in the matrix far away from the precipitate, where it is rapidly transported to the growing intergranular chromium carbide.

The asymmetric chromium depletion profiles adjacent to the precipitate-matrix interface as shown in Fig. 11 can be attributed to the growth behavior of the precipitate. As seen in Fig. 11A, the precipitate is growing from the grain boundary into the grain on the left. As the precipitate grows it preferentially depletes chromium from the left grain, thereby resulting in the asymmetric chromium depletion. Not only are the concentration profiles different on either side of the precipitate, but so is the shape of the precipitate matrix interface.

The interface the precipitate makes with the left grain is curved, while the interface with the grain on the right is straight. To minimize interfacial energy, an incoherent interface is expected to be curved. A curved incoherent interface reduces the interfacial surface area per unit volume of precipitate, thereby decreasing the interfacial energy. To the contrary, to minimize interfacial strain energy a partially coherent interface is much more likely to be straight due to the orientation relationship that the precipitate shares with the matrix. The significance of this finding to DDC will be discussed later in this paper in light of the precipitation-induced cracking hypothesis.

The precipitates and chromium depletion existent at 1600°F on-heating in FM52 are no longer present at 1600°F on-cooling. This is distinctly different than the dissolution and on-cooling precipitation behavior of A690. In A690 some intergranular chromium-rich carbides are observed at 1600°F on-cooling. These carbides form at locations where the migrated grain boundary intersects chromium-rich regions in the A690 matrix. The difference in dissolution and precipitation behavior of A690 and FM52 is related to grain boundary migration. In both alloys the peak temperature results in carbide dissolution, but in FM52 the grain boundaries remain fixed while they are found to migrate in A690. FM52's fixed grain boundaries provided a rapid diffusion path for chromium as the precipitate dissolved. This resulted in the homogenization of the near grain boundary microchemistry in FM52. This process does not happen in A690 where the boundaries migrate away from their original location, thereby leaving chromium-rich regions in the matrix where intergranular $M_{23}C_6$ precipitates were once located.

In preparation for the AEM analysis performed in this work, Desktop Specimen Analyzer (DTSA) (Ref. 45) was utilized to estimate the minimum detectability limit (MDL) of sulfur and phosphorous. This was done using the FM52 composition and the analytical conditions of the VG 603 microscope for a collection live time of 120 s. Each DTSA spectrum was generated with the addition of Poisson's noise, which occurs with EDS analysis and degrades the MDL. Assuming a 200-nm-thick specimen, which is reasonable given the weld metal FIB specimens, the MDL for sulfur and phosphorous was below 0.1 wt-%. This limit applies not only to individual point analyses but to the summed EDS spectra shown in Fig. 12. This MDL is more than an order of magnitude lower than the ~ 5 wt-% sulfur that would have to be segregated to the grain boundary to cause em-

brittlement (Refs. 14, 15). Furthermore, this very same AEM, operated under similar conditions, was able to detect intergranular sulfur in Ni at concentrations less than 3 wt-% (Refs. 46, 47), which further validates the approach taken in the current work. Furthermore, the grain boundaries examined in the AEM were random, and thereby most likely to experience segregation of sulfur. Still, no sulfur or phosphorous segregation were detected in FM52 at 1600°F (871°C) on-heating, 1600°F on-cooling (ductility minimum), or after a 60-s hold at 1600°F on-cooling.

The summed EDS spectra from the AEM map and point analyses in Fig. 12 have a similar shape with the exception of carbon. In the summed point analyses spectrum the carbon peak has a higher ratio with the other peaks than that observed for the summed AEM maps. This may be the result of increased carbon contamination that occurred during the point analyses where the electron beam was stationary on the sample for approximately 2.5 min/measurement. During the collection of maps, the total time ("real time") the probe dwelled at each pixel was about 240 ms. The longer collection dwell time with the point analyses would be expected to result in greater carbon contamination and a larger carbon peak in the summed EDS spectra (Fig. 12B).

Fractography

A variety of intergranular fracture surfaces have been shown for ductility dip cracks formed at various temperatures (Ref. 19). However, no direct comparisons have been made between the fracture surfaces generated as part of Gleeble®-based testing and those observed in actual multipass welds. In the current work the DDC fracture surface in an FM52 multipass weld (Fig. 14) was found to be very similar to that observed in an FM52 Gleeble® hot ductility specimen fractured at 1600°F (871°C) on-cooling (Fig. 13). Both fracture surfaces have a wavy appearance and contain chromium-rich carbides. It has also been suggested that the DDC susceptibility of FM52 is at a maximum at very high temperatures ($\sim 2400^\circ\text{F}$ (1316°C)) (Ref. 21). However, the similarity between the FM52 multipass weld and the FM52 1600°F on-cooling sample (Fig. 13 and 14, respectively) indicates that the DDC mechanism was reproduced in the Gleeble®. It also supports the hypothesis that ductility dip cracks in the multipass welds occur within the same on-cooling intermediate temperature range as the Gleeble® on-cooling ductility dip (1475°–1725°F (802°–941°C)). This hypothesis is further supported when combined with the crack count data (Fig. 14 in the Part I article (Ref. 1)), which exhibits a peak in

normalized total DDC crack length over the same temperature range. A similar trend has also been shown for DDC in Invar (Ref. 3).

Interpreting DDC fracture surfaces can provide further insight into the cracking mechanism. The shape of the fracture surface features can provide insight into the loading conditions that caused fracture. For example, a hard particle located in a ductile matrix that is subjected to uniaxial tension will form microvoids with the particle located at the center of the void. If the hard particle is located on a boundary that experiences sliding, the voids will form at the precipitate/boundary interface with the particle off-center of the void. This latter type of voiding is observed along grain boundaries in both Figs. 13 and 15 ahead of the ductility dip crack tip. If the ductility dip crack were to advance, these precipitate/cavity intergranular features would be incorporated onto the DDC fracture surface. The precipitates would be present between the cavities on the fracture surface instead of being at the center of the cavities as would be the case if the loading was simply tensile.

The way of fracture surface morphology has been observed in wedge cracks formed during creep testing of copper (Ref. 49) and tungsten (Ref. 50) whose grain boundaries were free of precipitates. The formation of these cracks has been attributed to the formation of cavities due to GBS followed by the coalescence of these cavities to form the crack (Ref. 50). This fracture surface appearance is consistent with GBS. However, it has also been suggested that the precipitation of partially coherent intergranular $M_{23}C_6$ carbides may also result in intergranular voids that form between precipitates (Ref. 20). This may come about because the misfit at the precipitate-matrix interfaces places the matrix in compression. The region of grain boundary between the precipitates would then be placed into tension.

Strain has a significant influence on precipitation of $M_{23}C_6$ carbides in FM52. At 1600°F (871°C) on-cooling, no chromium-rich precipitates are observed in the water quench sample that was not strained (Figs. 6 and 9). However, chromium-rich precipitates are observed on the fracture surface and intergranularly in FM52 that was hot ductility tested at 1600°F on-cooling followed immediately by a water quench in Fig. 13. In this sample only 1.4 s transpired between the time the hot ductility test was initiated at 1600°F, fractured, and then water quenched to 575°F (302°C). At this lower temperature no precipitation reaction is expected to occur (Ref. 1). An increase in precipitation and coarsening of $M_{23}C_6$ has been reported in multiple austenitic alloys under a variety of straining condi-

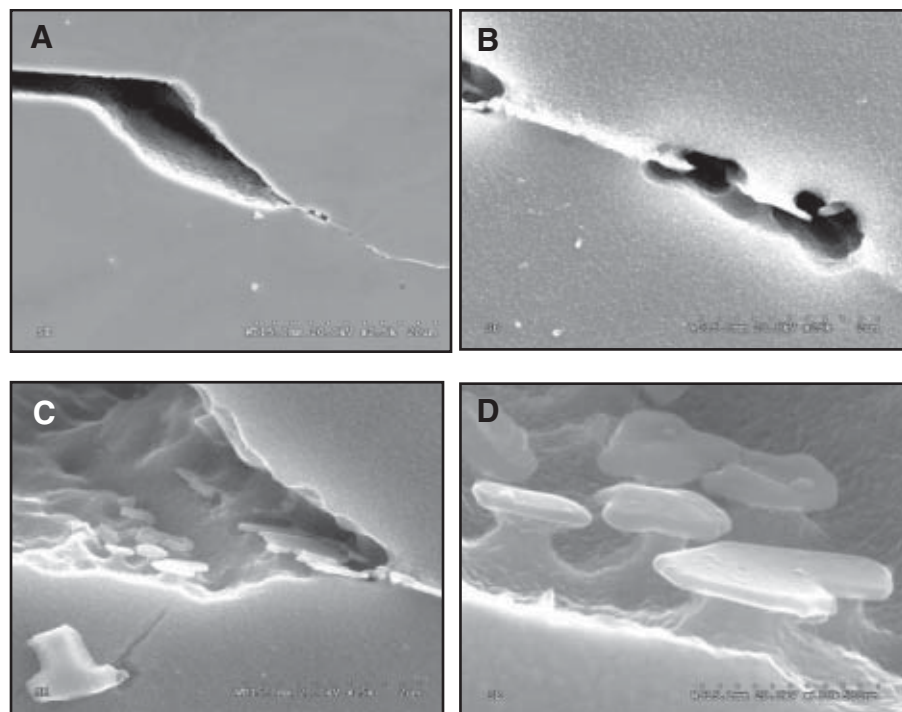


Fig. 15 — SEM fractographs from FM52 60-s hold at 1600°F hot ductility sample. A — Low magnification; B — higher magnification of voiding along intergranular precipitates; C — fracture surface; and D — chromium-rich precipitate discs along fracture surface.

tions (Refs. 51–53). In general, the kinetics of precipitation and coarsening increase with strain due to an increase in diffusivity of chromium and decrease in the thermodynamic barrier to nucleation (Ref. 51). This increase can be more than an order of magnitude greater than the precipitation kinetics of $M_{23}C_6$ in strain-free samples (Refs. 51, 53).

Predominant DDC Hypotheses in Light of Experimental Observations

P and S Embrittlement

No evidence was found that would support phosphorous and sulfur embrittlement as the cause for ductility dip cracking during the weld thermal cycle. DDC occurs in FM52 and A690 irrespective of the low sulfur and phosphorous concentrations: < 10 wt ppm S, and ≤ 50 wt ppm P in the bulk chemistry for both alloys. Therefore, it does not appear that S and P can be the cause of DDC, although increasing their concentration will most likely exacerbate DDC. Previous work performed on samples sectioned from FM52 multipass welds has revealed increases in phosphorous and sulfur concentrations at intergranular fracture surfaces (Ref. 12) and on DDC fracture surfaces (Ref. 16). As such, it is not possible to determine when the phosphorous and sulfur segregated to the boundaries.

The solubility of sulfur in nickel is at a

maximum at 2192°F (1200°C), 0.1 wt-%, then decreases to approximately 0.003 wt-% at 1179°F (Ref. 54). Although the phase boundary lines in the Ni-S system may change with the addition of chromium, iron, and other elements present in A690 and FM52, the general solubility trend can be useful to understanding the potential role of sulfur in DDC. The maximum solubility of sulfur in nickel occurs at approximately the peak temperature used for both A690 and FM52 (2422° and 2402°F, respectively (1317° and 1328°C)) in this work. If sulfur embrittlement contributes to DDC then the hot ductility should not recover with decreasing temperature, but possibly even decrease due to decreasing sulfur solubility with decreasing temperature. As the hot ductility curves show (Fig. 1), this is not the case in the alloys investigated. This may be because there is insufficient time at temperature for the sulfur to diffuse to the grain boundaries. However, the results presented in the Part I companion article demonstrates that ductility recovers and ductility dip crack length per grain boundary length decreases in FM52 with hold time at 1600°F. This is contrary to what would be expected if sulfur significantly contributed to DDC.

Precipitation-Induced Cracking (PIC)

In this work increasing intergranular precipitation before strain is applied improves ductility and decreases crack

length. This is true at all temperatures, with all alloys, and with all forms of intergranular precipitates formed within those alloys. However, the ductility minimum at 1600°F (871°C) corresponds to the same temperature at which $M_{23}C_6$ precipitates are formed when the sample is strained in both FM52 and A690. It has been proposed that the chromium concentration in the matrix can significantly affect the interfacial stresses at the $M_{23}C_6$ -matrix interface (Ref. 20). Increasing the chromium concentration in the matrix increases the precipitate-lattice misfit, thereby increasing the localized stress along the grain boundary that may, in turn, promote DDC. As the precipitate grows the matrix chromium concentration is depleted and the misfit at the interface is expected to decrease, thereby resulting in improved ductility (Ref. 20).

There are several key observations that are consistent with a PIC mechanism. First, DDC susceptibility is highest in the two alloys investigated in this work that are strong $M_{23}C_6$ carbide formers: A690 and FM52. The $M_{23}C_6$ carbide is partially coherent and some stress at the precipitate/matrix interface is expected due to lattice misfit. The second observation is that the partially coherent $M_{23}C_6$ carbides formed during straining at the ductility minimum temperature in both A690 and FM52. Consistent with the PIC hypothesis, these precipitates would be expected to have the greatest stress at the precipitate/matrix interface because they are forming into a matrix that is chromium-rich. Concurrently an external stress is being applied, which, when added to the interfacial stresses, would be expected to result in localized stresses along the grain boundary, thus producing intergranular cracking.

While the PIC hypothesis has some points of agreement with experimental observations, there are also several key findings that cannot be explained by the PIC hypothesis in its current form. The first observation is that DDC cracks also form in alloys that do not readily form $M_{23}C_6$ on-cooling. Both A600 and FM82H form incoherent intergranular precipitates (M_7C_3 and MC, respectively), and would therefore not be expected to generate stresses at the precipitate/matrix interface per the PIC hypothesis. It should be noted that $M_{23}C_6$, M_7C_3 , and TiC intergranular carbides have been observed in undeposited EN82 weld wire (Ref. 55). However, out of 140 second phases in FM82H examined by EDS in this work, only one did not contain Ti or Nb, neither of which are incorporated into $M_{23}C_6$. The one chromium-rich second phase was present after a 60-s hold at 1600°F on-cooling (Fig. 7B), where both the ductility was high and normalized ductility dip crack length was low.

The on-cooling ductility between 1725°F (941°C) and 1475°F (802°C) is significantly lower in A600 than it is on-heating. This same trend is reflected in the normalized ductility dip crack length, which is significant over the same temperature range (Ref. 1). This is the same temperature range over which the ductility dip occurs in FM52 and A690; however, FM52 and A690 have significantly fewer intergranular precipitates over this temperature range than A600 and FM82H. Intergranular precipitates can have a profound role in reducing grain boundary sliding as will be discussed below. Additionally, FM82H forms ductility dip cracks both on-heating and on-cooling. This occurs over a wide range of temperatures in FM82H from 1475°F (802°C) to 2100°F (1149°C) on-heating and from 2100°F to 1475°F on-cooling.

The second observation is that ductility dip cracks are observed in FM52 at 2100°F both on-heating and on-cooling, as was shown in the first paper (Ref. 1). This specific sample is significant for two reasons. First, the $M_{23}C_6$ carbide solvus temperature for FM52 is 2077°F (1136°C), therefore these carbides would not be expected to form while the test is being performed, although some carbides are expected to be existent in the on-heating sample because they had yet to fully dissolve. According to the PIC hypothesis the 2100°F (1149°C) on-cooling sample should be less susceptible to DDC. However, the on-cooling sample is actually more susceptible to DDC as seen in the normalized crack count data from Paper I, which is 0.6 $\mu\text{m}/\text{mm}$ for on-heating and 3.4 $\mu\text{m}/\text{mm}$ on-cooling (Ref. 1). Although this result is not expected given the PIC hypothesis, it is expected if GBS is occurring because there are fewer intergranular chromium carbides to resist GBS in the on-cooling sample, therefore its DDC susceptibility would be higher.

Lastly, the PIC hypothesis in its current form states that a decrease in chromium concentration at the precipitate-matrix interface will reduce misfit strains. This is only true when that depletion occurs along the partially coherent side of the precipitate. As shown in Fig. 11, it appears that the chromium is not depleted adjacent to the partially coherent precipitate-matrix interface, but rather along the incoherent precipitate-matrix interface that is growing into the grain on the left in Fig. 11. The observed chromium depletion will therefore have no effect on decreasing misfit strain since it is occurring along the incoherent interface. Thus, the PIC process may be a contributing factor to the observed dip in intermediate temperature ductility, but, taken alone, cannot fully explain all the observed variations in microstructure, ductility, and cracking sus-

ceptibility that occur during the weld thermal cycle.

Grain Boundary Sliding (GBS)

Grain boundary sliding is generally considered to be an operative deformation mechanism at temperatures above 0.5, the homologous temperature (T_m) (Refs. 56, 57). Strain rate is equally important to the type of failure mechanisms caused by grain boundary sliding. It has been shown that in commercially pure nickel at 700°C round intergranular cavities form when the strain rate is low (10^{-9} s^{-1}), but as the strain rate increases the type of intergranular damage transitions from round cavities to wedge-cracks, then to transgranular ductile fracture at approximately 0.1 s^{-1} (Ref. 58). Alloying additions can decrease the temperature/strain rate regime over which wedge type cracking occurs if the additions promote increases in size and volume fraction of intergranular particles and/or enhance recovery (Ref. 59). Both round cavities and wedge-cracks are a result of GBS, with wedge cracks being observed in hot ductility specimens tested as part of this program (Ref. 1). Grain boundary sliding can result in intergranular cracking when the grain interiors are stronger than the grain boundaries (Ref. 1). GBS can be reduced by an increase in intergranular particle size and volume fraction, and the formation of serrated grain boundaries (Refs. 5, 6, 58, 59). All of these grain boundary changes provide obstacles to GBS and can be thought of as increasing the friction of the grain boundary (Refs. 5, 58).

The GBS hypothesis proposes that the intermediate dip in ductility is a result of a creep-like phenomenon. Changes to the microstructure, like serrated grain boundaries and intergranular precipitates, will decrease DDC susceptibility (Ref. 60). Given these criteria, the larger, regularly spaced and homogeneously dispersed intergranular precipitates in the as-received A600 and A690 would be expected to have the lowest DDC susceptibility. This was found to be the case, as evidenced by the complete absence of DDC in either alloy during on-heating hot ductility tests (Ref. 1). It is important to note that this is the same type of intergranular carbide morphology that is prescribed for improving resistance to GBS in nickel-based superalloys (Ref. 61).

Increasing the size and volume fraction of intergranular precipitates by means of a 60-s hold at 1600°F (871°C) on-cooling or cooling from a the respective carbide solvus of the alloy decreased the DDC normalized crack length in both FM82H and FM52 (Ref. 1). The PIC hypothesis provides an explanation for the decreased crack length in FM52 but not FM82H. Ac-

cording to PIC, chromium depletion caused by $M_{23}C_6$ precipitation will decrease precipitate-matrix interfacial stress. This in turn will decrease the propensity to form ductility dip cracks once the sample is strained. However, PIC does not explain why there is a decrease in normalized DDC crack length in FM82H at 1600°F after an isothermal hold or when cooled from a lower peak temperature. The GBS hypothesis can explain both the observations for FM82H and FM52 since the increased volume fraction and size of intergranular precipitates observed in both alloys is expected to decrease grain boundary sliding and DDC susceptibility concomitantly.

The ductility dip in FM52 and A690 was preceded by the complete dissolution of $M_{23}C_6$ intergranular carbides. Similarly, dissolution of $M_{23}C_6$ intergranular carbides in SUS321H and SUS347H stainless steels resulted in increased grain boundary sliding and impaired creep rupture life (Ref. 62). $M_{23}C_6$ intergranular precipitates are considered important to improving intergranular strength in nickel based superalloys when formed as a chain of discrete globular particles (Ref. 63). The $M_{23}C_6$ intergranular precipitate volume fraction is very low in A690 and zero in FM52 at the ductility minimum temperature (1600°F on-cooling) immediately upon application of strain. When the grain boundaries are in this condition, and the driving force for dynamic recrystallization is low compared to higher temperatures, DDC susceptibility is expected to be the highest, which is the case. The on-cooling decrease in ductility and increase in ductility dip crack length in A600 can be explained in a similar manner as for A690 and FM52. The partial dissolution of intergranular carbides during the peak temperature portion of the thermal cycle rendered the grain boundaries more susceptible to sliding. However, what remains unclear is the exact role of $M_{23}C_6$ intergranular carbides in the formation of DDC since they form during the application of strain in both FM52 (Fig. 13) and A690. What is unclear is whether DDC occurs due to the dynamic formation of these intergranular precipitates or because the precipitates are not present to impede GBS at the application of strain.

Serrated boundaries are observed in both FM82H and FM52 after a 60-s hold at 1600°F (871°C) on-cooling. In FM82H, discrete NbC particles form along the grain boundary at the end of solidification. These particles prevent the boundary from migrating during post solidification cooling, which would straighten the boundary and reduce interfacial free energy. Unlike FM82H, FM52 does not contain sufficient Nb to form NbC. The serrated boundaries in FM52 (Fig. 7D) may

form in a similar way to what has been observed in AISI 316 stainless steel where an isothermal hold resulted in serration of the grain boundary followed by $M_{23}C_6$ precipitation (Refs. 64, 65). The serration of the grain boundaries was attributed to a decrease in the interfacial free energy, which offset the increase in total grain boundary area (Ref. 64). Although the serrated boundaries in FM82H and FM52 formed by different mechanisms, they both have a beneficial effect on DDC resistance. This observation is consistent with work performed on IN-792. Samples with serrated boundaries exhibited a several order of magnitude increase in time to stress rupture as compared to samples with straight boundaries (Ref. 66).

The formation of wedge-type cracks, like those observed in DDC, has also been attributed to grain boundary sliding (Refs. 58, 59, 67, 68). Grain boundary sliding is considered necessary for the formation of wedge cracks, which occur at higher strain rates than those that produce round-type cracks by diffusional processes (Refs. 58, 69). As demonstrated in Part I, the angular distribution of ductility dip cracks relative to the tensile axis was preferentially oriented in the direction of maximal shear, which is at a 45-deg angle to the tensile axis (Ref. 1). This is further evidence that GBS is playing a causal role in DDC.

Lastly, the recovery of ductility at temperatures above and below the ductility dip can be explained by the GBS hypotheses. At temperatures below the ductility minimum grain boundaries are more viscous and less likely to slide. At elevated temperatures the grain boundary sliding is impeded by dynamic recrystallization, which prevents intergranular wedge cracks from significantly growing. Thus, in summary, careful review of the data acquired in this research indicates that ductility dip cracking in these alloys is caused by GBS that may be exacerbated by highly localized stresses that develop along the matrix/ppt interface when $M_{23}C_6$ carbides form in A690 and FM52.

Comparison of Gleeble® Testing to Multipass Welds

The Gleeble® work performed in this two part series of papers was motivated by the difficulty in studying microstructural evolution and DDC susceptibility in a multipass weld. However, there are some differences in the Gleeble® testing employed herein that may affect the applicability of these results to multipass weld specimens. The first difference involves stress state. In the Gleeble®, the stress is uniaxial, whereas in multipass welds the strain state is expected to be multiaxial. Furthermore, the thin Gleeble® specimens are expected to be in a plane stress

condition, whereas multipass weld metal is most likely in a plane strain condition. Crack propagation would be expected to occur at much lower stresses in the plane strain condition. Understanding the affects of multiaxial stress state and plane stress vs. plane strain condition on DDC susceptibility is nontrivial and would require additional research. Specifically, how these two affect GBS and PIC in these alloys. However, the results from uniaxial Gleeble® hot ductility tests in this work provide a useful step in understanding this complex phenomenon.

The second difference between Gleeble® testing and multipass welds is the strain rate. In the Gleeble® testing the strain rate ($\sim 1s^{-1}$) is higher than would be expected in a multipass weld. However, it was found that this higher strain rate actually resulted in a more aggressive testing condition for screening the DDC susceptibility of alloys (Ref. 1). Additionally, in the Gleeble® test the samples were strained until they fractured into two pieces. This high level of strain is never encountered in multipass welds. This difference helps to explain why some ductility dip cracks were observed in FM82H Gleeble® specimens tested in this work, but multiple heats of FM82H were found to be free of DDC in multipass welds (Refs. 20, 22). With respect to strain, the Gleeble® testing performed in this work is more adverse than would be experienced in multipass welds.

In the Gleeble® tests performed as part of this work the material was only subjected to one thermal cycle, and the strain was not applied concurrently with cooling or heating. This is the third difference between Gleeble® and multipass welds. In multipass welds the sample is strained and heated or cooled at the same time over the course of multiple thermal cycles. This may result in greater precipitation of second phases that promote DDC.

Lastly, in multipass welds the peak temperature is higher than what was evaluated in the Gleeble® tests performed in this work. Higher peak temperatures will result in dissolution of NbC carbides, thereby freeing up carbon that can potentially form intergranular $M_{23}C_6$ precipitates. These precipitates may prove detrimental to DDC resistance, which requires further research.

Conclusions

The DDC susceptibility of A600, A690, FM82H, and FM52 has been determined using Gleeble® hot ductility testing and correlated to the microstructural evolution of these alloys during the first weld thermal cycle. The following conclusions can be drawn from this research:

1. No evidence of sulfur or phospho-

rous segregation was found in FM52 in water-quenched samples from the ductility minimum temperature, 1600°F (871°C) on-cooling, 1600°F on-heating, or after a 60-s isothermal hold at 1600°F. Based on this sulfur and phosphorous embrittlement does not cause DDC during the first weld thermal cycle, although they will most likely exacerbate DDC if present at higher concentration.

2. Within the ranges tested, grain size does not play a role in DDC for the alloys considered. The grain size of FM52 was 2.5 times greater than that of A690, but they both experienced a ductility minimum at 1600°F (871°C) on-cooling. Conversely, the grain sizes of A600 and A690 at the same temperature were the same, within experimental error, but there was no ductility dip in A600.

3. Dissolution of intergranular carbides was observed in A600, A690, and FM52 during the peak temperature portion of the thermal cycle. This dissolution preceded a reduction in ductility and increased susceptibility to DDC over an intermediate temperature range [1725°–1475°F (941°–802°C) on-cooling] in all three alloys. This decrease in intergranular carbide size and volume fraction appears to promote grain boundary sliding.

4. Cooling FM82H and FM52 from peak temperatures that correspond to their carbide solvus resulted in increased intergranular carbide coverage. Similarly, an isothermal hold at 1600°F (871°C) (the ductility minimum for A690 and FM52) resulted in more intergranular carbides in both FM82H and FM52. Increased intergranular carbide coverage reduces DDC susceptibility regardless of carbide type. This increase in intergranular carbide size and volume fraction would promote grain boundary sliding.

5. Ductility dip cracking in these alloys appears to be caused by GBS that may be exacerbated by highly localized stresses. These stresses may develop along the matrix/precipitate interface when $M_{23}C_6$ carbides form in the same time/temperature regime as the hot ductility test.

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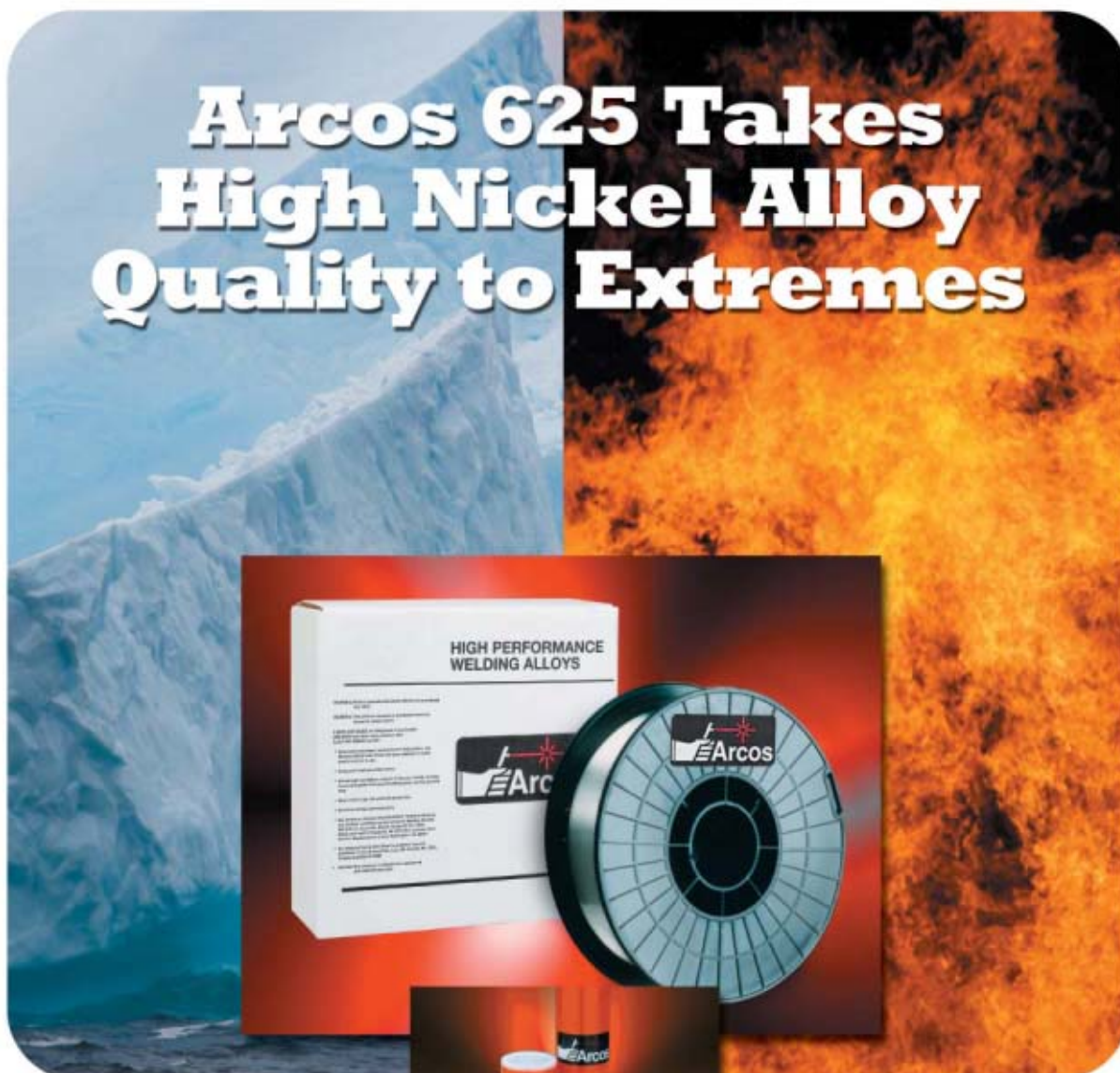
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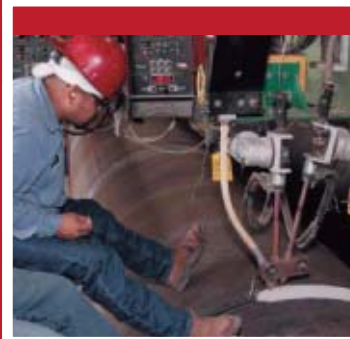


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