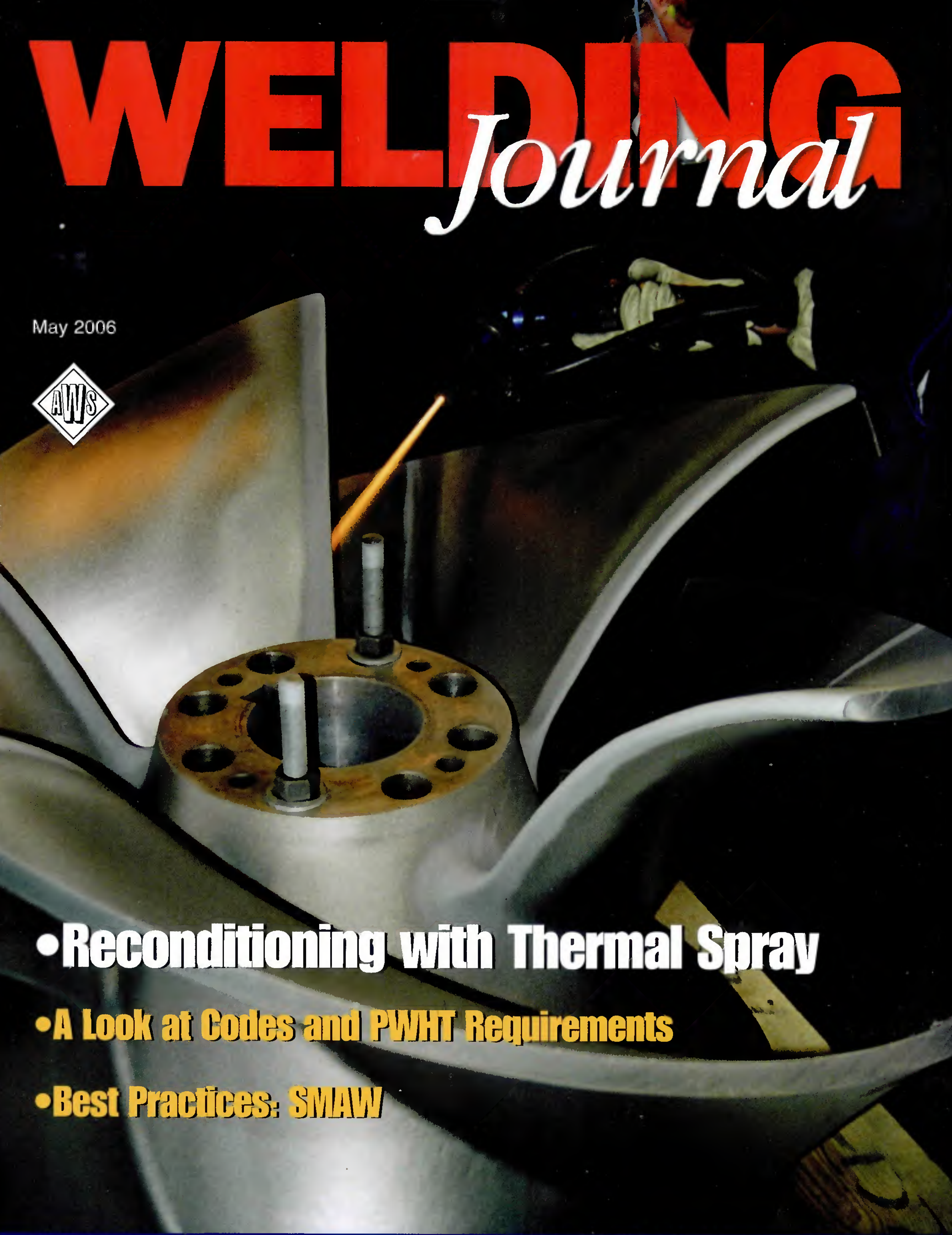
WELDING Journal

May 2006



- **Reconditioning with Thermal Spray**
- **A Look at Codes and PWHT Requirements**
- **Best Practices: SMAW**

PUBLISHED BY THE AMERICAN WELDING SOCIETY TO ADVANCE THE SCIENCE, TECHNOLOGY AND APPLICATION OF WELDING AND ALLIED PROCESSES, INCLUDING JOINING, BRAZING, SOLDERING, CUTTING, AND THERMAL SPRAYING

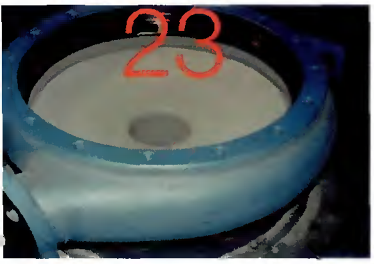

FACTORY DIRECT REBATE
April 1 - June 30, 2006
40% LARGER VIEWING AREA
THAN ANY OTHER AUTO-DARKENING PRODUCT
XTREME FIXED
$20.00 REBATE
Fixed Shade 10.5.
XTREME VARIABLE
$30.00 REBATE
Variable Shade 9-12.
INDUSTRIAL XTREME
INDUSTRIAL
$40.00 REBATE
Variable Shade 7-14 and 3 LCDs for unsurpassed optical quality.
Circle No. 3 on Reader Info-Card
CALL 800-223-4685 FOR A PARTICIPATING ARCONE® DISTRIBUTOR NEAR YOU.
Visit our website at arc1weldsafe.com for more information.
Rebate limited to end users only.
ARCONE®
ARCONE® is a division of A.C.E. International
Ph: 800-223-4685
85 Independence Dr.
Fax: 508-884-9666
Taunton, MA 02780
www.arc1weldsafe.com

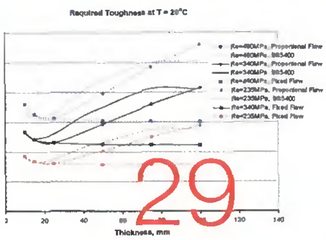
CONTENTS

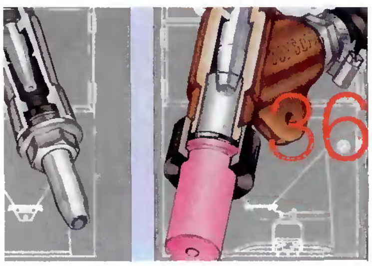
May 2006 • Volume 85 • Number 5

AWS Web site *http://www.aws.org*

Features







Welding Research Supplement

Cover courtesy of St. Louis Metallizing Co., St. Louis, Mo. The high-velocity oxyfuel process is used to apply a carbide coating to an impeller.

Departments

Welding Journal (ISSN 0043-2296) is published monthly by the American Welding Society for $120.00 per year in the United States and possessions, $160 per year in foreign countries: $7.50 per single issue for AWS members and $10.00 per single issue for nonmembers. American Welding Society is located at 550 NW LeJeune Rd., Miami, FL 33126-5671; telephone (305) 443-9353. Periodicals postage paid in Miami, Fla., and additional mailing offices. **POSTMASTER:** Send address changes to Welding Journal, 550 NW LeJeune Rd., Miami, FL 33126-5671.

EWI Engineer Receives Henry Granjon Prize

Edison Welding Institute (EWI), Columbus, Ohio, recently announced Wei Zhang, an applications engineer at the company, is a corecipient of the Henry Granjon Prize.

The Granjon Prize, sponsored by the International Institute of Welding (IIW), is an annual international competition among authors of papers devoted to research into welding technology or a related subject. The research is categorized into one of four areas of joining, surfacing, or cutting technology.

Zhang's paper "Probing heat transfer, fluid flow and microstructural evolution during fusion welding of alloys" was selected in the joining and fabrication category of the Granjon Prize competition. Zhang will present his research findings and accept the Granjon Prize during the opening ceremonies of the IIW Annual Assembly in Quebec, Canada, on August 27.

Praxair and Lincoln Electric Sign Mutual Cooperation Agreement

Praxair China, Shanghai, a subsidiary of Praxair, Inc., recently announced its joint venture, Shanghai Praxair Baosteel, Inc. (SPBI), has signed a cooperation agreement with Lincoln Electric China.

SPBI will supply cylinders of carbon dioxide, argon, and argon blends to Lincoln Electric's welding training center, applications engineering lab, and R&D laboratories in Baoshan District, Shanghai. Also, SPBI has donated a complete set of manifolds to allow Lincoln to use the gases effectively.

Lincoln Electric will allow Praxair to use the facilities to train its sales force, engineers, and customers, promote seminars, and demonstrate Praxair welding gases and solutions developments.

"The welding industry in China is growing rapidly," said Frank Young, vice president, North Asia region for Lincoln Electric. "As it grows, the demands for improved technologies, quality, and efficiency increase."

According to the company, Praxair China's welding technical center in Guangzhou Economic & Technology Development Zone, established in 2004, is the first such investment by a multinational industrial gases company in China.

Airgas Acquires Byrne Specialty Gases, Inc.

Airgas, Inc., Radnor, Pa., has acquired Byrne Specialty Gases, Inc. (BSG), a Seattle, Wash.-based distributor of specialty gases, related equipment, and cryogenic storage systems for the life sciences sectors in the Pacific Northwest.

The acquired operations, including two facilities in Seattle and Vancouver, Wash., employ 45 associates and generated more than $10 million in annual sales last year. Airgas will run the business as a dedicated unit within Airgas Nor Pac, one of 13 regional companies within the company, focused on specialty gases and life science sectors in the Northwest.

American Railcar Industries Announces Agreement to Purchase Custom Steel, Inc.

American Railcar Industries, Inc. (ARI), St. Charles, Mo., recently announced it has signed a definitive agreement to acquire the stock of Custom Steel, Inc., a subsidiary of Steel Technologies Inc.

Custom Steel operates a facility located adjacent to ARI's component manufacturing facility in Kennett, Mo., that produces value-added fabricated parts that primarily support ARI's railcar manufacturing operations. The purchase price is approximately $13 million plus approximately $5 million for inventories.

WELDING Journal

Publisher *Andrew Cullison*

Editorial
Editor/Editorial Director *Andrew Cullison*
Senior Editor *Mary Ruth Johnsen*
Associate Editor *Howard M. Woodward*
Assistant Editor *Kristin Campbell*
Peer Review Coordinator *Erin Adams*

Publisher Emeritus *Jeff Weber*

Graphics and Production
Managing Editor *Zaida Chavez*
Senior Production Coordinator *Brenda Flores*

Advertising
National Sales Director *Rob Saltzstein*
Advertising Sales Representative *Lea Garrigan Badwy*
Advertising Production *Frank Wilson*

Subscriptions
Leidy Brigman
leidy@aws.org

American Welding Society
550 NW LeJeune Rd., Miami, FL 33126
(305) 443-9353 or (800) 443-9353


NASCAR®
FANTASY WEEKENDS
FIRST PRIZE
Pit Crew for a day
GRAND PRIZE
VIP Package at the Brickyard
SECOND PRIZE
Jeff Gordon Racing School
MIG Welders
Engine Driven Welders
TIG Welders
CHECK OUT THE COMPLETE LINE OF LINCOLN WELDERS AT YOUR LOCAL WELDING DISTRIBUTOR

A New Beginning for RWMA

It was October 2000 when a proposal was distributed at the fall board of directors meeting of the Resistance Welding Manufacturers Association (RWMA). The proposal, titled "RWMA Timeline for a Sustaining Visioning Process," asked the board to refocus the strategic planning committee's role. After much review and discussion, the proposal was adopted, along with a budget to hire a consultant to assist the committee in this process.

This was the beginning of a long, tedious, and sometimes emotional undertaking — to take a hard look at an organization that had been formed in the 1930s by a group of resistance welding manufacturers who recognized the importance of a growing welding process. The RWMA's basic mission was to promote the technical and economic advantages of the resistance welding process, as well as to provide education and a technical forum. That mission still held true in fall 2000, some 70 years later.

The difference was that the world had changed. Although RWMA over the years had taken a leadership role in the resistance welding process by setting standards, publishing educational materials, conducting welding schools, setting up scholarships, and revamping its membership categories, it was not enough. Industry trends continued to change the face of the RWMA membership. The original full-service manufacturing companies had become more specialized. Smaller component companies formed from these groups and consolidation in the resistance welding industry continued. Global changes and economics also played a part in the changes in the organization.

Although the RWMA was financially sound and membership was steady, it was to the credit of the association's leaders on that fall afternoon that they recognized tremendous changes needed to be made to move the RWMA soundly into the future. The RWMA needed to change to remain relevant to its membership.

In spring 2001, a long and careful analysis of the situation began to be addressed. Strengths and opportunities along with related weaknesses and barriers were stated; most importantly, how RWMA could serve its membership and the welding industry in the future. At the spring 2003 member meeting, the new strategic plan to reorganize the entire organization was implemented.

Several directions were identified. Some were not pleasant. Others were, although lofty in goal, not realistic. The association could completely revamp itself, form alliances, join other similar trade associations, or simply disband. The latter was, of course, a last resort. The value and integrity of the RWMA brand identity, standards, and the strengths and knowledge of the membership allowed the leaders to focus on finding an organization that would share in their vision, provide support on a much greater scale to the membership, and open new doors to the future. Several organizations made presentations.

At the spring 2004 meeting, after narrowing down the choices, the board authorized a task force to draft a letter to the American Welding Society for further discussions. At the fall meeting in late September 2004, the RWMA board approved the merger with the AWS. The following spring, the RWMA held its last full member meeting as the "association" in Grand Rapids. In June 2005, RWMA became a standing committee of AWS with the new title of Resistance Welding Manufacturing Alliance.

In the November 2005 *Welding Journal*, I read, with some surprise, AWS Executive Director Ray Shook's editorial. In it, he related that his first AWS show was in 1976 and how, as a 26 year old, he had been in awe of the event. The 1976 St. Louis show was also my first. I was also in awe. As a young electrical/weld technician, my employer gave me the assignment to deliver, set up, and weld with a resistance spot welding machine at the opening ceremonies with then incoming AWS President Robert Foxall. We welded an aluminum AWS sign to be displayed at AWS headquarters. So, for me at least, 30 years later, it has all come back around.

I truly believe the RWMA made the right choice. The support, encouragement, and professionalism of the AWS staff has made this transistion very successful. I always believe you get out of something based on what you put in. It is now up to the RWMA leaders and members to take advantage of the opportunites given our committee. Throughout this article the words spring and fall kept popping up. As I write this editorial, spring is just now blooming. That means new growth, new hopes, and wonderful opportunites. Thank you AWS.

Larry E. Moss
RWMA Chairman


Going digital? Let Kodak cut your arrival time.
DEMO OUR DIGITAL VIEWING SOFTWARE AND SEE JUST HOW EASY IT IS TO MASTER. It's robust, yet intuitive—and a pleasure to use. And it's part of what makes Kodak the right partner for your journey to computed radiography. Kodak offers you a complete line of productivity-enhancing digital systems. And timesaving insights based on our experience helping other industries convert. You'll also enjoy peace of mind knowing you're supported by a worldwide team of over 4,000 Kodak technicians.
To learn how to get a free demo CD of KODAK INDUSTREX Digital Viewing Software go to www.kodak.com/go/TryINDUSTREX.
FILM PRODUCTS
DIGITAL PRODUCTS
FILM DIGITIZERS
GLOBAL SERVICE AND SUPPORT
Kodak and Industrex are trademarks of Eastman Kodak Company. © Eastman Kodak Company, 2005.
Circle No. 35 on Reader Info-Card
Kodak

Weldcraft's New Headquarters Receives Support from State of Wisconsin

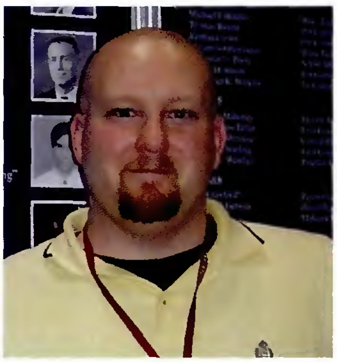
Wisconsin Governor Jim Doyle visited Weldcraft's new headquarters in Appleton, Wis. The company, which relocated from Burbank, Calif., established 50 new jobs in the area.

In recognition and support of Weldcraft's relocation from Burbank, Calif., to Appleton, Wis., Wisconsin Governor Jim Doyle recently visited with employees at the company's new headquarters.

As of January 1, Weldcraft relocated all manufacturing, process, and delivery to Appleton and established 50 new jobs in the area. Governor Doyle recognized the Wisconsin workforce expansion by providing $350,000 worth of grants and loans to be used for employee training and advancement, as well as for plant and technology developments.

The move to Appleton allows the company to align product research and development with Miller Electric Mfg. Co., another subsidiary of Illinois Tool Works (Weldcraft and Miller's parent company), and brings with it the potential for establishing additional jobs in Appleton.

Welding Student Accepted for Caterpillar's Manufacturing Professional Development Program



Jacob Shorey will be the first person with a welding engineering technology degree to start in Caterpillar's Manufacturing Professional Development Program.

Jacob Shorey, 26, a senior at Ferris State University studying welding engineering technology, has been accepted into Caterpillar's Manufacturing Professional Development Program (MPDP). He will be the first person with a welding engineering technology degree to participate in the program.

"This is hugely significant to me because I take pride in creating more opportunities for others in welding, and it will also allow me, as a welding engineer, to offer input to Caterpillar which may be very valuable to them," Shorey said. In May, he will graduate from Ferris with a bachelor of science degree in welding engineering technology.

The MPDP, which started in 2001, "helps develop high-potential recent college graduates with a desire to lead in a manufacturing environment." Approximately 20 to 40 college graduates are hired for the program each year. It also "provides manufacturing professionals with technical and management knowledge and abilities through a series of planned job experiences, classroom instruction, and activities during a three-year, multi-assignment program." Annual rotations are in process engineering, supervision, and logistics/purchasing.

Shorey learned about the program during his internship at Caterpillar in Aurora, Ill., which took place from May to August 2005. His supervisor, Matt Wiske, a graduate of the program, told him about it.

"In order to apply for this program, I had to make my interviewers (three of them) aware that I was interested in the program, and hoped that they would recommend me for it," Shorey explained. After completing the first step, the Gallup organization completed the second round of interviewing over the phone. "The results of that interview were then passed on to the MPDP coordinator for my ultimate consideration for the program," he said. In August 2005, Shorey found out he had been accepted.

Shorey will start at Caterpillar in East Peoria, Ill., on June 12. "I am excited about my upcoming career because it will allow me a chance to use much of my knowledge of welding and manufacturing to help me become successful," he said. "I am also looking forward to opportunities to work with new technology, leading-edge manufacturing, and also meeting cost and quality challenges throughout my assignments."

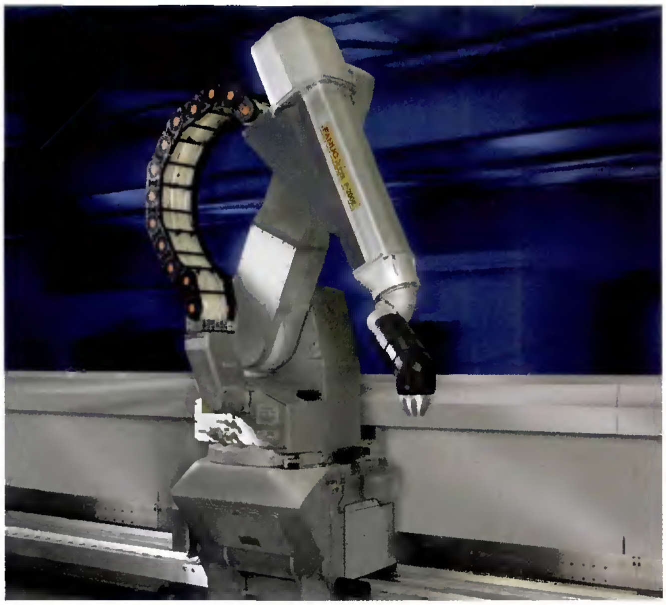
Brotje-Automation Builds Advanced Friction Stir Welding Machine

EDAC Technologies Corp. - Boeing Phantom Works will use a new friction stir welding machine purchased from Brotje-Automation GmbH to develop better ways to efficiently build stronger, lighter, and more complex-shaped components for aerospace products.

Brotje-Automation, in response to Boeing specifications, designed and built an eight-axis machine that is 88 ft long, 30 ft wide, and generates 4 tons of force. Also, it employs an advanced spindle design, process instrumentation, and control algorithms to produce contoured structural components up to 33 ft long, 13 ft wide, and 5 ft tall.

Brotje-Automation produced the machine in partnership with Gros-ite Precision Engineered Spindles, a division of EDAC Technologies of Farmington, Conn., which provided the coaxial spindle; Siemens AG of Erlanger, Germany, which provided the control system; and HBM GmbH of Darmstadt, Germany, which provided the instrumentation.

PACCAR Names FANUC Robotics a Preferred Supplier



FANUC Robotics America, Inc., Rochester Hills, Mich., has been named a preferred supplier of industrial robots by PACCAR, Inc. Since 1998, the company has installed robotic painting systems at PACCAR's North American Assembly plants and a chassis painting system at PACCAR's Leyland Truck Plant in England. Pictured above is the company's P-200E, a six-axis, electric servo-driven paint robot that combines motion performance with a range of process advantages to simplify operation, maintenance, and color changes.

Northwest Pipe to Supply $15 Million of Welded Steel Pipe

Northwest Pipe Co., Portland, Ore., has been named to supply Black & Veatch Construction, Inc., with approximately $15 million of welded steel pipe for the Perris Valley Pipeline Project. When the pipeline is complete, it will provide substantial water reliability and quality benefits to a significant portion of western Riverside County, Calif.

The company is to supply approximately 35,000 ft of 96- and 108-in.-diameter steel pipe. The pipe is expected to be manufactured in the company's Adelanto, Calif., division with delivery scheduled to begin in the second quarter of 2006.

Toyota Celebrates Opening of North American Production Support Center

Toyota recently celebrated the opening of its North American Production Support Center (NAPSC), a training facility located in Georgetown, Ky., which will serve Toyota's plants in the United States, Canada, and Mexico. The center will act as an extension for Toyota's Global Production Center (GPC), an initiative begun in 2003 to share best practices globally in a standardized manner.

Team members who will train at the center will simulate hands-on operations including the following: stamping, body weld, paint, plastics, assembly, quality control, and internal logistics. Future programs will include axle and engine assembly, machining, and casting functions.

The center is expected to employ 29 team members. Programs offered at the center include production, maintenance, supervisor, and management systems training, as well as classes and

A trainee inspects a door panel at Toyota's North American Production Support Center, as a regional trainer looks on. The center, located in Georgetown, Ky., will provide training for employees in the United States, Canada, and Mexico.

hands-on, shop-floor simulations in management training to show managers how to observe team members and how to coach them.

The 98,000-sq-ft facility was developed to the guidelines of the U.S. Green Building Council to ensure that it met environmental standards for site development, material selection, water savings, energy efficiency, and indoor environmental quality. Located in a former Toyota training center, the NAPSC represents a $12 million investment to expand and refurbish the facility with all new equipment.

Industry Notes

- Praxair, Inc., Danbury, Conn., recently opened a new packaged gases production facility in Tacoma, Wash. It is located in Tacoma's tide flats area and covers more than 44,000 square feet. According to the company, the plant is the largest cylinder fill plant in the state of Washington.
- McKnight Cylinder, Ruffs Dale, Pa., a gas cylinder refurbisher, has been licensed by The United States Department of Transportation as an approved high-pressure gas cylinder testing facility. With this license, the company can now provide testing to suppliers and end users of high-pressure industrial gases and natural gases.
- Innova Holdings, Inc., Fort Myers, Fla., an automation technology company providing hardware and software systems to the military, service, personal, and industrial robotic markets, has signed a letter of agreement with CoroWare, Inc., Bellevue, Wash., a systems integration firm with expertise in the area of mobile service robotics, under which the company will acquire all of the assets of CoroWare, including the newly formed CoroWare Test Labs subsidiary. The transaction is expected to be completed in the first quarter of 2006, subject to approval by Innova Holdings' Board of Directors, and customary regulatory approvals. Under terms of the agreement, CoroWare and its CoroWare Test Labs subsidiary will operate as wholly owned subsidiaries of Innova Holdings.
- John Begg, the president of the Southern African Institute of Welding, said at the International Institute of Welding Congress held in Cape Town in March that the future of industrial development in South Africa has perhaps never been as bright as it is now, and welding is one of the basic skills on which this development depends. The congress was hosted by the Southern African Institute of Welding. "There will be a significant

increase in demand, and the country has to be able to supply the necessary skills required in implementing the infrastructure projects associated with the country's economic growth," Begg said.

- Airgas, Inc., Radnor, Pa., has agreed to acquire the assets and operations of Airtec, Inc., an industrial gas and welding supply distributor with six locations in Wisconsin and one in Minneapolis, Minn. The Altoona, Wis., based business, which generated around $13 million in annual sales in 2005 and employs about 60 people, will be integrated into Airgas North Central, one of Airgas' 13 regional companies.
- Tregaskiss® Welding Products, Windsor, Ontario, Canada, has opened its first office in Shanghai, China. The office is located in the Xu Jia Hui Commercial Center. The company hopes to establish market share in China and plans to focus on its relationships with large international customers, including automotive manufacturers, in addition to smaller companies. Also, the company is working on establishing a sales and distribution network in the North and Northeast regions of China.
- KUKA Robotics Corp., Clinton Township, Mich., has signed Automation Engineering Corporation (AEC), Greenville, S.C., as a new system partner. AEC, a supplier of automated machinery and control systems, will integrate KUKA industrial robots into its new family of foundry automation cells. These customized cells are designed for casting, grinding, polishing, and material handling applications in the foundry industry.
- The Columbus, Ind., plant of AK Tube LLC, a subsidiary of AK Steel, has been approved for participation as a "Star" site in the Indiana Department of Labor's Voluntary Protection Program (VPP). The VPP Star designation signifies that the plant's employee safety programs go above and beyond Occupational Safety and Health Administration (OSHA) requirements, and reflects a cooperative relationship between management, employees, and OSHA. AK Tube LLC manufactures electric resistance welded carbon and stainless steel tubing for a variety of applications.
- Northrop Grumman Corp. has been recognized for its commitment to protecting and preserving the environment in San Diego. Continental Maritime, a subsidiary of the company's Newport News sector, has been selected by the California Water Environment Association (CWEA) as Southern California's Facility of the Year in the large industry category.
- Nachi Robotic Systems, Inc., has recently upgraded its Quality Mangement System (QMS) from QS9000/Tooling & Equipment Supplement: 1998 to ISO 9001:2000. This QMS upgrade includes all of the company's facilities in North America.◆

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:

Welding Journal Dept.
Attn: Mary Ruth Johnsen
550 NW LeJeune Rd.
Miami, FL 33126.

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

In May 2006, Outokumpu Copper Products will become Luvata

* ***Outokumpu Copper Products constituent companies include:***

Outokumpu American Brass
Outokumpu Copper Neumayer
Outokumpu Copper Nippert
Outokumpu Copper Strip
Outokumpu Copper Valleycast
Outokumpu Heatcraft
Outokumpu Poricopper
Outokumpu Wasacopper

BOOK REVIEW

BY ROBERT MURRAY

Underwater Welding Book in Review

ISBN 1-899293-99-X, softbound, 7 x 9.5 in., illustrated, ~300 pages, Troubador Publishing Ltd., Leicester, U.K., £19.99 (~$35); www.troubador.co.uk/matador, tel: (44) 116 255 9312.

David Keats's book, *Underwater Wet Welding*, is an excellent reference guide to welding. The majority of the book is about welding in general and not specifically underwater wet welding as the title suggests.

Credit must be given to Keats for taking the approach that a thorough understanding of the entire welding process is essential to becoming a proficient underwater wet welder. I found the layout of the book a bit confusing with the jumping back and forth between general shop welding and underwater wet welding. I would like to have seen the book made into two volumes: The first discussing metallurgy, welding, and weld inspection as it relates to surface welding in general; the second volume dealing with all aspects of underwater wet welding.

The section on "Health and Safety" also jumped back and forth between shop welding and underwater welding. Keats does give very sound guidance on electrical shock prevention, but does not offer an answer as to why underwater wet welding can be safe. It has to do with Ohm's law (I = E/R, where I = current, E = voltage, and R = resistance), and the 40 mA direct current (DC) safe body current established by the AODC referenced by Keats.

A diver will have a nominal limb-to-limb body resistance of 750 ohms; wet welding nominal closed circuit voltage is 29 VDC. Using Ohm's law, I = 29/750, the max current a welder/diver will be exposed to is 38 mA, which is within the safe body current limits. Being within the safe body current, along with following the safety guidelines outlined in Keats's book, is what makes underwater wet welding safe.

Another safety point Keats brings to light but does not elaborate on is ensuring all gases are free to escape. This is an extremely important safety concern since hydrogen and oxygen become disassociated from the water molecule in the form of gases during wet welding. By themselves, these gas molecules are harmless. However, if they are recombined they can become explosive, and if a substantial amount of gas has collected or significant amounts of hydrocarbons are present, the explosion could be lethal.

The section on "Basic Metallurgy" was very informative; however, a more in-depth explanation of the importance of carbon equivalency (CE) to underwater wet welding should have been given since CE is an essential variable for wet welding. I question Keats' statement that base metals with a high CE are not suitable for wet welding. Base metals with a high CE can be wet welded using austenitic electrodes, especially high-nickel electrodes.

Overall, I found the book to be well written. Keats did an excellent job with utilization of graphics in each section. I particularly liked the detail given in Sections 4 and 14 with electrode angles and manipulation.

The majority of the book is about welding in general. I found Sections 4 and 14 to be the only parts of the book that really got to the bare bones of underwater wet welding. With that said, this book will have a spot on my shelf with the rest of my welding reference books. ◆

ROBERT MURRAY is with the U.S. Navy, Special Programs, Naval Special Warfare, NAVSEA, and a member of the AWS Subcommittee on Underwater Welding.

LETTERS TO THE EDITOR

Reader Offers Possible Solution to Skilled Welder Shortage

Industry needs to get serious about solving its problem, because no one else is going to do it for them. They need to ask themselves a few basic questions.

1. What is this problem costing the company? ($1000, $10,000, $100,000, or $500,000 a year, both in present and future business.) If they don't know what it is costing them, they have an unidentified problem; therefore, it will never get fixed.

2. What am I willing to pay for a workable solution? Since welding apprenticeships, in general, are a thing of the past and will probably stay there.

I have a workable solution. Solicit current American Welding Society Certified Welding Inspectors (CWIs) and Certified Welding Educators (CWEs) for a position to aid in your company's growth, expansion, and future. They would represent the company in quality, integrity, and reputation to its customer base and provide in-house welder training at any time. If this person can fix a $100,000-a-year problem forever, wouldn't it be worth a premium price?

If your problem has a significant price tag on it, you could reap double rewards by investing in your CWI/CWE portfolio by spending a very modest amount to get that person qualified to the Certified Welding Supervisor standard. Then stand back, throw out any company politics, and let that person do a job no one else was capable of doing. This person will be a functioning member of production, and take on responsibilities he or she is better qualified to do than those now performing those duties. The company now can plan on a welding future instead of worrying about one.

Companies that claim they couldn't afford this solution only have one other solution — give up welding as a means of fabrication or production. If not, workmanship, quality, and liability will eat up profits, and by the time the company identified the true problem/solution, it'll be too late. Pay a contract company to do your welding. (Then see what the price tag really is.) The time for action is now.

Phil Evans
CWI, CWE
Callahan, Fla.

Dear Readers:

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

Bombardier to Help Link Beijing Airport to Summer 2008 Olympic Village

Bombardier will help build a 28-km airport link system in Beijing, China, that will utilize its Advanced Rapid Transit technology. The technology was used in Vancouver's SkyTrain system (shown here), the world's longest driverless system.

Bombardier Transportation, Montreal, Canada, has received an order from Changchun Railway Vehicles (CRC) as part of a contract awarded to CRC for the supply of 40 Advanced Rapid Transit (ART) MK II cars for the Beijing Capital International Airport Link. Bombardier's share of the contract is valued at approximately $44 million.

The 28-km airport link system will connect Dongzhimen station to the Beijing Capital International Airport and feature Bombardier's ART technology. The fleet will serve four different stations, from two of which passengers will be able to easily change trains to connect to the 2008 Olympic Games village.

Bombardier will participate in project management and will be responsible for vehicle systems engineering and integration, design and manufacture of the bogies, as well as propulsion and braking systems. CRC will manufacture the 40 ART MK II vehicles. Deliveries are scheduled to take place between 2007 and 2008 to coincide with the 2008 Summer Olympics in Beijing.

Advanced Rapid Transit systems in operation include Vancouver SkyTrain, the longest driverless systems in the world; New York City's 13-km AirTrain JFK; and the 29-km Kuala Lumpur Kelana Jaya line in Malaysia, which has carried more than 200 million passengers since opening to passenger service in 1998.

Bombardier participates in three joint ventures in China. Including those joint ventures, the company employs 2100 people in China.

Thompson Friction Welding Acquires DV Automation

Thompson Friction Welding recently acquired DV Automation, an automotive hemming technology company. DV Automation, which has become a wholly owned subsidiary of Thompson, has moved from its base in Chessington, Surrey, to Thompson's U.K. headquarters in Halesowen, West Midlands. The new subsidiary is being headed by managing director Alan Shilton.

Established in 1989, DV Automation produces a range of machines for hemming closures on vehicle bodies and provides a range of associated engineering services.

Key personnel remaining with the business include founder Mike Dorsett and sales manager Colin Green.

This acquisition follows Thompson's recent purchase of Blacks Equipment, a U.K. friction welding machine manufacturer and supplier of subcontract friction welding services. That purchase made Thompson the U.K.'s largest provider of subcontract friction welding services.

Vietnam's Welding Training Reaches International Standard

Dr. Gerd Kraume, vice general director of the German Welding Society, presented a certificate on March 31 of the international welding institute to the Viet-Duc (Vietnam-German) Center for Training and Technology Transfer under the Vietnam Directorate for Standards and Quality.

The certificate notes the European Union's Asian Investment Program's help in having Vietnam's workers to meet the EU standards and noted the six years of cooperation between the Vietnam Directorate for Standards and Quality and Germany's Koblenz Chamber of Small Industry.

Over the past six years, the Vietnam Center for Training and Technology Transfer has enrolled about 1000 welding students. By 2004, about 300 Vietnamese had been granted welding certificates by the European and International Welding Federations.

BlueScope Steel to Build Two New Steel Facilities in Indonesia

BlueScope Steel, the leading steel company in Australia and New Zealand, recently announced it will build two new steel facilities in Indonesia at a total cost of about $105 million, according to *Steel Trade Today*.

Its subsidiary PT BlueScope Steel Indonesia, the only producer of metal-coated steel in Indonesia, will construct a steel facility in Cilegon, Banten, at a cost of $101.1 million. It is expected to begin operations early in 2008 and produce 90,000 tons of metal-coated steel and 55,000 tons of color-coated steel per year.

Another subdsidiary, PT Blue Scope Lysaght Indonesia, will build a $3.9 million facility in Cibitung, West Java. It will produce steel roof tiles and have an annual production capacity of 8500 tons of welded steel mesh and 4500 tons of roll formers coated steel. No date has been given when the West Java plant will begin operations.

Clean Air Group to Acquire PlymoVent

Rabo Participaties, The Netherlands, Rabobank's private equity and venture capital division, announced recently it is investing in PlymoVent, a Swedish company that specializes in extraction and filtration technology for welding fumes, oil fumes, dust, and exhaust fumes, according to the Internet news service FAZ.net (*www.faz.net*). The bank and the company's management are making the investment jointly through their participating interest in Clean Air Group B.V. The parties are not disclosing the scope or amount of the equity investment.

Sellers of PlymoVent are the founder Gunner Linderström, Litorina Kapital, and MVI Holdings. The company has 156 employees. In addition to its office in Malmö and a factory in Lycksele, Sweden, PlymoVent has international branches in the United States, Canada, Germany, United Kingdom, and France.

Clean Air Group (Euromate) designs and produces smoke cabins and air-cleaning systems, as well as systems that extract welding fumes and odor, and grease control systems for commercial kitchens.◆

www.supersonicspray.com

THE ULTIMATE BONDING EXPERIENCE

LOW PRESSURE COLD SPRAY EQUIPMENT

SST Portable Model

SST Cabinet Model
Air filtration unit required.

SUPERSONIC SPRAY TECHNOLOGIES

CenterLine Windsor Limited, an industry leader in the design and manufacture of metal-forming and welding equipment, introduces Supersonic Spray Technologies (SST) – a fully integrated, self-contained metal repair solution. Utilizing cold spray, or Gas Dynamic Spray Technology, SST allows for the bonding of similar or dissimilar metallic materials.

Cold spray technology holds a number of ideal applications for the metal shaping and fabricating industries including metallic component restoration, sealing, surface modification, wear resistance, thermal barriers, corrosion protection, heat dissipation, and aesthetic coatings for materials that are sensitive to heat or oxidation.

KEY FEATURES:

- Metal particles are accelerated to more than 1100 MPH
- Low temperature spray drastically reduces oxidation, vaporization and residual stresses associated with traditional thermal spray or welding processes
- Sprayed material is highly machinable and corrosion-resistant
- The finished materials offer remarkably high densities and high electrical and thermal conductivities
- Material builds up as much as one inch
- Operates on electricity and compressed air only

INSTANTLY SPRAY ALUMINUM, ZINC, COPPER, BRASS & MORE

SST

centerline

Circle No. 19 on Reader Info-Card

For more information contact your CenterLine sales representative toll free at 1-800-268-8330

CANADA: 1993 Ambassador Drive, Windsor, Ontario N9C 3R5 • USA: P.O. Box 321187, Detroit, Michigan 48232-1187

BY DAMIAN J. KOTECKI

Q: For a great many years, our purchase specifications for common stainless steel bare wires such as ER308LSi and ER316LSi for GMAW or ER308L and ER316L for SAW have required 8 to 15 Ferrite Number (FN) calculated by diagram. We always referred to the DeLong Diagram, as that was included in the ASME Code, Section III, Division 1, as Fig. NB-2433.1-1.

We hadn't been paying much attention, but apparently that figure was changed to the WRC-1992 Diagram some time ago. We now feel we should "modernize" by referring to the newer diagram, but we wonder whether the calculated FNs will change.

Should we make any changes to the FN requirements in our purchase specification?

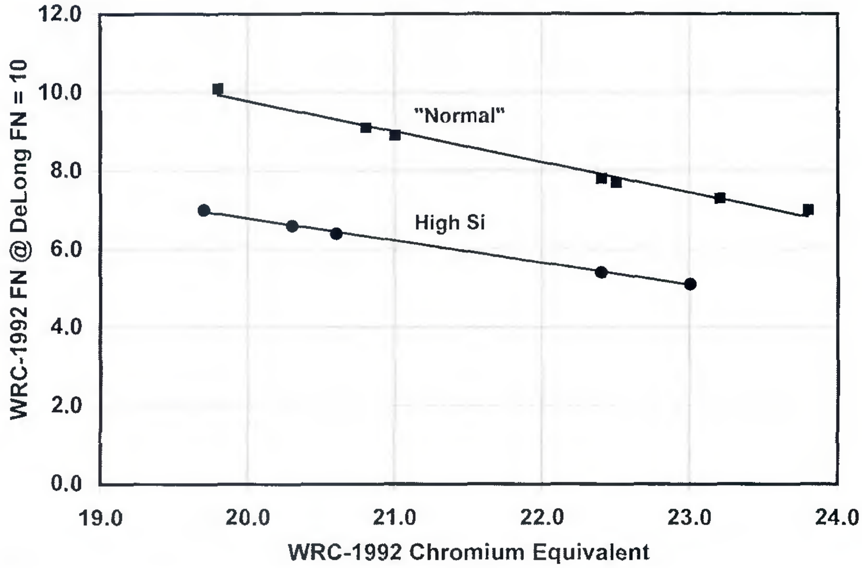


Fig. 1 — 10 FN from the DeLong Diagram transferred to the WRC-1992 Diagram as a function of alloy content.

A: Actually, the Fig. NB-2433.1-1 was changed from the DeLong Diagram to the WRC-1992 Diagram in the 1994 Winter Addendum to the ASME Code. So you are more than ten years behind. The change was made because it was shown, by comparing more than 200 measured Ferrite Numbers (FNs) vs. calculated FNs, that the WRC-1992 Diagram produced predictions consistently closer to the measured results, with a scatter band half as wide as that obtained with the same data using the DeLong Diagram. In particular, it was noted that the FN predictions of the two diagrams were closer together when the alloy composition was

Table 1 — Compositions for 10 FN Calculated According to the DeLong Diagram

Alloy	Composition (%)				DeLong Diagram			WRC-1992 Diagram		
	Si	Cr	Ni	Mo	CR_{eq}	Ni_{eq}	FN	CR_{eq}	Ni_{eq}	FN
ER308L	0.4	19.60	9.55	0.2	20.4	12.6	10.0	19.8	11.5	10.1
ER308L	0.4	20.61	10.90	0.2	21.4	13.9	10.0	20.8	12.8	9.1
ER316L	0.4	18.46	11.10	2.5	21.6	14.1	10.0	21.0	13.1	8.9
ER316L	0.4	19.90	13.00	2.5	23.0	16.0	10.0	22.4	14.9	7.8
ER309L	0.4	22.97	14.03	0.2	23.8	17.0	10.0	23.2	16.0	7.3
ER317L	0.4	18.96	13.10	3.5	23.1	16.1	10.0	22.5	15.1	7.7
ER317L	0.4	20.33	14.90	3.5	24.5	17.9	10.0	23.8	16.9	7.0
ER308LSi	0.8	19.50	10.24	0.2	20.9	13.2	10.0	19.7	12.2	7.0
ER308LSi	0.8	20.07	11.00	0.2	21.5	14.0	10.0	20.3	12.9	6.6
ER316LSi	0.8	18.10	11.45	2.5	21.8	14.4	10.0	20.6	13.4	6.4
ER316LSi	0.8	19.90	13.85	2.5	23.6	16.9	10.0	22.4	15.8	5.4
ER309LSi	0.8	23.00	14.62	0.0	24.2	17.6	10.0	23.0	16.6	5.1

lean than when the alloy composition was richer.

Keep in mind, however, that predicting ferrite in weld metal has a lot in common with predicting weather. We all admit to a degree of uncertainty in both activities.

There is no simple answer to your question. One way to approach it is to pick bare wire compositions that produce FN predictions within your FN range according to the DeLong Diagram, then see what happens to the FN predictions when they are changed to the WRC-1992 Diagram.

Bare wires can be produced with two silicon levels for the most part, the "normal" range of 0.30 to 0.65% and the "hi sil" range of 0.65 to 1.00%.

Usual practice is to use "normal" silicon for SAW and "hi sil" for GMAW. I'll consider both cases. I've arbitrarily chosen 10 FN by DeLong as the comparison point for the hypothetical compositions, and adjusted the nickel and chromium contents to remain at 10 FN for all alloys chosen.

Table 1 was constructed by arbitrarily fixing several of the chemical composition variables of all wires at values commonly found, and then manipulating the remaining composition variables within the allowable ranges of the AWS A5.9 specification. The fixed composition variables for all hypothetical wires are 0.02%C, 1.2%Mn, 0.2%Cu, and 0.06%N.

Compositions at the lean end of the AWS classification range and at the rich end were selected for all alloys except ER309L and ER309LSi to illustrate the trends. In the cases of ER309L and ER309LSi, it is necessary to raise the nickel higher than the specification allows, even with the Cr at the bare minimum of the specification, in order to force the FN calculated by the DeLong Diagram down to the arbitrarily chosen 10 FN. In the real world, ER309L and ER309LSi tend to be produced with higher nitrogen than the arbitrarily chosen 0.06% in order to manipulate the calculated FN of the wire while staying within the AWS A5.9 composition limits.

Table 1 includes the calculated chromium and nickel equivalents, and calculated FN, according to both the DeLong Diagram and the WRC-1992 Diagram.

For the lean ER308L composition in Table 1, the FN calculated by the WRC-1992 Diagram is almost exactly the same as that calculated by the DeLong Diagram. However, as the alloy content increases, the WRC-1992 Diagram tends to predict lower FN than does the DeLong Diagram, and this tendency increases with increasing alloy content.

It is illustrative to plot the FN calculated according to the WRC-1992 Diagram vs. the WRC-1992 chromium equivalent. This is done in Fig. 1 as two separate trend lines. One trend line is for the "normal" silicon compositions, and the other trend line is for the "hi sil" compositions. This is done to illustrate the point that the DeLong Diagram treats silicon as a ferrite-promoting element, while additional data used in developing the WRC-1992 Diagram led to the conclusion that silicon is not a ferrite-promoting element, at least up to 1.2% or higher.

You will get slightly different results if you assume a different nitrogen content, because the coefficient for nitrogen in the nickel equivalent of the DeLong Diagram is greater than the coefficient for nitrogen in the WRC-1992 Diagram. But the general trend will be similar to that shown here.

From Fig. 1 it should be quite clear that transferring a calculated FN requirement from the DeLong Diagram to the WRC-1992 Diagram is not a straightforward operation. For a given calculated FN, an adjustment is appropriate. That adjustment depends upon the nominal alloy content of the particular filler metal classification. For 308L, you probably need to make no adjustment in order to obtain the same actual deposit FN you were getting previously. For 316L, you would get about the same actual deposit FN by reducing the requirement for calculated FN according to the WRC-1992 Diagram by about 2 FN from your requirement for calculated FN according to the DeLong Diagram. And for 309L filler metal, you would get the same actual deposit FN by reducing the requirement for calculated FN according to the WRC-1992 Diagram by 3 to 5 FN from your requirement for calculated FN according to the DeLong Diagram.♦

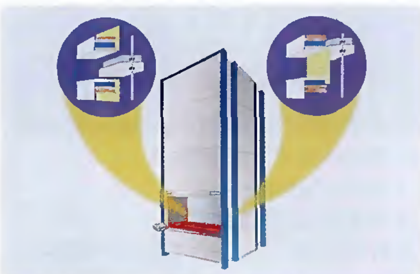
DAMIAN J. KOTECKI is technical director for stainless and high-alloy product development for The Lincoln Electric Co., Cleveland, Ohio. He is president of the American Welding Society, a vice president of the International Institute of Welding (IIW), a member of the A5D Subcommittee on Stainless Steel Filler Metals; D1 Committee on Structural Welding, D1K Subcommittee on Stainless Steel Welding; and a member and past chair of the Welding Research Council Subcommittee on Welding Stainless Steels and Nickel-Base Alloys. Send your questions to Dr. Kotecki c/o Welding Journal, 550 NW LeJeune Rd., Miami, FL 33126; or Damian_Kotecki@lincolnelectric.com.

GTAW/SMAW Machine Features Extended Power Range

The Syncrowave® 200 AC/DC GTAW/SMAW machine features an extended power range for welding thicker materials. It provides 5- to 200-A output power (150 A at 40% duty cycle), enough to weld ¼-in. aluminum in AC GTAW. It helps users enhance weld appearance with an easy-to-use, built-in pulse control that also helps eliminate melt-through and distortion. The machine tailors its arc starts with Syncro Start™, a selectable arc start condition feature where users can choose from soft, standard, or hot starting. The Fan-On-Demand™ improves power efficiency, reduces noise, and lessens the amount of contaminants pulled into the machine by running the fan only when needed. Auto-Postflow protects the weld pool and tungsten electrode from oxidation. For SMAW applications, the machine incorporates Adaptive Hot Start™ that automatically increases the amperage during the arc start, preventing the electrode from sticking to the work, and DIG control that performs a similar function during the weld to keep the electrode running smoother. A 115-V auxiliary power receptacle is located on the front of the machine. The machine also comes with a Weldcraft® WP17 Super Flex air-cooled GTAW torch, featuring a 12.5-ft Super Flex braided nylon power cable. Additionally, it comes with a 100% brass Smith regulator/flowmeter and a SMAW electrode holder, completing the accessory kit for both GTAW and SMAW.

Miller Electric Mfg. Co. 100
PO Box 100, Lithonia, GA 30058

Vertical Lift Module Designed with Automatic Shutter Doors



The Remstar Shuttle™ XP Vertical Lift Module (VLM) features automatic shutter doors that form a physical barrier between the user and the VLM's extractor shaft for added safety in welding supply applications. It is an enclosed system of vertically arranged trays, extraction platform, and computerized controls for automated retrieval of stored materials. To protect the user or material from accidentally falling into the product's shaft during operation, shutter doors automatically close during all vertical extractor operations. These steel parting doors form a physical barrier between the user and shaft, and are important in multiaccess units that span more than one level since they allow users on multiple floors to safely work on presented trays while the unit is delivering trays to other extraction windows.

Remstar International, Inc. 101
41 Eisenhower Dr., Westbrook, ME 04092-2032

Alloy Steel Products Developed to Resist Abrasion, Impact

WELLBRAZE is a solid sheet (homogenous) with a high manganese and nickel content. It can be welded with all low-hydrogen production welding processes (E7018, E9018, E11018, E12018, and 12018 manual electrodes). Also, it can be drilled with ordinary high-speed drills. The size range of material available is as follows: thickness ⅛ to 6 in.; widths 48, 72, and 96 in.; and lengths 144, 240, and 288 in. WELL-CLAD is an impact and wearing, chromium-carbide overlay applied to a ductile, easy-to-weld, easy-to-form, low-carbon-steel substrate. It was developed for severe wear applications.

Wellington Alloys 102
PO Box 250298, Franklin, MI 48025

Line of Protective Clothing Includes Overalls, Coats

The company's line of functional heat-resistant protective clothing is made of CarbonX® fabric. This fabric provides protection while being comfortable enough to wear next to the skin. When exposed to intense heat or flame, the fibers will carbonize and then expand, reducing the oxygen content within the fabric. It will not char, shrink, or burn when exposed to heat and flame. Also, the fabric is not chemically treated — it is a yarn created by spinning oxidized polyacrylonitrile fiber with an Aramid strengthening agent. The line includes overalls, aprons, and coats. A forearm sleeve and heat sink pads are available as well. Overalls and coats come in SM through XXL sizes, with XXXL and XXXXL available by special order.

Torch Wear 103
2374 Edison Blvd., Twinsburg, OH 44087

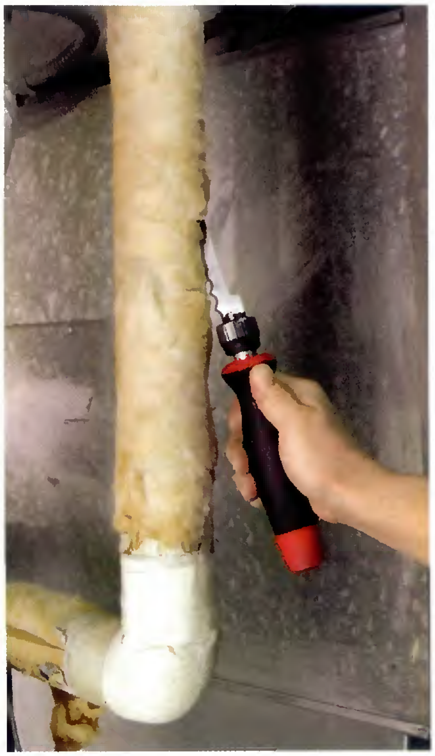
GTAW Torch Contains Low-Profile Design

The patented MT-125 is a compact water-cooled micro GTAW torch. It features a low-profile nozzle that can fit into ⅜-in.-diameter holes and, for greater torch maneuverability, includes 2-, 3.5-, and 5-in. body length options along with 45-, 90-, or 180-deg head configurations. Rated at 100% duty cycle up to 125 A, it gives users the ability to weld on virtually any GTAW application. Also, it uses a replaceable silicone rubber insulating sleeve and head components. It requires 1 liter of water/min at a minimum pressure of 40 lb/in.^{2} or 1.2 liters of water/min at a maximum pressure of 50 lb/in.^{2}

Weldcraft 104
2741 N. Roemer Rd., Appleton, WI 54911

Job Saw Accessory Blades Offered in Various Styles

A line of accessories for the Quik-Lok Job Saw allows versatility for the user to cut, scrape, and saw. The blades feature a ½-in. Universal Blade Tang and fit the Job Saw handle. The Quik-Lok blade release system allows for quick removal of the blade from the handle for storage. In-



cluded in the blade offering are a carbide grout blade, putty blade, paint scraper, linoleum blade, straight blade, wavy blade, roofer's blade, utility blade, hunter's blade, and a raker grout blade. They are made from stainless steel or nickel-plated high-carbon steel to resist rust and corrosion. In addition, they are available individually and in a 11-piece utility kit with Job Saw handle. A belt sheath is also available that attaches to a belt up to 2½ in. wide.

Milwaukee Electric Tool Corp. **105**
13135 W. Lisbon Rd., Brookfield, WI 53005

Metal Mesh Safety Shield Protects Workers from Flying Debris

The Metal Mesh Safety Shield protects workers from flying debris thrown off by cutting machines and grinding wheels. The shield hangs from its top edge with enough drape to wrap around dangerous flying objects, stopping their momentum and allowing them to drop to the ground. It allows air and light to pass through, providing for air circulation and worker supervision. The mesh is available in heights of 2 to 20 ft and in an 1/8- or 3/16-in. weave, both 19 gauge stainless steel mesh wire. The 1/8-in. 19 gauge weighs 100 lb per 100 sq ft, and 3/16-in. 19 gauge weighs 80 lb per 100 sq ft. Hooks are available to secure the mesh, and each hook locks in three strands of steel mesh, creating the full draping effect.

Wilson Industries, Inc. **106**
123 Explorer St., Pomona, CA 91768

Fire Suppression Option Available for Dust Collectors

The advanced fire suppression option, when added to the standard, spark arresting system available on all RoboVent systems, offers users an additional layer of security and protection against fires. The system uses both chemical and physical mechanisms to extinguish a dust collector fire depending on its size and severity. If a fire becomes large and raises the temperature in the collector, then the HFC-227 fire suppression agent will be released to extinguish the flame. HFC-227 is heptafluoropropane, a safe, colorless, odorless gas that leaves no residue and requires no cleanup after being released.

Great Lakes Air Systems **107**
1238 Anderson Ct., Clawson, MI 48017

Nozzle Reduces Oxygen Consumption for High-Definition Plasma Cutting

The company has redesigned its high-definition plasma cutting nozzles by elimi-

— *continued on page 79*

Reconditioning Power-Generation Components with Thermal Spray

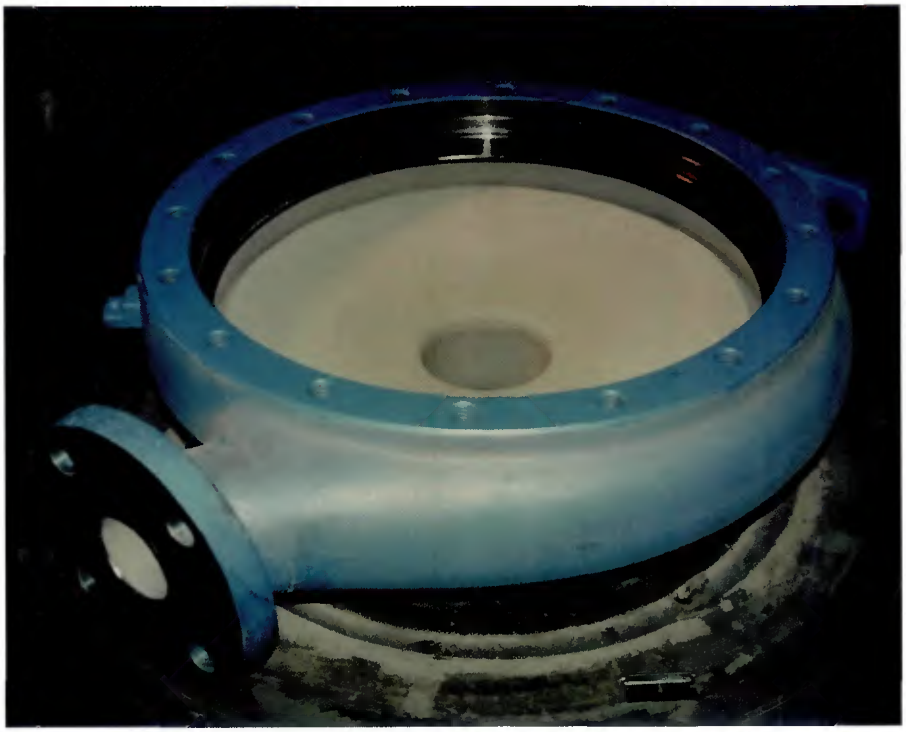


Fig. 1 — Applying a high-velocity oxyfuel (HVOF) sprayed carbide coating minimizes the wear and corrosion to the interior of this pump housing.

Thermal spraying offers versatility, economy, speed, and low heat input for restoring parts that normally would need to be replaced

BY KLAUS DOBLER

The growth of power-generation facilities throughout the world has been unprecedented. With this expansion, plant superintendents and maintenance supervisors will tell you that a tremendous amount of effort is expended behind the scenes to keep these power-generating facilities running smoothly. These facilities face numerous corrosion and/or wear issues, and maintenance must regularly be performed on various machines and systems. In an effort to reduce downtime, plant superintendents and maintenance supervisors have turned to and have come to depend upon thermal spray technology to extend the life of power-generating components and sys-

KLAUS DOBLER (kdobler@slmco.info) is with St. Louis Metallizing Co., St. Louis, Mo. St. Louis Metallizing is a member of the International Thermal Spray Association (ITSA), an organization promoting the capabilities of thermal spray technology.

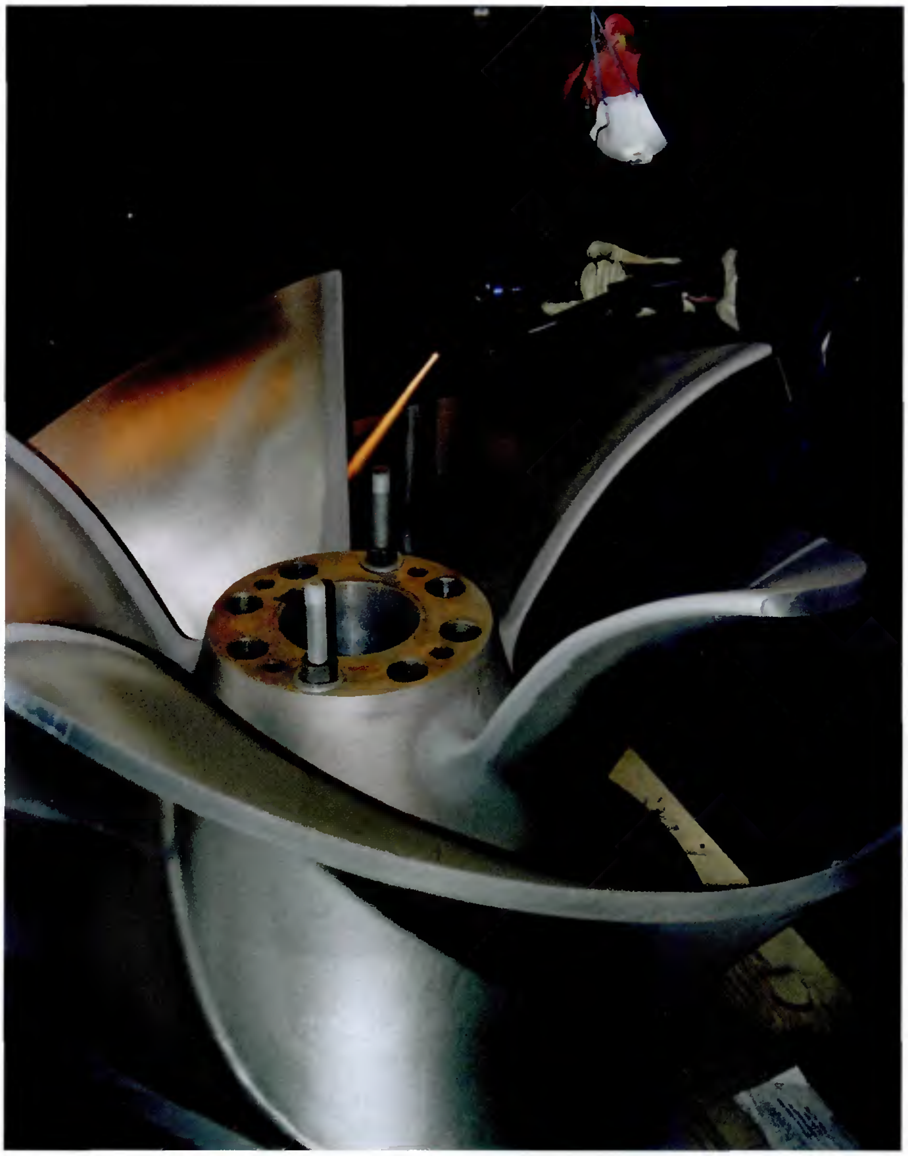


Fig. 2 — The leading edges of this impeller receive a wear-resistant carbide coating using the HVOF thermal spray process.

tems. Coatings manufactured by this technology are being used throughout the power-generating industry in applications such as water pumps, conveyor screws, boiler tubes, and coal crushers.

Pump Repair — Housings, Impeller Fins, Seal Sections, and Wear Rings

Pumps are used in almost every facet of a power-generating facility and must often endure abrasion as well as cavitation wear. The double suction pump is commonly used to move river water through a power plant. As river water commonly contains fine sand and even small stones, several sections of a pump can be attacked including the impeller fins, the pump housing, the impeller's seal section, and the wear ring.

The fins of the impeller are abrasively worn by the fine sand and the small stones and broken down by cavitation. Over time, pump efficiency will be reduced. Similarly, the housing of the pump also faces wear (Fig. 1) from the sand and/or rocks as water is pumped through it. If left unchecked, the housing will eventually wear away to the point where the pump may rupture. In both cases, the thermal spray solution is to apply a very hard and wear-resistant tungsten carbide coating onto the fins and leave it in the as-sprayed state — Figs. 1, 2. This HVOF sprayed coating contains about 1% porosity and has a very high hardness (1300–1400 HV 300 or ~ R_c 70).

The seal section of the impeller shaft undergoes abrasive wear when fine sand slips into the packing material and scores the journal. If the journal becomes too worn, water will eventually penetrate beyond the seal section and start corroding the bear-

Thermal Spray Processes

Flame Spraying

In the flame spraying process, oxygen and a fuel gas, such as acetylene or natural gas, are fed into a torch and ignited to create a flame. Either powder or wire is injected into the flame where it is melted and sprayed onto the workpiece.

Flame spraying can be readily performed in the shop or on-site and is generally low cost. Some of the materials that are typically applied are stainless steels, nickel aluminides, Hastelloy® alloys, tin, and babbitt. With relatively low particle velocities, the flame spray process provides thicker build-ups for a given material than the other thermal spray processes. The low particle velocities result in coatings that are more porous and oxidized as compared to other thermal spray coatings. Porosity can be advantageous in areas where oil is used as a lubricant, because a certain amount of oil is always retained within the coating, thus increasing its life. Oxides in the coating increase hardness and enhance wear resistance.

Arc Spraying

In the arc spray process, two wires are simultaneously brought into contact with each other at the nozzle. The electrical load placed on the wires causes the tips of the wires to melt when they touch. An atomizing gas such as air or nitrogen is used to strip the molten material off the wires and to transport it to the workpiece. Arc spraying is reasonably inexpensive and readily usable in the field. Low particle velocities enable high maximum coating thickness for a given material. Materials typically applied by arc spraying include stainless steels, Hastelloys®, nickel aluminides, zinc, aluminum, and bronze.

Recent advancements in nozzle and torch configurations provide greater control over coating quality and spray pattern. For example, the wires can be sprayed finely or coarsely. A 'fine' spray leads to smooth, very dense coatings whereas a 'coarse' spray enables greater coating thickness.

— continued on page 25

— continued from page 24

Plasma Spraying

Plasma spraying is generally regarded as the most versatile of all the thermal spray processes. During operation, gases such as argon and hydrogen are passed through a torch. An electric arc dissociates and ionizes the gases. Beyond the nozzle, the atomic components recombine, giving off a tremendous amount of heat. In fact, the plasma core temperatures are typically greater than 10,000°C — well above the melting temperature of any material. Powder is injected into this flame, melted, and accelerated toward the workpiece.

Plasma spraying was initially developed and remains the preferred process for applying ceramic coatings such as chromia, zirconia, and alumina. However, metals can be readily sprayed with this method. The particle velocities for plasma are higher than for those of flame and arc spraying and result in coatings that are typically denser and have a finer as-sprayed surface roughness. The tradeoff is that the maximum coating thickness for a given material is usually reduced.

HVOF

The high-velocity oxyfuel (HVOF) process was invented only 20 years ago, yet it has thrust the thermal spray application range into areas that were once unattainable. In HVOF spraying, a combination of process gases such as hydrogen, oxygen, and air are injected into the combustion chamber of the torch at high pressure and ignited. The resultant gas velocities achieve supersonic speeds. The powder is injected into the flame and also accelerated to supersonic speeds. The results are the densest thermal spray coatings available.

The HVOF process is the preferred technique for spraying wear- and/or corrosion-resistant carbides as well as alloys of Hastelloy®, Triballoy®, and Inconel® alloys. Due to the high kinetic energy and low thermal energy that the HVOF process imparts on the spray materials, HVOF coatings are very dense, with less than 1% porosity, have very high bond strengths, fine as-sprayed surface finishes, and low oxide levels.

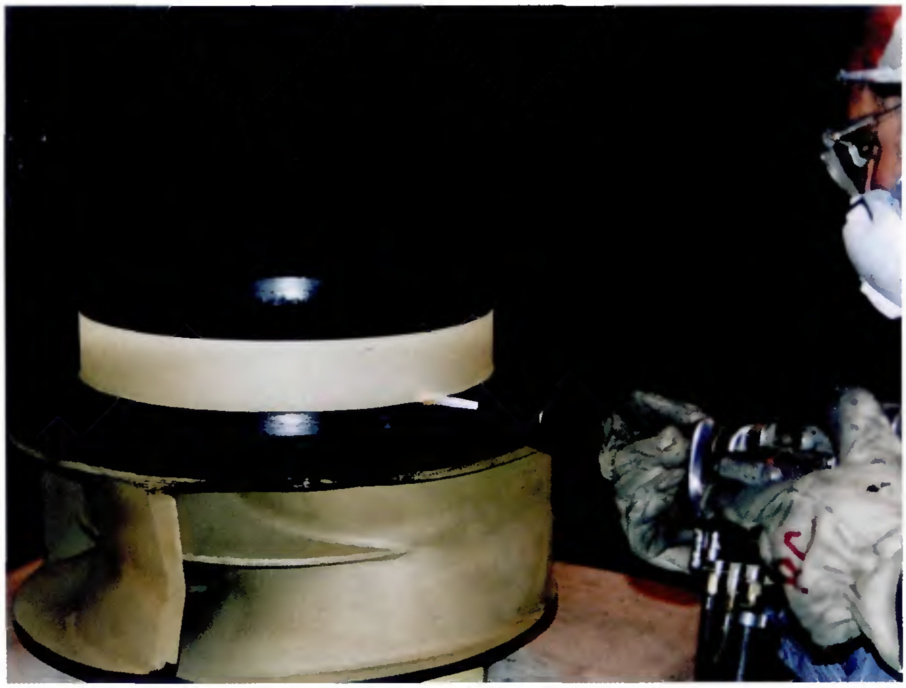


Fig. 3 — A craftsman rebuilds a ring section of an impeller by flame spraying it with a bronze coating, which will be machined to its final dimensions.

ings. An effective solution is to undercut the journal, plasma spray a chromium oxide coating, and finish the journal to size. Chromium oxide is characterized by a very high hardness (1300–1400 HV 300 or ~ R_c 70), a low coefficient of friction and excellent wear properties against abrasion in lubricated environments.

Lastly, the wear rings begin to erode as fine sand flows through the gap between the impeller and the housing. As it wears and widens, the efficiency of the pump is reduced. These wear rings can be efficiently reconditioned by applying bronze onto the rings and machining them to size — Fig. 3.

Coal Crusher Roll Repair — Journals and Seal Sections

In this case, a coal crusher (about 12 in. in diameter and 7 ft long) required repair on the seal section and the bearing section. A quick analysis of the seal section reveals that the coal dust generated during grinding penetrated the gap between the packing material and the journal, imbedding itself into the packing material and creating abrasion on the journal. The solution was to undercut the section, HVOF spray chromium carbide, then finish the journal to size. Chromium carbide has a hardness value of 950–1050 HV 300 (~R_c 65) and has good wear resistance properties against dry abrasion. With regard to the bearing section, the bearing scored the journal. Similar to the solution for the seal section, the journal was undercut, sprayed with stainless steel, then ground to size.

Reconditioning an Abrasively Worn Conveyor Screw

Conveyor screws are used in power plants to transport limestone into the boilers. One customer used a screw manufactured from carbon steel that needed to be replaced/repaired once a year due to the abrasion of the limestone. The thermal spray solution was to apply a thin layer of wear-resistant tungsten carbide on the shaft and both sides of the flights using the HVOF system. This repair procedure has extended the life of the screw significantly.

Outlook

Thermal spraying has established itself as a viable and cost-effective means for reconditioning worn components in the power-generating industry. The case histories presented in this article represent power-generating components that are currently being repaired with thermal spray technology. More importantly, they demonstrate that thermal spray coatings can increase component service life by 50 to 75%. By understanding the variety of successful applications, companies can duplicate and/or adapt these coating solutions to their own equipment. Moreover, a choice can be made that will save substantial downtime, increase profits, thereby resulting in an excellent return on the investment. ◆

Masking for Thermal Spray Coatings

The choice of maskant affects the integrity of the coating and production costs

BY ELLIOTT R. SAMPSON

When specific areas of a part must be thermally sprayed, the areas that are not to be coated must be masked. The masking method and materials used need to be selected based on the spray equipment and automation employed to apply the coating. The choice of maskant for each job is essential to the ultimate integrity of the coating and the total cost to process the part(s).

Early masking materials were taken from materials developed for other industries, for example tapes used for coil and cable wrapping, electrolytic shielding, and other applications in the electrical and electronic industries. Suppliers of thermal spray equipment, tape and molded rubber products worked to advance masking technology and techniques as higher performance was required. As a result they are the primary suppliers of most masking materials produced and sold today.

The use of metal masking has been commonplace for more than 50 years. It has been used for the repetitive spraying of production parts and High-Velocity Oxyfuel (HVOF) masking. Metal is typically used for HVOF masking because the velocity of the particles sprayed by many HVOF systems cuts through common tape and masking compounds. Careful consideration has to be given to the mask design as well as the removal of over spray from the mask. Because tolerances are given on blueprints as +⅛, −0 in., care must be taken in the spray operation to maintain these tolerances. The sprayer should not allow material to "bridge" from the masking onto the part. This could shadow the area to be sprayed or cause bonding problems when the masking is removed. Metal masks for HVOF are used in two forms, foil and solid pieces. The foil is considered disposable and the solid pieces are chemically stripped and reused.

Table 1 — Description of Masking Materials

Material	Form	Application	Masking for Grit Blasting	Masking for Spraying[1]	Removal
Fiberglass	Tape	Manual	Light Only	All	Peel
Silicone rubber-coated fiberglass	Tape	Manual	Normal	All	Peel
Aluminum foil	Tape	Manual	No	All	Peel
Teflon®	Tape	Manual	No	All[2]	Peel
Electroplater's tape	Tape	Manual	No	All	Peel
Stop-off	Paint	Brush or Spray	No	All	Water rinse
Printer's ink	Paint	Brush or Spray	No	All	Degreaser
Rubber sheet or preforms	Rod, sheet, preforms	Manual	All	All	Peel
Rubber masks	Molded pieces	Manual	All	All	Manual
Brush or spray rubber compounds	Liquid and Peel	Manually Spray	All Solvent	All	Soften in
Teflon®	Rod, sheet	Cut to fit, Place manually	No	All	Manual
Fiberglass	Sheet	Cut to fit, Place manually	No	All	Manual
Carbon	Rod, bar	Cut to fit, Place manually	No	All	Manual

Notes: 1. For processes other than HVOF.
2. Needs to be double wrapped for ceramics.

Types of Masking

Tapes

Fiberglass — This tape has a silicone adhesive and it will resist the heat of combustion, plasma, and arc processes. The disadvantage is that edge definition is difficult to maintain due to the fiberglass strands.

Rubber-coated fiberglass — The advantage of this tape is that, with the silicone rubber, the tape will maintain edge definition and resist deterioration by the blast. The heat resistance of the fiberglass is also a characteristic of this tape.

Aluminum foil — Used in far fewer instances for everything except HVOF spraying. Its disadvantages include a tendency for spray material to build up on the tape and cause shadows on areas where spray is required, and overheating can make the adhesive difficult to remove.

Teflon® — This tape is very pliable and as a result can be used on parts with complex geometries. Its disadvantages are the same as those for aluminum foil tape.

Vinyl electroplater's — Electrician's tape and duct tape are occasionally used for the arc spray process. Care must be taken to avoid using these materials where the buildup would overheat the masking material causing serious cleanup problems.

Rubber Masking

Silicone rubber — This is used in sheet and O-ring form. The sheet is used many times in areas adjacent to where the part is masked. The advantage is that it can be reused many times for both the blast and spray steps and is less expensive than tape.

Specialty and proprietary rubber molds and sheet — One proprietary material, Preban (Airex Rubber Products Corp., Portland, Conn.), has been used in molds for aircraft parts for both the blasting and spraying operations. A silicon-based compound, Machbloc™ (Tapeworks, Bethlehem, Pa.), can also hold up to blasting and some HVOF processes.

ELLIOTT R. SAMPSON (ersarc@msn.com) *is with TAFA Inc., Concord, N.H. Reprinted:* Spraytime, *Vol. 10, No. 4, International Thermal Spray Association,* www.thermalspray.org.

Liquid masking — There are various materials offered by suppliers of thermal spray equipment that are commonly used. While they are easy to apply, they do not resist the aggressive characteristics of the blast media. This usually determines that the liquid masking has to be applied after the blasting process.

Materials

Materials used are silicon rubber and Teflon® tapes, aluminum foil, heat-resistant paints, metal, rubber, fiberglass sheet, carbon plugs or brushes and Teflon®. Table I details the various materials used.

Masking Techniques for Specific Processes

Each thermal spray process has its own set of requirements for masking. Below are some guidelines to consider:

Combustion Spraying — Both wire and powder combustion spraying utilize a flame to melt the feedstock and propel it to the substrate. The maximum temperature reached with combustion spraying is 5000° to 6000°F. The masking materials used do not see the full effects of the temperature but, because of the flame, they should have the capability to withstand an open flame that will tend to heat the masking materials over 200°F.

HVOF Spraying — The comments under combustion spraying apply but, because of the velocity of the particles against the substrate, most masking materials other than metal cannot be used. This creates another problem, which is spray material buildup on the masks. The buildup can be eliminated by the use of acid and/or mechanical removal for some materials. When planning to strip and reuse, the mask must be made from Inconel® or stainless steel. Because the initial cost is much higher, many masks are made from plain carbon steel. These masks are thrown away when the buildup of overspray becomes unacceptable. Sometimes these masks are thrown away after each job. There are permanent masks and masks built as shadow masks from shim stock which is disposed of after use. Holes are masked with Teflon®, rubber plugs, or epoxy. The epoxy is baked out at the end of the process. This eliminates bridging of the spray material which can cause lengthy cleanup times.

Arc spraying — Because of the efficiency and high air flows of the arc spray process, the masking area is much cooler than with other spray equipment. A wider range of materials can be used due to the lack of flame. In some cases, ordinary masking tape is used. Where thick coatings are applied, heat from the high volume of sprayed metal can adversely affect any tape used on the part.

Plasma spraying — The plasma spraying process melts powder in a partially ionized mixture at temperatures ranging from 9000° to 30,000°F. This requires the masking materials selected to be the most heat resistant. Because the masking tends to lose definition on its edges during blasting, a separate masking layer may be required for the blast in order to maintain definition of the mask edge.

Cold Spray — This is the lowest temperature of all spray processes, 300° to 500°F, but has aggressive supersonic particle velocities. The process naturally produces a more defined edge pattern so masking can sometimes be eliminated. Masking materials for plasma can be used as well as sheet metal as a shadow mask.

Parting Advice

Masking can affect the quality, productivity, and profitability of the job. Serious consideration to your masking procedures will ensure the desired end result. ♦

This month's AWS Foundation spotlights:

Spotlight on a scholar

"My name is Mike Sebergandio. During my four years at Pennsylvania College of Technology, studying Welding Engineering Technology, I learned a great deal about welding and the welding industry. I also learned that the AWS is a driving force behind this industry as well as a contributor to many scholarships. These scholarships help aid students in welding programs with their educational expenses. I was fortunate to receive two of these scholarships. One was a $1000 scholarship and the other was a scholarship to travel to Osaka, Japan to learn about bridge welding at Matsuo Bridge Company. One scholarship greatly helped me with my expenses, while the trip to Japan greatly helped my perception of welding. I realized just how important welding is in our world and how great it is to be a part of something, although often overlooked, that helps people in so many ways. I am grateful that the AWS continues to offer scholarship opportunities so students can have the same positive experiences in the welding industry that I have had. Currently I am a Welding/Manufacturing Engineer at CNH America and I am working toward my master's degree in Manufacturing Systems Engineering at Lehigh University. I continue to stay active in my local AWS section here in Lancaster, Pa."

Spotlight on a scholarship

Matsuo Bridge Company is one of Japan's leading fabricators of steel for bridges, buildings, and other structures, including the world's longest suspension bridge. Established in 1925, the company operates steel fabrication plants in Sakai (Osaka), Chiba (Tokyo), and Shanghai. Dedicated to promoting international exchange, the Matsuo Bridge Company, Ltd. Scholarship provides either $2500 or a two- to three-week training opportunity for students enrolled in a civil or welding engineering school in the U.S. to study Japanese steel fabrication and construction at Matsuo's facilities in Japan. The goal is to foster goodwill and mutual understanding among members of the international steel industry.

The American Welding Society Foundation has helped thousands of students who otherwise would be unable to afford a welding education. We are proud of the fact that we help hundreds of welding students annually by providing them with funding towards their education. In fact, we are the only industry foundation set up specifically to further welding education and, in so doing, create the careers that sustain and grow our industry.

These funds are from your generous contributions. If you don't contribute, we will not be able to expand our work and our students' educations. And there is so much work to be done.

Please make a scholarship contribution, or set up your own Section or National Named Scholarship. Contact the AWS Foundation at 1-800-443-9353, ext. 212.

Circle No. 10 on Reader Info-Card

AWS Foundation, Inc.

Building Welding's Future through Education

Welding for the Strength of America

Assessing Toughness Levels for Steels to Determine the Need for PWHT

BY D. J. ABSON, Y. TKACH, I. HADLEY, AND F. M. BURDEKIN

Fracture mechanics calculations were used to determine toughness levels for C-Mn and low-alloy steels then compared to code recommendations regarding postweld heat treatment

Postweld heat treatment (PWHT) is applied to welded steel assemblies primarily to reduce the likelihood of brittle fracture. This is achieved through a reduction in the level of tensile residual stresses and through tempering of hard, potentially brittle, microstructural regions. There are, of course, economic and logistical incentives to avoid PWHT wherever possible.

This article reviews previous fracture mechanics methods used to form the basis of recommendations for fabrication codes, and outlines a generalized fracture mechanics approach to illustrate the implications, in terms of defect tolerance and toughness requirements, of not carrying out PWHT on welded steel structures. A series of curves is generated showing the relationship between material strength, material thickness, service temperature, and required impact properties.

The objective of this article is to demonstrate the use of fracture mechanics procedures to define minimum toughness requirements for welded fabrications so that PWHT is not needed.

Approach

Fracture mechanics calculations used previously as a basis for code recommendations have been reviewed, and further independent calculations have been carried out, based on the methods described in BS 7910:1999 (incorporating Amendment Number 1) (Ref. 1). The assessment was implemented using TWI's *Crackwise 3* software (Version 3.13).

Example calculations were carried out to determine the minimum required material fracture toughness for a variety of cases, in order to define limits for the avoidance of PWHT. However, it should be noted that the results of the calculations are intended to demonstrate the principle of analysis procedures such as BS 7910 for justifying the avoidance of PWHT, and to illustrate the trends in toughness requirements with variables such as material strength and thickness. For a particular structure, the actual requirement may be higher or lower than that shown in this article, depending on factors such as the actual stress applied to the component, the presence of areas of stress concentration, and the effectiveness of nondestructive examination (NDE). The results of this study should, therefore, not be applied directly to actual fabrications without expert consideration.

The Use of Fracture Mechanics in Assessing the Need for PWHT

Justification for Considering a Fracture Mechanics Approach

While limiting thickness criteria beyond which PWHT is required have been

D. J. ABSON and I. HADLEY are with The Welding Institute, Granta Park, Great Abington, Cambridge, U.K. Y. TKACH, formerly with TWI, is now with Corus Technical Centre, Moorgate, Rotherham, U.K. F. M. BURDEKIN was formerly a professor at University of Manchester Institute of Technology, Manchester, U.K.

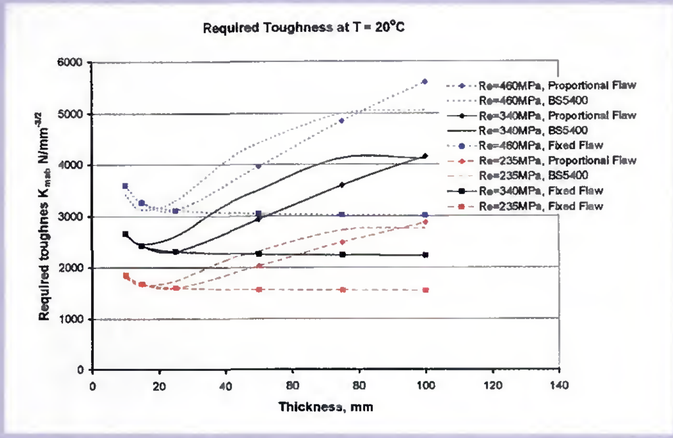


Fig. 1 — Results from fracture mechanics analyses for proportional and fixed flaws, and a comparison with BS 5400 requirements.

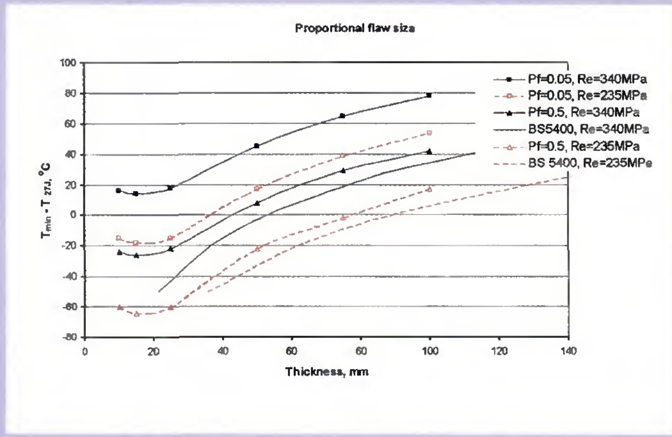


Fig. 2 — Minimum toughness requirements for exemption from PWHT, plotted as ($T_{min} - T_{27J}$); proportional flaw assumed.

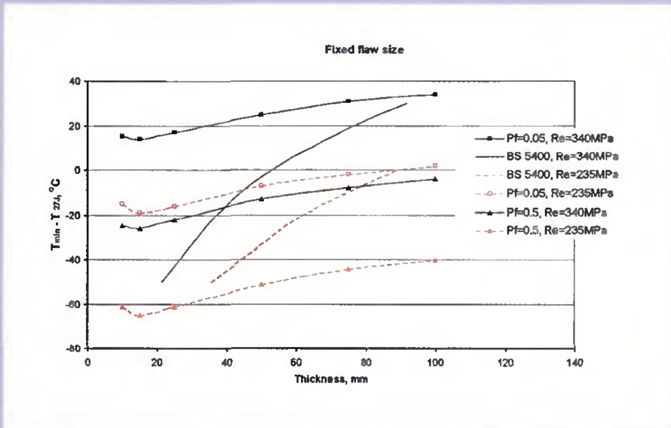


Fig. 3 — Minimum toughness requirements for exemption from PWHT, plotted as ($T_{min} - T_{27J}$); fixed flaw size assumed.

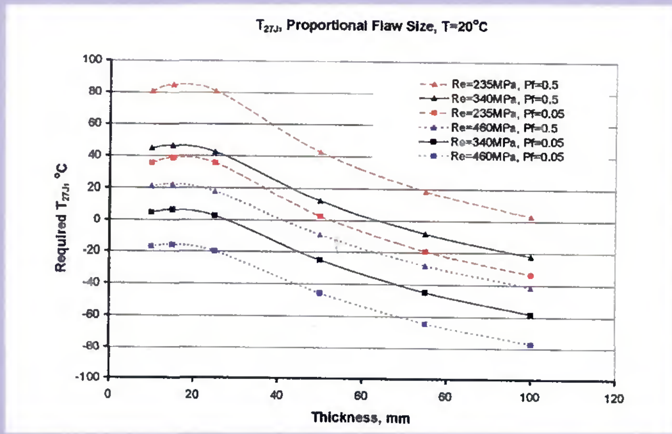


Fig. 4 — Minimum toughness requirements for exemption from PWHT, plotted in terms of required value of T_{27J}, T_{min} = 20°C, and proportional flaw size assumed.

in use for many years for pressure vessels and piping, and can be considered to have been validated by custom and practice, the scientific derivations of these criteria may not always be known. In the United Kingdom, the original requirements for low-temperature applications of pressure vessels and storage tanks were based on an extensive series of notched and welded wide plate tests carried out at The Welding Institute (TWI) in the 1960s (Ref. 2). However, it is likely that the criteria for many other codes were devised on the basis of engineering experience and best practice at the time. The basis on which the criteria were derived may not be so relevant today, owing to various factors. For example,

- Steelmaking technology and welding consumables manufacture have improved considerably in the last 25 to 30 years. As a consequence, the fracture toughness of base steels and welds has improved.
- Improved understanding of welding defects has enabled the development of improved welding procedures and methods.
- Knowledge of welding residual stresses and the influence of these stresses and material thickness upon the fracture event (through fracture mechanics) has improved.
- Nondestructive testing methods have improved since the derivation of some of the codes. For example, ultrasonic inspection has been widely used as a regular inspection tool only in the past 25 to 30 years. Prior to this, radiography (a technique that is not well suited to the detection of planar flaws) would often have been the main technique used to identify embedded defects.

An alternative approach for deciding whether PWHT is necessary to avoid failure by fracture is by conducting a fracture mechanics assessment of the as-welded joint, using a recognized procedure such as that described in BS 7910 (Ref. 1). It is obvious that a criterion for PWHT based on a fracture mechanics assessment is more complicated than a criterion based on material thickness alone. Nevertheless, the use of a fracture mechanics method is an attractive option to determine whether PWHT is necessary for the avoidance of failure by fracture.

A fracture mechanics analysis essentially provides a relationship between stress levels (applied and residual), flaw sizes, and material properties (fracture toughness and yield strength). In determining whether PWHT is required, assumptions have to be made about stress levels and the size of flaws that might escape detection during inspection. The toughness level required to avoid failure can thus be determined.

Fracture mechanics-based procedures have been used previously as the basis for determining maximum thicknesses for as-welded construction in the U.K. bridge and building codes (Refs. 3, 4), and also for the Eurocode 3 requirements. Details of these requirements were discussed in a previous article (A Review of Postweld Heat Treatment Code Exemptions, *Welding Journal*, March 2006, pp. 63–69).

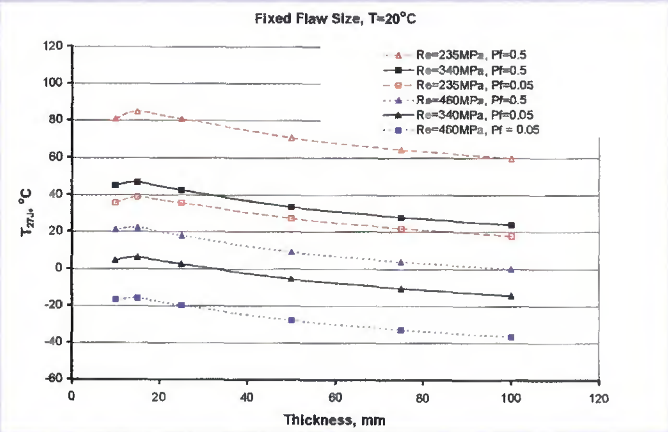


Fig. 5 — Minimum toughness requirements for exemption from the PWHT, plotted in terms of required value of T_{27J}, T_{min} = 20°C, and fixed flaw size assumed.

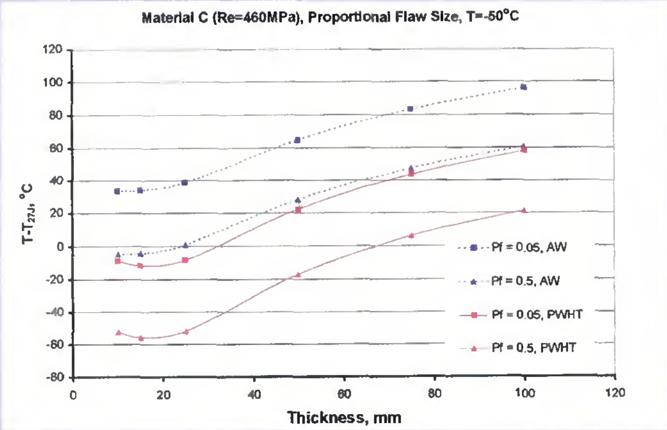


Fig. 6 — Minimum toughness requirements for a high-strength steel (R_e = 460 MPa), plotted as ($T_{min} - T_{27J}$); T_{min} = –50°C and proportional flaw size assumed.

The Influence of Increasing Wall Thickness on the Measured Fracture Toughness of C-Mn Steels

The basic assumption of fracture mechanics analyses is that fracture will occur in a material when the crack tip driving force, i.e., the applied stress intensity, exceeds the material's resistance to fracture initiation, i.e., the fracture toughness of the material.

So far as the crack tip driving force is concerned, the total applied stress intensity, $K_{I,Total}$, depends on both the applied stress intensity and the stress intensity due to residual stresses resulting from the welding process. Hence, this factor can be expressed as

$$K_{I,Total} = K_{I,Primary\ Stresses} + K_{I,Residual\ Stresses}$$

Higher levels of stress triaxiality in thicker sections render them more susceptible to fracture. For these reasons, the reduction of residual stress levels in thicker components by PWHT may be necessary, in order to reduce the likelihood of brittle fracture.

Regarding materials' resistance to fracture, it is generally observed that the measured fracture toughness of a ferritic steel tested in the lower transition region decreases with increased thickness of the specimen being tested. In the case of a through-thickness crack (for example, in the case of fracture mechanics test specimens), this phenomenon can be explained in terms of two factors.

1. Weakest link theory. The likelihood of a crack front sampling a region of low toughness increases with the amount of material it samples. That is, the average measured fracture toughness is expected to decrease with increased crack front length.

2. Crack tip constraint. The fracture process is also highly dependent on crack tip constraint (triaxiality), which in turn is a function of the geometry of the specimen being tested, including specimen thickness, loading mode, and crack depth. (The last two variables are usually standardized in fracture mechanics testing.) As the thickness of a SENB (single edge notched bend) specimen increases, so a greater proportion of the crack front experiences high crack tip constraint, and the fracture toughness decreases, until in the limit the plane strain fracture toughness, K_{Ic}, is reached.

Engineering Critical Assessment Based on a Fracture Mechanics Approach

Analyses Used as the Basis for BS 5400:2000 and BS 5950:2000

The basis for the original requirements of BS 5400 (Ref. 5) for bridges and the related requirements for BS 5950 (Ref. 6) for buildings in the early 1980s is given in Ref. 3. The requirements were based on a combination of existing experience, the results of notched and welded wide plate tests, and a framework based on a fracture mechanics analysis using the then current edition of BSI Document PD 6493 (which subsequently became BS 7910 (Ref. 1)).

The assumptions about initial flaw sizes and applied and residual stress levels have a strong influence on the resulting calculated requirements for fracture toughness. These then have to be related first to limiting thickness conditions and second to Charpy test requirements. For most practical applications of welded structures and pressure-related components, toughness requirements are expressed in terms of the Charpy V-notch impact test. Therefore, if fracture mechanics methods are to be used, it is also necessary to have available a relationship between fracture mechanics-based toughness and Charpy test energy absorption.

As a result of the development of improved correlations between fracture mechanics toughness and Charpy energy absorption (Ref. 7), updated fracture mechanics treatments from PD 6493 to BS 7910 and the need to improve the treatment for typical stress concentration regions, a collaborative project was undertaken in the late 1990s between TWI and UMIST. The results from this project were used as a background for revised requirements for the avoidance of brittle fracture in BS 5400:2000 and BS 5950. Examples of the results from these previous analyses are compared with those derived in the present work in Figs. 1–3, and discussed in the Fracture Mechanics section of the Discussion.

New Calculations Carried out in the Present Work

Example calculations were carried out in the present project, independently of the work described in the previous section, to determine the minimum material fracture toughness for a variety of cases, in order to define limits for the avoidance of PWHT. The starting assumptions for the analysis were somewhat different from those described in the previous section, as summarized in Table 1. The model used to calculate the necessary material fracture toughness was based upon a semielliptical surface-breaking flaw in a flat plate of thickness B. Note that the results of the calculations are intended to demonstrate the principle of analysis procedures such as in BS 7910 (Ref. 1) for the avoidance of PWHT. The findings should not be applied directly to actual fabrications without expert consideration.

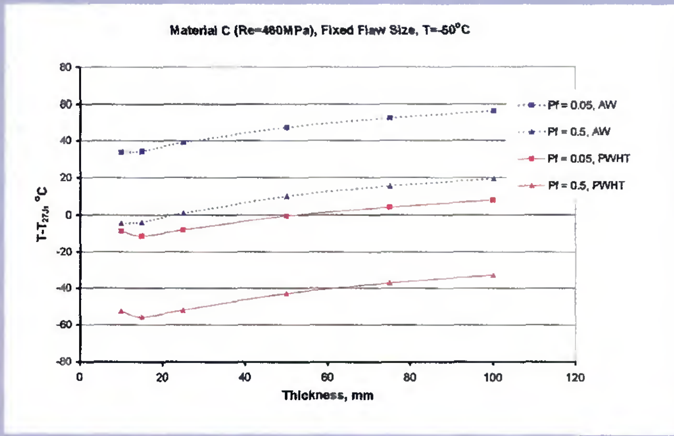


Fig. 7 — Minimum toughness requirements for a high-strength steel (R_e = 460 MPa), plotted as ($T_{min} - T_{27J}$); T_{min} = –50°C and fixed flaw size assumed.

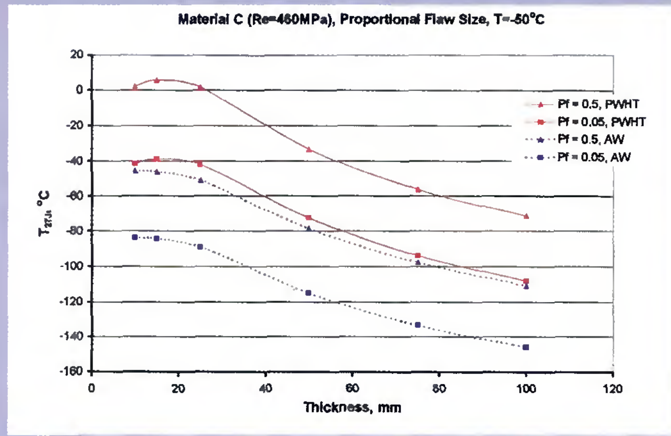


Fig. 8 — Minimum toughness requirements for a high-strength steel (R_e = 460 MPa), plotted in terms of T_{27J} requirement; T_{min} = –50°C and proportional flaw size assumed.

Table 1 — A Comparison of the Assumptions Underlying the Fracture Mechanics Model Used in this Work, and that Used in Deriving the Fracture Avoidance Rules of BS 5400:2000

Parameter	This Study	Reference 5 (background to BS 5400:2000)
Flaw height, a	• a = 0.1 B, but a ≥ 3 mm (proportional flaw) • 3 mm (fixed flaw)	a = 0.15 B, but 3 mm ≤ a ≤ 12 mm
Applied stress	0.67 R_e	0.75 R_e*
P_f	0.05 and 0.50	0.40
Flaw type, flaw aspect ratio, residual stress	similar	

Pf = probability that toughness of a test specimen will exceed the toughness Kmat
Kmat = required minimum fracture toughness
B = plate thickness
Re = yield strength
*refers to the so-called "base case," k = 1

Table 2 — Base Material Room-Temperature (20°C) Mechanical Properties

Material	Yield Strength (R_e), MPa	Tensile Strength (R_m), MPa
A	235	360
B	340	510
C	460	680

Table 3 — Base Material Mechanical Properties at –50°C

Material	Yield Strength (R_e), MPa	Tensile Strength (R_m), MPa
A	295	452
B	400	600
C	520	769

Joint Geometry

The welded joint was assumed to be a butt joint weld in flat plates of equal thickness (B). Plate thicknesses ranging from 10 to 100 mm were examined. Other geometries could have been readily accommodated in this approach, but the flat plate geometry was chosen for the purpose of illustration.

Flaw Type and Size

All flaws examined were of the semi-elliptical, surface-breaking type, oriented parallel with respect to the welding direction, representing flaws that may be found within the weld metal or heat-affected zone of a welded joint.

In terms of flaw size, two cases were studied. First, the flaw size was considered to be proportional to the thickness of the plate. The flaw height was chosen to be B/10, where B is the plate thickness (with the restriction that a minimum flaw height of 3 mm was allowed). This flaw height, which is assumed to be the approximate height of a weld bead, is also assumed to be a credible size of flaw that might arise and remain undetected in a multipass fusion weld. In all cases, the flaw aspect ratio (a/2c) was set to 0.1, thus defining the flaw length.

In the second case, the flaw size was fixed, independent of plate thickness. A flaw height of 3 mm was chosen, and a flaw length of 30 mm, i.e., a/2c = 0.1.

Again, it must be emphasized that these flaw dimensions are used for illustrative purposes; the actual sizes to be used for assessment in a particular fabrication will depend on the type and quality of the NDE method used.

Material Properties

Three materials with yield strengths from 235 to 460 N/mm^2 were considered, their room-temperature tensile properties are listed in Table 2. The mechanical properties of the respective weld metals were assumed to be equal to those of the base materials. The analyses were repeated for Material Design Minimum Temperatures (T_{min}) of 20°C and –50°C; assumed base material properties at 20°C and –50°C are listed in Table 3.

Stresses

The primary stress was assumed to be a membrane stress of magnitude equal to two-thirds of the room-temperature yield strength of the base material, i.e.,

$$P_m = (2/3)\, R_{e(RT)}$$

The secondary stress, i.e., the residual stress due to welding, was assumed to be a membrane stress of magnitude equal to the room-temperature yield strength of the base material, i.e.,

$$Q_m = R_{e\,(r.t.)}$$

Residual stress relaxation was enabled, as per BS 7910 (Ref. 1).

A stress intensity magnification factor

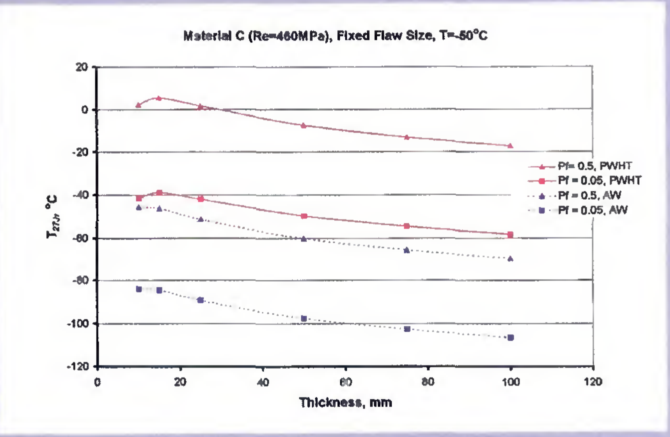


Fig. 9 — Minimum toughness requirements for a high-strength steel (R_e = 460 MPa), plotted in terms of T_{27J} requirement; T_{min} = –50°C and fixed flaw size assumed.

(M_{km}) due to the presence of the weld toe was assumed, using the two-dimensional solution specified by BS 7910 (Ref. 1). In addition, an arbitrary membrane stress concentration factor, k_{tm}, of 1.2 was assumed to apply, to take into account possible stress-raising features such as joint misalignment. Note that gross stress concentrating features such as holes are not considered in this simple model, and that such features would considerably increase the required fracture toughness.

Fracture Toughness

The minimum required fracture toughness, K_{mat}, was calculated from the previous information using TWI's *Crackwise 3* software.

An estimate of the equivalent T_{27J}, i.e., the temperature at which a full-size Charpy V-notch impact specimen absorbs 27 J, was then calculated for two "probabilities of failure," P_f = 0.05 and P_f = 0.5, using the correlation between fracture toughness and Charpy energy given in Annex J of BS 7910 (Refs. 1, 7). This correlation (the so-called "Master Curve") is based on a well-validated correlation between the temperature to achieve an absorbed Charpy energy of 27 J and that to achieve a fracture toughness of 3160 N/mm$^{3/2}$ (100 MPa$\sqrt{m}$) in a 25-mm-thick section. The reason for considering two different values of P_f lies in the different levels of reliability that may be required for a structure, which in turn will influence the value of P_f chosen. (P_f is actually the probability that the toughness of a specimen will exceed the toughness K_{mat}; note that it is not the probability of failure of the structure itself.)

Note that the Master Curve is primarily a tool for estimating minimum expected fracture toughness from Charpy energy for the purpose of making decisions on the repair of welding flaws, in which case a value of P_f = 0.05 is usually adopted. It is not intended to be used to estimate Charpy energy requirements from fracture toughness requirements, but if used in this way a value of P_f = 0.50 might be appropriate, to avoid excessive conservatism in the Charpy energy requirement. The appropriate level of P_f will probably lie somewhere between 0.05 and 0.5, and will depend on factors such as the consequences of failure of a structure, and whether the structure is redundant, i.e., whether an alternative load path is available. In this study, both P_f = 0.05 and P_f = 0.5 were used, since the main objective was to illustrate the trends in Charpy energy requirement associated with increasing material strength and thickness, and decreasing T_{min}.

Results of Fracture Mechanics Assessment

The results of the analyses are shown in Figs. 1–9.

The required toughness (K_{mat}) for the three materials and the two types of flaws (proportional and fixed) is shown against thickness in Fig. 1. The figure refers to the requirements at T_{min} = 20°C, but the results for T_{min} = –50°C were virtually coincident, assuming the value of K_{mat} to be that associated with the temperature T_{min}. The equivalent curves used to derive the BS 5400: Part 3 rules are also shown for comparison with the results of the current study. It can be seen that, for the geometries and flaw sizes investigated in the present work, the required toughness actually decreases slightly with increasing section thickness from 10 to 25 mm. This is simply because BS 7910 (Ref. 1) uses two failure criteria — brittle fracture and plastic collapse of the uncracked ligament. For these thinner sections, plastic collapse tends to dominate, and the toughness requirement therefore initially decreases with thickness. As thickness increases beyond 25 mm, fracture becomes the dominant failure mode.

The calculated minimum material fracture toughness values were then correlated with a required value of T_{27J}, using the Master Curve correlation. Since the Master Curve is based on K_{mat} values measured on a 25-mm-thick specimen, a correction is required to account for thickness effects. The Master Curve thickness correction is based on a "weakest link" theory, i.e., the larger the specimen tested, the greater the likelihood of the flaw sampling an area of low toughness. Consequently, components thicker than 25 mm require increased fracture toughness (and hence decreased T_{27J}) compared with 25-mm-thick components. Conversely, components less than 25 mm thick would be expected to require less toughness (and hence increased T_{27J}) compared with 25-mm-thick components. The precise shape of the T_{27J} vs. thickness curve is then dependent upon both how the calculated values of K_{mat} vary with thickness and the Master Curve thickness correction.

Figure 2 shows the minimum Charpy requirements (in terms of a specified value of temperature difference between T_{min} and T_{27J}) for the avoidance of postweld heat treatment as a function of thickness, t_{max}, for the case of initial flaw sizes assumed to be proportional to the thickness. Figure 3 shows the equivalent requirements assuming a fixed flaw height of 3 mm. In the case of the fixed flaw size, the toughness requirement levels off for thicknesses above 70 mm, while for the proportional flaw, the required material toughness increases with section thickness.

The required material fracture toughness at the design minimum temperature increases with material strength. Figures 2 and 3 show that for both proportional and fixed flaw size cases, the curves for different strength levels (R_e = 235 and 340 MPa) lie approximately parallel to one another, with higher toughness requirements (larger value of $T_{min} - T_{27J}$) for higher-strength steels. They also show that higher toughness levels are required for a lower probability factor in the Charpy energy absorption/fracture toughness correlation, and that higher Charpy energy requirements apply to the "proportional flaw" than to the "fixed flaw."

Figure 4 provides the calculated T_{27J} values against thickness for service at T_{min} = 20°C for the proportional flaw size case and for all three materials considered, while Fig. 5 shows the corresponding information for the fixed flaw size case. T_{27J} values were calculated for two probabilities of failure, namely, P_f = 0.05 and P_f = 0.5. The results show how material strength and section thickness, as well as the original assumptions made about flaw size and the value of P_f, influence the calculated T_{27J} requirement. As expected, the most onerous values of T_{27J} were obtained for the high-strength material (material C, R_e = 460 MPa) of thickness 100 mm. At T_{min} = 20°C and a probability of failure P_f = 0.05, the required T_{27J} temperature of the high-strength material for the proportional flaw size case is –77°C.

For the fixed flaw size case, the equivalent figure would be –37°C. For a probability level of 0.5, the corresponding figures are –41° and 0°C.

Since the height of the proportional flaw is assumed to be 0.1 times the thickness, the above proportional flaw size calculation assumes the existence of a surface flaw of 10-mm through-wall height and length 100 mm. The fixed flaw size case assumes that a surface flaw 3 mm high and 30 mm long could be present in the structure (and could be missed by nondestructive examination). In practice, whether or not PWHT is required would therefore depend in part on judgments about the size of flaw that could be reliably detected, and the probability figure considered appropriate. For example, the figure $P_f = 0.4$ for the BS 5400: Part 3 rules was chosen largely on the basis of fitting existing service experience of the avoidance of fracture failures, with particular reference to bridge failures.

It should be noted that steels with strength $R_e = 460$ MPa can be supplied with excellent Charpy properties, and the use of 100 mm thickness at 20°C in the as-welded condition is therefore possible, subject to the specification of appropriate Charpy energy and NDE.

Equivalent calculations can be carried out for $T_{min} = -50°C$, using Figs. 2 and 3. Since $T_{min} - T_{27J}$ is virtually independent of T_{min}, the T_{27J} requirements shown above for $T_{min} = 20°C$ simply shift by the change in minimum service temperature, i.e., by 70°C. Consequently, the requirements for a high-strength ($R_e = 460$ MPa) 100-mm-thick section steel shift to $-147°C < T_{27J} < -111°C$ (proportional flaw assumption) or $-107°C < T_{27J} < -70°C$ (fixed flaw assumption). Given such onerous requirements on Charpy energy, PWHT may be the only option for thick-section, high-strength steels operated at low temperature (for example, pressure equipment under blow-down conditions).

An additional analysis was carried out to investigate and illustrate the influence of PWHT on the estimated minimum requirements of the material toughness to avoid failure by fracture. The method used was similar to that used for the as-welded state, except that the magnitude of secondary (residual) stress was assumed to be 20% of the yield strength of the base material, as recommended by BS 7910 (Ref. 1).

The minimum required fracture toughness, temperature T_{27J} and values of ($T_{min} - T_{27J}$) were calculated for material C (high-strength steel) in the as-welded condition (AW) and after PWHT. The results, given in Figs. 6–9, reveal a large reduction in fracture toughness requirements for the material after PWHT. For example, the required minimum fracture toughness for a section thickness of 100 mm (proportional flaw size) decreases from 5500 $N/mm^{-3/2}$ in the as-welded condition to 3000 $N/mm^{-3/2}$ after PWHT. In terms of Charpy requirement, the values of ($T_{min} - T_{27J}$) shift by approximately 38°C (50°C for the fixed flaw assumption).

Discussion

Fracture Mechanics Assessment

As noted earlier, the required fracture toughness (K_{mat} values) for a thick-section welded joint made from high-strength steel was found to approach 5500 $N/mm^{3/2}$ (173.8 $MPa\sqrt{m}$) at the minimum operating temperature. This requirement may be somewhat difficult to satisfy in the weld and heat-affected zones of many structural steels without careful control of welding consumables and procedures, particularly as fracture toughness is generally observed to decrease with both section thickness and material strength.

As material yield strength increases, not only do specified toughness levels commonly increase, but it becomes increasingly difficult to meet toughness requirements without PWHT, as noted earlier. For example, for steel C ($R_e = 460$ MPa) 25 mm thick, intended for service at –50°C in the as-welded condition, the results of the fracture mechanics model calculations show that, for a failure probability $P_f = 0.05$, $T_{27J} = -89°C$ is needed. This would probably be impossible to achieve in a base and HAZ of a C-Mn steel of this strength. It may be noted that, for the example given, the PD 5500 (Ref. 26) toughness requirement would be 40 J at –76°C ($T_{27J} \approx -185°C$), while the API 620 (Ref. 19) requirement would be 40 J at –67°C ($T_{27J} \approx -76°C$). Thus, while the requirements of the codes have generally been found to be conservative, the degree of conservatism clearly varies, and may not always be present for the higher-strength grades of steel. For fine-grained C-Mn steels of this strength level that are intended for service at low temperatures, it may therefore be appropriate to carry out a fracture mechanics analysis to see whether PWHT can be safely omitted.

The fracture mechanics calculations have generated graphs that give some pointers to areas where existing code requirements are too restrictive, and also some indication that PWHT would be appropriate where it is currently not required. It may be possible to assemble available compositional, toughness, residual stress, and welding data from TWI and other databases, in order to generate similar families of curves, based on measured data. Preliminary graphs could be used to identify significant gaps for which a program of testing could be drawn up. By using such graphs, individual applications could then be considered, using material toughness and material thickness, carbon equivalent, and minimum welding parameters to demonstrate the case for the omission of PWHT or for increases in the limiting thickness. It will, of course, be necessary to convince insurance companies and classification societies involved with the plant or structure of the viability of this approach, and it is therefore desirable that they are involved in any discussions from the outset of the work.

In the present investigation, it has been confirmed that a fracture mechanics assessment, with assumed values of defect size and material strength, provides a cost-effective method of investigating whether PWHT is necessary in order to avoid failure by fracture. The cost of performing the analyses is relatively modest and, in some cases, the costs saved if PWHT can be avoided are large.

The strength of the welds considered in the calculations contained in this article were assumed to be matched to that of the base materials. In practice, welds are usually designed to slightly overmatch the base material properties. In this case, the residual stresses in the direction parallel to the weld bead are expected to be higher than the yield strength of the base material. The adverse effects this has upon the critical toughness may be partially accounted for by the increased strength of the weld metal. The effects of weld overmatching (or undermatching) are worthy of more detailed consideration on a case-by-case basis.

General Discussion

While fracture mechanics analyses such as in this article and those carried out as a basis for BS 5400/BS 5950 and by Mohr (Ref. 8) can give an indication of what changes in the codes it may be possible to justify, the elimination of any anomalies can only be brought about if adequate toughness data become available. This is clearly one area where an irksome restriction exists, and where a program of welding and mechanical testing would demonstrate whether any changes should be made in the relevant specifications. Another approach is, with the agreement of all interested parties, to carry out a fracture mechanics assessment on a case-by-case basis. As noted in the earlier article, with this approach, Leggatt et al. (Ref. 9) showed that, in some of the examples they considered, PWHT was not necessary.

Conclusions

BS 7910 level 2 assessments have been

carried out for two values of material design minimum temperature, using assumed values of material strength, flaw size, and stress. The BS 7910:1999, Annex J, correlation between fracture toughness and Charpy impact energy was used to derive toughness requirement in terms of T_{27J}, and the results have been compared with previous fracture mechanics-based analyses, including those underpinning the current BS 5400: Part 3 rules for fracture prevention in steel bridges. From this study, the following conclusions have been drawn:

1. If it is required to make a case for exemption from specific code requirements for PWHT, it may be possible to do so on the basis of a fracture mechanics analysis for a particular case. Such an approach will require consideration of the fracture toughness at the minimum service temperature, the quality of fabrication in terms of maximum sizes of flaw likely to be present, and the maximum stress levels (applied and residual) that will occur.

2. Fracture mechanics analyses carried out in the present work have been compared with those used as a basis for the general structural code requirements, and have given comparable results.

3. In a fracture mechanics assessment with assumed values of defect size and material strength, as expected, the toughness requirement can generally be expressed as a function of the difference in temperature between the material design minimum temperature (T_{min}) and the temperature at which the Charpy energy is at least 27 J. The toughness requirements become more onerous with increasing material strength and, more especially, with increasing thickness when the initial flaw size is assumed to be proportional to the thickness.

4. As examples, for T_{min} = 20°C, the toughness requirements are not unduly onerous, given the quality of modern steels and weldments, and the calculations provide an example where there is some justification for increasing the thickness limit beyond which PWHT is required in current codes.

5. For T_{min} = –50°C, the toughness requirements are sufficiently onerous that it might be appropriate to give a PWHT, even at the lower levels of thickness, for the higher strength grades. Possible examples are quenched and tempered steels, in certain applications, where the toughness may be inadequate at low design temperatures.

6. The required fracture toughness (K_{mat} values) for a high-strength, thick-section welded joint was found to approach 5500 N/mm$^{3/2}$ (173.8 MPa$\sqrt{m}$). This requirement may be somewhat difficult to satisfy in the weld and heat-affected zones of many structural steels without careful control of welding consumables and procedures, particularly as fracture toughness is generally observed to decrease with both section thickness and material strength.◆

References

1. BS 7910:1999, *Guide on Methods for Assessing the Acceptability of Flaws in Metallic Structures*, incorporating Amendment 1, now superseded by BS 7910:2005: *Guide on Methods for Assessing the Acceptability of Flaws in Metallic Structures*.

2. Woodley, C. C., Burdekin, F. M., and Wells, A. A. 1964. Mild steel for pressure equipment at sub-zero temperatures. *British Welding Journal* 11(3):123–134.

3. Burdekin, F. M. 1981. Materials aspects of BS5400: Part 6, paper 4 in *The Design of Steel Bridges*, Eds. K. C. Rockey and H. R. Evans, Granada ISBN 0 24611339 1.

4. Ogle, M. H., Burdekin, F. M., and Hadley, I. 2003. Material selection requirements for civil structures. *Proc. IIW Int. Conf. on Welded Construction for Urban Infrastructure*, 56th Annual Assembly of the IIW, Bucharest, Romania, Ed. D. Dehelean, International Institute of Welding, pp. 201–229.

5. BS 5400-3: 2000 (incorporating Corrigendum 1). *Steel, Concrete and Composite Bridges*, Part 3 — Code of practice for design of steel bridges.

6. BS 5950-1:2000. *Structural Use of Steelwork in Building*. Code of practice for design — Rolled and welded sections.

7. Wallin, K. 1994. New improved methodology for selecting Charpy toughness criteria for thin high-strength steels. IIW Document X-1290-94.

8. Mohr, W. C. 1997. Fracture mechanics to justify the minimum thickness for PWHT: Girth butt-welded steel pipe. Edison Welding Institute Report for Research Members MR9708.

9. Leggatt, R. H., Muhammed, A., Smith, A. T., and Cheaitani, M. J. 1999. Using fracture mechanics to claim exemption from PWHT — Four case studies. TWI Report for Research Members 679/1999.

Acknowledgments

Helpful discussions with C. S. Wiesner and other colleagues at TWI are gratefully acknowledged. The work was carried out within the Core Research program of TWI, which was funded by its industrial members.

Grit Blasting: Starting Your Thermal Spray Job Correctly

Proper roughening of the surface is as important as the thermal spraying itself

BY ELLIOTT R. SAMPSON

Grit blasting, or the roughening of the substrate to be thermal sprayed, is as important as the spraying itself. It cleans the surface and roughens the substrate to form an anchor tooth pattern to improve the coating adhesion. The measurement and control of the surface roughness pattern needs to be better monitored and controlled for thermal spray coatings. This article is based on my experience working for a manufacturer of grit blast equipment. It looks at what is common practice, current writings, and recommended procedures to improve this practice.

The Grit Blasting Process

The apparatus used is classified as either a suction-type blaster or pressure type. Suction uses a converging/diverging blast nozzle design to create a vacuum at the throat to draw the grit into the nozzle and propel it against the substrate.

Relationship between the Air Jet I.D. and the Grit Blast Nozzle

The inside diameter is critical to maintaining a consistent blast profile, which results in consistent bond strength of the coating. Figure 1 displays diagrams of two suction guns showing the air supply hose and the grit hose. The air hose focuses the air at the nozzle using an air jet of specific internal diameter to accelerate the air through the nozzle. The larger hose serves to propel the grit by a venturi or suction action through the nozzle and against the substrate.

Figure 2 shows the working of a pressure type system. In this system, the blast gun in the cabinet on the left only has one hose and the high-pressure air accelerates the grit against the substrate. The middle cabinet is the cyclonic separator, which vacuums the used grit out of the cabinet and sends it through the cyclone. The cyclone spins the used grit in a centrifugal action, allowing the heaviest grit to be reused and the fine particles to be transported to the dust collector.

The material to be reused is then recharged in the pressure chamber below the cyclone and used in the grit blast process. A suction-type system does not use a pressure pot but will use either a cyclonic separator or just recycle the heavier (larger) grit that falls into the bottom of the grit blast cabinet.

The vacuum action caused by connecting a dust collector to the cabinet will draw suspended fine particles of grit into the collector, which separates the particles and deposits them at the bottom of the collector. The right-hand cabinet in Fig. 2 is a dust collector that collects the fine particles in cloth "bags." The bags are periodically shaken, which transfers the residue to the bucket at the bottom of the unit. The bucket is sealed until the operator releases it for emptying. Dust collectors are utilized on all grit blast cabinets.

The Grits

The grits used range from aluminum oxide to chilled cast iron to crushed slags from metal production or coal-fired boilers. The latter two types are sold under a number of trade names. The term "grit" indicates an angular particle shape as opposed to "shot," which indicates a spherical shape. Shot, such as steel shot, is not used for thermal spray surface preparation since it does not produce the required rough surface profile. Glass beads are not used for the same reason.

Grit size is indicated by an identification number, such as G40

ELLIOTT R. SAMPSON (ersarc@msn.com) *is with TAFA Inc., Concord, N.H.* *Reprinted:* Spraytime, *Vol. 11, No. 2, International Thermal Spray Association,* www.thermalspray.org.

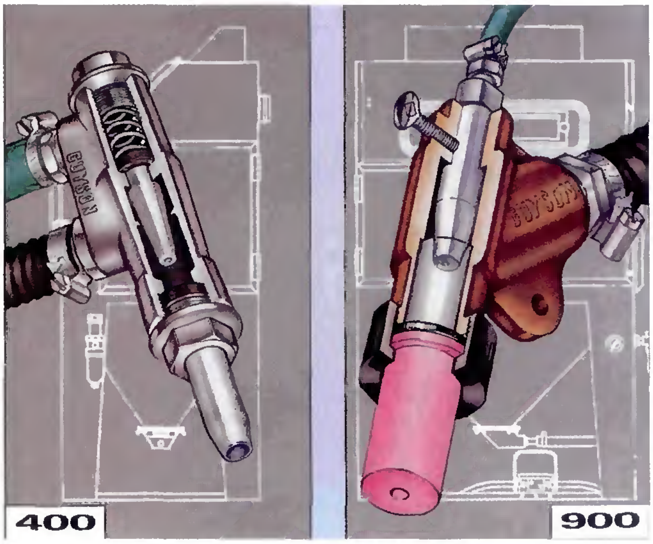


Fig. 1 — Cross sections of two suction grit blast guns. (Courtesy of Guyson Corp., Saratoga Springs, N.Y.)

Fig. 2 — Cross sections of grit blast system units. (Courtesy of Guyson Corp., Saratoga Springs, N.Y.)

for a cast iron grit or No. 60 for a nonmetallic abrasive grain such as alumina. The size defines a distribution of particle sizes for that particular size.

Grit size is determined by sieving using sieves conforming to ASTM E 11-87. Although there is no standard that defines the testing method to be used for grits, the procedures in ASTM C371-89, *Standard Test Method for Wire-Cloth Sieve Analysis of Nonplastic Ceramic Powders,* can be used as a guideline for nonmetallic grits and those in ASTM B214-99, *Standard Test Method for Sieve Analysis of Metal Powders,* for metallic grits. The SAE J444 standard contains the size specifications for cast iron grit. For example, G40 grit must be 100% –40 mesh, >70% +40 mesh, and >80% +80 mesh. The size specifications for nonmetallic grits, or abrasive grains, are contained in the ANSI B74.12 standard. For example, No. 60 grit must be 100% – 35 mesh; max 35% + 50 mesh; min 35% –50 mesh, +60 mesh; min 50% –50 mesh; min 60% combined, retained on 60 and 70 mesh; and max 5% –100 mesh.

These size distributions contained in the above standards are economically feasible to produce while still producing the desired result with economical production rates. The cost to produce a single mesh size grit, such as 100% –40, 100% +45, would be prohibitive.

Masking

Masking of parts prior to blasting is extremely important. The areas not to be sprayed must be protected from the aggressive grit, which can cause serious roughening and/or removal of base material. Many times a masking material that can withstand the grit blast is also designed to withstand the heat from the spray process. The masking for blasting is removed after grit blasting and before spraying. There are some cases where the blasting mask doesn't have spray masking under it. In such cases the spray masking is applied after removal of the blast masking. This is the choice of the thermal spray operator or his manager.

Summary

Blasting is an essential part of most thermal spray processing. If properly used and controlled, it provides for a consistently strong bond by providing the proper anchor tooth pattern; and if performed close to the spray application, assures the cleanest, contamination-free surface.

NACE International specification RP0287-2002, *Field Measurement of Surface Profile of Abrasive Blast-Cleaned Surfaces Using a Replica Tape,* is very helpful to measure blast profile on corrosion work and thermal spray work. To purchase the specification, visit *www.nace.org* and enter the specification number in the search site window. ♦

Electrode Orientation in Shielded Metal Arc Welding

The orientation of the electrode in relation to the workpiece and the weld groove controls the direction and location of the arc and is an important factor in the quality of a shielded metal arc weld. Improper electrode positioning can result in slag entrapment, porosity, and weld undercut. Proper orientation in the joint depends on the type and size of electrode, welding position, and joint geometry. The positioning of the electrode relative to the joint and the workpiece is described by the travel angle and the work angle.

The term travel angle denotes the angle (less than 90 deg) between the electrode axis and a line perpendicular to the weld axis, in a plane determined by the electrode axis and the weld axis. The term work angle denotes the angle (less than 90 deg) between a line perpendicular to the major workpiece surface and a plane determined by the electrode axis and the weld axis.

When the electrode is pointed in the direction of welding, the technique is termed forehand welding. The travel angle, then, is known as the push angle. When the electrode is pointed in the opposite direction to that of welding, the technique is termed backhand welding. The travel angle in backhand welding is called the drag angle. These angles are shown in the figure.

Typical electrode orientation and welding technique for groove and fillet welds for use on carbon steel with carbon steel electrodes are listed in Table 1.

Table 1 — Typical Shielded Metal Arc Electrode Positioning and Welding Technique for Carbon Steel Electrodes

Joint Type	Welding Position	Work Angle (Deg)	Travel Angle (Deg)	Welding Technique
Groove	Flat	90	5–10*	Backhand
Groove	Horizontal	80–100	5–10	Backhand
Groove	Uphill	90	5–10	Forehand
Groove	Overhead	90	5–10	Backhand
Fillet	Horizontal	45	5–10*	Backhand
Fillet	Uphill	35–55	5–10	Forehand
Fillet	Overhead	30–45	5–10	Backhand

*Travel angle may be 10 to 30 deg for electrodes with heavy iron powder coverings.

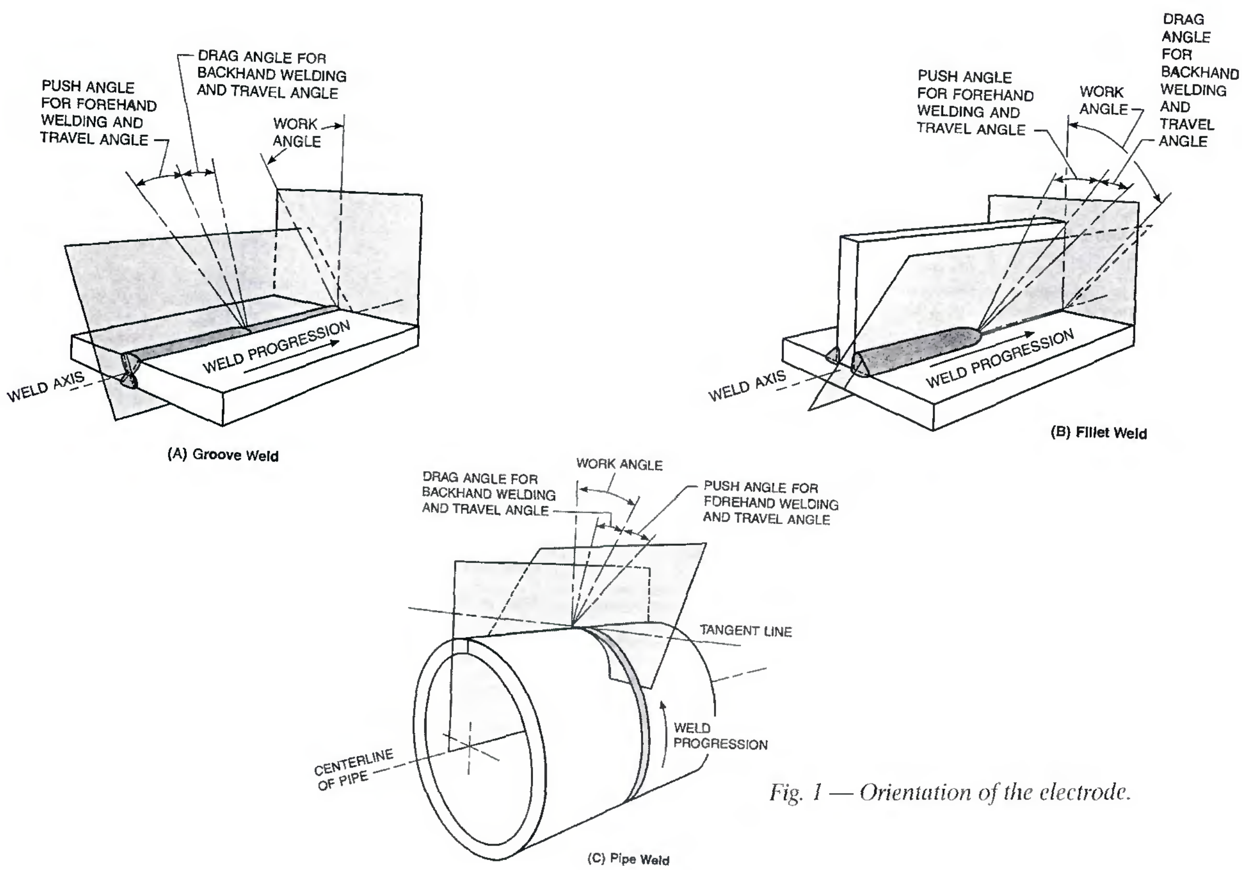


Fig. 1 — Orientation of the electrode.

Excerpted from the *Welding Handbook*, Vol. 2, ninth edition.

Welding in Aircraft and Aerospace Conference
September 19 and 20
Dayton, Ohio

Welding is finally making a big play in the aircraft industry. Two technologies in particular, friction stir welding and additive manufacture, are leading the way. At the conference in Dayton, Ohio, attendees will learn the latest about the welding processes that are starting to replace rivets as the main means of joining aluminum and about the many systems now in use where various welding processes are being used to build high-performance parts "from the ground up."

Welding the New Materials for the Automotive Industry Conference
October 31
FABTECH International & AWS Welding Show
Atlanta, Ga.

Welding engineers are often being asked these days to figure out how to weld the avalanche of new materials targeted for use in tomorrow's automobiles. The lighter-weight steels have moved up several notches in strength. Here the engineers are looking at the advanced high-strength steels (AHSS), the TRIP steels, and the dual-phase steels. Aluminum is another relative newcomer. A new generation of resistance spot welding plus laser beam welding are very much in the running as the main joining processes for these new materials.

Quality Control in Welding Conference
November 1
FABTECH International & AWS Welding Show
Atlanta, Ga.

Quality control is something that must be kept up front in the planning of welds. It is not enough to rely solely on control charts, statistical process control, or Taguchi methods to get the job done properly. The human factor must take front seat. Here is where we get into such aids as certified material testing reports for electrodes and real-time sensing and control of welding processes. This is how weld quality can be assured the first time around.

Spot Welding Conference
November 2
FABTECH International & AWS Welding Show
Atlanta, Ga.

Resistance spot welding continues to dominate the automotive industry and other industries where sheet metal has to be joined. But recently, a host of new processes, all of which are capable of applying spot welds, are attracting all sorts of attention. This list includes the likes of laser weldbonding, ultrasonic welding, friction stir welding, and kinetic spot welding. Will these new methods make life difficult for the more established resistance welding systems? Resistance welding is fighting back with some innovations of its own.

For more information, please contact the AWS Conferences and Seminars Business Unit at (800) 443-9353, ext. 223. You can also visit the Conference Department at *www.aws.org* for upcoming conferences and registration information.

NJC Developing New Technologies for Joining Titanium and Its Alloys

The lightweight, high strength-to-weight ratio, and excellent corrosion resistance of titanium and its alloys have led to the use of these metals in aerospace, chemical, marine, and medical industries. These properties also can enhance the performance of many Department of Defense (DOD) weapon systems, such as ships and combat vehicles.

For example, lightweight materials, including titanium alloys, are being considered to help the Navy achieve the demanding requirements for improved performance and weight reduction for next-generation surface combatants and aircraft carriers. The substitution of titanium alloys for steel will result in a 40% weight reduction. Other performance benefits of titanium are corrosion resistance in a saltwater environment, fire resistance, and a reduced magnetic signature. The Navy Joining Center (NJC) is part of a number of project teams that are developing advanced joining technologies for fabrication of complex titanium structures for Navy applications.

To date, the use of titanium on Navy ships has been limited to components used in seawater service such as piping systems, heat exchangers, pumps, and other auxiliary equipment. Titanium has not been used for structural components except for special submersible vehicles. The limited use of titanium is primarily a result of the relatively high costs for material and fabrication. Recent improvements in processing and melting techniques have reduced the cost to the point where the performance advantages of titanium make it attractive for consideration in additional Navy applications.

Some components that have been identified for possible conversion from steel to titanium include elevator doors, hatches and scuttles, mast components, exhaust uptakes/intakes, and island structures. The titanium alloys being investigated for weld development are Ti-6Al-4V (Grades 5 and 23), Ti-5Al-1Sn-1Zr-1V-0.8Mo (Grade 32), Ti-3 Al-2.5V (Grade 9), and Ti-6Al-2Sn-4Zr-2Mo.

Titanium components are presently welded with the gas tungsten arc welding (GTAW) process for most Navy applications. However, the cost of using GTAW for large Navy vessel components and structures is not practical. The use of gas metal arc welding (GMAW) to join titanium has been limited due to poor arc stability and excessive spatter. To overcome these limitations, the NJC is developing pulsed gas metal arc welding (P-GMAW), controlled metal transfer (CMT) GMAW, and friction stir welding (FSW) for ship structure applications. Each of these processes offers higher productivity and reduced fabrication costs. Pulsed GMAW is well established for use in shipbuilding on steel and aluminum, but not for titanium. Both P-GMAW and CMT processes improve control of the weld deposit and minimize distortion and spatter.

Fig. 1 — NJC built this complex titanium structure to evaluate a number of different joining processes that could be used to fabricate next-generation military combat vehicles.

The U.S. Army also is considering titanium alloys to reduce weight and improve the performance of its combat vehicles. Titanium is being considered for both armor and structure applications. For the armor applications, titanium can be used in monolithic form or combined with other metallic and nonmetallic materials to alter performance.

Successful joints have been produced with a variety of dissimilar material combinations using ultrasonic soldering. This process uses ultrasonic energy to remove surface oxides, which eliminates the need for oxide-reducing fluxes. A variety of test panels have been produced that have successfully passed ballistic testing.

Edison Welding Institute (EWI) recently produced the complex structure shown in Fig. 1 to demonstrate that a number of different joining processes could be used to produce high-quality titanium structures. A hybrid construction approach was employed to build this structure from ¼- and ½-in.-thick titanium. The goal in manufacturing this structure was to demonstrate the process maturity of several new joining processes for next-generation ground combat vehicles.

Robotic P-GMAW, hybrid laser welding, and FSW processes were used to fabricate the structure that met all requirements for weld quality and dimensional accuracy.

Titanium alloys are becoming very attractive for uses outside of the traditional applications in aerospace and medical industries. Both the U.S. Navy and U.S. Army are now taking advantage of these metals to meet the challenging performance goals in their respective systems. New welding processes are being developed to enable the DOD to continue to meet both performance and affordability goals for U.S. war fighters.

For more information on this joining project and other NJC activities, contact **Nancy Porter,** *nancy_porter@ewi.org,* (614) 688-5104, or **Chris Conrardy,** *chris_conrardy@ewi.org,* (614) 688-5191. ♦

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

5th Int'l Conference on NDE in Relation to Structural Integrity for Nuclear and Pressurized Components. May 10–12, San Diego, Calif. Contact EPRI at *www.epri.com.*

♦**Sheet Metal Welding Conference XII.** May 10–12, VisTaTech Center, Livonia, Mich. Sponsored by the AWS Detroit Section. Contact Mike Palko (313) 805-6199, or visit *www.awsdetroit.org.*

Int'l Thermal Spray Conference and Exposition. May 15–18, Seattle, Wash. Visit *www.asminternational.org/itsc.*

37th Int'l Symposium on Robotics ISR 2006 and 4th German Conference on Robotics: Robotik 2006. May 15–17, Int'l Congress Centre, Munich, Germany. Contact *www.isr2006.com.*

11th Beijing Essen Welding & Cutting Fair. May 16–19. China Int'l Exhibition Centre, Beijing, China. Contact *http://essen.cmes.org/en/index.htm.*

37th Int'l Steelmaking Seminar. May 21–24, Porto Alegre, Rio Grande do Sul, Brazil. Sponsored by ABM (Metallurgy and Materials Assn. of Brazil). E-mail Sandra Feraccini at *sandra.feraccini@abmbrasil.com.br.*

EASTEC 2006 Exposition and Conf. May 23–25, Eastern States Exposition, W. Springfield, Mass. Contact Society of Manufacturing Engineers (313) 271-1500; *www.sme.org.*

Rapid Prototyping and Manufacturing 2006, and 3-D Scanning: Reverse Engineering, Analysis, and Inspection. May 23, 24, Pheasant Run, Saint Charles, Ill. Contact Society of Manufacturing Engineers (313) 271-1500; *www.sme.org.*

♦**WELDMEX 2006.** May 31–June 2, Cintermex, Monterrey, Mexico. Contact Chuck Cross (410) 252-1322; *chuckcross17@msn.com.*

Automotive Industry Advancements with NDT. June 7–9, Sheraton Birmingham Hotel, Birmingham, Ala. Contact ASNT, (800) 222-2768, *www.asnt.org.*

SURFEX 2006. June 21, 22, G-Mex Int'l Centre, Manchester, U.K. To feature surface coatings, adhesives, corrosion, printing inks, and construction chemicals. Contact *info@orrest.com*; *www.orrest.com.*

The Next Industrial Revolution: Nanotechnology and Manufacturing. Aug. 23, 24, Pollard Technology Conference Center, Oak Ridge, Tenn. Contact: Society of Manufacturing Engineers, *www.sme.org/nanomfg.*

2006 Annual Assembly and Int'l Conf. of the Int'l Institute of Welding (IIW). Aug. 27–Sept. 2, Québec City, Canada. E-mail the Organizing Committee *iiwassembly2006@cwbgroup.com*, or visit *www.iiw2006.com.*

♦**Welding in Aircraft and Aerospace Conference.** Sept. 19, 20. Dayton, Ohio. Contact American Welding Society, (800/305) 443-9353, ext. 223; or visit *www.aws.org/conferences.*

Materials Science and Technology Conference 2006. Oct. 15–19, Cinergy Center, Cincinnati, Ohio. Visit *www.matscitech.org.*

♦**AA/AWS Aluminum Welding Conference.** Oct. 30, Georgia World Congress Center, Atlanta, Ga., at the FABTECH International & AWS Welding Show. Contact American Welding Society, (800/305) 443-9353, ext. 223; or visit *www.aws.org/conferences.*

ICALEO 2006, Int'l Congress on Applications of Lasers & Electro-Optics. Oct. 30–Nov. 2, Doubletree Paradise Valley Resort, Scottsdale, Ariz. Visit *www.icaleo.org.*

♦**Conference on Ways to Weld New Materials in the Automotive Industry.** Oct. 31, Georgia World Congress Center, Atlanta, Ga., at the FABTECH International & AWS Welding Show. Contact American Welding Society, (800/305) 443-9353, ext. 223; or visit *www.aws.org/conferences.*

♦**FABTECH International & AWS Welding Show.** Oct. 31–Nov. 2, Georgia World Congress Center, Atlanta, Ga. Contact American Welding Society, (800) 443-9353, ext. 462; *www.aws.org.*

♦**Quality Control in Welding Conference.** Nov. 1, Atlanta, Ga., at the FABTECH International & AWS Welding Show. Contact American Welding Society, (800) 443-9353, ext. 462; or visit *www.aws.org/conferences.*

♦**Spot Welding Conference.** Nov. 2, Atlanta, Ga., at the FABTECH International & AWS Welding Show. Contact Amer-

ican Welding Society, (800) 443-9353, ext. 462; or *www.aws.org/conferences*.

MetalForm Mexico. Nov. 7–9, Centro Banamex, Mexico City. Contact *marcela.ordaz@giprex.com*.

Aerospace Testing Expo North America. Nov. 14–16, Anaheim Convention Center, Anaheim, Calif. For information, visit *www.aerospacetesting-expo.com/northamerica/contact.html*.

Southeast Asia Wire and Tube Trade Fairs. Oct. 16–18, 2007, Bangkok, Thailand. Contact Messe Düsseldorf North America, *info@mdna.com; www.mdna.com*.

Educational Opportunities

Modern Furnace Brazing. May 10–12; Oct. 18–20, Madison Heights, Mich. Instructors include Robert Peaslee, David Bielec, and Amit Jain. Contact: M. Huesing, (248) 585-6400, *mhuesing@wallcolmonoy.com*; or visit *www.wallcolmonoy.com*.

Hands-On Welding Summer Workshop. July 10–14, Ball State University, Muncie, Ind. Fee: $300. Contact: William Ed Wyatt, instructor, (765) 289-0459; *wyatt.w@worldnet.att.net*.

Fastening Technology and Bolted Joint Design Seminars. Aug. 23, 24, Baltimore, Md.; Nov. 8, 9, Chicago, Ill. For details visit *www.SeminarsForEngineers.com*.

Boiler and Pressure Vessel Inspectors Training Courses and Seminars. Columbus, Ohio. Contact Richard McGuire, (614) 888-8320, *rmcguire@nationalboard.org*, *www.nationalboard.org*.

CWI/CWE Course and Exam. This 10-day program prepares students for the AWS CWI/CWE exam. For schedule and entry requirements, contact Hobart Institute of Welding Technology (800) 332-9448, *www.welding.org*.

CWI Preparation. Courses on ultrasonic, eddy current, radiography, dye penetrant, magnetic particle, and visual at Levels 1–3. Meet SNT-TC-1A and NAS-410 requirements. On-site training available. T.E.S.T. NDT, Inc., 193 Viking Ave., Brea, CA 92821; (714) 255-1500; *ndtguru@aol.com*; *www.testndt.com*.

CWI Preparatory and Visual Weld Inspection Courses. Classes presented in Pascagoula, Miss., Houston, Tex., and Houma and Sulphur, La. Course lengths range from 40 to 80 hours. Contact Real Educational Services, Inc., (800) 489-2890; *info@realeducational.com*.

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

Fabricators and Manufacturers Assn., and Tube and Pipe Assn. Courses. Contact (815) 399-8775; *www.fmametalfab.org; info@fmametalfab.org*.

Hellier NDT Courses. For schedule of courses, contact Hellier, 277 W. Main St., Ste. 2, Niantic, CT 06357, (860) 739-8950, FAX: (860) 739-6732.

Machining and Grinding Courses. Contact TechSolve at *www.TechSolve.org*.

Machine Safeguarding Seminars. Contact Rockford Systems, Inc., PO Box 5525, Rockford, IL 61125, (800) 922-7533; FAX: (815) 874-6144; *www.rockfordsystems.com*.

NACE Int'l Training and Certification Courses. Contact Nat'l Assoc. of Corrosion Engineers, (281) 228-6223, FAX: (281) 228-6329, *www.nace.org*.

Plastics Welding School. Offers 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; info@malcom.com*.

Shielded Metal Arc Welding of 2-in. Pipe in the 6G Position — Uphill. 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*. Conducted by the Steel Structures Technology Center. Contact (248) 893-0132, *www.steelstructures.com*.

Tool and Die Welding Courses. Contact Hobart Institute of Welding Technology, 400 Trade Square East, Troy, OH 45373; (800) 332-9448; *www.welding.org*.

Unitek Miyachi Corp. Training Services. Offers personalized training services on resistance and laser beam welding and laser marking. Contact (626) 303-5676; *www.unitekmiyachi.com; info@unitekmiyachi.com*.

Victor Training Seminars. Programs for gas apparatus and service repair technicians, end users, and sales personnel. Visit *www.victorequip.com*.

Welding Introduction for Robot Operators and Programmers. This one-week course is offered at the Troy, Ohio, facility, or presented at a corporate location tailored to specific needs. Contact Hobart Institute of Welding Technology, (800) 332-9448, ext. 5603; *www.welding.org*.

Welding Skills Training Courses. Courses include weldability of ferrous and nonferrous metals, arc welding inspection and quality control, preparation for recertification of CWIs, and others. Contact: Hobart Institute of Welding Technology, 400 Trade Square East, Troy, OH 45373, (800) 332-9448; *www.welding.org*.

An Important Event on Its Way?

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

2006 AWS Certification Schedule

Certification Seminars, Code Clinics and Examinations

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

Certified Welding Inspector (CWI)

Location	Seminar Date	Exam Date	Site Code
Newark, NJ	May 7-12	May 13	NJ27706
Spokane, WA	May 7-12	May 13	WA27806
Long Beach, CA	May 7-12	May 13	CA27906
Monterrey, Mex.	(contact *info@dalus.com*) May 15-19	May 20	-----
St. Louis, MO	May 21-26	May 27	MO28106
Miami, FL	May 21-26	May 27	FL28006
Atlanta, GA	May 21-26	May 27	GA28206
Beaumont, TX	Jun. 4-9	Jun. 10	TX03907
Sacramento, CA	Jun. 4-9	Jun. 10	CA04007
Fargo, ND	Jun. 4-9	Jun. 10	ND04107
Miami, FL	EXAM ONLY	Jun. 15	HQ07607
Philadelphia, PA	Jul. 9-14	Jul. 15	PA04207
Orlando, FL	Jul. 9-14	Jul. 15	FL04307
Corpus Christi, TX	EXAM ONLY	Jul. 15	TX08207
Monterrey, Mex.	(contact *info@dalus.com*) Jul. 10-14	Jul. 15	-----
Miami, FL	EXAM ONLY	Jul. 20	HQ08107
Baton Rouge, LA	Jul. 16-21	Jul. 22	LA04407
Kansas City, MO	Jul. 16-21	Jul. 22	MO04507
Chicago, IL	Jul. 23-28	Jul. 29	IL04607
Portland, ME	Jul. 23-28	Jul. 29	ME04707
Albuquerque, NM	Jul. 30-Aug. 4	Aug. 5	NM04807
Columbus, OH (at NBBPVI*)	Jul. 31-Aug. 4	Aug. 5	OH09307
Memphis, TN	Aug. 6-11	Aug. 12	TN04907
Salt Lake City, UT	Aug. 6-11	Aug. 12	UT05007
Miami, FL	EXAM ONLY	Aug. 17	HQ07807
Houston, TX	Aug. 13-18	Aug. 19	TX05207
Charlotte, NC	Aug. 20-25	Aug. 26	NC05307
Rochester, NY	EXAM ONLY	Aug. 26	NY08607
Syracuse, NY	Sep. 10-15	Sep. 16	NY05507
Miami, FL	EXAM ONLY	Sep. 21	HQ07907
Minneapolis, MN	Sep. 17-22	Sep. 23	MN05607
Seattle, WA	Sep. 17-22	Sep. 23	WA05707
San Diego, CA	Sep. 17-22	Sep. 23	CA05807
Anchorage, AK	EXAM ONLY	Sep. 23	AK08407
Dallas, TX	Sep. 24-29	Sep. 30	TX05907
Detroit, MI	Sep. 24-29	Sep. 30	MI06007
Milwaukee, WI	Sep. 24-29	Sep. 30	WI06107
Denver, CO	Oct. 8-13	Oct. 14	CO06207
Phoenix, AZ	Oct. 8-13	Oct. 14	AZ06307
Miami, FL	EXAM ONLY	Oct. 19	HQ08007
Pittsburgh, PA	Oct. 15-20	Oct. 21	PA06407
Tulsa, OK	Oct. 15-20	Oct. 21	OK06507
San Antonio, TX	Oct. 15-20	Oct. 21	TX06607
Chicago, IL	Oct. 22-27	Oct. 28	IL06707
Atlanta, GA	Oct. 22-27	Oct. 28	GA06807
Reno, NV	Oct. 29-Nov. 3	Nov. 4	NV06907
Baltimore, MD	Oct. 29-Nov. 3	Nov. 4	MD07007
Long Beach, CA	Nov. 5-10	Nov. 11	CA07107
Beaumont, TX	Nov. 5-10	Nov. 11	TX07207
Portland, OR	Nov. 5-10	Nov. 11	OR07307
Monterrey, Mex.	(contact *info@dalus.com*) Nov. 6-10	Nov. 11	-----
Louisville, KY	Nov. 12-17	Nov. 18	KY07407
St. Louis, MO	EXAM ONLY	Dec. 2	MO08507
Miami, FL	Dec. 3-8	Dec. 9	FL07507
Columbus, OH (at NBBPVI*)	Dec. 11-15	Dec. 16	OH09407
Corpus Christi, TX	EXAM ONLY	Dec. 16	TX08307

* Mail seminar registration and fees for Columbus seminars only to National Board of Boiler & Pressure Vessel Inspectors, 1055 Crupper Ave., Columbus, OH 43229-1183. Phone (614) 888-8320. Exam application and fees should be mailed to AWS.

9-Year Recertification for CWI and SCWI

Location	Seminar Dates	Exam Date	Site Code
Pittsburgh, PA	Jun. 12-17	NO EXAM**	RSV235
San Diego, CA	Aug. 28-Sep. 2	NO EXAM**	RSV245
Dallas, TX	Nov. 13-18	NO EXAM**	RSV255
Orlando, FL	Dec. 4-9	NO EXAM**	RSV265

**For current CWIs 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	Site Code
Spokane, WA	May 8-12	May 13	CWS7
Beaumont, TX	Jun. 5-9	Jun. 10	CWS8
Portland, ME	Jul. 24-28	Jul. 29	CWS9
Salt Lake City, UT	Aug. 7-11	Aug. 12	CWS10
Milwaukee, WI	Sep. 25-29	Sep. 30	CWS11
Portland, OR	Nov. 6-10	Nov. 11	CWS12

Certified Radiographic Interpreter (RI)

Location	Seminar Dates	Exam Date	Site Code
Orlando, FL	Jul. 10-14	Jul. 15	RIP14
Chicago, IL	Jul. 24-28	Jul. 29	RIP15
Long Beach, CA	Nov. 6-10	Nov. 11	RIP16
Louisville, KY	Nov. 13-17	Nov. 18	RIP17

Certified Welding Educator (CWE)

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

Senior Certified Welding Inspector (SCWI)

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

Certified Welding Engineer – (CWEng)

Exam can be taken at any site listed under Certified Welding Inspector. No preparatory seminar is offered. Two exam days are necessary for this certification.

Certified Welding Fabricator

This program is designed to certify companies to specific requirements in the ANSI standard AWS B5.17, *Specification for th Qualification of Welding Fabricators*. There is no seminar or exam fc this program. Call ext. 475 for more information.

Code Clinics

D1.1, API-1104, Welding Inspection Technology, and Visual Inspection workshops are offered at all sites where the Certified Welding Inspector seminar is offered (usually first two days).

On-site Training and Examination

On-site training is available for larger groups or for programs that are customized to meet specific needs of a company. Call ext. 219 f more information.

For information on any of our seminars and certification programs, visit our website at **www.aws.org** or contact AWS at (800/305) 443-9353, Ext. 273 for Certification and Ext. 449 for Seminars.

Please **apply early** to save Fast Track fees. **This schedule is subject to change without notice.** Please verify the dates with th Certification Dept. and confirm your course status before making final travel plans. Note: **sites originally scheduled in Ne Orleans** have been canceled.

American Welding Society

Founded in 1919 to advance the science, technology and application of welding and allied processes includ joining, brazing, soldering, cutting and thermal sprayin

BY HOWARD M. WOODWARD

How D1 Gets Done

Members of the AWS D1, Structural Welding Committee, met to discuss D1.1, Structural Welding Code — Steel, *during their meeting in Raleigh, N.C., in March. For more about AWS D1 see "An Insider's Look at D1" on page 48.*

Hobart Inspires Students to Consider Welding Careers

On March 14, Hobart Institute of Welding Technology, Troy, Ohio, once again opened its doors to host its annual Students' Night "Careers in Welding" program. President **André Odermatt** stated, "Welders are desperately needed and welding training can be the first step to a rewarding career."

Keynote speaker **Randy Ward**, United Association of Plumbers and Pipefitters, discussed details of apprenticeship in the 350,000-member organization. Emcee and Dayton Section Chair **Chris Anderson** introduced **Zane Michael** of Motoman, Inc. Michael studied welding at the Institute, and progressed to serving as a welding instructor there before becoming interested in robotics. He earned his master's degree and is presently director of marketing and product development at his company. He urged the students to work hard, stay in school, and maintain a positive work attitude to achieve success. Zane's formula for success in any endeavor is "Good Attitude, Education, Experience, and Performance."♦

More than 100 local welding students and guests participated in Hobart's annual event.

AWS Is Heavily Involved in Thermal Spray Technology

BY ROSS HANCOCK, director, marketing communications

The AWS C2 Committee on Thermal Spray serves to establish standards for design data, manufacturing practices, and inspection methods. In addition, it strives to make available up-to-date information on thermal spraying. The committee provides for the interchange of ideas, knowledge, and experience in the science and art of thermal spraying, cooperating with other societies and governmental departments for the benefit of the entire industry.

Volunteers also serve on several subcommittees: Machine Element Repair and Restoration (C2A); SSPC/NACE/AWS Tri-Society Thermal Spray Committee on the Corrosion Protection of Steel (C2B); Thermal Spray Coatings for Reinforced Concrete (C2C); Thermal Spraying: Theory, Practice, and Application (C2D); Conference and Show (C2E); Thermal Spray Operator Qualification (C2F); ASTM/AWS Joint Task Group on Thermal Spray Equipment (C2G); and Thermal Spray Metallographic Sample Preparation and Evaluation (C2H).

The committee's published ANSI-approved standards include two industry guides and four specifications: AWS C2.16/C2.16M:2002, *Guide for Thermal Spray Operator Qualification;* AWS C2.18-93, *Guide for the Protection of Steel with Thermal Sprayed Coatings of Aluminum and Zinc and Their Alloys and Composites;* AWS C2.20/C2.20M:

— *THERMAL continued on page 48*

— THERMAL continued from page 47

2002, *Specification for Thermal Spraying Zinc Anodes on Steel Reinforced Concrete;* AWS C2.21/C2.21:2003, *Specification for Thermal Spray Equipment Acceptance Inspection;* and AWS C2.25/C2.25M:2002, *Specification for Thermal Spray Feedstock — Solid and Composite Wire and Ceramic Rods.*

The committee cooperated with NACE (National Association of Corrosion Engineers) and SSPC (Society for Protective Coatings) to publish a specification for corrosion protection of steel in atmospheric environments: AWS C2.23M/C2.23:2003 (NACE No. 12, SSPC-CS 23.00), *Specification for the Application of Thermal Spray Coatings of Aluminum, Zinc, and Their Alloys and Composites (Metallizing) for the Corrosion Protection of Steel.*

Standards currently under preparation or review by the C2 Committee are AWS C2.19, *Specification for Thermal Spray Coatings for Machine Element OEM and Repair Applications;* AWS C2.22, *Guide for Metallographic Sample Preparation and Evaluation of Thermal Spray Coatings;* and AWS C2.24, *Modified Layer Removal Method — Procedure for Evaluating Residual Stresses in Thermal Spray Coatings.*

The chairman of the C2 Committee is **Ted Call,** of Power Spray, Inc. The committee's vice chair is **Manish Bhursari,** of Praxair Surface Technologies.

To learn more about committee work or to volunteer as a member of the C2 Committee, contact secretary **Brian McGrath,** *bmcgrath@aws.org;* (800) 443-9353, ext. 311. ♦

An Insider's Look at D1

BY JOHN GAYLER, secretary to the D1 Committees

The AWS D1 Structural Welding Committee met March 17 in Raleigh, N.C., to fulfill a long agenda including approval of revisions for the 2008 edition of the D1.1, *Structural Welding Code — Steel,* a final report on D1.8/D1.8M:2005, *Structural Welding Code — Seismic Supplement,* and resolution of final comments on the upcoming new code for titanium structures (AWS D1.9). Also addressed during the meeting were final comment resolutions and approval of revisions for AWS D1.3, *Structural Welding Code — Sheet Steel,* and AWS D1.6, *Structural Welding Code — Stainless Steel.* New editions of both codes are expected to be published by the end of this year.

This D1 Committee also is responsible for the AASHTO/AWS D1.5, *Bridge Welding Code,* AWS D1.4, *Structural Welding Code — Reinforcing Steel,* and AWS D1.2, *Structural Welding Code — Aluminum.*

Numerous awards were presented to its outstanding members.

Tom Schlafly, American Institute of Construction, was recognized for his service as chairman, D1A Subcommittee on Design (D1.1 Code), from 1999–2006.

Bruce Butler, Walt Disney World Co., was recognized for his service as chairman of the D1K Subcommittee on Stainless Steel for the D1.6 Code, 1999–2006.

Service awards were presented to **John Meyers** who celebrated 20 years' service, and **Nick Altebrando, Donald Shapira, Wladyslaw Jaxa-Rozen, Ron Medlock,** and **Dan Baird** for 10 years of service each.

The Structural Welding Committee has been very active. In 1976, the committee was responsible for just one document, AWS D1.1, *Structural Welding Code — Steel.* Over the past 30 years, the committee has published six additional structural welding codes, including the new seismic supplement. With the addition of the titanium structural code and a guide on strengthening and repair (still in early draft stages), the committee will be responsible for nine structural standards.

To efficiently manage updating of these standards, the Structural Welding Committee has established 15 Subcommittees to handle the workload. Currently, more than 150 dedicated volunteers serve on these subcommittees. These subcommittees are always looking for qualified individuals willing to actively participate in code-writing activities. The D1 structural committees meet twice a year, once in the spring and once in the fall, usually over a four-day period from Tuesday to Friday. Upcoming meetings are posted on the committee Web site, *www.aws.org/technical/d1/.*

All meetings are open to the public. Individuals interested in joining one of these subcommittees should contact the committee secretary, **John Gayler,** at *gayler@aws.org,* or fill out an online application on the Committee web site.

D1 Structural Welding Committee officers include Chairman **Donald D. Rager,** Rager Consulting; First Vice Chairman **Duane K. Miller,** The Lincoln Electric Co.; and Second Vice Chairman **Allen W. Sindel,** Sindel & Associates. The D1 Subcommittees include D1A Subcommittee on Design (D1.1); D1B Subcommittee on Qualification (D1.1); D1C Subcommittee on Fabrication (D1.1); D1D Subcommittee on Inspection (D1.1); D1E Subcommittee on Stud Welding (D1.1); D1F Subcommittee on Strengthening and Repair (D1.1); D1G Subcommittee on Aluminum (D1.2); D1H Subcommittee on Sheet Steel (D1.3); D1I Subcommittee on Reinforcing Steel (D1.4); D1J Subcommittee on Bridge Welding (D1.5); D1K Subcommittee on Stainless Steel (D1.6); D1L Subcommittee on Seismic Applications (D1.8); D1N Subcommittee on Titanium (D1.9).

In addition, there are two permanent task groups. One works on new materials (D1.1, Tables 3.1 and 3.2), and the other works on the general requirements for D1.1. ♦

The D1L Subcommittee on Seismic Issues recently published D1.8/D1.8M:2005, Structural Welding Code — Seismic Supplement.

Tech Topics

Standard for PINS

Development work has begun to revise the following standard. You are invited to contribute to this work. Contact **Rakesh Gupta**, ext. 301.

A5.9/A5.9M:200X, *Specification for Bare Stainless Steel Welding Electrodes and Rods.* This specification prescribes the requirements for classification of solid and composite stainless steel electrodes (both as wire and strip) for gas metal arc welding, submerged arc welding, and other fusion welding processes. It also includes wire and rods for use in gas tungsten arc welding. Classification is based on chemical composition of the filler metal. Additional requirements are included for manufacture, sizes, lengths, and packaging. A guide is appended to the specification concerning the classification system employed and the intended use of the stainless steel filler metal. Stakeholders: Everyone in the welding industry.

Standards for Public Review

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. This column also advises of ANSI approval of documents. The following standards are submitted for public review (the expiration date is shown in parentheses). To order draft copies, contact **Rosalinda O'Neill,** ext. 451, *roneill@aws.org.*

A4.3-93(R2006), *Standard Methods for Determination of the Diffusible Hydrogen Content of Martensitic, Bainitic, and Ferritic Steel Weld Metal Produced by Arc Welding.* Reaffirmed — $25 (5/1/06).

A4.4M:2001(R2006), *Standard Procedures for Determination of Moisture Content of Welding Fluxes and Welding Electrode Flux Coverings.* Reaffirmed — $25 (5/1/06).

A5.3/A5.3M:1999(R2006), *Specification for Aluminum and Aluminum-Alloy Electrodes for Shielded Metal Arc Welding.* Reaffirmed — $25 (5/8/06).

A5.15-90(R2006), *Specification for Aluminum and Aluminum-Alloy Electrodes for Shielded Metal Arc Welding.* Reaffirmed — $25 (5/8/06).

A5.32/A5.32M-97(R2006), *Specification for Welding Shielding Gases.* Reaffirmed — $25 (5/15/06).

C4.6M(ISO9013:2002):200X, *Thermal Cutting — Classification of Thermal Cuts — Geometric Product Specification and Quality Tolerances.* Revised — $25 (4/24/06).

D16.2M/D16.2:200X, *Guide for Components of Robotic and Automatic Arc Welding Installations.* Revised — $27 (4/24/06).

New Standards Approved by ANSI

B2.1-1-234:2006, *Standard Welding Procedure Specification (SWPS) for Argon Plus 25% Carbon Dioxide Shielded Flux Cored Arc Welding of Carbon Steel (M-1/P-1/S-1) Groups 1 and 2, ⅛ through 1½ in. thick, E7XT-X, As-Welded or PWHT Condition, Primarily Pipe Applications.* 2/28/06.

B2.1-1-235:2006, *Standard Welding Procedure Specification (SWPS) for Argon Plus 2% Oxygen Shielded Gas Metal Arc Welding (Spray Transfer Mode) of Carbon Steel (M-1/P-1/S-1) Groups 1 and 2, ⅛ through 1½ in. thick, ER70S-3, Flat Position Only, As-Welded or PWHT Condition, Primarily Pipe Applications.* 2/28/06.

B2.4:2006, *Specification for Welding Procedure and Performance Qualification for Thermoplastics.* 2/16/06.

Revised Standards Approved by ANSI

F1.1M:2006, *Method for Sampling Airborne Particulates Generated by Welding and Allied Processes.* 2/16/06.

F1.2:2006, *Laboratory Method for Measuring Fume Generation Rates and Total Fume Emission of Welding and Allied Processes.* 2/16/06.

Extended Standards Approved by ANSI

A4.2M/A4.2:1997, *Standard Procedures for Calibrating Magnetic Instruments to Measure the Delta Ferrite Content of Austenitic and Duplex Ferritic-Austenitic Stainless Steel Weld Metal.* 11/6/07.

A5.3/A5.3M:1999, *Specification for Aluminum and Aluminum-Alloy Electrodes for Shielded Metal Arc Welding.* 2/11/07.

A5.4-92R, *Specification for Stainless Steel Electrodes for Shielded Metal Arc Welding.* 8/7/07.

A5.7-84R, *Specification for Copper and Copper Alloy Bare Welding Rods and Electrodes.* 12/19/07.♦

Pros Sought for Technical Committees

Thermal Spraying

The C2B Committee seeks volunteers to help revise **C2.18-93,** *Guide for the Protection of Steel with Thermal Sprayed Coatings of Aluminum and Zinc and Their Alloys and Composites.*

Contact **Brian McGrath,** *bmcgrath@aws.org,* (800) 443-9353, ext. 311.

Welding Handbook

The Welding Handbook Committee seeks volunteers to help update *Welding Handbook,* Volume 4 — Materials and Applications.

This volume will cover the ferrous metals including cast iron, carbon- and low-alloy steels, high-alloy steels, coated steels, tool-and-die steels, as well as stainless, and heat-resistant steels.

Other topics include clad metals and dissimilar metals, surfacing, maintenance and repair welding, and underwater welding and cutting.

If you have expertise in any of these topics and want to contribute to this important work, contact Secretary **Annette O'Brien,** *aobrien@aws.org,* (800) 443-9353, ext. 303; FAX (305) 443-7404.

Iron Castings

The D11 Committee seeks volunteers to help revise **D11.2-89,** *Guide for Welding Iron Castings.*

Experts in the welding of iron castings as well as users of iron castings are urged to participate. Contact **John Gayler**, *gayler@aws.org,* (800) 443-9353, ext. 472.

Weld Testing Pro

The AWS B4 Committee on Methods of Inspection seeks volunteers to help with the updating of AWS B4.0, *Standard Methods for Mechanical Testing of Welds.*

If you want to contribute to the preparation of this document, contact Brian McGrath, *bmcgrath@aws.org,* (800/305) 443-9353, ext. 311, or visit *www.aws.org/join_a_committee.* ♦

AWS Builds on Indian Seminar Series

Described as a "major educational initiative," **Damian J. Kotecki,** AWS president, was the first to tour India to present a series of seminars for members of the Indian Institute of Welding. His topic was Welding of Stainless Steels.

Continuing in that tradition, **Jeffrey F. Henry,** director, Materials Technology Center, Alstom Power Inc., was this year's "AWS ambassador to India." Henry presented full-day seminars on the topic, Welding of New Generation Chrome-Moly Steels, to Institute members in the cities of Madras, Mumbai, Surat, Tiruchirappalli, New Delhi, and Pune.

In recognition of his 12-day lecture tour, President Kotecki presented Henry with a plaque of appreciation, saying, "Mr. **Chander C. Girotra** of the Indian Institute of Welding as well as other Indian experts who participated in your lectures were very pleased to have such a highly qualified United States expert as yourself able to present to them on this very specialized topic."

K. M. Panthaki, Indian Institute of Welding president, said they chose the subject of welding Cr-Mo steels because of its growing market size, and applications in reactors, boilers, and hydrocrackers that operate at higher temperatures and pressures. He said, "Newer alloys are being developed and it is time we in India get updated since we do not have any R&D base in the energy-related field and material sciences."♦

Jeffrey Henry discussed Cr-Mo steels for engineers in New Delhi, India.

New AWS Supporters

New Sustaining Company

NDE Consultation Services, Inc.
2117 Don Ave.
Westminster, MD 21157
www.ndecs.com
Representative: Sonya C. Fedoruk

NDE Consultation Services, Inc., serving the mid-Atlantic region and beyond, was founded in 1988 with a commitment to excellence in the field of nondestructive testing and inspection.

The company performs a comprehensive array of specialized inspections and nondestructive testing on fabricated structures, as well as industrial and commercial products.

New Supporting Company

Darrah Electric Co.
5914 Merrill Ave.
Cleveland, OH 44102

Educational Institutions

Alaska Vocational Technical Center
PO Box 889, Seward, AK 99664

Austin Community College
1020 Grove Bldg.
Austin, TX 78741

Community Technical
and Adult Education
1014 SW 7th Rd., Ocala, FL 34474

Decatur Area Technical Academy
300 E. Eldorado St.
Decatur, IL 62523

Delaware Area Career Center
1610 State Rte. 521
Delaware, OH 43015

North Land Job Corps
100A MacDonough Dr.
Vergennes, VT 05456

New Affiliate Companies

Bob Barker Co, Inc.
134 N. Main St.
Fuquay-Varina, NC 27526

Bunger Steel, Inc.
8112 W. Buckeye Rd.
Phoenix, AZ 85043

D & T Steel, Inc.
225 Northcutt Rd.
Pelion, SC 29123

Danco Precision, Inc.
601 Wheatland St.
Phoenixville, PA 19460

Engineering & Steel Construction, Inc.
12775 NW 123rd St., Bay #6
Medley, FL 33178

Excel Tower Services, Inc.
2307 Womble Brooks Rd.
Wilson, NC 27893

International Aircraft Welding, LLC
1833 W. Plantside Dr.
Louisville, KY 40299

L.V. E., Inc.
6813 Chrisphalt Dr.
Bath, PA 18014

Miller Metal Fabrication
PO Box 309
16819 S. Dupont Hwy.
Harrington, DE 19952

Ming Kee Construction Engineering Ltd.
200 Wang Toi Shan
Ho Lik Piu Kam Tin
Yuen Long Nt, Hong Kong

On & Offshore Quality Control Services
PO Box 911, Austin, TX 78767

Sureway Tool & Engineering Co.
11241 Melrose Ave., Unit A
Franklin Park, IL 60131

The Holiday Group, Inc.
2514 Whitelaw St.
Cuyahoga Falls, OH 44221

TIGG Corp.
800 Old Pond Rd., Ste. 706
Bridgeville, PA 15017♦

Membership Counts

Member Grades	As of 4/1/06
Sustaining	441
Supporting	248
Educational	357
Affiliate	320
Welding distributor	52
Total corporate members	**1,418**
Individual members	44,151
Student + transitional members	4,985
Total members	**49,136**

SECTION NEWS

DISTRICT 1
Director: Russ Norris
Phone: (603) 433-0855

BOSTON
MARCH 7
Activity: The Section toured Steel-Fab, Inc., Fitchburg, Mass., to study the production of flood-control water gates and various custom fabrications for the shipbuilding industry, including turbine casings, reduction gear casings, and specialized valves. **Mark Freeman** and **Scott Houle** conducted the tour.


Shown at the Boston Section tour are (from left) Tom Ferri, program chair, and tour guides Mark Freeman and Scott Houle.

GREEN & WHITE MTS.
FEBRUARY 16
Activity: The Section members toured Melanson Fabrication to study its operations using shears, press brake, automated plasma and water jet cutting machines, and welding stations. **Matt Santwire**, customer service, conducted the program.

MARCH 16
Activity: The Green & White Mountains Section held a Students' Night program including demonstrations of SMA, GMA, and GTA welding, and the oxyacetylene cutting process. The presenters included **John Steel, Jim Reid, Gerry Ouelette,** and **Geoff Putnam.**

MAINE
JANUARY 25
Activity: The Section hosted its first annual vendors night program at Southern Maine Community College, South Portland, Maine, led by welding instructor **Mark Legal**. Product demonstrations were conducted by Arc One, Hypertherm, Miller Electric, Smith Equipment, and Walter Abrasives. District 1 Director **Russ Norris** presented appreciation plaques to **Jeff Fields,** Bath Iron Works, and **Scott Lee,** Metso Paper Co. for their dedication to assisting the Maine SkillsUSA welding team. More than 50 people attended the event.


Shown at the Philadelphia Section tour of Orgo-Thermit are (from left) speaker Rich Jordan, Section Vice Chair Jim Korchowsky, Frik Hefer, and Randy Dry.

PHILADELPHIA
JANUARY 21
Activity: The Section hosted a welding competition at Cumberland County Technical School in Bridgeton, Pa., for 18 contestants. **David Terpolilli,** 17, of Franklinville, Pa., a senior at Delsea Regional High School, placed first.

MARCH 8
Speaker: **Richard Jordan,** president
Affiliation: Orgo-Thermit, Inc.
Topic: Thermit welding railroad track
Activity: Following the talk to the Philadelphia Section, Jordan presented a demonstration of the thermit welding process assisted by **Frik Hefer** and **Randy Dry** from Orgo-Thermit.


Russ Norris, District 1 director, is shown at the Maine Section's vendor's night program.

DISTRICT 2
Director: Kenneth R. Stockton
Phone: (732) 787-0805

DISTRICT 3
Director: Alan J. Badeaux Sr.
Phone: (301) 934-9061

Lancaster Section members gather around a poster of NASCAR driver Tony Stewart. From left are Joe Young, his brother and father, Chris Ochs, and Kevin Lynn of Lincoln Electric.

York-Central Pa. Section Chair Claudia Bottenfield and welding students (wearing doo rags), cluster around William DeLong (center), AWS past president.

Shown at the Northeastern Carolina Section program are (from left) speaker Mike Clark and Roy Thompson.

Ruth Z. Hendrick accepts a speaker gift from Bill Rhodes, chairman, Southwest Virginia Section.

LANCASTER

MARCH 1

Activity: The Section hosted a mini trade show at Lancaster Mennonite High School.

YORK-CENTRAL PA.

MARCH 2

Activity: The Section hosted its mini trade show and students' night program at York County School of Technology in York, Pa. The students were treated to a free dinner and a unique doo rag as a gift. Special guests at the program were AWS Past President **William DeLong,** and **Brian Yarrison,** welding instructor and host for the program. About 70 people attended the event.

DISTRICT 4

Director: Ted Alberts
Phone: (540) 674-3600, ext. 4314

NE CAROLINA

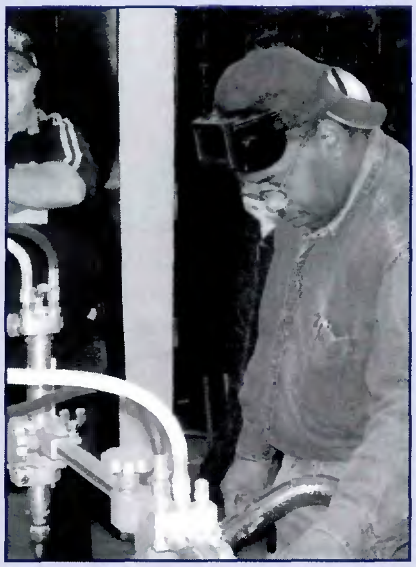
FEBRUARY 23

Speaker: **Mike Clark**

Affiliation: FARO Technologies

Topic: Computerized measuring equipment

Activity: The meeting was held in Winterville, N.C.



Willie Davis demonstrated cutting techniques for the Palm Beach Section.

SOUTHWEST VIRGINIA

FEBRUARY 23

Activity: The Section met at Greenfield Education Center in Botetourt, Va., to learn about the center's new intensive welder training program scheduled to begin this month. The presenters included **Ruth Z. Hendrick, Sandra R. McMinnis,** and **Randy Sink,** welding instructor.

DISTRICT 5

Director: Leonard P. Connor
Phone: (954) 981-3977

PALM BEACH

FEBRUARY 15

Speaker: **Larry Kahn**

Affiliation: Praxair Welding Supply, Pompano Beach, Fla.

Topic: Oxyacetylene welding and equipment

Activity: Following the presentation, **Willie Davis** demonstrated the new cutting equipment.

SOUTH CAROLINA

FEBRUARY 16

Activity: The Section members toured Metal Trades, Inc., in North Charleston, S.C. **Todd Komara,** CWI, conducted the tour to present an overview of its quality control and welding processes.

DISTRICT 6

Director: Neal A. Chapman
Phone: (315) 349-6960

Larry Kahn discussed oxyacetylene processes for the Palm Beach Section.

Shown at the South Carolina Section tour are (from left) Chairman Gale Mole, CWI Todd Komara with his wife.

DISTRICT 7

Director: Don Howard
Phone: (814) 269-2895

COLUMBUS

MARCH 9
Speaker: **Chris Thornton**
Affiliation: Special Metals Welding Products Co.
Topic: Nickel-base alloys
Activity: Following the talk, Thornton conducted a discussion on applications for nickel products, formulations of nickel consumables, consumables selection for making transition joints, and cladding for corrosion protection.

John Lawmon (left), Columbus Section treasurer, presents a speaker gift to Chris Thornton.

DAYTON

FEBRUARY 21
Speakers: **Jim Hannahs,** welding engineer, ret.; and **Monte Swigart,** Fanuc Robotics
Topic: Resistance spot welding
Activity: Hannahs led off the meeting by covering the basics of spot welding. Swigart covered mid-frequency inverters and servo guns for robotic spot welding. The meeting was held at Motoman, Inc., in Troy, Ohio.

Jim Hannahs (left) and Monte Swigart discussed spot welding for the Dayton Section members in February.

MARCH 14
Activity: The Dayton Section held its Students' Night program in Troy, Ohio, hosted by Hobart Institute of Welding Technology. **Randy Ward** of United Associations of Journeymen and Apprentices, and **Zane Michael** from Motoman, presented talks on careers in welding. See photo and story on page 47. **Don Howard,** District 7 director, attended the event.

Randy Ward (left) and Zane Michael discussed careers in welding for the Dayton Section's Student Night audience.

PITTSBURGH

FEBRUARY 21
Speaker: **Jim Gabster,** senior manager
Affiliation: BOC Gases, Butler, Pa.
Topic: Fuel gas selection and safety awareness
Activity: The program was held at Steamfitters Local No. 449.

Robert Cosgrove (left) and Peter Kinney discussed DOT requirements for the Pittsburgh Section members in March.

Shown at the Pittsburgh Section program are (from left) speaker Jim Gabster and Chairman Roger Hilty.

Attendees are shown at the Birmingham Section workshop.

Chuck Padden (left) and Larry Vanderstelt (center) display their membership awards presented by Bob Wilcox, Detroit Section executive committee member.

Shown at the Birmingham Section workshop are (from left) Chairman Jim Cooley, Frank Neeley, and Dan Sims.

Don Czerniewski (left) receives a speaker gift from David Beneteau, Detroit Section technical programs director.

MARCH 14
Speaker 1: **Robert Cosgrove,** materials testing specialist 1, structures design and construction
Affiliation: New York State DOT
Speaker 2: **Peter Kinney,** project engineer
Affiliation: Robert W. Hunt Co., Pennsylvania DOT
Topics: New York and Pennsylvania DOT's requirements affecting Procedure Qualification Records (PQRs) and Welding Procedure Specifications (WPSs) for D1.1, *Structural Welding Code — Steel.*
Activity: This Pittsburgh Section program, held at Steamfitters Local #449, consisted of daytime and evening lectures.

DISTRICT 8

Director: Wallace E. Honey
Phone: (256) 332-3366

NASHVILLE

FEBRUARY 23
Activity: **John Kahl** and **Jason Whitman** of Lincoln Electric presented a talk on the latest in electrodes and welding technology and equipment. The meeting was held at World Testing, Inc., in Mt. Juliet, Tenn.

Annual Nashville Section Picnic
SATURDAY, MAY 13
Long Hunter State Park
RSVP to **Jim Kirby** (615) 242-2701

WESTERN CAROLINA

Scholarship Golf Tournament
SATURDAY, MAY 20
Bonnie Brae Golf and Country Club
near Donaldson Center, Greenville, S.C.
RSVP to **Duke Moses** (864) 989-6791

DISTRICT 9

Director: John Bruskotter
Phone: (504) 394-0812

BIRMINGHAM

FEBRUARY 21
Activity: The Section met at Shelby County School of Technology to participate in a vendor workshop. The presenters included representatives from Lincoln Electric, Miller Electric, ESAB, ALFRA, **Dan Sims** from Profax, Tri-Tool, **Frank Neeley** from Southern Welding Supply, Airgas South, and Smith Cutting Equipment. The attendees participated in hands-on demonstrations of the new products. **Jimmy Brewer** won an automatic welding hood from Airgas South, and **Joel Hicks** won the drawing for a cash prize.

DISTRICT 10

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

DISTRICT 11

Director: Eftihios Siradakis
Phone: (989) 894-4101

DETROIT

MARCH 9
Activity: The Section toured the Industrial Control Repair, Inc., facility in Warren, Mich. **Don Czerniewski,** vice president, presented an overview of the company's capabilities for rebuilding and servicing welding-related equipment from small components to large robots. **Bob Wilcox** presented the Gold Membership Award to **Chuck Padden** for 50 years of service to the Society. **Larry Vanderstelt** received his Silver Membership Award for 25 years of service.

NORTHWEST OHIO

FEBRUARY 15
Activity: **James E. Zywocki,** head welding instructor, led the Section members on a tour of United Association, Local Union #50, Piping Industry Training

Center, in Northwood, Ohio. Highlights included the welding, plumbing, HVAC, valve repair, and computer training classrooms and labs.

WESTERN MICHIGAN

FEBRUARY 20

Activity: **Holly Stevens,** sales representative, led the Section members on a tour of the Flex-Cable facilities in Morley, Mich.

DISTRICT 12

Director: Sean P. Moran
Phone: (920) 954-3828

DISTRICT-WIDE EVENT

FEBRUARY 9

Activity: Manitowoc Cranes, Manitowoc, Wis., opened its welder training and crane-manufacturing facilities to 111 members from the Fox Valley, Lakeshore, Racine-Kenosha, and Milwaukee Sections, plus members from Milwaukee Area Technical College Student Chapter. **Jim Hoffman** conducted the tour. **Ben Mueller** received his Gold Membership Award for 50 years of service to the Society. **Sean Moran,** District 12 director, formally welcomed members of the newly formed AWS Student Chapter. **Bob Snodgrass** (Lakeshore Section) and **Jim Hoffman** conducted a Q&A session. Professional Welder Competition winners **Scott Braun** and **Troy Jaeger** were introduced and congratulated on their achievements. The dinner was held at the nearby Holiday Inn. This activity was the first in a series of annual programs designed to bring all of the District 12 Sections together.

LAKESHORE

JANUARY 12

Speaker: **Magnus Carlsson,** application manager

Affiliation: SSAB Hardox Corporation, Oxelösund, Sweden

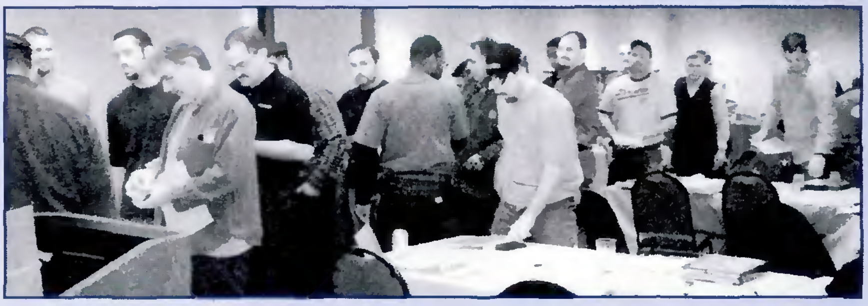
Topic: Laser beam welding of ultrahigh-strength steels

Activity: The program was held at the Lighthouse Inn.

Magnus Carlsson discussed how to weld ultrahigh-strength steels at the Lakeshore Section program.

Bryce Kale (left) accepts the CWI of the Year Award from Jesse Hunter, District 13 director, at the J.A.K. Section meeting.

The Indiana Section SkillsUSA welding contest judges are (from left) John Myers, Chairman Bennie Flynn, Claire Peetz, J. R. Hollers, Vice Chair Gary Dugger, Don Davis, Nick Laskar, and Mike Hastings.



Shown are a few of the 57 CWI candidates who participated in the Indiana Section's certification training and testing program in March.

DISTRICT 13

Director: Jesse L. Hunter
Phone: (309) 359-3063

J.A.K.

OCTOBER 28

Activity: The Section hosted its annual awards-presentation ceremony at Davidson's West Restaurant in Kankakee, Ill. **Jesse L. Hunter,** District 13 director, hosted the event and presented the awards. **Bryce Kale,** Robert W. Hunt Co., received the Howard E. Adkins CWI of the Year Award. **Davey Hall,** Ironworkers Local 395, Hammond, Ind., received the Private Educator of the Year Award. Service Recognition Awards were presented to **Deborah Woodruff,** Section secretary and Kankakee County auditor; **Michael Spangler,** vice chair and a welding instructor at both Kankakee Area Career Center and Kankakee Community College (KCC); **Art Suprenant,** KCC welding program director, ret., and Lincoln Indy Race Team; and Chairman **John Willard,** Robert W. Hunt Co.

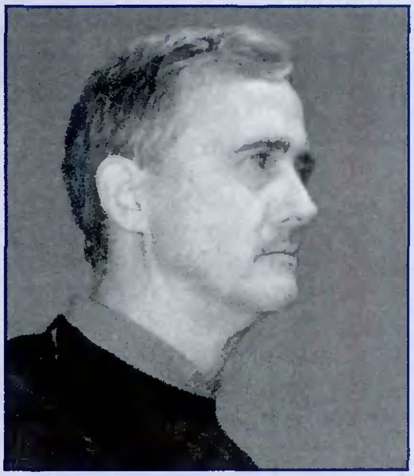
DISTRICT 14

Director: Tully C. Parker
Phone: (618) 667-7744

INDIANA

FEBRUARY 18

Activity: The Section participated in the SkillsUSA Indianapolis Regional Welding Contest. Seventeen students from five schools competed in GTA, SMA, and GMA welding and oxyacetylene cutting trials. The top four qualifiers will go to the state competition. Judges for the contest were **John Myers, Chair Bennie Flynn, Claire Peetz, J. R. Hollers, Vice Chair Gary Dugger, Don**



W. Pat Garten spoke at the Indiana Section program on February 20.

District 14 Director Tully Parker (left) is shown with Frank McKinley, Lexington Section chairman in February.

Ken Katen discussed micro welding at the Lexington Section program.

Shown at the North Texas Section program are (from left) Ernest D. Levert Sr., past AWS president; Kate Kotecki; Damian Kotecki, AWS president; Howie Sifford, Section chairman; and Oren Reich, District 17 director.

Davis, Nick Laskar, and **Mike Hastings,** a welding instructor at Central 9 Career Center, Greenwood, Ind., where the event was held.

February 20
Speaker: **W. Pat Garten,** president
Affiliation: Sutton Garten Welding Supplies and Gases
Topic: History of Sutton Garten Company

March 4, 5
Activity: The Indiana Section hosted the AWS CWI, CWE, and CWS preparation courses and exam for 57 candidates. Key participants included Chairman **Bennie Flynn,** Vice Chair **Gary Dugger,** and Secretary **Bob Richwine.**

LEXINGTON

February 23
Speaker: **Ken Katen**
Topic: Micro welding techniques
Activity: The program was held at central Kentucky Technical College in Lexington, Ky.

ST. LOUIS

January 19
Activity: The Section members toured Jerry Bickel Race Cars in Moscow Mills, Mo., to study its welding and fitup processes. **Jerry Bickel,** owner, and **Bud Payton** conducted the tour.

DISTRICT 15

Director: Mace V. Harris
Phone: (952) 925-1222

DISTRICT 16

Director: Charles F. Burg
Phone: (515) 233-1333

DISTRICT 17

Director: Oren P. Reich
Phone: (254) 867-2203

NORTH TEXAS

February 21
Speaker: **Damian J. Kotecki,** AWS president
Affiliation: The Lincoln Electric Co., technical director for stainless and high-alloy product development
Topic: Stainless steel filler metals
Activity: In attendance were AWS Past President **Ernest D. Levert Sr.,** District 17 Director **Oren Reich, Al Burnson,** and **Robert Klug** from ASM International, and Damian's wife, **Kate Kotecki.**

OZARK

March 16
Activity: **Bill Watkins,** supervisor, led the Section members on a tour of Ridewell Corp. in Springfield, Mo. Highlights included large laser beam welding machines and numerous robots building truck suspension components.

TULSA

February 11
Activity: The Section held its Ladies' Night program at Freddie's Steak House in Sapulpa, Okla. **Ray Wilsdorf** was presented the District 17 Meritorious Award by **Oren Reich,** District 17 director.

DISTRICT 18

Director: John L. Mendoza
Phone: (210) 353-3679

SABINE

FEBRUARY 21

Speaker: **Ron Winthrop,** president and general manager
Affiliation: Englobal Corp., Beaumont, Tex.
Topic: Quality assurance and quality control functions on major construction projects
Activity: Chairman **Grady Hatton** discussed the nomination process for the election of officers and directors for next year. The meeting was held at Lone Star Steak House in Beaumont.

MARCH 21

Speaker: **John Green,** chief deputy
Affiliation: Jefferson County Sheriff's Office, Beaumont, Tex.
Topic: The true story about conditions in Iraq
Activity: The program was held at Lone Star Steak House in Beaumont, Tex.

DISTRICT 19

Director: Phil Zammit
Phone: (509) 468-2310, ext. 120

Renton Technical College Student Chapter

FEBRUARY 23

Activity: The newly formed Renton Technical College Student Chapter, Renton, Wash., held its charter meeting and election of officers.

Elected were **Ben Begole,** chair; **Rex Jennings** and **Samantha Wanzer,** vice chairs; **Shane Jamison,** secretary; **David Giest,** membership chair; **Kenneth Westor,** treasurer; and Advisor **Dan Aragon.**

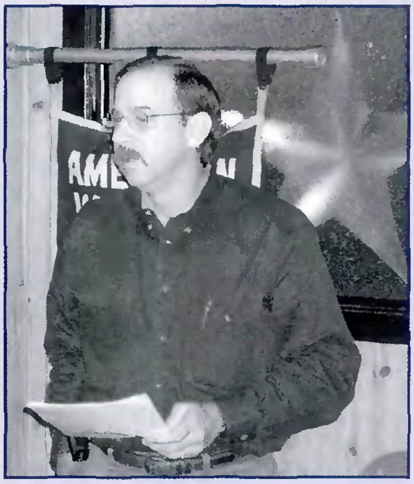
Spokane Skills Center Student Chapter

MARCH 14

Activity: The recently formed Spokane Skills Center Student Chapter held its election of officers.

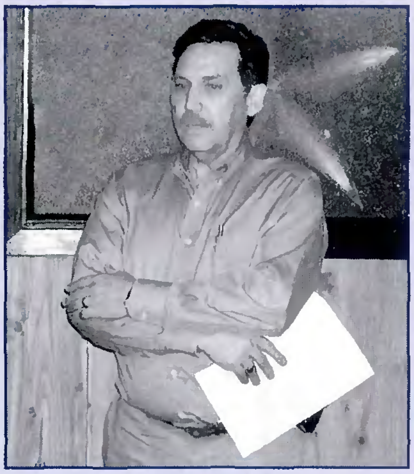
Elected were **Tom Robinson,** chair; **Charles Goulding** and **David Miller,** vice chairs; **Jacob Fisher,** secretary; **Matt Lewis,** treasurer; and **Adam Leath,** membership chair. Advisor **Andrew Syder** is a welding instructor at the Center. Attending the event were **Phil Zammit,** District 19 director, **Chuck Daily,** and members of the Spokane Section. See the photo on next page.

Ray Wilsdorf (right) accepts the District 17 Meritorious Award from Oren Reich, District 17 director, at the Tulsa Section meeting.



Chairman Grady Hatton addressed the Sabine Section in February.

John Green (left) accepts a speaker appreciation plaque from Sabine Section Chair Grady Hatton.

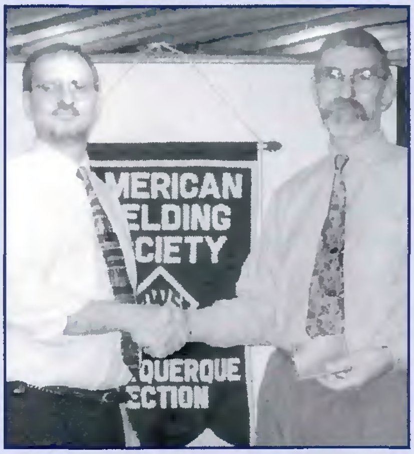


Ron Winthrop discussed quality topics at the Sabine Section program in February.

Shown at the Renton Technical College Student Chapter's first meeting are (from left) Chair Ben Begole, Vice Chairs Rex Jennings and Samantha Wanzer, Advisor Dan Aragon, Secretary Shane Jamison, and Membership Chair David Giest.

Shown at the Spokane Skills Center Student Chapter program are (back row, from left) Rich Irving, Spokane Section treasurer; Phil Zammit, District 19 director; Charles Goulding, David Miller, and Advisor Andrew Syder. Shown front row, from left, are Chair Tom Robinson, Jacob Fisher, Chuck Daily, Adam Leath, and Matt Lewis.

Chairman Tom Lienert (left) and David Moghaddam display their awards presented at the Albuquerque Section meeting in October.



AWS President Damian J. Kotecki (right) is shown with Tom Lienert, Albuquerque Section chairman, at the February program.

Richard Holdren (right) receives a speaker gift from Tom Lienert, Albuquerque Section chair, in March.

DISTRICT 20

Director: Nancy M. Carlson
Phone: (208) 526-6302

ALBUQUERQUE

OCTOBER 13
Speaker 1: **Tom Lienert,** chairman
Affiliation: Los Alamos National Labs
Topic: Scholarships, welding careers, and the SENSE program
Speaker 2: **David Moghaddam,** instructor
Affiliation: New Mexico Junior College
Topic: Hot tapping
Activity: The Section hosted a Students' Night program. The Section Educator Award was presented to **Bill Adams.** Chair **Tom Lienert** received the Section Meritorious Award, and **David Moghaddam** received the District Educator Award.

NOVEMBER 10
Activity: The Albuquerque Section hosted a Students' Night program. **Dan MacCallum** discussed scholarships, welding careers, and the SENSE program. **Woody Norwood** and **Gene Ostmeyer** gave talks on OSHA standards. The meeting was held at Albuquerque Technical Vocational Institute.

JANUARY 26
Speaker: **Matt Johnson**
Affiliation: Los Alamos National Laboratory
Topic: Factors affecting properties and soundness of flux cored arc weldments
Activity: This Albuquerque Section meeting was held at Amerisuites in Albuquerque, N.Mex.

FEBRUARY 23
Speaker: **Damian J. Kotecki,** AWS president
Affiliation: The Lincoln Electric Co., technical director for stainless and high-alloy product development
Topic: Stainless steel filler metals
Activity: This Albuquerque Section program was held at Cowgirl Barbeque and Western Grill in Santa Fe, N.Mex.

MARCH 16
Speaker: **Richard L. Holdren**
Affiliation: Edison Welding Institute
Topic: Conflicts between welding quality and welding inspection
Activity: Albuquerque Section Chair **Tom Lienert** received the Distinguished Service Award. The program was held at LaBaron Conference Center in Albuquerque, N.Mex.

IDAHO-MONTANA

FEBRUARY 28, MARCH 1
Activity: The Section members participated in a two-day equipment and welding show held at Eastern Idaho Technical College, Idaho Falls, Idaho. **Kyle Kofford,** a welding instructor at the college, in collaboration with NORCO, Miller Electric, Hypertherm, Hobart, Eutectic, and local distributors presented a show enabling visitors to try the latest welding equipment.

MARCH 3
Activity: The Section toured Premier Technology, Inc., in Pocatello, Idaho, a fabricator of welded structures for the nuclear, food, transportation, and space propulsion industries. It also refurbishes glass used for viewing ports in nuclear applications.

SOUTHERN COLORADO

MARCH 21
Speakers: **Dave Fullen,** district manager; and **Myron Delgado,** sales representative
Affiliation: The Lincoln Electric Co.
Topic: New inverter square wave technology for subarc welding
Activity: The program was held at Pikes Peak C. C., Colorado Springs, Colo.

DISTRICT 21

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

NEVADA

OCTOBER 18
Activity: The Section members toured Vo-Tech High School in the Las Vegas Clark County School District. **Rick Boyer,** welding program instructor, conducted the tour. The school has its own Student Chapter. **Henry Leaty** was presented his Life Membership Award for 35 years of service to the Society.

NOVEMBER 15
Activity: The Nevada Section members toured ATTC (Area Technical Trade Center) in North Las Vegas. **Brian Stout,** welding instructor, nicknamed Mr. Pipefitter, conducted the tour.

JANUARY 10
Activity: The Nevada Section members visited the Community College of Southern Nevada, Henderson Campus. The hosts, **Tony Adams** and **Shannon Girard**, detailed the school's two-year program, including its nondestructive testing and code courses.

DISTRICT 22

Director: Kent S. Baucher
Phone: (559) 276-9311

SAN FRANCISCO

MARCH 1
Speaker: **Jerry Spencer**
Affiliation: OKI Bering
Topic: Understanding and applying the basics of respiratory protection
Activity: This program was held at Spenger's Restaurant in Berkeley, Calif.

International

EMIRATES WELDING

FEBRUARY
Speaker: **Hasan Shaikh**
Topic: Corrosion control in welded joints.
Activity: The program was held in Dubai, U.A.E.

Shown at the Albuquerque Section program in March are (from left) Secretary Dan MacCallum, Chair Tom Lienert, Treasurer Pierrette Gorman, and Vice Chair Mike Thomas.

The Idaho-Montana Section members are shown during their tour of Premier Technology in March.

Chair Robert Mertz (left) is shown with speaker Jerry Spencer at the San Francisco Section program.

Shown at the Southern Colorado Section program are (from left) Dave Fullen, Chairman Lee Corn, and Myron Delgado.

Shown at the Emirates Welding Section program are (standing, from left) A. Art, A. Manna, Murugappan, and Secretary R. Bashkar. Sitting, from left, are Treasurer N. Pal, speaker Hasan Shaikh, S. Baskaran, Chairman Bernard D'Silva, and P. D. Hathi.

Member-Get-A-Member Campaign

Listed below are the March 16, 2006, standings for participants in the 2005–2006 Member-Get-A-Member Campaign. See page 49 of this *Welding Journal* for the rules and prize list. For complete information, contact the AWS Membership Department (800/305) 443-9353, ext. 480. The period covered is *6/01/05 – 5/31/06.*

Winner's Circle

Members who have sponsored 20 or more new Individual Members, per year, since 6/01/99. The superscript denotes the number of times the member has achieved Winner's Circle status if more than once.

J. Compton, San Fernando Valley^{5}
E. Ezell, Mobile^{3}
J. Merzthal, Peru^{2}
G. Taylor, Pascagoula^{2}
B. Mikeska, Houston
R. Peaslee, Detroit
W. Shreve, Fox Valley
M. Karagoulis, Detroit
S. McGill, Northeast Tennessee
T. Weaver, Johnstown/Altoona
G. Woomer, Johnstown/Altoona
R. Wray, Nebraska

President's Guild

Members sponsoring 20 or more new Individual Members.

J. Compton, San Fernando Valley — 23
M. Haggard, Inland Empire — 22

President's Roundtable

Members sponsoring 11–19 new Individual Members.

C. Daily, Puget Sound — 16
G. Taylor, Pascagoula — 13
N. Bothma, International — 11
G. Fudala, Philadelphia — 11

President's Club

Members sponsoring 6–10 new Individual Members.

J. Williams, Houston — 10
G. Gardner, Ozark — 9
T. White, Pittsburgh — 9
D. Wright, Kansas City — 9
D. Norum, North Texas — 8
J. Christianson, Saginaw Valley — 7

President's Honor Roll

Members sponsoring 1–5 new Individual Members

W. Shreve, Fox Valley — 5
D. Wilson, Inland Empire — 4
R. Wright, Southern Colorado — 4
P. Zammit, Spokane — 4
T. Buchanan, Mid-Ohio Valley — 3
A. Mattox, Lexington — 3
J. Mendoza, San Antonio — 3
R. Merreighn, Mississippi Valley — 3
G. Merriman, Chicago — 3
R. Quintero, Corpus Christi — 3
R. Sands, Northwest — 3
J. Smutny, Spokane — 3
M. Tsai, Taiwan Int'l — 3
T. Alston, Sierra Nevada — 2
R. Bernstein, South Florida — 2
J. Cusick, Kansas — 2
J. Durbin, Tri-River — 2
M. Hill, Lexington — 2
M. Hobbs, Louisville — 2
J. Hobgood, J.A.K. — 2
W. Kuchta, Cleveland — 2
E. Levert, North Texas — 2
P. Newhouse, British Columbia — 2
R. Rux, Wyoming — 2
C. Schiner, Wyoming — 2
H. Shore, Johnny Appleseed — 2
S. Siviski, Maine — 2
K. Stelzl, New York — 2
J. Vansambeek, Lakeshore — 2
H. Villela, San Francisco — 2
H. Wilden, Reading — 2

Student Sponsors

Members sponsoring 3 or more new Student Members.

C. Daily, Puget Sound — 108
G. Euliano, Northwestern Pa. — 71
R. Durham, Cincinnati — 39
R. Evans, Siouxland — 35
T. Kienbaum, Colorado — 32
D. Newman, Ozark — 26
M. Anderson, Indiana — 24
S. Siviski, Maine — 24
H. Hughes, Mahoning Valley — 23
A. Baughman, Stark Central — 22
S. Robeson, Cumberland Valley — 22
J. Daugherty, Louisville — 20
T. Geisler, Pittsburgh — 20
C. Hobson, Olympic — 20
R. Boyer, Nevada — 19
D. Combs, Santa Clara Valley — 19
R. Shrewsbury, Tri-State — 19
C. Donnell, Northwest Ohio — 18
G. Smith, Lehigh Valley — 18
W. Ketler, Willamette Valley — 17
M. Arand, Louisville — 15
R. Munns, Utah — 15
B. Olson, Sangamon Valley — 15
C. Overfelt, Southwest Virginia — 15
T. Strickland, Arizona — 15
A. Stute, Madison-Beloit — 15
A. Mattox, Lexington — 14
J. Carey, Boston — 13
C. Jones, Houston — 13
A. Reis, Pittsburgh — 13
M. Koehler, Milwaukee — 12
B. Olson, Sangamon Valley — 12
J. Smith Jr., Mobile — 12
T. Buchanan, Mid-Ohio Valley — 11
D. Griep, New Jersey — 11
R. Zabel, Southeast Nebraska — 11
H. Browne, New Jersey — 10
K. Paolino, Connecticut — 10
J. Pawley, Lexington — 10
M. Batchelor, Boston — 9
W. Galvery, Long Bch/Orange Cty — 9
J. McCarty, St. Louis — 9
D. Roskiewich, Philadelphia — 9
C. Chancy, LA/Inland Empire — 8
G. Gammill, Northeast Mississippi — 7
T. Moffit, Tulsa — 7
A. Badeaux, Washington, D.C. — 6
J. Boyer, Lancaster — 6
J. Carney, Western Michigan — 6
R. Chase, LA/Inland Empire — 6
J. Craiger, Indiana — 6
C. Kipp, Lehigh Valley — 6
C. Schiner, Wyoming — 6
R. Hilty, Pittsburgh — 5
D. Kowalski, Pittsburgh — 5
R. Rux, Wyoming — 5
J. Smith, Tri-River — 5
J. Sullivan, Holston Valley — 5
L. Davis, New Orleans — 4
W. Harris, Pascagoula — 4
R. Hutchison, Long Bch/Orange Cty — 4
J. Morash, Boston — 4
R. Olesky, Pittsburgh — 4
S. Stevenson, Cumberland Valley — 4
C. Williams, Atlanta — 4
C. Bridwell, Ozark — 3
P. Carney, Lehigh Valley — 3
J. Ciaramitaro, N. Central Florida — 3
J. Cox, Northern Plains — 3
R. Haag, Wyoming — 3
D. Hamilton, Chattanooga — 3
M. Hill, Lexington — 3
J. Knapp, Tulsa — 3
R. Ledford, Birmingham — 3
D. Lynnes, Northern Plains — 3
T. Moore, New Orleans — 3
J. Stevens, Northern Michigan — 3
D. Twitty, El Paso — 3
D. Vranich, North Florida — 3 ♦

Guide to AWS Services

550 NW LeJeune Rd., Miami, FL 33126
Phone (800) 443-9353; (888) WELDING; FAX (305) 443-7559
Internet: *www.aws.org*
Phone extensions appear in parentheses.

AWS PRESIDENT

Damian J. Kotecki
Damian_Kotecki@lincolnelectric.com
The Lincoln Electric Co.
22801 St. Clair Ave.
Cleveland, OH 44117-1199

ADMINISTRATION

Executive Director
Ray W. Shook.. *rshook@aws.org* ....(210)

CFO/Deputy Executive Director
Frank R. Tarafa.. *tarafa@aws.org* ....(252)

Associate Executive Director
Cassie R. Burrell.. *cburrell@aws.org* ....(253)

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

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

COMPENSATION and BENEFITS

Director
Luisa Hernandez.. *luisa@aws.org* ......(266)

DATABASE ADMINISTRATION

Corporate Director
Jim Lankford.. *jiml@aws.org* ....(214)

INT'L INSTITUTE OF WELDING

Senior Coordinator
Sissibeth Lopez . . *sissi@aws.org* ......(319)
Provides liaison services with other national and international professional societies and standards organizations.

GOVERNMENT LIAISON SERVICES

Hugh K. Webster. ...... *hwebster@wc-b.com*
Webster, Chamberlain & Bean
Washington, D.C.
(202) 466-2976; FAX (202) 835-0243
Identifies funding sources for welding education, research, and development. Monitors legislative and regulatory issues of importance to the industry.

Brazing and Soldering Manufacturers' Committee

Jeff Weber.. *jweber@aws.org* ....(246)

RWMA — Resistance Welding Manufacturing Alliance

Jeff Weber.. *jweber@aws.org* ....(246)

WEMCO — Welding Equipment Manufacturing Committee, and WIN — Welding Industry Network

Natalie Tapley.. *tapley@aws.org* ....(456)

CONVENTION and EXPOSITIONS

Exhibiting Information ....(242, 295)

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

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

PUBLICATION SERVICES

Department Information ....(275)

Managing Director
Andrew Cullison.. *cullison@aws.org* ....(249)

Welding Journal

Publisher/Editor
Andrew Cullison.. *cullison@aws.org* ....(249)

National Sales Director
Rob Saltzstein.. *salty@aws.org* ....(243)

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

Welding Handbook

Welding Handbook Editor
Annette O'Brien.. *aobrien@aws.org* ....(303)

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

Director
Ross Hancock.. *rhancock@aws.org* ....(226)

Senior Manager, Marketing
Linda Henderson...*lindah@aws.org* ....(298)

MEMBER SERVICES

Department Information ....(480)

Associate Executive Director
Cassie R. Burrell.. *cburrell@aws.org* ....(253)

Director
Rhenda A. Mayo... *rhenda@aws.org* ....(260)
Serves as a liaison between Section members and AWS headquarters. Informs members about AWS benefits and activities.

EDUCATION SERVICES

Director, Education Services Administration and Convention Operations
John Ospina.. *jospina@aws.org* ....(462)

Director, Education and Government Advocacy
Richard J. DePue.. *rdepue@aws.org* ....(237)

Director, Education Product Development
Christopher Pollock.. *cpollock@aws.org* (219)

Tracks effectiveness of programs and develops new products and services. Coordinates in-plant seminars and workshops. Administers the S.E.N.S.E. program. Assists Government Liaison Committee with advocacy efforts. Works with Education Committees to disseminate information on careers, national education and training trends, and schools that offer welding training, certificates, or degrees.

Also responsible for conferences, exhibitions, and seminars on topics ranging from the basics to the leading edge of technology. Organizes CWI, SCWI, and 9-year renewal certification-driven seminars.

AWS WEB SITE ADMINISTRATION

Web Site Coordinator

AWS AWARDS, FELLOWS, COUNSELORS

Managing Director
Wendy S. Reeve.. *wreeve@aws.org* .....(293)
Coordinates AWS awards and AWS Fellow and Counselor nominees.

CERTIFICATION OPERATIONS

Department Information ....(273)

Director, Technical Services
Tina Burke . . . *tburke@aws.org* ....(215)

Director, Operations
Terry Perez.. *tperez@aws.org* ....(470)

Director, Int'l Business Accreditation and Welder Certification
Walter Herrera.. *walter@aws.org* ....(475)
Provides information on personnel certification and accreditation services.

TECHNICAL SERVICES

Department Information ....(340)

Managing Director
Andrew R. Davis.. *adavis@aws.org* .....(466)
Int'l Standards Activities, American Council of the International Institute of Welding (IIW)

Director, National Standards Activities
Peter Howe.. *phowe@aws.org* ....(309)
Machinery and Equipment Welding, Robotic and Automatic Welding, Computerization of Welding Information

Manager, Safety and Health
Stephen P. Hedrick.. *steveh@aws.org* ..(305)
Metric Practice, Personnel and Facilities Qualification, Safety and Health, Joining of Plastics and Composites

Technical Publications

AWS publishes about 200 documents widely used in the welding industry.
Senior Manager
Rosalinda O'Neill.. *roneill@aws.org* ....(451)

Staff Engineers/Committee Secretaries
Annette Alonso.. *aalonso@aws.org* .....(299)
Welding in Sanitary Applications, Automotive Welding, Resistance Welding, High-Energy Beam Welding, Aircraft and Aerospace, Oxyfuel Gas Welding and Cutting

John L. Gayler.. *gayler@aws.org* ....(472)
Structural Welding, Welding Iron Castings

Rakesh Gupta.. *gupta@aws.org* ....(301)
Filler Metals and Allied Materials, Int'l Filler Metals, Instrumentation for Welding, UNS Numbers Assignment

Cynthia Jenney .. *cynthiaj@aws.org* ....(304)
Definitions and Symbols, Brazing and Soldering, Brazing Filler Metals & Fluxes, Technical Editing

Brian McGrath . *bmcgrath@aws.org* ....(311)
Methods of Inspection, Mechanical Testing of Welds, Thermal Spray, Arc Welding and Cutting, Welding in Marine Construction, Piping and Tubing, Titanium and Zirconium Filler Metals, Filler Metals for Naval Vessels

Selvis Morales.....*smorales@aws.org* ...(313)
Welding Qualification, Friction Welding, Joining of Metals and Alloys, Railroad Welding

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 District director.

Interested parties should write a letter stating which office they seek, including a statement of qualifications, their willingness and ability to serve if nominated and elected, and 20 copies of their biographical sketch.

This material should be sent to James E. Greer, Chairman, National Nominating Committee, American Welding Society, 550 NW LeJeune Rd., Miami, FL 33126.

The next meeting of the National Nominating Committee is scheduled for October 31, 2006. The term of office for candidates nominated at this meeting will commence January 1, 2008. ♦

Honorary Meritorious Awards

The Honorary-Meritorious Awards Committee makes recommendations for the nominees presented for Honorary Membership, National Meritorious Certificate, William Irrgang Memorial, and the George E. Willis Awards. These awards are presented during the AWS Exposition and Convention held each spring. The deadline for submissions is December 31 prior to the year of awards presentations. Send candidate materials to Wendy Sue Reeve, Secretary, Honorary-Meritorious Awards Committee, 550 NW LeJeune Rd., Miami, FL 33126. Descriptions of the awards follow.

National Meritorious Certificate Award: This award is given in recognition of the candidate's counsel, loyalty, and devotion to the affairs of the Society, assistance in promoting cordial relations with industry and other organizations, and for the contribution of time and effort on behalf of the Society.

William Irrgang Memorial Award: This award is administered by the American Welding Society and sponsored by The Lincoln Electric Co. to honor the late William Irrgang. It is awarded each year to the individual who has done the most to enhance the American Welding Society's goal of advancing the science and technology of welding over the past five-year period.

George E. Willis Award: This award is administered by the American Welding Society and sponsored by The Lincoln Electric Co. to honor George E. Willis. It is awarded each year to an individual for promoting the advancement of welding internationally by fostering cooperative participation in areas such as technology transfer, standards rationalization, and promotion of industrial goodwill.

International Meritorious Certificate Award: This award is given in recognition of the candidate's significant contributions to the worldwide welding industry. This award should reflect "Service to the International Welding Community" in the broadest terms. The awardee is not required to be a member of the American Welding Society. Multiple awards can be given per year as the situation dictates. The award consists of a certificate to be presented at the awards luncheon or at another time as appropriate in conjunction with the AWS President's travel itinerary, and, if appropriate, a one-year membership in the American Welding Society.

Honorary Membership Award: An Honorary Member shall be a person of acknowledged eminence in the welding profession, or who is accredited with exceptional accomplishments in the development of the welding art, upon whom the American Welding Society sees fit to confer an honorary distinction. An Honorary Member shall have full rights of membership. ♦

Publications Sales/Orders

World Engineering Xchange (WEX), Ltd.
Toll-free (888) 935-3464 (U.S., Canada)
(305) 824-1177; FAX (305) 826-6195
www.aws.org/standards

Journal Reprints

Order quality custom reprints from
Claudia Stachowiak, FosteReprints
Toll-free (866) 879-9144, ext. 121
sales@fostereprints.com

AWS Foundation, Inc.

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

550 NW LeJeune Rd., Miami, FL 33126
(305) 445-6628; (800) 443-9353, ext. 293
e-mail: *vpinsky@aws.org*
general information:
(800) 443-9353, ext. 689

AWS Mission Statement

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

It is the intent of the American Welding Society to build AWS to the highest quality standards possible. The Society welcomes your suggestions. Please contact any staff member, or AWS President Damian J. Kotecki, as listed on the previous page.

Shielded metal arc welding (SMAW) has many advantages. The equipment is relatively simple, inexpensive, and portable. The electrode provides both the shielding and the filler metal. The process is not as sensitive to wind and draft as some other arc welding processes. The process is suitable for most of the commonly used metals and alloys, and the typical electrode can reach into areas of limited access.

Important Variables

Electrodes

Always choose the correct electrode for the job. Don't be tempted to "make do" with a substitute electrode. Electrodes are designed for use on specific metals, and their performance will be poor if they are used on metals other than intended. Learn the different electrode types and their intended operation. The electrode diameter selected will depend largely on the thickness of the material, the position of welding, and type of joint. Generally, larger electrodes are selected for thicker materials and welding in the flat position.

Current

Either alternating current (AC) or direct current (DC) can be used with SMAW provided the appropriate electrode is selected. Each current type has its advantages and limitations. Most covered electrodes operate better on direct current electrode positive (DCEP), although some are designed to work better on direct current electrode negative. Arc striking is generally easier with DC, as well as holding a short arc length. Arc stability is usually better with DC. Always double check to make sure the power source is connected for the right polarity.

Operation

Each electrode type and size has a best current range for operation. Operating outside of that range can cause erratic metal transfer. Optimum amperage also depends on the position of welding and the joint type. It is a good idea to keep a notebook to record equipment settings for different applications. Also, make sure you follow the Welding Procedure Specification (WPS) if one is provided.

Voltage

Voltage with shielded metal arc welding is dependent on arc length. Long arcs produce high voltage and short arcs produce low voltage. As a rule, the arc length should not exceed the diameter of the core wire of the electrode, although the length is shorter than this value for electrodes with thick coverings. A steady hand is important to prevent power fluctuations, which can be detrimental to the weld.

Travel Speed

Heat input, penetration, and bead shape are all affected by travel speed. The more slowly you move the electrode along the joint, the more heat is delivered to the weld pool, which affects the cooling rate. Cooling rate has an effect on the metallurgical structure of the weld metal and heat-affected zone. Moving faster reduces the heat input. If the speed is too much, the bead deteriorates and the penetration suffers. If the speed is too slow, the weld bead becomes wide and the penetration is shallow because the arc dwells on the weld pool rather than directed into the base metal. Speed should be adjusted so that the arc is slightly ahead of the weld pool.

Typical Problems

Cracking

Cracks can occur from moisture, use of the wrong electrode for the material, improper current settings, excessive restraint, and poor welding technique. Also, if the weld is too small for the pieces being joined and it cools quickly, the shrinking stresses may be too much for the strength of the weld to overcome. Hydrogen-induced cracking is combatted with the use of dry low-hydrogen electrodes and proper preheat.

Distortion

Distortion is often caused by improper heat input and joint restraint. If distortion begins to appear, check to see if the welding current is too high. Also make sure the pieces are tightly clamped. The welding heat may cause them to move. Using an alternating bead sequence will help balance the forces that cause distortion.

Undercut

A groove in the base metal at the toes of the weld can be caused if the current is too high for the application or improper techniques are used. High amperage, a long arc, incorrect electrode position, travel speed, and insufficient dwell time in a weave bead can all contribute to undercut.

Spatter

Excessive current can cause spatter, as well as the wrong type or size of electrode. Also, make sure the polarity is correct for the electrode. If all settings and materials are correct, you might try holding a shorter arc to trap more spatter in the molten weld pool. Some electrodes are more prone to spatter than others.

Porosity

Usually porosity is the result of some type of contamination in the weld area, too much current, or gas entrapment in the weld metal. Make sure the joint is properly cleaned before welding and the electrodes are in good condition. Follow recommended preheating and interpass temperatures. Using the recommended amperage and holding the proper arc length also will help prevent porosity.

Slag

Slag can become trapped in the weld metal or between the weld metal and the base metal. Be sure to thoroughly clean the weld between passes. Also check to make sure the proper current is used. When it is too low, the molten weld pool might freeze before the slag completely floats to the top. Also, the slag may flow ahead of the arc if the welder is not careful. Take care when welding downhill and between a convex bead and the sidewall of a groove.

Arc Blow

Arc blow can be a significant problem with DC when welding ferritic steel. Unbalanced magnetic fields that arise can deflect the arc and eject the transferring metal droplets. If it presents a problem, try placing the workpiece lead connections as far as possible away from the joints to be welded. Positioning the electrode so that the arc force counteracts the arc blow also helps, as well as lowering the current and maintaining the shortest possible arc length. Alternating current rarely presents a problem with arc blow because the magnetic field is constantly reversing.

AWS Filler Metal Specifications for SMAW

Carbon Steel	A5.1/A5.1M
Low-Alloy Steel	A5.5

Stainless Steel	A5.4
Cast Iron	A5.15
Nickel Alloys	A5.11/A5.11M
Aluminum Alloys	A5.3/A5.3M
Copper Alloys	A5.6

Comparison of ISO and AWS Classifications[a]

ISO 2560	AWS A5.1	A5.M
E4310	E6010	E4310
E4311	E6011	E4311
E4312	E6012	E4312
E4313	E6013	E4313
E4318	E6018	E4318
E4319	E6019	E4319
E4320	E6020	E4320
—	E6022	E4322
E4327	E6027	E4327
E4914	E7014	E4914
E4915	E7015	E4915
E4916	E7016	E4916
E4916-1	E7016-1	E4916-1
E4918	E7018	E4918
E4918-1	E7018-1	E4918-1
—	E7018M	E4918M
E4924	E7024	E4924
E4924-1	E7024-1	E4924-1
E4927	E7027	E4927
E4928	E7028	E4928
E4948	E7048	E4948

a. The requirements for the equivalent classifications are not necessarily identical in every respect.

Usability Characteristics of SMAW Electrodes

E6010 (E4310) electrodes are characterized by a deeply penetrating, forceful, spray-type arc and readily removable, thin, friable slag. Fillet welds usually have a relatively flat weld face and have a rather coarse, unevenly spaced ripple. The coverings are high in cellulose, usually exceeding 30% by weight.

These electrodes are recommended for all welding positions. They frequently are selected for joining pipe and generally are capable of welding in the vertical position with either uphill or downhill progression.

Sizes larger than 3/16 in. (5.0 mm) generally have limited use in other than flat or horizontal-fillet welding positions. These electrodes have been designed for use with DCEP (electrode positive).

E6011 (E4311) electrodes are designed to be used with AC current and to duplicate the usability characteristics and mechanical properties of the E6010 (E4310) classification. Although also usable with DCEP (electrode positive), a decrease in joint penetration will be noted when compared to the E6010 electrodes. Arc action, slag, and fillet weld appearance are similar to those of the E6010 electrodes.

The coverings are also high in cellulose and are described as the high-cellulose potassium type.

Sizes larger than 3/16 in. (5.0 mm) generally have limited use in other than flat or horizontal-fillet welding positions.

E6012 (E4312) electrodes are characterized by low penetrating arc and dense slag, which completely covers the bead. This may result in incomplete root penetration in fillet welded joints. The coverings are high in titania, usually exceeding 35% by weight, and usually are referred to as the "titania" or "rutile" type. Also, small amounts of certain calcium compounds may be used to produce satisfactory arc characteristics on DCEN (electrode negative).

Fillet welds tend to have a convex weld face with smooth even ripples in the horizontal welding position, and widely spaced rougher ripples in the vertical welding position that become smoother and more uniform as the size of the weld is increased.

The **E6012 (E4312)** electrodes are all-position electrodes and usually are suitable for welding in the vertical position with either the upward or downward progression. However, more often the larger sizes are used in the flat and horizontal welding positions. The larger sizes are often used for single-pass, high-speed, high-current fillet welds in the horizontal welding position.

Weld metal from these electrodes is generally lower in ductility and may be higher in yield strength (1 to 2 ksi [0.7 to 1.4 MPa]) than weld metal from the same size of either the E6010 or E6011 electrodes.

E6013 (E4313) electrodes, although very similar to the E6012 (E4312) electrodes, have distinct differences. Their

Mandatory Classification Designators*

EXXYY
EXXYYM
EXXYY—1 HZ R

Designates an electrode. This designator may be deleted from the product imprint required for identification of the electrode.

Designates the tensile strength (minimum), in ksi, or MPa ÷ 10 of the weld metal when produced in accordance with the test assembly preparation procedure of this specification.

Designates the welding position in which electrodes are usable, the type of covering, and the kind of welding current for which the electrodes are suitable.

Designates an electrode (E7018M) [E4918M] intended to meet most military requirements (greater toughness, lower moisture content — both as received and after exposure — and mandatory diffusible hydrogen limits for weld metal).

Optional Supplemental Designators:

Designates that the electrode meets the requirements of the absorbed moisture test (an optional supplemental test for all low-hydrogen electrodes except the E7018M [E4918M] classification, for which the test is required).

Designates that the electrode meets the requirements of the diffusible hydrogen test (an optional supplemental test of the weld metal from low-hydrogen electrodes, as received or conditioned — with an average value not exceeding Z mL of H_2 per 100 g of deposited metal, where Z is 4, 8, or 16).

Designates that the electrode (E7016, E7018, or E7024) [E4916, E4918, E4924] meets the requirements for improved toughness — and ductility in the case of E7024 [E4924].

*Note: The combination of these designators constitutes the electrode classification.

flux covering makes slag removal easier and gives a smoother arc transfer than E6012 electrodes. This is particularly the case for the small diameters 1/16, 5/64, and 3/32 in. (1.6, 2.0, and 2.5 mm). This permits satisfactory operation with lower open-circuit AC voltage.

E6013 electrodes were designed specifically for light sheet metal work. However, the larger diameters are used on many of the same applications as E6012 electrodes and provide low penetrating arc. The smaller diameters provide a less penetrating arc than is obtained with E6012 electrodes. This may result in incomplete penetration in fillet welded joints.

The potassium compounds permit the electrodes to operate with AC at low amperages and low open-circuit voltages.

E6013 electrodes are similar to the E6012 electrodes in usability characteristics and bead appearance. The arc action tends to be quieter and the bead surface smoother with a finer ripple.

E6013 electrodes usually cannot withstand the high amperages that can be used with E6012 electrodes in the flat and horizontal welding positions. Amperages in the vertical and overhead positions, however, are similar to those used with E6012 electrodes.

E7014 (E4914) electrode coverings are similar to those of E6012 (E4312) and E6013 (E4313) electrodes, but with the addition of iron powder for obtaining higher deposition efficiency.

The iron powder also permits the use of higher amperages than are used for E6012 and E6013 electrodes. The amount and character of the slag permit E7014 electrodes to be used in all positions.

The E7014 electrodes are suitable for welding carbon and low-alloy steels. Typical weld beads are smooth with fine ripples. Joint penetration is approximately the same as that obtained with E6012 electrodes, which is advantageous when welding over a wide root opening due to poor fit. The face of fillet welds tends to be flat to slightly convex. The slag is easy to remove.

E6019 (E4319) electrodes, although very similar to E6013 and E6020 (E4313 and E4320) electrodes in their coverings, have distinct differences. E6019 (E4319) electrodes, with a rather fluid slag system, provide deeper arc penetration and produce weld metal that meets a 22% minimum elongation requirement, meets the Grade 1 radiographic standards, and has an average impact strength of 20 ft-lbf (27 J) when tested at 0°F (–20°C).

E6019 (E4319) electrodes are suitable for multipass welding of up to 1-in.- (25- mm-) thick steel. They are designed for use with AC, DCEN, or DCEP. While 3/16 in. (5.0 mm) and smaller diameter electrodes can be used for all welding positions (except vertical welding position with downward progression), the use of larger diameter electrodes should be limited to the flat or horizontal fillet welding position. When welding in the vertical welding position with upward progression, weaving should be limited to minimize undercut.

E6020 (E4320) electrodes have a high iron oxide covering. They are characterized by a spray type arc, produce a smooth and flat, or slightly concave weld face and have an easily removable slag.

A low viscosity slag limits their usability to horizontal fillets and flat welding positions. With arc penetration ranging from medium to deep (depending upon welding current), E6020 electrodes are best suited for thicker base metal.

Electrodes of the **E6022 (E4322)** classification are recommended for single-pass, high-speed, high-current welding of groove welds in the flat welding position, lap joints in the horizontal welding position, and fillet welds on sheet metal. The weld face tends to be more convex and less uniform, especially since the welding speeds are higher.

E7024 (E4924) electrode coverings contain large amounts of iron powder in combination with ingredients similar to those used in E6012 and E6013 (E4312 and E4313) electrodes. The coverings on

E7024 electrodes are very thick and usually amount to about 50% of the weight of the electrode, resulting in higher deposition efficiency.

The E7024 (E4924) electrodes are well suited for making fillet welds in the flat or horizontal position. The weld face is slightly convex to flat, with a very smooth surface and a very fine ripple. These electrodes are characterized by a smooth, quiet arc, very low spatter, and low arc penetration. They can be used with high travel speeds. Electrodes of these classifications can be operated on AC, DCEP, or DCEN.

Electrodes designated as **E7024-1 (E4924-1)** have the same general usability characteristics as E7024 electrodes. They are intended for use in situations requiring greater ductility and a lower transition temperature than normally is available from E7024 electrodes.

E6027 (E4327) electrode coverings contain large amounts of iron powder in combination with ingredients similar to those found in E6020 electrodes. The coverings on E6027 electrodes are also very thick and usually amount to about 50% of the weight of the electrode.

The E6027 electrodes are designed for fillet or groove welds in the flat welding position with AC, DCEP, or DCEN, and will produce a flat or slightly concave weld face on fillet welds in the horizontal position with either AC or DCEN.

E6027 electrodes have a spray-type arc. They will operate at high travel speeds. Arc penetration is medium. Spatter loss is very low. These electrodes produce a heavy slag which is honeycombed on the underside. The slag is friable and easily removed.

Welds produced with E6027 electrodes have a flat to slightly concave weld face with a smooth, fine, even ripple, and good wetting along the sides of the joint. The weld metal may be slightly inferior in radiographic soundness to that from E6020 electrodes. High amperages can be used, since a considerable portion of the electrical energy passing through the electrode is used to melt the covering and the iron powder it contains. These electrodes are well suited for thicker base metal.

E7027 (E4927) electrodes have the same usability and design characteristics as E6027 electrodes, except they are intended for use in situations requiring slightly higher tensile and yield strengths than are obtained with E6027 (E4327) electrodes. They must also meet chemical composition requirements. In other respects, all previous discussions for E6027 (E4327) electrodes also apply to E7027 (E4927) electrodes.

Low-Hydrogen Electrodes

Electrodes of the low-hydrogen classifications E6018 (E4318), E7015 (E4915), E7016 (E4916), E7018 (E4918), E7018M (E4918M), E7028 (E4928), and E7048 (E4948) are made with inorganic coverings that contain minimal moisture. All low-hydrogen electrodes, in the as-manufactured condition or after conditioning, are expected to meet a maximum covering moisture limit of 0.6% or less.

In order to maintain low-hydrogen electrodes with minimal moisture in their coverings, these electrodes should be stored and handled with considerable care. Electrodes that have been exposed to humidity may absorb considerable moisture and their low-hydrogen character may be lost. Then conditioning can restore their low-hydrogen character.

E7015 (E4915) electrodes are low-hydrogen electrodes to be used with DCEP (electrode positive). The slag is chemically basic.

E7015 electrodes are commonly used for making small welds on thick base metal, since the welds are less susceptible to cracking. They are also used for welding high-sulfur and enameling steels. Welds made with E7015 electrodes on high-sulfur steels may produce a very tight slag and a very rough or irregular bead appearance in comparison to welds with the same electrodes in steels of normal sulfur content.

The arc of E7015 electrodes is moderately penetrating. The slag is heavy, fri-

Typical Amperage Ranges for SMAW

Electrode		A5.1	E6010, E6011	E6012	E6013	E6019	E6020	E6022	E6027, E7027	E7014	E7015, E7016	E6018, E7018M, E7018	E7024, E7028	E7048
Diameter														
A5.1 (in)	A5.1M (mm)	A5.1M	E4310, E4311	E4312	E4313	E4319	E4320	E4322	E4327, E4927	E4914	E4915, E4916	E4318, E4918M, E4918	E4924, E4928	E4948
1/16	1.6		--	20 to 40	20 to 40	--	--	--	--	--	--	--	--	--
5/64	2.0		--	25 to 60	25 to 60	35 to 55	--	--	--	--	--	--	--	--
3/32*	2.4*, 2.5*		40 to 80	35 to 85	45 to 90	50 to 90	--	--	--	80 to 125	65 to 110	70 to 110	100 to 145	--
1/8	3.2		75 to 125	80 to 140	80 to 130	80 to 140	100 to 150	110 to 160	125 to 185	110 to 160	100 to 150	105 to 155	140 to 190	80 to 140
5/32	4.0		110 to 170	110 to 190	105 to 180	130 to 190	130 to 190	140 to 190	160 to 240	150 to 210	140 to 200	130 to 200	180 to 250	150 to 220
3/16	5.0		140 to 215	140 to 240	150 to 230	190 to 250	175 to 250	170 to 400	210 to 300	200 to 275	180 to 255	200 to 275	230 to 305	210 to 270
7/32	5.6		170 to 250	200 to 320	210 to 300	240 to 310	225 to 310	370 to 520	250 to 350	260 to 340	240 to 320	260 to 340	275 to 365	--
1/4	6.0		210 to 320	250 to 400	250 to 350	310 to 360	275 to 375	--	300 to 420	330 to 415	300 to 390	315 to 400	335 to 430	--
5/16	8.0		275 to 425	300 to 500	320 to 430	360 to 410	340 to 450	--	375 to 475	390 to 500	375 to 475	375 to 470	400 to 525	--

*This diameter is not manufactured in the E7028 [E4828] classification.
6/2/2003

able, and easy to remove. The weld face is convex, although a fillet weld face may be flat.

E7015 electrodes up to and including the 5⁄32 in. (4.0 mm) size are used in all welding positions. Larger electrodes are used for groove welds in the flat welding position and fillet welds in the horizontal and flat welding positions.

Amperages for E7015 electrodes are higher than those used with E6010 electrodes of the same diameter. The shortest possible arc length should be maintained for best results with E7015 electrodes. This reduces the risk of porosity. The necessity for preheating is reduced; therefore, better welding conditions are provided.

E7016 (E4916) electrodes have all the characteristics of E7015 (E4915) electrodes, plus the ability to operate on AC. Most of the preceding discussion on E7015 electrodes applies equally well to the E7016 electrodes.

Electrodes designated as **E7016-1 (E4916-1)** have the same usability and weld metal composition as E7016 electrodes except that the manganese content is set at the high end of the range. They are intended for welds requiring a lower transition temperature than is normally available from E7016 electrodes.

E7018 (E4918) electrode coverings are similar to E7015 coverings, except for the addition of a relatively high percentage of iron powder. The coverings on these electrodes are slightly thicker than those of the E7016 electrodes.

E7018 low-hydrogen electrodes can be used with either AC or DCEP. As is common with all low-hydrogen electrodes, a short arc length should be maintained at all times.

In addition to their use on carbon steel, the E7018 electrodes are also used for joints involving high-strength, high-carbon, or low-alloy steels. The fillet welds made in the horizontal and flat welding positions have a slightly convex weld face, with a smooth and finely rippled surface. The electrodes are characterized by a smooth, quiet arc, very low spatter, and medium arc penetration. E7018 electrodes can be used at high travel speeds.

Electrodes designated as **E7018-1 (E4918-1)** have the same usability and weld metal composition as E7018 (E4918) electrodes, except that the manganese content is set at the high end of the range. They are intended for welds requiring a lower transition temperature than is normally available from E7018 electrodes.

E6018 (E4318) electrodes possess operating and mechanical property characteristics similar to E7018 (E4918) except at a lower strength level. The electrode coating and low-hydrogen characteristics are also similar. This electrode is desirable where matching or undermatching weld deposit is required. Electrodes that meet this classification may also be suitable for buffer layer application in cladding operations.

E7018M (E4918M) is intended to be used with DCEP type current in order to produce the optimum mechanical properties. However, if the manufacturer desires, the electrode may also be classified as E7018 (E4918) provided all the requirements of E7018 (E4918) are met.

In addition to their use on carbon steel, the E7018M electrodes are used for joining carbon steel to high-strength low-alloy steels and higher carbon steels. Fillet welds made in the horizontal and flat welding positions have a slightly convex weld face, with a smooth and finely rippled surface. The electrodes are characterized by a smooth, quiet arc, very low spatter, and medium arc penetration.

E7028 (E4928) electrodes are very much like the E7018 electrodes. However, E7028 electrodes are suitable for fillet welds in the horizontal welding position and groove welds in the flat welding position only, whereas E7018 electrodes are suitable for all positions.

The E7028 electrode coverings are much thicker. They make up approximately 50% of the weight of the electrodes. The iron content of E7028 electrodes is higher (approximately 50% of the weight of the coverings). Consequently, on fillet welds in the horizontal position and groove welds in the flat weld-

Typical Storage and Drying Conditions for Covered Arc Welding Electrodes

AWS Classification		Storage Conditions[a,b]		
A5.1	A5.1M	Ambient Air	Holding Ovens	Drying Conditions[c]
E6010, E6011	E4310, E4311	Ambient Temperature	Not recommended	Not recommended
E6012, E6013, E6019, E6020 E6022, E6027 E7014, E7024 E7027	E4312, E4313, E4319, E4320, E4322, E4327, E4914, E4924 E4927	80°–20°F [30°–10°C] 50% max relative humidity	20° to 40°F [10° to 20°C] above ambient temperature	275–25°F [135°–15°C] 1 hour at temperature
E6018, E7015 E7016 E7018, E7028, E7018M, E7048	E4318, E4915 E4916 E4918, E4928, E4918M, E4948	Not recommended	50° to 250°F (30° to 140°C) above ambient temperature	500° to 800°F (260° to 425°C) 1 to 2 hours at temperature

Notes:
a. After removal from manufacturers' packaging.
b. Some of these electrode classifications may be designated as meeting low moisture absorbing requirements. This designation does not imply that storage in ambient air is recommended.
c. Because of inherent differences in covering composition, the manufacturers should be consulted for exact drying conditions.

ing position, E7028 electrodes give a higher deposition rate than the E7018 electrodes for a given size of electrode.

Electrodes of the **E7048 (E4948)** classification have the same usability, composition, and design characteristics as E7018 electrodes, except that E7048 electrodes are specifically designed for exceptionally good vertical welding with downward progression.

Usability Designations of Stainless Steel SMAW Electrodes

Designation -15. The electrodes are usable with DCEP (electrode positive) only. While use with alternating current is sometimes accomplished, they are not intended to qualify for use with this type of current. Electrode sizes 5⁄32 in. (4.0 mm) and smaller may be used in all positions of welding.

Designation -16. The covering for these electrodes generally contains readily ionizing elements, such as potassium, in order to stabilize the arc for welding with alternating current. Electrode sizes 5⁄32 in. (4.0 mm) and smaller may be used in all positions of welding.

Designation -17. The covering of these electrodes is a modification of the -16 covering in that considerable silica replaces some of the titania of the -16 covering. Since both the -16 and the -17 electrode coverings permit AC operation, both covering types were classified as -16 in the past because there was no classification alternative until the 1992 revision of AWS A5.4. However, the operational differences between the two types have become significant enough to warrant a separate classification.

On horizontal fillet welds, electrodes with a -17 covering tend to produce more of a spray arc and a finer rippled weld-bead surface than do those with the -16 coverings. A slower freezing slag of the -17 covering also permits improved handling characteristics when employing a drag technique. The bead shape on horizontal fillets is typically flat to concave with -17 covered electrodes as compared to flat to slightly convex with -16 covered electrodes.

When making fillet welds in the vertical position with upward progression, the slower freezing slag of the -17 covered electrodes requires a slight weave technique to produce the proper bead shape. For this reason, the minimum leg-size fillet that can be properly made with a -17 covered electrode is larger than that for a -16 covered electrode. While these electrodes are designed for all-position operation, electrode sizes 3⁄16 in. (4.8 mm) and larger are not recommended for vertical or overhead welding.

Designation -26. This designation is for those electrodes that are designed for flat and horizontal fillet welding and that have limited out of position characteristics. In practice, most of these electrodes give higher deposition rates than their all-positional counterparts owing to their thicker coatings that contain higher levels of metal powders. The thicker coating gives larger fillet welds that are typically flat to concave. It also reduces the effects of core wire overheating, making 18-in.-long electrodes possible for the larger electrodes, even with stainless steel core wire. Higher currents are usually required to achieve the necessary penetration compared to the all-positional types.

Electrodes with the -26 designation are recommended for welding only in the flat and horizontal fillet positions. The manufacturer's suggested operating currents should be consulted. Out of position welding may be possible with electrode sizes up to 1⁄8 in. (3.2 mm) diameter.◆

Thermal Spray Applications Pictured in Brochure

A glossy, 8-page, full-color brochure details and illustrates the company's many applications for the thermal spray process to minimize wear, corrosion, and downtime in the power, chemical, construction, manufacturing, mining, aerospace, and chemical industries. Its coatings are described to withstand galling, fretting, electrogalvanic pitting, abrasive wear, thermal oxidation, and corrosion. Described are its spraying processes, including combustion, plasma, high-velocity oxyfuel (HVOF), and electric arc, suitable for use on virtually any metal or ceramic. The company's quality control services verify porosity, microhardness, carbide distribution, oxide content, bond coat-substrate interface, top coat-bond coat interface, percentage of unmelted particles in the coating, and the overall coating quality.

St. Louis Metallizing Co. **112**
4123 Sarpy Ave., St. Louis, MO 63110

Hoses and Accessories Pictured in Catalog

Information on more than 60 hoses and 400 fitting styles, plus associated equipment and accessories are illustrated and described in the company's Catalog 4400. It contains an expanded introductory section with helpful hose hints, photos, technical data, and detailed drawings. It features the Size, Temperature, Application, Media, and Pressure (STAMP) method for specifying hose, and offers expanded information on user-oriented topics including crimpers, custom tube assemblies, downloadable CAD drawings, and other interesting information.

Parker Catalog Services **113**
8940 Tyler Blvd., Mentor, OH 44060

Baldrige Quality Book and Pocket Guide Updated

Baldrige Award Winning Quality, 15th Edition: How to Interpret the Baldrige Criteria for Performance Excellence, and *The Pocket Guide to the Baldrige Award Criteria, 12th Edition*, both authored by Mark

— *continued on page 74*

— continued from page 72

Graham Brown, have been updated for 2006. The focus is on the organization's business ethics and governance systems, and the company's plans to stay operational during emergencies such as natural disasters or a terrorist act. The Guidebook answers common questions about the Baldrige award criteria, then presents concise explanations of what excellent companies do in each of the seven Baldrige category headings. The 384-page, soft cover book costs $45. The 3- x 5-in., soft cover Guidebook is $5.95. Contact *www.productivitypress.com.*

DIN Welding Standards in English on a CD-ROM

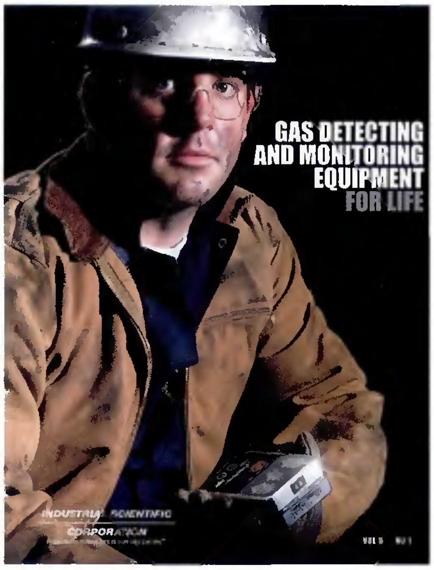
The *DIN/DVS Handbook 8, Welding 1, 6th edition,* in English, is presented on a CD-ROM. It consists of an up-to-date collection of 39 DIN standards on welding consumables and the destructive testing of welded joints. Included are 26 European standards and 11 that are identical to the International standards. The handbook is intended to facilitate the implementation of standards and enhance the benefits of industry-wide cooperation in standards work. The CD is available in both single-user and network versions. Contact *foreign-sales@beuth.de* for more information.

Pocket Welding Guide Updated in 28th Edition

The *Pocket Welding Guide,* 28th edition, has been updated with the addition of new filler metals, preheat temperatures for metals, and the AISI designation system for carbon and low-alloy steels. It includes troubleshooting guides, welding symbols, joints and positions, causes and fixes for common welding problems, and many other topics. It is a ready reference book for every welder's toolbox. The price is $4.95. Contact Hobart Institute of Welding Technology, (800) 332-9448, ext. 5433, *www.welding.org/cart/training/gwbooks.htm.*

Gas Detection Equipment Pictured in Catalog

A free, 74-page, full-color catalog features the company's complete line of portable and fixed gas detectors, service offerings, and technical reference library. Included are single and multigas portable monitors, confined-space kits, fixed monitoring systems, repair services, and rental information. Featured are the latest products iNet Instrument Network™, GasBadge® Plus and Pro single-gas monitors, M*Cal™ and Cal Plus™ calibration stations, Stainless Steel iTrans™ fixed-point



monitor, and 820 Controller. Included are detailed product specifications, third-party approval information, accessories, calibration equipment, and ordering information. A reference section includes data on properties of hazardous gases, sensor data, industry applications, a glossary of health and safety terms, and a guide to understanding hazardous locations and approval markings.

Industrial Scientific Corp. 114
1001 Oakdale Rd., Oakdale, PA 15071

Catalog Helps Select the Right Band Saw Blade

The new saw blade catalog includes detailed instructions to help choose the right band saw blade for cutting almost any material. Listed are 21 types of blades in a variety of pitches and widths. Included are bimetal, tungsten-carbide tipped, carbon steel, knife-edge, tungsten grit, and diamond grit blades for cutting everything from mild steels to exotic alloys, silicon, glass, plastic, and low-density materials like foam. A solutions and applications manager section answers common questions regarding the best blade, feed, cutting fluid, machine, and speed for most any application.

DoALL Sawing Products 115
254 N. Laurel Ave., Des Plaines, IL 60016

Toyota Product Development Detailed

The Toyota Product Development System, subtitled Integrating People, Process, and Technology, uses extensive examples comparing Toyota with a U.S. competitor to demonstrate value stream mapping as a powerful tool for continuous improvement. The 400-page, hard-cover book costs $40. It details the Lean Product Development concept in 18 chapters. Included are an appendix, bibliography, and index. For more information or to purchase, contact Productivity Press. Visit *www.productivitypress.com* or call (888) 319-5852.

Wall Colmonoy Elects a VP

John Sturch

Wall Colmonoy, Madison Heights, Mich., has elected **John Sturch** vice president of its aeronautical and aerospace group. Most recently, Sturch served as general manager of the company's Oklahoma City business unit.

Division Managers Named at Praxair Distribution

Praxair Distribution, Inc., Danbury, Conn., a subsidiary of Praxair, Inc., has named **Bob Phillips** Northeast U.S. division general manager. Previously, Phillips was director of safety, environmental and engineering services. **Ken Faulkner** was named division sales manager, and **Doug Crayton** designated division operations manager for the recently acquired Constar LLC packaged gas business in Norcross, Ga. Faulkner has 34 years of industry experience in Georgia and the Carolinas, including ten years with Constar. Crayton previously was senior vice president of risk management for Matheson Tri-Gas in Rock Hill, S.C.

Praxair Appoints President and Executive VP

Stephen F. Angel

Ricardo Malfitano

Praxair, Inc., Danbury, Conn., has appointed **Stephen F. Angel** president and chief operating officer, and **Ricardo Malfitano** executive vice president. Angel, with the company for five years, previously served as executive vice president. Malfitano, who joined the company in 1978, most recently served as senior vice president.

Genstar Appoints National Sales Manager

Dave Myers

Genstar Technologies, Chino, Calif., has appointed **Dave Myers** national sales manager for instrumentation, specialty gas, and high-purity products. Most recently, Myers has worked in the high-pressure gas alternative fuels business.

Compliance Manager Selected at August Mack Environmental

August Mack Environmental, Inc., Indianapolis, Ind., has promoted **Charles Schnurpel** to senior compliance manager. Schnurpel previously served as staff environmental scientist and project compliance manager.

MG Systems and Welding Designates Sales Managers

Scott Kessler

MG Systems and Welding, Menomonee Falls, Wis., has named **Scott Kessler** as national sales manager and **Dick Parrott** as western regional sales manager. Kessler previously was employed in various industrial, manufacturing, and sales management posts. Parrott has 20 years of experience in the metal cutting and fabrication industry.

President and CEO Announced for Handy & Harman Precious Metals

Philip L. Malliet has been promoted to president and chief executive officer of the Handy & Harman Precious Metals Group, Milwaukee, Wis. The group includes Lucas-Milhaupt, Inc., Milwaukee, Wis.; Handy & Harman of Canada, Ltd., Rexdale, Ont.; and Protechno S.A., Riberac, France. Since 2004, Malliet served

— *continued on page 78*

—continued from page 76

as vice president and general manager of the Precious Metals Group.

Wright Brothers Names Technical Services Manager

Wright Brothers, Montgomery, Ohio, a local independent gas supplier, has promoted **Dave Patterson** to manager of technical services. Most recently, Patterson served as a lead technician for the company's gas site management program.

Vest Named Manufacturing Manager at Stedman


David Vest

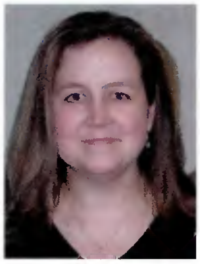
David Vest has been appointed manufacturing manager at Stedman, Aurora, Ind. Vest has 27 years' experience in engineering and plant management positions. The company manufactures numerous products including impactors, crushers, cage mills, hammer mills, wood hogs, and breaker shredders.

Key Post Filled at Laboratory Testing, Inc.


Frank Peszka

Laboratory Testing, Inc., Hatfield, Pa., has appointed **Frank Peszka** quality assurance manager, succeeding **Don DiFilippo** who has retired. Peszka joined the company in 2004 as a quality assurance specialist. The company specializes in metal and alloy testing, specimen machining, failure analysis, and calibration services.

Marketing Specialist Announced at Tregaskiss Welding Products


Kelly Chadwick

Tregaskiss Welding Products, Windsor, Ont., Canada, named **Kelly Chadwick** a marketing specialist. Chadwick has more than five years' experience as a marketing manager for a manufacturer of indexing tables for robotic welding, and mechanical power transmission products.

Obituaries

Eric Holby


Eric Holby

Eric Holby, 82, an AWS Life Member, died February 8 in Geneva, Ill. He was a member of the American Welding Society for more than 50 years, during which time he served on a number of technical committees including the Structural Welding Committee, Rocket & Missile Committee, and the B-3 Committee on Qualification where he served as chairman for six years.

He published more than 70 technical articles and papers in *Welding Journal,* *Power Engineering, Welding Engineer,* and other publications. He contributed major sections to the *Welding Encyclopedia,* 13th edition, and *ASM Handbook.*

During the 1960s, he served as chief welding engineer at DK Aerospace Co., in Batavia, Ill., where he was responsible for metallurgy, welding, design, and nondestructive evaluation of major components for NASA space vehicles. He established the research programs that led to reliable procedures for joining exotic alloys in thicknesses down to 0.002 in. He was involved in the development of welding procedures for the joining of titanium structural elements for the Air Force C-5A.

In 1971, he joined Pioneer Service and Engineering Co. as chief welding engineer. In 1973 the firm was sold to Fluor Corp., where he was promoted to corporate manager of welding and metallurgy. During Mr. Holby's tenure, Fluor designed and built nuclear- and fossil-fueled power plants in the United States, South Africa, Europe, Middle East, Taipei, and Japan.

Mr. Holby retired from Fluor in 1987. He spent the next few years building his own company, IFR Engineering. The firm specialized in the investigation of welding and metallurgical failures.

He established the Eric Holby Animal Welfare Foundation to operate an animal refuge and provide funding to a number of animal shelters, World Wildlife, National Wildlife Federation, Nature Conservancy, and similar groups.

He is survived by his wife, Dorothy, and son, Eric.

Paul W. Ramsey

Paul Ramsey

Paul Willard Ramsey, 87, AWS president 1975–1976, died March 9 in Milwaukee, Wis.

An AWS member since 1956, Mr. Ramsey served as District 7 director, a Director-at-large, chairman of the Milwaukee Section, and AWS executive director 1982–1986. He was a member of the 1993 class of AWS Fellows.

Mr. Ramsey was a member of the Executive and Finance Committee, served on the Technical Council and Districts Council, and as chairman of the Welding Handbook Committee, and the Publications and Promotional Council. He also served on the Welding Research Council's University Research Committee, Midwest Welding Conference, and the American Council of the International Institute of Welding. He chaired various technical meetings and was a frequent speaker at AWS Section meetings. He authored numerous technical papers, and was granted four patents in the welding field.

Mr. Ramsey received numerous recognitions for his contributions to the welding industry, including the National Meritorious Award (1971), Plummer Memorial Education Award (1978), Samuel Wylie Miller Memorial Award (1980), McKay-Helm Award (1990), R. D. Thomas Memorial Award (1993), R. D. Thomas Jr. International Lecture Award (1993), George E. Willis Award (1999), and the International Meritorious Certificate Award (2003).

Nationally recognized as a leader in welding research and applications for advanced joining technologies, he received a Distinguished Service citation from the University of Wisconsin where he earned his master's degree in metallurgical engineering.

Mr. Ramsey worked for A. O. Smith Corporation for 31 years, where for many years he was manager of research and development at its welding research laboratory in Milwaukee. He worked as an independent consultant until shortly before his death.

A U.S. Navy veteran, Mr. Ramsey was deeply involved in North Shore Presbyterian Church activities and civic affairs in Wauwatosa, Wis., where he served on the Plan Commission, was president of the Common Council, and was an alderman for 16 years. In his later years, he served as a tutor for children in the Milwaukee public schools, and served as president of his condo association and of the "Snipe Lake Association," his summer home near Eagle River, Wis.

A lover of nature and the wilderness, Mr. Ramsey was an avid canoeist, fisherman, and hunter, who "was happiest with a paddle, fishing rod, or a rifle in his hands."

Mr. Ramsey is survived by his wife, Shirley, a sister, two sons, a daughter, three grandchildren, and one great-granddaughter.◆

NEW PRODUCTS

— *continued from page 22*

nating the bleed holes and balancing the gas flow, which directs 100% of the oxygen directly to the plasma cutting process. This engineering change by the company on the Oxygen-Saver Nozzle reduces oxygen consumption by 20 to 70%. In addition, the nozzle features a high-tolerance, one-piece copper design.

Thermacut, Inc. 108
19 Sullivan St., PO Box 1197, Claremont, NH 03743-1197

Angle Grinders Feature Antivibration Handles

The company has upgraded its entire line of angle grinders with antivibration handles. The ergonomic design of the Vibratech handle eliminates the direct contact between the spindle and the grip, reducing vibration. Also, vibration is further diminished by absorbent elastomer between the spindle and grip. The antivibration handles are available on all the company's angle grinders.

Metabo Corp. 109
1231 Wilson Dr., West Chester, PA 19380

Drill Incorporates New Powerful Magnet

The company has introduced an upgrade to its HMD925 power feed model portable magnetic drill with the incorporation of an advanced magnetic base. The magnetic base still measures 3⅛ W x 6⁹⁄₁₆ in. L, but develops 1680 lb dead lift strength and 775 lb drillpoint breakaway force on 1-in.-thick plate, and 1124 and 612 lb, respectively, when tested on ⅜-in.-thick plate. The revamped drill maintains its holemaking capacity of 7/16 to 1¼ in. diameter through materials up to 2 in. thick using the power feed option and Hougen Rotabroach® annular cutting tools. In the manual feed mode, maximum capacity is 1½ in. diameter through 2-in.-thick stock.

— *continued on page 81*

2006 POSTER SESSION COMPETITION – CALL FOR ENTRIES

FABTECH International & AWS Welding Show
Atlanta, October 30 – November 2, 2006

Deadline for submission of entries is August 1.

Students, educators, researchers, engineers, technical committees, consultants, and anyone else in a welding or joining related field are invited to participate in the world's leading annual welding event, by visually displaying their technical accomplishments in a brief graphic presentation suitable for close, first-hand examination by interested individuals.

This is the ideal forum to present:

- results that are best communicated visually;
- information more suited for display rather than verbal presentation before a large audience;
- new techniques or procedures that are best discussed in detail individually with interested viewers;
- brief reports on work in progress;
- results that call for the close study of photomicrographs or other illustrative materials.

Posters accepted for competition will be judged based on technical content, clarity of communication, novelty/relevance of the subject and ideas conveyed, and overall aesthetic impression. Each poster may have up to four authors collaborating on it.

Cash prizes are awarded to the students for First, Second, and Third Place winners in each of four separate categories (a total of 12 prizes, plus non-cash awards for the category of "Professionals"). The awards are for the poster, and the total prize money will be divided equally among the authors, as follows:

1st Place:	$200
2nd Place:	$100
3rd Place:	$ 50

Judges will choose the winners during the show in Atlanta, and ribbons will be affixed to the winning posters for everyone to see. **Contestants do not need to be present to win.** The categories are:

- **Students in a High School Welding Program.** Junior or senior high school students enrolled in a welding concentration at the time of submittal.
- **Students in a Two-Year College or Certificate Program.** Students enrolled in two-year college and/or certificate programs at time of submittal.
- **Undergraduate Students.** For students enrolled in baccalaureate engineering or engineering technology programs at the time of submittal.
- **Graduate Students.** For students enrolled in graduate degree programs in engineering or engineering technology at time of submittal.
- **Professionals** (cash award does not apply to this category). For anyone working in the welding industry or related field

Submission of posters must fall under one of the five categories and follow a specific format. Deadline is August 1. Individuals interested in participating should contact Martica Ventura for more information at 800-443-9353 (305-443-9353 outside U.S.), ext. 224, or visit the AWS website at *www.aws.org/expo/posters.html*

American Welding Society

Founded in 1919 to advance the science, technology and application of welding and allied processes including joining, brazing, soldering, cutting and thermal spray.

Circle No. 9 on Reader Info-Card

NEW PRODUCTS

— continued from page 79

Other operational and construction features remain the same, including the measurements of 17⅛ H x $10\frac{13}{16}$ W x $11\frac{3}{16}$ in. L, and weight at 37 lb. The electrical system is a heavy-duty 120 V, 50/60 Hz at 960 W, featuring a 7.2-A motor delivering a high torque 450 rpm. All of the operational controls are located on the feed handle side of the unit.

Hougen Manufacturing, Inc. 110
PO Box 2005, Flint, MI 48501-2005

Wheels for Stainless Steel Applications Improve Performance

Norton Charger™ Plus wheels contain a zirconia alumina abrasive to cut and grind stainless steels. The smooth grinding action enhances the cut rate and life of the wheel. The clean bond contains no sulfur, iron, or chlorine, eliminating the opportunity for contamination, and makes the wheel softer acting. For stainless applications, the wheels are available in ⅛-in. thickness for cutting and light grinding, and ¼-in. thickness for heavier stock removal. Users can grind faster with less force and less fatigue. Charger Plus Type 27⅛- and ¼-in.-thick grinding and cutting wheels are available in 4, 4½, 5, 6, 7, and 9 in. diameters with both ⅞ and ⅝–11 in. center holes. Type 28 saucer wheels are available in 7 and 9 in. diameters, ¼ in. thickness, and ⅝–11 center holes.

Saint-Gobain Abrasives, Inc. 111
1 New Bond St., PO Box 15008, Worcester, MA 01615-0008

CAREER OPPORTUNITIES

MANAGING DIRECTOR OF CERTIFICATION
MIAMI, FLORIDA

The American Welding Society is seeking a Managing Director to be responsible for the overall function of the AWS Certification Department at its Headquarter operations in Miami, Florida. The successful candidate should possess a four- year degree, preferably in engineering or welding/industrial technology, and demonstrate proven ability to grow and expand AWS business operations worldwide. Applicants possessing an AWS certification and/or a broad knowledge base of certification programs will be strongly considered. This individual must be able to handle supervisory, technical, and business matters in a challenging and exciting work environment.

AWS is a drug-free workplace and an EOE.

E-mail your resume with salary requirements to cburrell@aws.org

American Welding Society
550 N.W. LeJeune Rd. • Miami, FL 33126
(800) 443-9353 • (305) 443-9353 • Visit our website at http://www.aws.org

Product Developer - Welding Consumables

This is a R&D position working within the technical department. The primary responsibility of this position is to develop new products and improve the current range of shielded metal arc electrodes, submerged arc fluxes and flux cored wires manufactured by Special Metals Welding Products Company. Additional responsibilities include preparing raw material purchase specifications and improving manufacturing processes.

The requirements for this position are a science or engineering qualification to BS or equivalent, the ability to work in a logical and disciplined manner and to communicate results accurately. This is a key position within a very successful and progressive business, which will require enthusiasm and the ability to work within a small team in a "hands on" environment. Previous experience in the development of welding consumables is preferred but suitable candidates with associated experience in other industries will also be considered.

Respond to: jmartin@smwpc.com or FAX: 824-464-8993.

Red-D-Arc Welderentals

When you're ready to weld.

North America's leader in the welder-rental industry is looking for key individuals to join our team.

Red-D-Arc Welderentals, an Airgas company, is North America's largest welder rental company. We presently operate a rental fleet of over 30,000 welding machines with over 30 branch locations in the U.S., Canada and Mexico. Our business includes rentals, leasing and used & new sales of welding equipment and welding-related accessories.

We require highly motivated people with excellent communication skills, superior interpersonal skills, proven customer service aptitude and the ability to work in a fast-paced team environment. Knowledge of welding equipment and welding processes is an asset.

For more information or to submit a resume visit our website at reddarc.com

Don't miss your opportunity to become part of a dynamic team of industry leaders. Red-D-Arc offers a competitive wage and benefits package. If you are interested in exploring employment opportunities further, please contact us today.

THANK YOU

The 2006 Graduating Class of Welding Engineering Technology Students from Ferris State University Would Like to Thank the Following:

Jeffrey Carney, Dept. Chair/
Associate Professor

Kenneth A. Kuk, C.Mfg.E.
Professor

David Murray
Associate Professor

Bradley Brew
Assistant Professor

Jeffrey Hardesty
Assistant Professor

Linda Faysal
Department Secretary

Thank you all for your help and assistance over the past four years. We greatly appreciate your dedicated support and guidance.

Put Your Sales Products and Services To Work for You this July 2006

- •Welding
- •Metal Fabricating
- •Inspection
- •Safety

Generate sales leads by showcasing your full-color catalog or product photo, a product description, website, or other sales literature. These 1/6 page insertions reach 70,000 qualified buyers. Great responses for just pennies a contact.

Closing 5/19/2006.

Call our sales team at: 1-800-443-9353 Ext. 243 or e-mail: salty@aws.org

EQUIPMENT FOR SALE OR RENT

WELD PLUS

e-mail: melissa@weldplus.com
CINCINNATI, OHIO
Fax: 513-467-3585
Website: weldplus.com

WELD PLUS, INC.
800-288-9414 Pete, Paul, Dennis or Melissa

JUST IN!! Jetline 2002 Dual Process LWI-144Z Internal Longitudinal Seam Welder. 150' Total Welding/Clamping Length. Flat Sheet or I.D. Welding from 56' to any Max. Diameter you can handle!

OVER 50 "NEW 2006" POSITIONERS IN STOCK!!!

"BRAND NEW 2006" IN OUR STOCK!!
PANDJIRIS POSITIONERS!! JETLINE SEAMERS!!
MBC POSITIONERS!!! WEBB TURNING ROLLS!!!

Well Over 150 Positioners Total, Up to 60 Tons!! Head/Tailstocks, Turntables up to 100 tons. Manipulators up to 14' x 14'. Travel Cars, Longitudinal Seamers from 6 in. to 26 ft. Turning rolls up to 400 Tons. Circular Weld Systems, Welding Lathes, Motoman and Panasonic welding robots.

"WE KNOW WELDING"
TALK TO US!! .... COME VISIT US!!

ATTENTION!

Welding Equipment Sales Personnel.
We pay you for finding us good used welding systems, seamers, positioners, manipulators, turning rolls, etc.
We will buy your customers' trade-ins.

WELD PLUS, INC.
1-800-288-9414

Portable System Stops Distortion up to 90% Better
"A natural for welders"

www.Bonal.com
1-800-638-2529

LANDMARK
INDUSTRIAL, INC.

Quality Equipment for Your Inspection Needs!

- Flaw detection-*affordable, portable units*
- Thickness gages-*single or multi-function units*
- Immersion inspection-*automated systems*
- Corrosion mapping-*automated systems*
- Pipeline weld inspection-*advanced systems*

info@landmarkprecision.com
www.landmarkprecision.com

We buy and sell
WELDING RODS & WIRE
ALL TYPES ALL SIZES**
ALL QUANTITIES

Excess Welding Alloys, Inc.
A division of Weld Wire Company Inc.

800-523-1266 FAX 610-265-7806
www.weldwire.net

We Buy & Sell Surplus
Welding Rod & Wire
All types, sizes & Quantities

Liberty Alloys INC.

Call us first!

800-523-2791
PA: 610-825-1250
FAX: 610-825-1553

RED-D-ARC®
Quality-Checked™ Used Equipment
www.red-d-arc.com

An Excellent Selection of Used Welding and Positioning Equipment for Sale

1-800-245-3660
Service Centers Across North America

VERSA-TIG™
MULTIPLE TIG TORCH SELECTORS
www.versa-tig.com

cash4usedrobots.com
We buy and sell
740-383-8383

Welding Positioners & Turning Rolls
New and Used

Large selection in stock for immediate delivery.

www.allfabcorp.com

Call, Fax or Email for a free catalog.

All-Fab Corp.

Email: sales@allfabcorp.com
Web: www.allfabcorp.com
Phone: 269-673-6572
Fax: 269-673-1644

---

robots4welding.com

Toll free: 1-800-762-6862

Turning Rolls
Positioners
& Manipulators
New and Used

Joe Fuller LLC
@ www.joefuller.com
or email joe@joefuller.com

Phone: 979-277-8343
Fax: 281-290-6184

Place Your Classified Ad Here!

Contact Frank Wilson,
Advertising Production Manager

1-800-443- 9353, ext. 465
fwilson@aws.org

BUSINESS FOR SALE

Business for Sale

DIVERSIFY - Small 23-year-old business for sale. Manufacture stored energy micro welding equipment. Pulse arc, spot, tack and fusion percussion welders used in the jewelry, crafts, medical, electronic, and automotive assembly industries. Owners retiring.

Confidential, please write:

Business 4 Sale
PO Box 893
E. Greenwich, RI 02818

ADVERTISER INDEX

IFC = Inside Front Cover
IBC = Inside Back Cover
OBC = Outside Back Cover
RI = Reader Information Card

WELDING RESEARCH

SUPPLEMENT TO THE *WELDING JOURNAL*, MAY 2006
Sponsored by the American Welding Society and the Welding Research Council

Prediction of Ferrite Number of Duplex Stainless Steel Clad Metals Using RSM

Response surface methodology (RSM) was used to establish a relationship between process parameters and Ferrite Number for duplex stainless steel clad metals

BY T. KANNAN AND N. MURUGAN

ABSTRACT. Duplex stainless steel clad metals contain delta ferrite, which is expressed in terms of Ferrite Number (FN). The amount of ferrite present in the deposit is a function of chemical composition of the filler and base metals, welding process, type of shielding gas, welding procedure, and heat input during cladding. Excessive ferrite in duplex stainless steel claddings can result in poor ductility, toughness, and corrosion resistance. Likewise, insufficient ferrite can also produce inferior mechanical and corrosion resistance properties. Hence, control of ferrite in duplex stainless steel cladding is essential to obtain the required mechanical and corrosion-resistant properties.

This paper highlights the application of response surface methodology to develop mathematical models and to analyze various effects of flux cored arc welding (FCAW) process parameters on the FN of duplex stainless steel clad metals. The experiments were conducted based on four-factor, five-level, central composite rotatable design with full replications technique and mathematical models developed using multiple regression technique. The developed mathematical models are very useful for predicting and controlling the FN in duplex stainless steel cladding. The main and interaction effects of input process parameters on calculated FN (by WRC-1992 diagram) and measured FN have been presented in graphic form, which helps in selecting FCAW process parameters to achieve the required FN.

T. KANNAN (kannan_kct@yahoo.com) *is an assistant professor of mechanical engineering, Kumaraguru College of Technology, Coimbatore, Tamil Nadu, India. N. MURUGAN* (drmurugan@yahoo.com) *is professor of mechanical engineering, Coimbatore Institute of Technology, Coimbatore, Tamil Nadu, India.*

KEYWORDS

Duplex Stainless Steel
FCAW
Ferrite Number
Heat Input
Mathematical Models
Response Surface Methodology

Introduction

Weld cladding is a process in which a thick layer of a weld metal is deposited onto a carbon- or low-alloy-steel base metal to provide a corrosion-resistant surface. It finds extensive use in numerous industries such as paper, chemical, fertilizer, nuclear, food processing, petrochemical, and other allied industries. The desirable characteristics of cladding material are reasonable strength, weldability to the steel, resistance to general and localized corrosion attack, and good corrosion fatigue properties (Ref. 1). In recent years, duplex stainless steel is extensively used for weld cladding because it has excellent chloride stress corrosion cracking resistance, pitting and crevice corrosion resistance, yield strength, ductility, impact toughness, and weldability (Ref. 2).

The composition and properties of clad metals are strongly influenced by dilution, as illustrated in Fig.1. It is the amount of base metal melted (B) divided by the sum of the filler metal added and base metal melted (A+B). Dilution reduces the alloying elements and increases the carbon content in the clad layer, which reduces corrosion resistance properties and causes other metallurgical problems. It also affects the ferrite content in claddings. The amount of ferrite present in duplex stainless steel clad metals influences mechanical and corrosion properties. Both strength and stress corrosion cracking resistance may be reduced when the FN is less than 30, and there is a loss of both ductility and toughness of the clad metal when the FN is above 70 in duplex stainless steel weld claddings (Ref. 3). Hence, control of the FN is essential to achieve optimum corrosion resistance and mechanical properties (Ref. 4). This can be effectively done by properly selecting the process parameters after thoroughly understanding the direct and interaction effects of process parameters on dilution.

The economics of stainless steel weld cladding are dependent on achieving the specific chemistry at the highest practical deposition rate in a minimum number of layers (Ref. 5). Heat input also affects the FN. Ferrite Number increases with a decrease in heat input. With increasing cooling rate (low heat input), the solid-state transformation is suppressed, and the residual ferrite content increases.

In stainless steel weld cladding, it is essential to understand how the dilution affects the composition and FN so as to control the corrosion resistance and mechanical properties.

During the last two decades, four constitution diagrams have found the widest application in predicting ferrite content from weld deposit composition. These include the Schaeffler Diagram, DeLong Diagram, WRC-1988 Diagram, and WRC-1992 Diagram. The Schaeffler Diagram, published in 1947, has been exten-

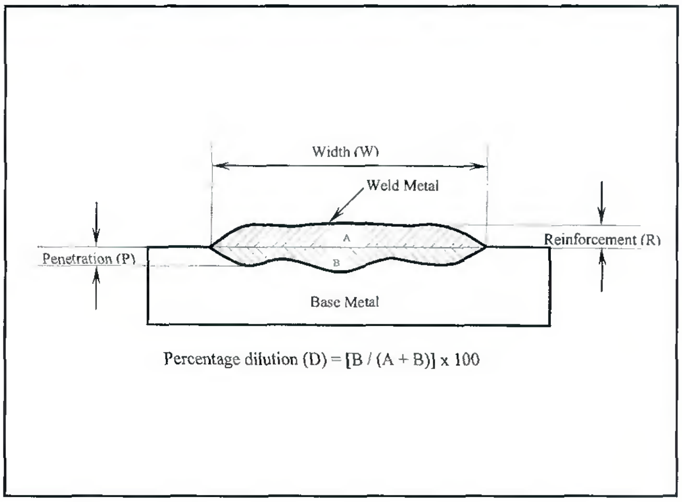


Fig. 1 — Weld bead geometry.

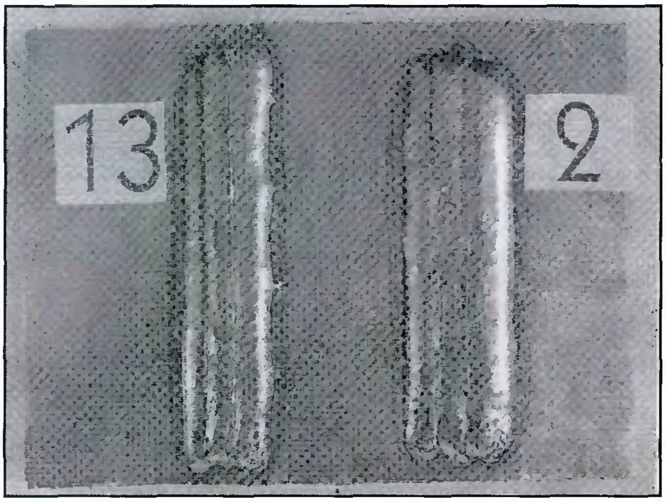


Fig. 2 — Typical cladded plate (Trial Nos. 13 and 2).

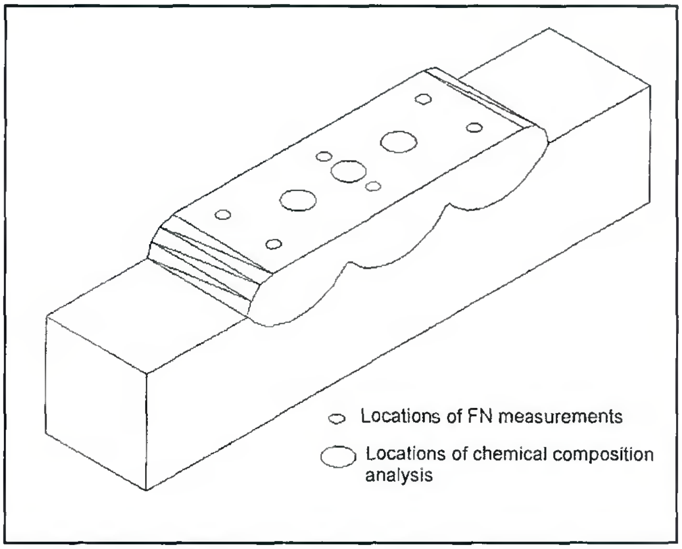


Fig. 3 — Locations of the FN and chemical analysis measurements.

sively used for estimating the ferrite content of stainless steel weld metals and weld microstructure from its composition (Ref. 6). This diagram does not consider the powerful effect of nitrogen in promoting austenite, which tends to seriously overestimate the weld metal ferrite (Ref. 7). Also, the Schaeffler Diagram was used to predict the ferrite in terms of "percent ferrite," which is imprecise. The second widely used prediction diagram, the DeLong Diagram, was published in 1974 and incorporated some improvements (Ref. 8). It has a FN scale and includes a coefficient for nitrogen in the nickel equivalent. This diagram is specifically designed for 300-series stainless steel welds containing small amounts of ferrite. Prediction of the FN in duplex stainless steel welds is not possible using the DeLong Diagram because nickel and chromium equivalents fall outside the range of this diagram (Ref. 4).

The WRC-1988 Diagram overcomes many of the problems associated with the Schaeffler and DeLong Diagrams (Ref. 4). It was developed with data measured by the most recent definition of the FN scale. In recent years, duplex stainless steels have been used more frequently. Some of these steels and their weld metals contain significant amounts of copper, which is not included in nickel equivalent of WRC-1988 Diagram, and hence, its FN prediction accuracy is less.

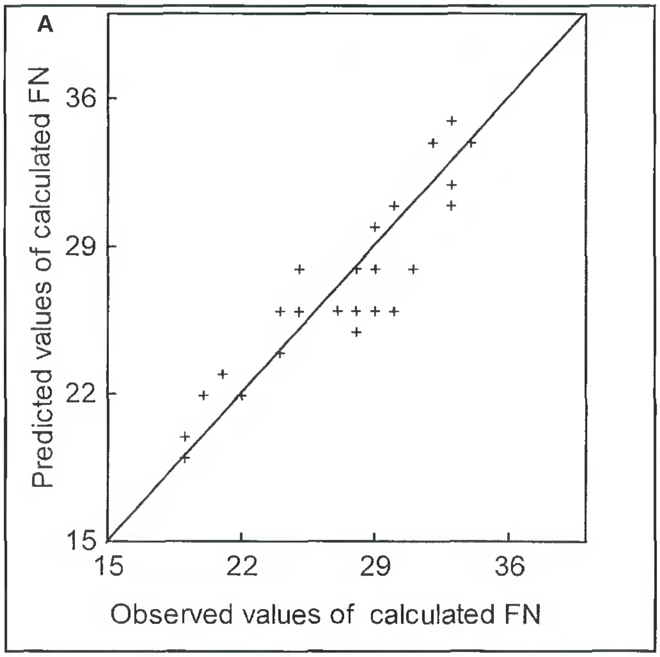
The WRC-1992 Diagram (Ref. 9) is the most recent of the diagrams mentioned above, and it is officially adopted by the ASME *Boiler and Pressure Vessel Code* for predicting the FN when the FN cannot be measured.

Among the four constitution diagrams used for estimating the FN of duplex stainless steel weld/clad metals from its composition, the WRC-1992 Diagram is more suitable due to the reasons below.

- It has a Ferrite Number (FN) scale.
- It includes a coefficient for nitrogen in the nickel equivalent.
- Nickel and chromium equivalents fall inside the range of this diagram.
- Copper term is included in nickel equivalent, hence, FN prediction accuracy is improved.
- Axes of the diagram can be extended to predict dilution effects in dissimilar

Table 1 — Chemical Composition of Filler and Base Metals

Material	Elements, %											FN
	C	Si	Mn	P	S	Al	Cr	Mo	Ni	N_2	Cu	
IS: 2062	0.150	0.160	0.870	0.015	0.016	0.031	—	—	—	—	—	—
E2209T1-4/1	0.023	0.760	1.030	0.024	0.002	—	23.14	3.05	9.22	0.13	0.09	47



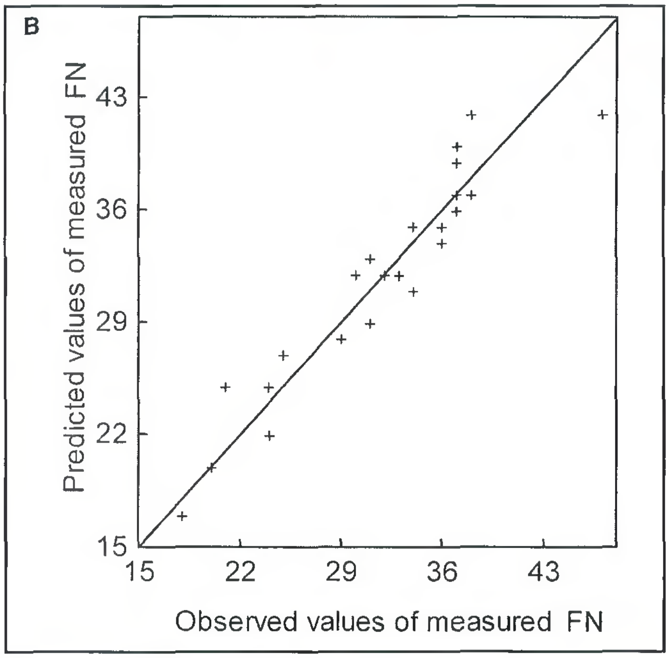


Fig. 4 — A — Scatter diagram of calculated FN model; B — scatter diagram of measured FN model.

Table 2 — Welding Parameters and Their Levels

Parameter	Unit	Notation	Factor levels				
			−2	−1	0	+1	+2
Welding current	A	I	200	225	250	275	300
Welding speed	cm/min	S	20	30	40	50	60
Contact tip-to-workpiece distance	mm	N	22	24	26	28	30
Welding gun (push) angle	degree	T	70	75	80	85	90

welding/cladding applications.

The above diagrams do not accurately reflect the effects of welding process, technique, and cooling rate on the FN. Therefore, a study on the effects of welding parameters on the calculated FN (by WRC-1992 Diagram) and the measured FN of duplex stainless steel clad metals may be useful. However, there is little published information available with regard to the effect of welding parameters on the FN of duplex stainless steel clad metals.

This paper highlights an experimental study carried out to analyze the effects of various FCAW process parameters on the calculated FN (by WRC-1992 Diagram) and the measured FN of duplex stainless steel cladding.

Experimental Procedure

The experiments were conducted using a constant voltage programmable welding machine (UNIMACRO 501C). In this machine, welding current can be set directly instead of changing wire feed rate for changing current level. Test plates of size 200 x 150 x 20 mm were cut from low-carbon structural steel (IS: 2062) plate, and its surfaces were ground to remove oxide scale and dirt before cladding. Flux cored duplex stainless steel welding wire of 1.2 mm diameter was used for depositing the weld beads. The chemical composition of filler and base metals is given in Table 1. Carbon dioxide (CO_2) gas at a constant flow rate of 18 L/min was used for shielding. The experimental setup used consisted of a traveling carriage with a table for supporting the specimens. The welding gun was held stationary in a frame mounted above the worktable, and it was provided with an attachment for both up and down movement and angular movement for setting the required contact tip-to-workpiece distance and welding gun angle, respectively. The experiments were conducted by laying three beads using a stringer bead technique with a constant overlap of 40%. An interpass temperature of 150°C was maintained during the cladding experiments.

Among the many independently controllable primary and secondary process parameters affecting the FN, the primary process parameters *viz* welding current (I) and welding speed (S), and the secondary process parameters *viz* contact tip-to-workpiece distance (N) and welding gun angle (T), were selected as process parameters for this study. The welding current, welding speed, and voltage are the primary parameters contributing to the heat input, influencing FN variations in the claddings. The machine used for this study was constant voltage type, hence it was decided to select the welding current and welding speed as primary process parameters. So far, few studies have been carried out on the effects of contact tip-to-workpiece distance and welding gun angle on the FN, therefore it was decided to select the contact tip-to-workpiece distance and welding gun angle (push angle) as secondary process parameters. The working ranges of all selected parameters were fixed by conducting trial runs. This was carried out by varying one of the factors while keeping the rest of them at constant values (Ref. 10). The working range of each process parameter was decided upon by inspecting the bead for a smooth appearance without any visible defects such as surface porosity, undercut, etc. The

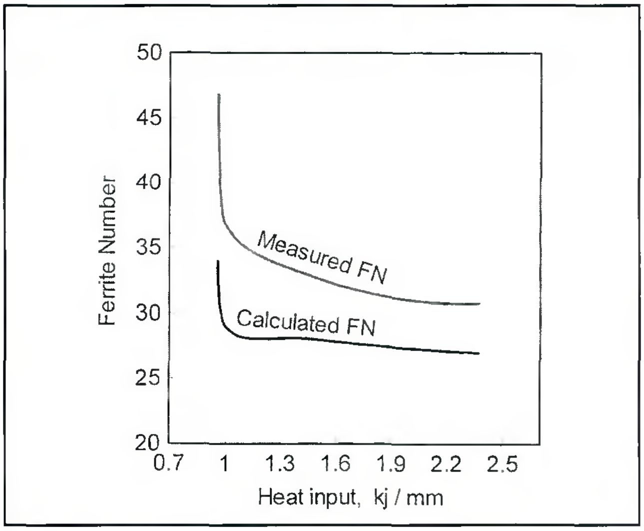


Fig. 5 — Effect of heat input on FN.

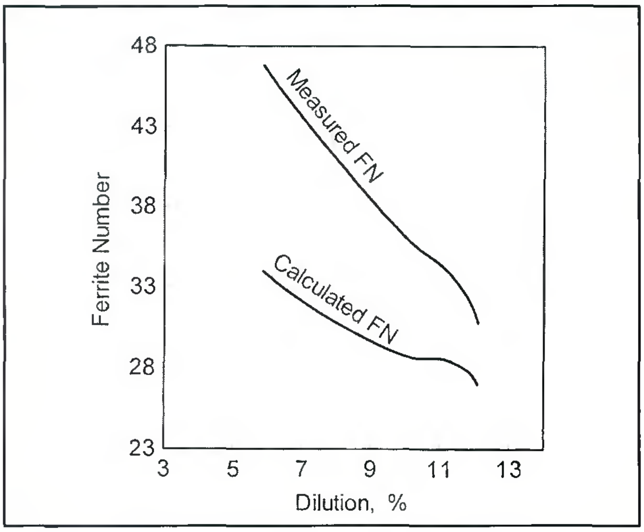


Fig. 6 — Effect of dilution on FN.

Table 3 — Design Matrix with FN and Dilution

Trial No.	Design matrix				Calculated FN (by WRC-1992)	Measured FN	Dilution (%)
	I	S	N	T			
01	–1	–1	–1	–1	33	37	07.86
02	+1	–1	–1	–1	27	31	12.10
03	–1	+1	–1	–1	31	36	11.35
04	+1	+1	–1	–1	22	24	11.98
05	–1	–1	+1	–1	33	38	06.54
06	+1	–1	+1	–1	28	34	08.82
07	–1	+1	+1	–1	29	37	09.69
08	+1	+1	+1	–1	24	25	11.16
09	–1	–1	–1	+1	30	38	08.97
10	+1	–1	–1	+1	29	31	13.75
11	–1	+1	–1	+1	21	21	18.52
12	+1	+1	–1	+1	19	20	20.58
13	–1	–1	+1	+1	32	37	07.46
14	+1	–1	+1	+1	29	34	09.14
15	–1	+1	+1	+1	28	25	18.00
16	+1	+1	+1	+1	20	24	14.80
17	–2	0	0	0	34	47	05.86
18	+2	0	0	0	24	25	16.48
19	0	–2	0	0	33	36	05.31
20	0	+2	0	0	19	18	17.35
21	0	0	–2	0	24	33	11.71
22	0	0	+2	0	33	37	09.01
23	0	0	0	–2	25	34	10.54
24	0	0	0	+2	24	29	13.98
25	0	0	0	0	29	32	10.33
26	0	0	0	0	25	30	13.60
27	0	0	0	0	30	33	10.73
28	0	0	0	0	28	33	11.71
29	0	0	0	0	25	30	13.76
30	0	0	0	0	24	33	10.99
31	0	0	0	0	24	33	10.67

upper limit of a factor was coded as +2, and the lower limit was coded as –2. The coded values for intermediate values were calculated using the equation

$$X_i = 2[2X - (X_{max} + X_{min})] / (X_{max} - X_{min}) \quad (1)$$

Where X_i is the required coded value of a variable X; X is any value of the variable from X_{min} to X_{max}; X_{min} is the lower limit of the variable and X_{max} is the upper limit of the variable. The chosen levels of the selected process parameters with their units and notations are given in Table 2.

The design matrix chosen to conduct the experiments was a central composite rotatable design (Ref. 11), which is shown in Table 3. In this work, 31 deposits were made using a cladding condition corresponding to each treatment combination of parameters as shown in Table 3 at random. At the end of each run, settings for all four parameters were disturbed and reset for the next deposit. This was essential to introduce variability caused by errors in experimental settings (Ref. 12).

A typical cladded plate is shown in Fig. 2. To measure the FN of the clad metals, the cladded plates were cross sectioned at their midpoints to obtain test specimens of 20 mm wide. The top surface of each specimen was ground flat. The FN measurement was carried out using a Ferritescope. Six readings were taken on the top surface along the longitudinal axis of the three beads with the Ferritescope calibrated in accordance with procedures specified in ANSI/AWS A4.2. The average values found are given in Table 3. Using the same specimens, three test burns were taken on the top surface of the claddings to find out chemical composition using an optical emission spectrometer (ARL 3460). The average of three readings was calculated and tabulated in Table 4. Figure 3 shows the locations of the FN and chemical analysis measurements. The chromium and nickel equivalents (Cr_{eq} and Ni_{eq}) of WRC-1992 Diagram were calculated using Equations 2 and 3. These values are also given in Table 4.

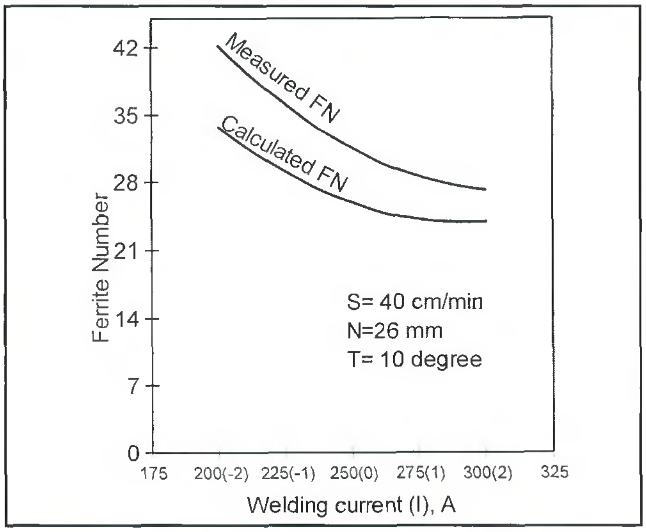


Fig. 7 — Effect of welding current on calculated and measured FN.

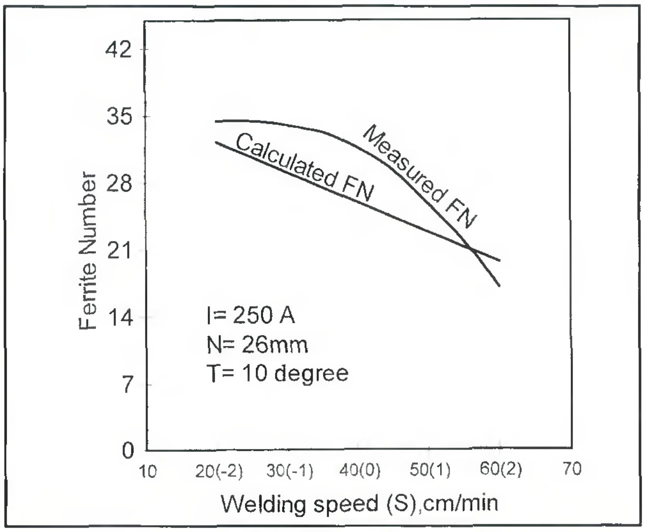


Fig. 8 — Effect of welding speed on calculated and measured FN.

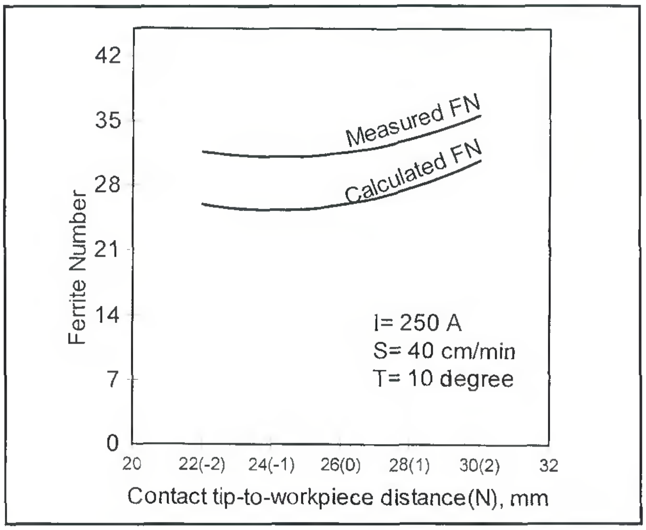


Fig. 9 — Effect of contact tip-to-workpiece distance on calculated and measured FN.

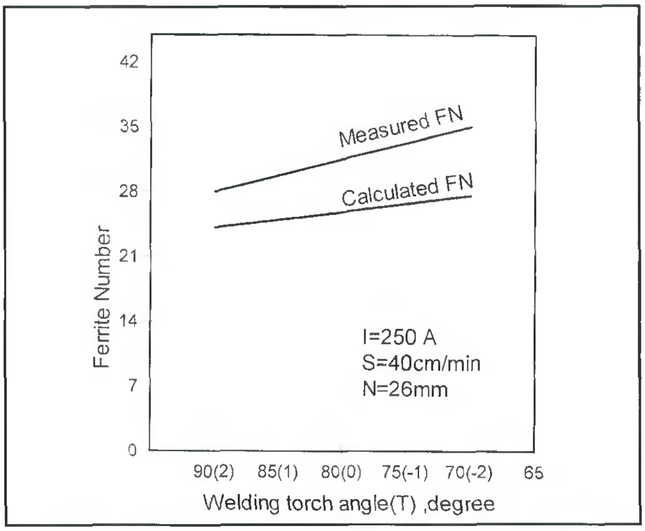


Fig. 10 — Effect of welding gun angle on calculated and measured FN.

$$Cr_{eq} = Cr+Mo+0.7Nb \quad (2)$$

$$Ni_{eq} = Ni+35C+20N+0.25Cu \quad (3)$$

From the calculated chromium and nickel equivalents, FN values were predicted using WRC-1992 Constitution Diagram in Table 3. To study the effect of process parameters on dilution, dilution values for all specimens were measured using the following procedure. Each weld was cross sectioned at mid length, polished and etched with 2% Nital. The bead profiles were traced using a reflective type optical profile projector at a magnification of 10X, and then the deposit area and plate fusion area were measured using a digital planimeter. The measured dilution values are given in Table 3.

Development of Mathematical Models

The response function representing FN can be expressed using the equation

$$Y = f(X_1, X_2, X_3, X_4) \quad (4)$$

where Y = response [FN], X_1 = welding current (I) in A, X_2 = welding speed (S) in cm/min, X_3 = contact tip-to-workpiece distance (N) in mm, and X_4 = welding gun angle (T) in degrees.

The second order response surface model (Ref. 13) for the four selected parameters is given by Equation 5.

$$Y = \beta_o + \sum_{i=1}^{4} \beta_i X_i + \sum_{i=1}^{4} \beta_{ii} X_i^2 + \sum_{i=1}^{4} \beta_{ij} X_i X_j \quad (5)$$

The above second order response surface model could be expressed as follows:

$$Y = \beta_o + \beta_1 I + \beta_2 S + \beta_3 N + \beta_4 T + \beta_{11} I^2 + \beta_{22} S^2 + \beta_{33} N^2 + \beta_{44} T^2 + \beta_{12} IS + \beta_{13} IN + \beta_{14} IT + \beta_{23} SN + \beta_{24} ST + \beta_{34} NT \quad (5A)$$

Where β_o is free term of the regression equation, the coefficients β_1, β_2, β_3, and β_4 are linear terms, the coefficients β_{11}, β_{22},

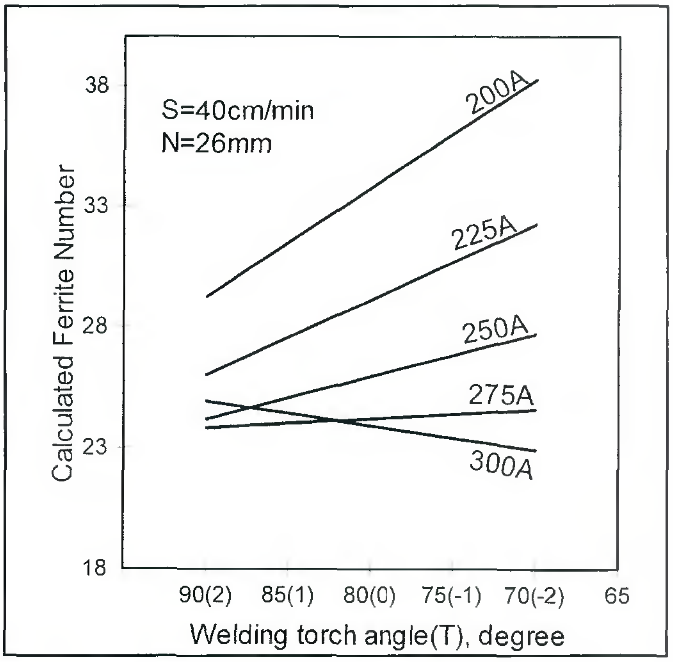


Fig. 11 — Interaction effects of welding current and welding gun angle on calculated FN.

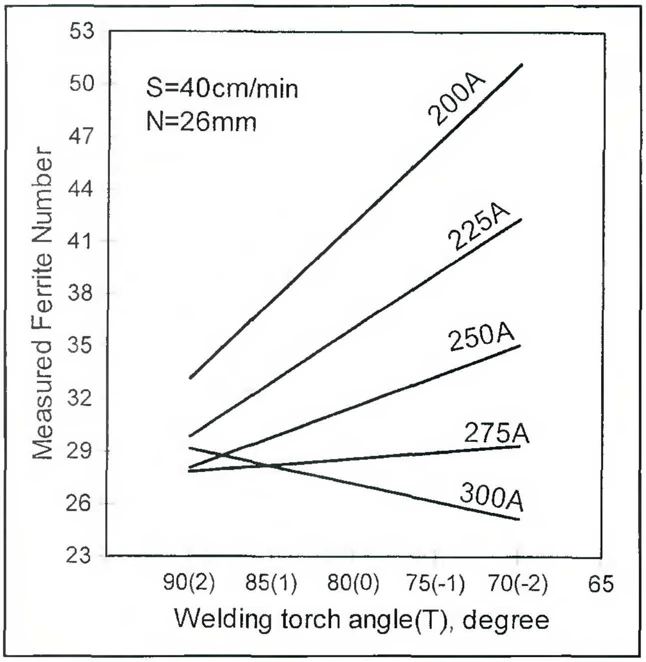


Fig. 12 — Interaction effects of welding current and welding gun angle on measured FN.

Table 4 — Cladding Compositions

Trial	Elements, %									Equivalents	
No.	Cr	Mo	Nb	Ni	C	N	Cu	Mn	Si	Cr_{eq}	Ni_{eq}
1	21.64	3.05	0.018	8.86	0.037	0.132	0.058	0.902	0.598	24.71	12.81
2	21.10	3.08	0.018	8.56	0.041	0.140	0.056	0.903	0.575	24.20	12.80
3	21.24	3.06	0.018	8.76	0.035	0.137	0.055	0.925	0.633	24.31	12.74
4	19.96	2.87	0.017	8.08	0.053	0.119	0.052	0.930	0.598	22.85	12.32
5	21.88	3.20	0.018	9.32	0.036	0.134	0.056	0.892	0.581	25.09	13.08
6	21.22	3.00	0.017	8.38	0.037	0.134	0.053	0.9916	0.570	24.23	12.85
7	21.28	3.13	0.018	8.73	0.038	0.155	0.056	0.959	0.651	24.43	13.17
8	20.50	2.80	0.017	8.00	0.041	0.138	0.054	0.937	0.602	23.32	12.21
9	21.59	3.02	0.018	8.99	0.029	0.142	0.057	0.928	0.590	24.63	12.86
10	20.78	3.03	0.017	8.41	0.041	0.113	0.052	0.839	0.537	23.82	12.12
11	19.16	2.86	0.017	7.74	0.053	0.107	0.049	0.899	0.557	22.03	11.73
12	19.02	2.73	0.017	7.70	0.052	0.110	0.049	0.900	0.555	21.76	11.74
13	21.85	3.10	0.019	9.08	0.029	0.141	0.059	0.919	0.626	24.96	12.73
14	21.03	3.16	0.018	8.67	0.039	0.134	0.056	0.936	0.583	24.20	12.73
15	20.21	2.94	0.017	7.85	0.047	0.104	0.051	0.934	0.571	23.17	11.59
16	19.21	2.71	0.017	8.24	0.047	0.117	0.050	0.858	0.527	21.92	12.23
17	21.94	3.28	0.019	8.34	0.031	0.131	0.060	0.978	0.676	25.23	12.75
18	19.98	2.98	0.017	7.61	0.053	0.132	0.052	0.912	0.568	22.97	12.66
19	21.48	3.27	0.018	8.85	0.030	0.144	0.057	0.866	0.545	24.76	12.78
20	19.27	2.80	0.016	7.46	0.043	0.156	0.048	0.934	0.579	22.07	12.48
21	20.54	2.91	0.017	8.40	0.041	0.116	0.052	0.939	0.636	21.02	12.17
22	21.37	3.15	0.018	8.71	0.036	0.117	0.053	0.901	0.542	24.53	12.32
23	20.31	2.99	0.017	8.31	0.045	0.119	0.053	0.917	0.559	23.31	12.29
24	19.81	2.90	0.017	8.09	0.050	0.112	0.053	0.909	0.560	22.72	12.09
25	20.76	2.98	0.018	8.63	0.033	0.124	0.055	0.914	0.603	23.75	12.28
26	21.04	2.95	0.018	8.08	0.055	0.139	0.050	0.890	0.534	23.70	12.80
27	21.05	3.11	0.018	8.63	0.033	0.124	0.055	0.982	0.642	24.17	12.28
28	20.61	3.12	0.018	8.44	0.041	0.114	0.053	0.916	0.608	23.74	12.17
29	20.43	2.95	0.018	8.63	0.033	0.124	0.055	0.928	0.619	23.40	12.25
30	20.13	2.95	0.018	8.27	0.034	0.123	0.052	0.935	0.610	23.10	11.94
31	20.18	2.95	0.018	8.63	0.033	0.124	0.055	0.942	0.598	23.14	12.28

β_{33}, and β_{44} are quadratic terms, and the coefficients β_{12}, β_{13}, β_{14}, β_{23}, β_{24}, and β_{34} are interaction terms. The coefficients were calculated using QA six sigma software and the same was verified by using *SYSTAT* 10.2 software. After determining the coefficients, the mathematical models (Equations 6 and 7) were developed as follows:

Calculated FN (By WRC-1992 Diagram) $= 26.429 - 2.458I - 3.125S + 1.208N - 0.875T + 0.674I^2 - 0.076S^2 + 0.549N^2$

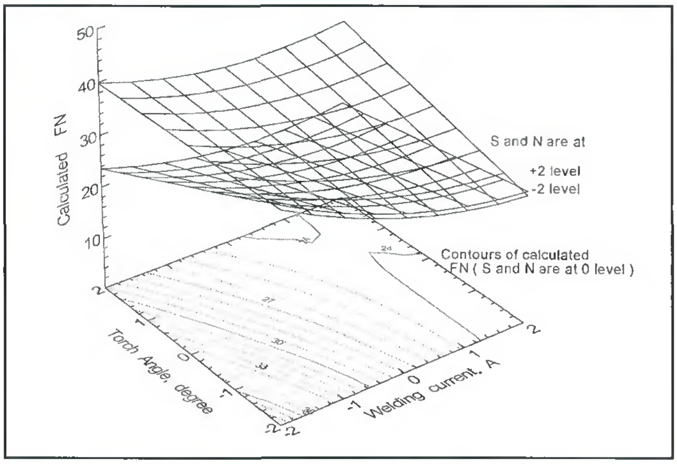


Fig. 13 — Contour plot and response surface plot for interaction effects of welding current and welding gun angle on calculated FN.

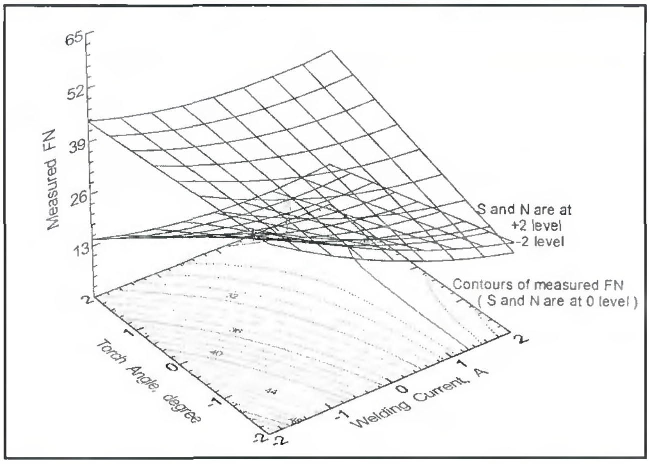


Fig. 14 — Contour plot and response surface plot for interaction effects of welding current and welding gun angle on measured FN.

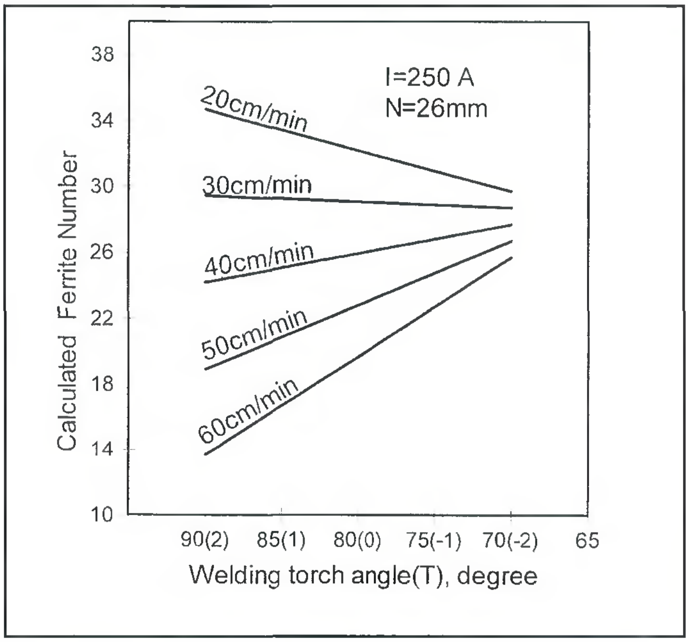


Fig. 15 — Interaction effects of welding speed and welding gun angle on calculated FN.

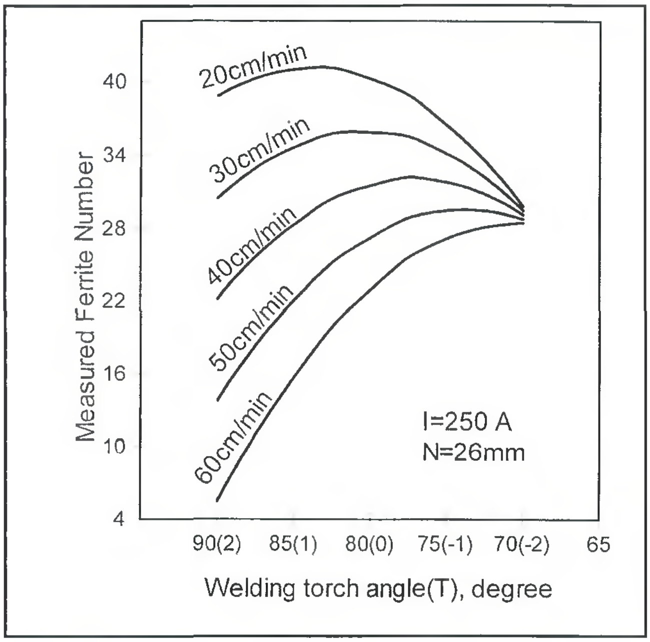


Fig. 16 — Interaction effects of welding speed and welding gun angle on measured FN.

$- 0.451T^2 - 0.562IS - 0.188IN + 0.688IT + 0.312SN - 1.062ST + 0.562NT$ (6)

Measured FN $= 32.000 - 3.750I - 4.333S + 1.000N - 1.750T + 0.729I^2 - 1.521S^2 + 0.479N^2 - 0.396T^2 - 0.375IS - 0.375IN + 1.375IT + 0.250SN - 2.000ST + 0.250NT$ (7)

To develop final mathematical models, the insignificant coefficients were eliminated without affecting the accuracy of the developed models by using t-test. This is done by back elimination technique, using QA six sigma software and the same was verified by using *SYSTAT* 10.2 software.

The final mathematical models were constructed by using these coefficients. The developed final mathematical models (Equations 8 and 9) with process parameters in coded form are given below.

Calculated FN (By WRC-1992 Diagram) $= 25.942 - 2.458I - 3.125S + 1.208N - 0.875T + 0.725I^2 + 0.600N^2 + 0.688IT - 1.062ST$ (8)

Measured FN $= 31.596 - 3.750I - 4.333S + 1.000N - 1.750T + 0.771I^2 - 1.479S^2 + 0.521N^2 + 1.375IT - 2.000ST$ (9)

It was found that the reduced models are better than the full models because the reduced models have higher values of R^2 (adjusted) and lesser values of standard error of estimates than that of full models. The values of R^2 (adjusted) and standard error of estimates for full and reduced models are given in Table 6.

The adequacies of the developed models were tested using the analysis of variance (ANOVA) technique (Ref. 14). As per this technique, if the calculated F-ratio values for the developed models do not exceed the standard tabulated values of F-ratio for a desired level of confidence (95%), and the calculated R-ratio values of the developed models exceed the standard tabulated values of R-ratio for a desired level of confidence (95%), then the models are said to be adequate within the confidence limit. The calculated values of F-ratio and R-ratio are given in Table 7. This shows that the developed models are adequate. The validity of these models were again tested by drawing scatter diagrams as shown in Fig. 4A and B, which show the observed and predicted values of

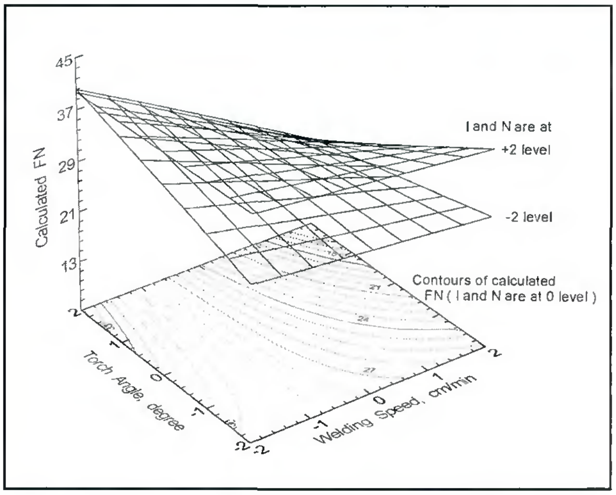


Fig. 17 — Contour plot and response surface plot for interaction effects of welding speed and welding gun angle on calculated FN.

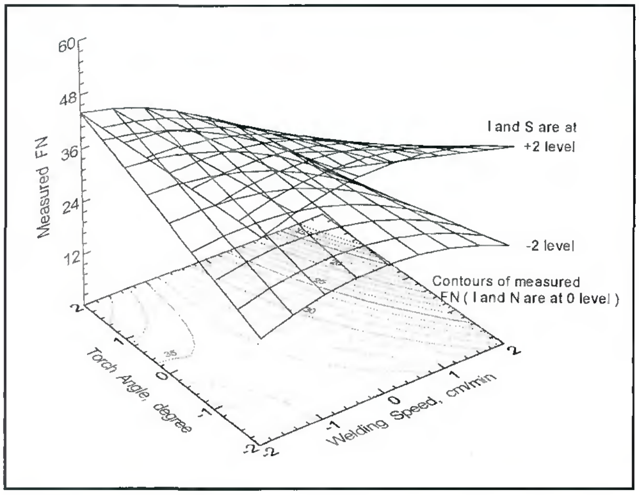


Fig. 18 — Contour plot and response surface plot for interaction effects of welding speed and welding gun angle on measured FN.

Table 5 — Heat Input and Corresponding Values of Dilution and FN

S. No.	Trial No.	I	S	N	T	V (Volts)	Heat Input (kJ/mm)	Dilution (%)	Calculated FN	Measured FN
1	17	200	40	26	80	32	0.96	05.86	34	47
2	07	225	50	28	75	38	1.00	09.69	29	37
3	28	250	40	26	80	40	1.50	11.71	28	33
4	02	275	30	30	75	43	2.37	12.10	27	31

calculated and measured FN.

Conformity tests were conducted using the same experimental setup to conform the results of the experiments. The results of the conformity tests shown in Table 8 depict the accuracy of the developed models, which is above 94%.

Results and Discussions

The above developed models (Equations 8 and 9) can be used to predict the calculated FN (by WRC-1992 Diagram) and the measured FN by substituting the coded values (–2, –1, 0, +1, +2) of the respective process parameters. The effects of heat input and dilution on FN are represented in graphical form in Figs. 5 and 6. The responses calculated using the developed mathematical models for each set of coded welding parameters are also represented in graphical form in Figs. 7–18.

Effects of Heat Input on FN

Heat input is a relative measure of the energy transferred per unit length of weld. It is an important characteristic because it influences the cooling rate, which may affect the mechanical properties and metallurgical structure of the weld and heat-affected zones. Heat input is typically calculated as the ratio of the power (i.e., voltage x current) to the velocity of the heat source (i.e., the arc). In this study, the heat input values were calculated for specimens welded at cladding conditions corresponding to trial numbers 2, 7, 17, and 28, which are given in Table 5. These are represented in graphical form in Fig. 5. It is evident from Fig. 5 that the FN increases with a decrease in heat input. At higher cooling rates (low heat input), the transformation of ferrite to austenite will be suppressed, resulting in higher residual ferrite content in the claddings (Refs. 15 and 16).

Effects of Dilution on FN

The composition and properties of clad metals are strongly influenced by the dilution obtained. Control of dilution is very important in cladding, where low dilution is typically desirable. When the dilution is low, the final deposit composition is close to that of the filler metal, and the corrosion resistance of the cladding is maintained.

The calculated values of dilution for trial numbers 2, 7, 17, and 28 (Table 5) are represented in graphical form in Fig. 6. It is evident from Fig. 6 that FN decreases with increases in dilution. An increase in dilution enhances the C content and reduces the Cr and Ni content of the cladding. The reduction of Cr and Ni and the enhancement of C in the cladding with the increase of dilution occurred primarily because the base metal had no Cr and Ni and higher C with respect to the chemical composition of the duplex stainless steel electrode.

The change in dilution governing chemical composition of the cladding affects chromium and nickel equivalents (Ref. 17) estimated by the WRC-1992 Diagram. The increase in dilution reduces chromium equivalent and moderately decreases the nickel equivalent of the cladding, which results in reduced FN. The lower dilution in claddings resulted in higher FN in the clad metals (Ref. 18).

Direct Effects of Process Parameters on Calculated and Measured FN

Direct Effects of Welding Current on Calculated and Measured FN

From Fig. 7 it is evident that calculated and measured FN decrease with an increase in welding current. This may be due to an increase in heat input and dilution with an increase in welding current. An increase in welding current resulting in enhanced heat input and higher current density causing a larger volume of the base plate to melt and hence increased dilution. This decreases the FN of the claddings.

Direct Effects of Welding Speed on Calculated and Measured FN

From Fig. 8 it is evident that the calculated and measured FN decrease with an increase in welding speed. This may be due to increased dilution of the base metal in the pool with an increase in welding speed, since the weight of deposited metal per unit of length decreases while the cross section of the bead decreases very little (Refs. 19 and 20). The speed, therefore, exerts an influence on the composition of the weld bead analogous to that of current. The effect of dilution is more dominant than the effects of heat input on the FN with increased welding speed, hence the FN decreases with the increase in welding speed.

Direct Effects of Contact Tip-to-Workpiece Distance on Calculated and Measured FN

It is evident from Fig. 9 that calculated and measured FN increase slightly with an increase in contact tip-to-workpiece distance. An increase in contact tip-to-workpiece distance increases the circuit resistance, which reduces the welding current. This decrease of welding current reduces the penetration of the arc, and hence, reduces the dilution (Ref. 21). The decrease in dilution increases the FN of the clad metals. The changes in contact tip-to-workpiece distance do not affect the heat input much.

Direct Effects of Welding Gun Angle on Calculated and Measured FN

From Fig. 10 it is evident that calculated and measured FN increase with the increase in welding gun angle. The reason is when the angle is increased in forehand welding, the arc force pushes the weld metal forward, i.e., toward the cold metal, which reduces penetration and dilution (Ref. 22). This results in increased FN of the clad metals. The changes in welding gun angle do not affect the heat input much.

Interaction Effects of Process Parameters on Calculated and Measured FN

Interaction Effects of Welding Current and Welding Gun Angle on Calculated and Measured FN

From Figs. 11 and 12 it is evident that the FN decreases with an increase in welding gun angle when welding current is from 200 to 275 A, and the rate of increase in FN also decreases with an increase in welding current up to 275 A. But when welding current is 300 A, the FN decreases with a decrease in welding gun angle. Figures 13 and 14 show the response surface and the contour plot of FN for the interaction of welding gun angle and welding current. From the contour surface, it is found that the FN has its lowest value when welding current is at its maximum value and the welding gun angle is at its maximum value. The highest value of FN is obtained when welding current is at its minimum value and the welding gun angle is at its minimum value.

Interaction Effects of Welding Speed and Welding Gun Angle on Calculated and Measured FN

From Figs. 15 and 16 it is evident that FN increases with a decrease in welding gun angle when welding speed is from 40 to 60 cm/min. The rate of increase in FN also decreases with the increase in welding speed up to 40 cm/min, but when welding speed is from 20 to 40cm/min, FN decreases with a decrease in welding gun angle. Figures 17 and 18 show the response surface and the contour plot of FN for interaction of welding gun angle and welding speed. From the contour surface, it is found that the FN has the lowest value, when welding speed is at its maximum value and the welding gun angle is at its maximum value. The FN has highest value when welding speed is at its minimum and the welding gun angle is at its maximum value.

Conclusions

The effects of welding current, welding speed, contact tip-to-workpiece distance, and welding gun angle on the FN in duplex stainless steel deposits were investigated. The following are the conclusions derived from this investigation:

1) A five-level, four-factor full-factorial design matrix based on the central composite rotatable design technique can be used for the development of mathematical models to predict calculated (by WRC-1992

Table 6 — Comparison of R^2 Values and Standard Error of Estimates for Full and Reduced Models

Parameters	R^2 values		Standard error of estimates	
	Full models	Reduced models	Full models	Reduced models
Calculated FN	0.757	0.780	2.160	2.053
Measured FN	0.833	0.863	2.529	2.290

Table 7 — Analysis of Variance for Testing Adequacy of the Models

Parameter	1st order Terms		2nd order Terms		Lack of fit		Error terms		F-ratio	R-ratio	Whether model is adequate
	SS	DF	SS	DF	SS	DF	SS	DF			
FN(C)	433	4	67	10	36.92	10	37.8	6	0.547	9.590	adequate
FN (M)	852	4	194	10	91.00	10	12.0	6	3.406	59.82	adequate

FN(C) – Calculated FN, FN (M) – Measured FN, SS – Sum of squares, DF – Degrees of freedom
F-ratio (10, 6, 0.05) = 4.09, R-ratio (14, 6, 0.05) = 3.96

Table 8 — Results of Conformity Tests

Process parameter in Coded form				Predicted Values of FN (using models)		Actual Values of FN		Error, %	
I	S	N	T	FN(C)	FN (M)	FN(C)	FN (M)	FN (C)	FN (M)
–0.11	–0.22	0.09	–0.3	27	33	28	32	3.70	–3.03
–0.79	–0.35	0.94	1.02	30	36	30	34	0.00	–5.56
–0.66	0.03	0.90	1.03	28	39	28	40	0.00	2.56

% Error = $\frac{\textit{Actual value} - \textit{Predicted value}}{\textit{Predicted value}}$ x 100. FN(C) – Calculated FN, FN (M) – Measured FN

Diagram) and measured FN of duplex stainless steel cladding deposited by FCAW.

2) The Ferrite Number calculated from the cladding compositions using WRC-1992 Diagram agrees reasonably well with the measured FN.

3) The Ferrite Number decreases with the rise in heat input and dilution.

4) The Ferrite Number decreases with a rise in welding current and welding speed and increases with a decrease in welding gun angle and rise in contact tip-to-workpiece distance.

5) A decrease in welding gun angle increases the FN when welding current was low, but the FN decreases slightly with a decrease in welding gun angle when welding current was high.

6) A decrease in welding gun angle increased the FN when welding speed was high, but the FN decreased slightly with a decrease in welding gun angle when welding speed was low.

Acknowledgments

The authors wish to thank M/S Bohler welding, Austria, for providing flux cored duplex stainless steel welding wire for this work. The financial support for this work from All India Council of Technical Education and University Grants Commission are gratefully acknowledged. The authors also wish to thank the management of Coimbatore Institute of Technology and Kumaraguru College of Technology for providing all the necessary facilities to carry out this research work.

References

1. Hasson, D. F., Zanis, C., Aprigliaho, L., and Fraser. 1978. Surfacing of 3.25% nickel steel with Inconel® 625 by the gas metal arc welding-pulsed arc process. *Welding Journal* 57(1): 1-s to 8-s.

2. Karlsson, L., Ryen, L., and Pak, S. 1995. Precipitation of intermetallic phases in 22% duplex stainless weld metals. *Welding Journal* 74(1): 28-s to 40-s.

3. Kotecki, D. J. 1997. Ferrite determination in stainless steel welds. *Welding Journal* 76(1): 24-s to 36-s.

4. Siewert, T. A., McCowan, C. N., and Olson, D. L. 1988. Ferrite Number prediction to 100FN in stainless steel weld metal. *Welding Journal* 67(12): 289-s to 298-s.

5. Welding, brazing, and soldering. 1993. *ASM Handbook*, Volume 6, ASM International, Materials Park, Ohio.

6. Schaeffler, A. L. 1949. Constitution diagram for stainless steel welds metal. *Metal Progress* 56(11): 680 to 680B.

7. Kotecki, D. J. 1978. Welding parameters effects on open-arc stainless steel weld metal ferrite. *Welding Journal* 57(4): 109-s to 117-s.

8. DeLong, W. T. 1974. Ferrite in austenitic stainless steel weld metal. *Welding Journal* 53(7): 273-s to 286-s.

9. Kotecki, D. J., and Siewert, T. A. 1992. WRC-1992 Constitution diagram for stainless steel weld metals: A modification of the WRC-1988 Diagram. *Welding Journal* 57(4): 171-s to 178-s.

10. Murugan, N., and Parmer, S. 1995. Effects of MIG process parameters on the geometry of the bead in the automatic surfacing of stainless steel. *International Journal for the Joining of Materials* 7(2): 71 to 80.

11. Cochran, W. G., and Cox, G. M. 1987. *Experimental Designs*. p. 370, New York, John Wiley & Sons.

12. Harris, P., and Smith, B. L. 1983. Factorial technique for weld quality prediction. *Metal Construction* 15(11): 661 to 666.

13. Montgomery, D. C. 2003. *Design and Analysis of Experiments*. p. 429. John Wiley & Sons (ASIA) Pte. Ltd.

14. Gunaraj, V., and Murugan, N. 1999. Prediction and comparison of the area of the heat-affected zone for the bead on plate and bead on joint in submerged arc welding of pipes. *Journal of Material Processing Technology* 95: 246 to 261.

15. Vitek, J. M., David, S. A., and Hinman, C. R. 2003. Improved ferrite number prediction model that accounts for cooling rate effects — part 1: model development. *Welding Journal* 82(1): 10-s to17-s.

16. Vitek, J. M., David, S. A., and Hinman, C. R. 2003. Improved ferrite number prediction model that accounts for cooling rate effects — part 2: model results. *Welding Journal* 82(2): 43-s to 50-s.

17. Ghosh, P. K., Gupta, P. C., and Goyal, V. K. 1998. Stainless steel cladding of structural steel plate using the pulsed current GMAW process. *Welding Journal* 77(7): 307-s to314-s.

18. Kotecki, D. J. 1996. Dilution control in single wire stainless steel submerged arc cladding. *Welding Journal* 75(2): 35-s to 45-s.

19. Jean Cornu. 1988. *Advanced Welding Systems*, Vol. 2, IFS (Publications) Ltd., U.K.

20. Raveedra, J., and Parmar, R. S. 1987. Mathematical models to predict weld bead geometry for flux cored arc welding. *Metal Construction* 189(1): 31R to 35R.

21. Kim, J. W., and Na S. J. 1995. A study on the effect of contact tube-to-workpiece distance on weld pool shape in gas metal arc welding. *Welding Journal* 74(5): 141-s to152-s.

22. Funk and Rieber. 1985. *Handbook of Welding*, PWS–KENT Publishing Co.

Welding Aluminum Sheet Using a High-Power Diode Laser

A look at fillet welds in lap joints of aluminum Alloy 5182

BY K. HOWARD, S. LAWSON, AND Y. ZHOU

ABSTRACT. The feasibility has been studied of producing fillet welds in lap joints in Alloy 5182 aluminum sheet with a high-power diode laser. Laser energy absorption and bead formation were found to be very sensitive to surface conditions. Sanding and cleaning of workpieces reduced the weld area significantly compared to as-received sheet surface conditions. Cleaning, however, reduced oxide tail defects and consistently produced welds with increased throat. The addition of dark substances to the surface of the sheets was shown to increase absorptivity, although not necessarily increasing the weld throat. Effects of laser beam presentation were studied, and operating ranges were defined. Mechanisms of pool development in fillet welds in lap joints were explored. It was found that production of fillet welds lap joints in aluminum sheet with the diode laser is feasible for industrial use and may be especially useful for welding of hem joints in automotive closure panels.

Introduction

The recent emergence of high-power direct diode lasers into the marketplace has opened interesting and attractive possibilities to sheet metal welding technology. The need to embrace new joining technologies is becoming particularly apparent in the automotive industry, where lightweight materials such as aluminum are becoming more commonly used. The high-power diode laser (HPDL) offers opportunities to meet some of the unique challenges of joining aluminum.

The HPDL offers several advantages over CO_2 and Nd:YAG lasers, which are perhaps the most used in laser welding applications. The wavelength of the HPDL, at 800 nm, corresponds to a higher absorptivity in aluminum than the longer wavelengths of Nd:YAG and CO_2 lasers (Ref. 1). Other attractive features of the HPDL include a much smaller system footprint and increased system efficiency compared to Nd:YAG and CO_2 lasers (Ref. 2). The power density of the diode laser beam limits it to conduction-mode welding applications, which results in a very stable, quiescent weld pool. The absence of violent fluid motion, which is present in keyhole-mode welding (Refs. 3–5), results in a very smooth and attractive weld surface appearance. In addition, the stable conduction mode allows for good control of penetration depth. The small size of the laser head allows for access into many tight areas, and therefore eliminates the need for fiber-optic delivery that is commonly used with Nd:YAG lasers; the ability to weld directly reduces power loss and therefore supports the high system efficiency of the HPDL.

Butt joint welds with consistent fusion have been produced easily and reliably with the HPDL at the University of Waterloo, as well as by other laboratories (Refs. 6–8). The ease of production of butt joint welds makes the HPDL an excellent candidate for production of tailor welded blanks. Our preliminary results show that overlap welding, however, is not particularly suitable for the HPDL, since the conduction mode-nature of the process makes it difficult to break the stubborn aluminum oxide layer between sheets (Ref. 9).

The HPDL appears to be particularly well suited to fillet welds in lap joints; however, there are many complexities to explore concerning the process and setup. Diode laser welding, therefore, may be very appropriate for production of fillet welds in lap joints in hem joints (Fig. 1) of automotive closure panels, where controlled weld penetration and shape as well as excellent surface appearance are imperative. Research on diode laser welding of aluminum alloys at the University of Waterloo has focused on fillet welds in lap joints.

Other researchers (Refs. 6–8) have introduced the advantages of the high-power diode laser and its ability to produce welded joints in sheet metal. However, knowledge of the mechanisms of this new process is, so far, very limited. Due to the inherent characteristics of the HPDL, details of the weld pool dynamics and material-surface interactions may be quite different from those occurring in CO_2 and Nd:YAG laser welding processes.

The objective of this research is to consider the feasibility of incorporation of the HPDL welding process into industry, as well as to develop an understanding of the mechanisms of the diode laser welding process and some unique considerations in the use of the process.

Equipment and Experiment Setup

All welding was performed autogenously using a Nuvonyx ISL-4000L diode laser system mounted on a Panasonic VR-16 welding robot. The Nuvonyx ISL-4000L is a 4-kW AlGaAs diode laser with a wavelength of 800 nm. A rectangular beam of 0.5 x 12 mm at the focal plane is generated by focusing light from four diode arrays of 20 diode bars each. The rectangular beam shape gives the Nuvonyx ISL-4000L the unique ability to perform welding with motion parallel to the long axis of the beam, and operations such as heat treating, cladding, and paint stripping with motion parallel to the short axis of the beam.

Tight, uniform clamping in these experiments was delivered by a fixture as illustrated in the system schematic — Fig. 2. Clamping bars machined from high-strength steel allowed the transfer of strong clamping forces through a thin, streamlined geometry. The design of the fixture and the clamping bars allowed for

KEYWORDS

Fillet Welds in Lap Joints
Aluminum
Weld Throat
Weld Pool
High-Power Diode Laser (HPDL)
Weld Bead Formation

K. HOWARD, S. LAWSON, and Y. ZHOU are with the University of Waterloo, Waterloo, Ont., Canada.

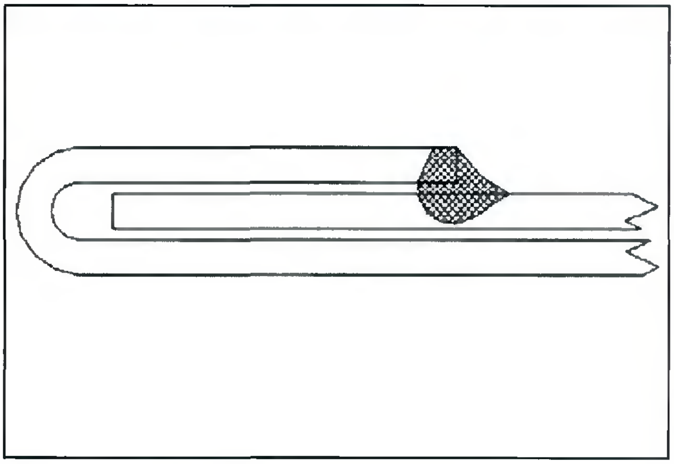


Fig. 1 — Cross section of fillet weld in lap joint configuration.

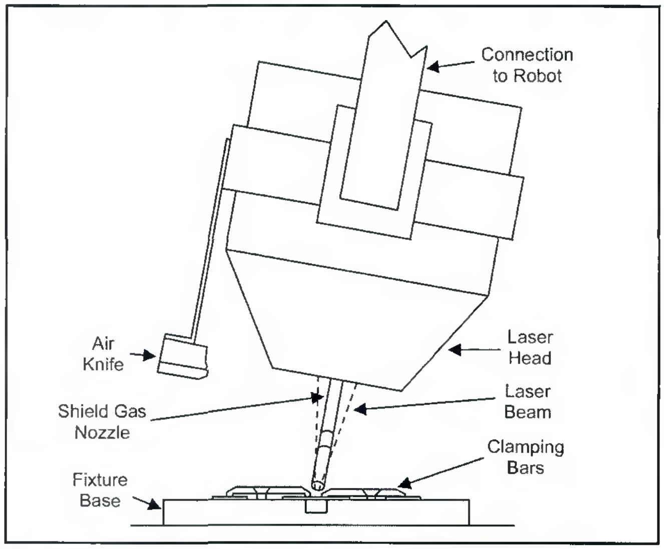


Fig. 2 — Diode laser welding fixture and shielding gas setup.

Table 1 — Density and Composition of Main Alloying Elements for Aluminum Alloys 5182, 6111, and 6013

Alloy	Density ($kg\ m^{-3}$)	Main Alloying Elements (wt-%) Mg	Si	Mn	Cu
5182	2650	4–5	0.2 max	0.2–0.5	0.15 max
6111	2710	0.5–1	0.6–1.1	0.1–1.1	0.5–0.9
6013	2710	0.8–1.2	0.6–1	0.2–0.8	0.6–1.1

full access of the HPDL to the weld joint without interfering with the shielding gas flow or air knife. A 304 stainless steel backing bar was used for all fillet welds in lap joints discussed here, in order to avoid excessive conduction of heat into the backing bar while providing firm clamping support.

Shielding was provided by feeding 99.999% pure argon through a specially designed nozzle. The shield gas nozzle was attached to the bracket surrounding the laser head and angled to provide a laminar flow of gas from the front of the weld pool.

All welding was performed with the laser beam axis tilted laterally at 5 deg or more from the normal to the sheet surface, as shown in Fig. 2, as a precaution to prevent energy from being reflected back into the laser cavity and possibly causing damage.

The majority of fillet welds in lap joints in this study were produced on 1.5-mm- (0.059-in.-) thick 5182-O aluminum alloy. Additional welds were made joining 1.5-mm-thick aluminum Alloy 5182 to 1.5-mm-thick aluminum Alloy 6013 or 1-mm- (0.039-in.-) thick aluminum Alloy 6111. Table 1 lists the chemical compositions and densities of the alloys used in this study (Refs. 10, 11). A constant travel speed of 1 m/min (39.4 in./min) was maintained throughout all of the welding experiments. While much higher welding speeds are possible for joining of thinner sheet material and for butt joint welding, this speed was selected to allow for good consistency of results while varying other welding parameters.

In these experiments, clamping, surface condition, and beam presentation were varied in a systematic manner. The effects of each of these variables were studied mainly by examining the cross sections of welds produced with each set of parameters. Weld cross-sectional area was used as an indicator of absorptivity. Beside weld area and shape, the weld throat measurement was used as an important performance criteria for comparing welding procedures. Weld throat is a direct predictor of weld strength and has been used as a quality indicator for hem welds in industry (Ref. 12).

In a fillet weld of leg length equal to the sheet thickness h, the theoretical throat equals 0.707 h. It has been experimentally verified (Ref. 13) that when material properties of weld metal and base metal are similar, transverse fillet welds with actual throats smaller than this will generally fail in shear through the weld throat, while larger actual throat will tend to shift the location of overload failure to the base metal. Therefore, in this work, the acceptance criteria for welding procedures (sets of specific welding parameters) included the ability to consistently generate a minimum weld throat of 0.707 h. Weld throat was measured using image analysis software as the shortest distance between the edge of the sheet interface (or any existing oxide tail) and the weld bead surface.

Challenges in Diode Laser Welding of Aluminum

A main challenge in applying most joining technologies to aluminum is its tendency to form a thick, coherent oxide layer. This oxide layer has a melting temperature much higher than that of aluminum itself, and it has significant mechanical strength. The oxide layer can therefore remain as a solid film, even when metal surrounding it is molten, resulting in severe incomplete fusion defects. In addition, a thick oxide layer can act as an insulator to heat flow, which is a significant issue in a conduction mode welding process. Figure 3 shows an example of a weld with lack of heat transfer from top sheet to bottom sheet and severe oxide tail defects.

It has been found that employing aggressive clamping along the length of the joint can reduce the problems with oxide tails and heat conduction (Refs. 9, 14). The issues associated with oxide layers are not as significant with keyhole mode laser welding processes, since the drilling action of the vaporized keyhole in the material

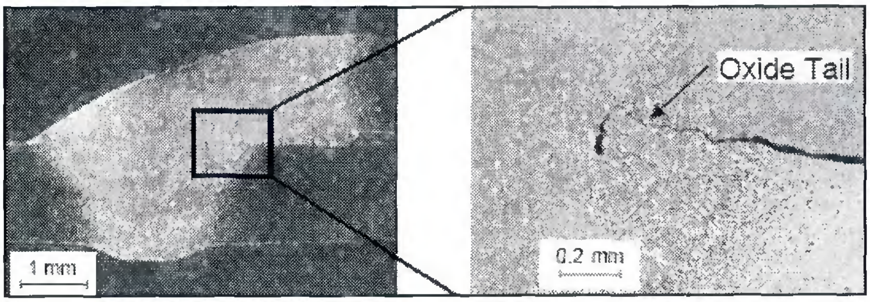


Fig. 3 — Fillet weld in lap joint with insufficient clamping showing oxide tail defect. Travel speed 1 m/min.

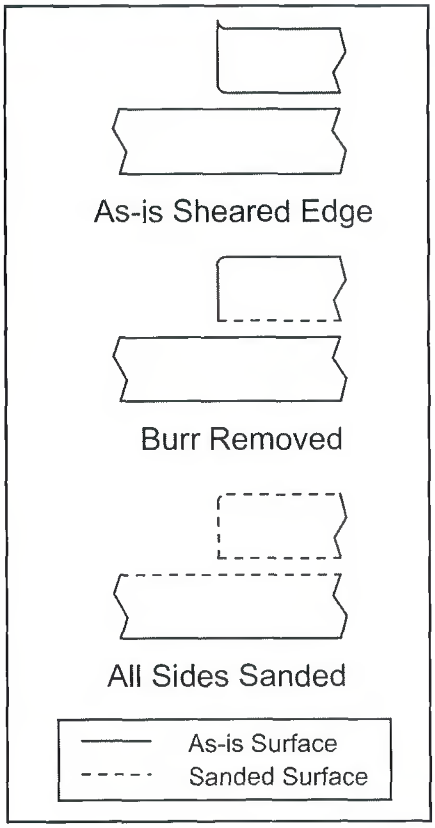


Fig. 4 — Sanding and cleaning conditions.

will tend to break up and disperse oxide layers allowing good fusion. The same calm nature of the conduction weld pool that allows for a smooth, attractive surface appearance and controlled weld shape also reduces the ability of the weld pool to disrupt an oxide barrier.

The absorptivity of aluminum at 800 nm is quoted at 13% for a pure, polished aluminum surface in a vacuum with no oxide layer present (Ref. 1). In practice, the actual absorptivity will be influenced by the presence of an oxide layer, other surface contaminants, and surface roughness (Ref. 3).

The effects of surface condition on laser welding processes have been investigated by various researchers (Refs. 3, 15, 16). Some have stated (Ref. 16) that surface conditions have little effect on laser welding and cutting operations since the surface of the workpiece melts or is vaporized soon after beam irradiation starts. Yet others (Refs. 3, 15) have stated that increasing surface roughness by sanding, for example, will increase the absorptivity of the material. Surface conditions can be expected, however, to play a larger role in conduction mode than in keyhole mode welding, since the formation of a keyhole increases the energy absorbed by multiple reflections and plasma interactions inside of the keyhole (Refs. 3, 4). The complexities of the laser beam/surface interaction with diode laser welding have yet to be studied in detail.

Results

Effect of Surface Condition

Effect of Cleaning

Six different surface preparation conditions were considered in order to gain an understanding of surface effects on weld properties. Samples were prepared either with the as-received surface condition and as-sheared edge, with the burred face of the upper sheet sanded, or with all sides involved in the joint of both sheets sanded, as shown in Fig. 4. The three sanding conditions shown were then repeated, followed by wiping all surfaces with acetone. In this investigation, "sanding" denotes dry manual grinding with a 240-grit silicon carbide metallographic abrasive paper until no traces of original surface color or texture remained. Surface examination after sanding confirmed that no significant quantities of debris or abrasive were embedded. All welds were performed at 4 kW power and speed of 1 m/min.

It can be seen in Figs. 5 and 6 that as the amount of cleaning increased, the weld area decreased. This implies that the surface conditions had a large effect on the overall absorptivity of the system. In addition, as expected, the oxide tail length decreased as amount of cleaning increased. The combined trends of decreasing weld area and decreasing oxide tail led to a slight overall increase in weld throat as cleaning was increased. Although increased cleaning appeared to decrease the thermal efficiency of the welding process, the benefit of reduction in oxide tail outweighed the disadvantage of decreased absorptivity.

It was clear that in the case of diode laser welding on aluminum, the surface condition did have a significant effect on the absorptivity of the material and that sanding and cleaning the surface did not increase the absorptivity of the aluminum sheet surface, but rather decreased it. This suggested that an oxide layer and/or other surface contaminants present on the as-received sheet surface were acting to increase the absorptivity. When the surface was sanded, the surface oxide was disrupted, and it was expected that it was removed to a large extent.

Although new oxide always forms instantaneously on aluminum in air, the newly formed oxide layer was expected to be much thinner. Although the surface roughness was increased by sanding, the absorptivity decreased as a result of reducing the oxide layer and surface contaminants. It appeared that for the diode laser welding process on aluminum, the effect of reducing the surface contaminants was much more significant than the effect of increasing surface roughness.

As mentioned previously, Xie and Kar (Ref. 16) have suggested that surface conditions of the solid material do not largely affect the laser welding process, since most of the beam interaction is with the molten pool. However, a later work by the same authors (Ref. 17) found that the presence of surface oxidation had a measurable influence on the absorption of laser energy by steel sheets. Ono et al. (Ref. 18) and Fujii et al. (Ref. 19) have also found that existing oxide layers on steel and aluminum influenced both energy absorption and fluid flow during welding.

Evidence of a continuous and coherent oxide layer remaining on the surface of the weld pools has been observed in the present study. For example, Fig. 7 shows the surface of a bead-on-plate weld. A shiny track in the center of the weld surface can be seen where the oxide layer has apparently been disrupted near the laser impingement, possibly due to high temperature at laser impingement, fluid motion, or volumetric expansion of the liquid. However, the remainder of the weld pool has remained covered in a solid oxide layer that has rippled as the weld progressed, but was not broken.

Figure 8 shows the top surface of a fillet weld in a lap joint made with an as-received surface condition. The marks on the surface of the oxide layer showing the rolling direction can clearly be seen on the surface of the weld bead. In addition,

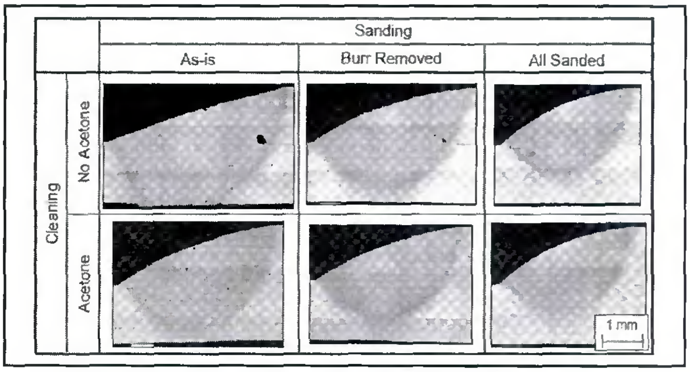


Fig. 5 — Effect of cleaning on weld cross sections. Fillet welds in lap joints on 1.5-mm-thick aluminum Alloy 5182 at 1 m/min.

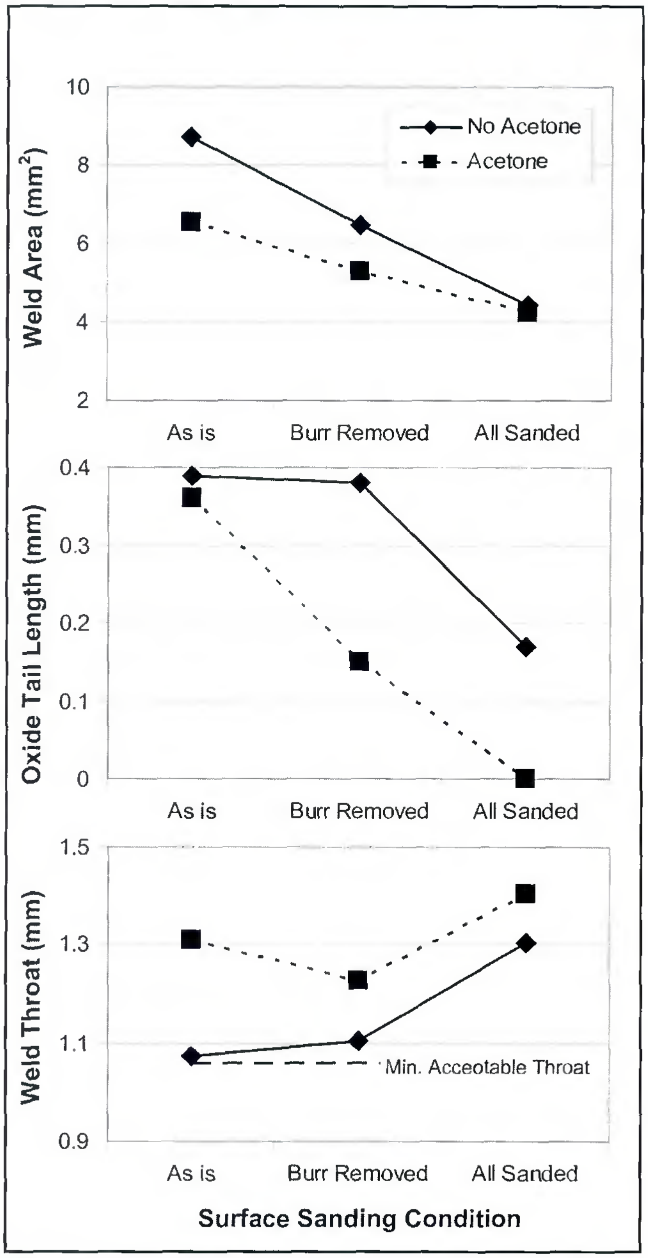


Fig. 6 — Effect of cleaning on weld cross-sectional area, oxide tail length, and weld throat. Fillet welds in lap joints on 1.5-mm-thick aluminum Alloy 5182 at 1 m/min.

some scratches that existed on the surface of the bottom sheet prior to welding have remained intact and terminate at the weld center. The oxide layer of the bottom sheet has been pushed up by the forming weld pool, while the oxide layer on the top sheet has been pulled down, with a shiny track in the center of the weld bead.

Effect of Surface Coatings

The apparent increase in reflectivity with surface cleaning suggested that surface absorptivity could be increased by coating surfaces with substances that are relatively inactive chemically, but dark at visible wavelengths. In Fig. 9, surfaces were sanded and cleaned with acetone (A), and then coated by rubbing with a standard HB clay-graphite pencil (B) or a permanent black felt-tip marker (C). It was seen that the area of the weld with pencil was significantly larger than the weld made on cleaned sheets. Although the weld made with marker on the surface showed porosity caused by decomposition of the surface coating, the weld area was even larger than with pencil.

Measurements (Fig. 10) of these cross sections, however, revealed that although welds produced with coatings had a much larger cross-sectional area, the geometries of the welds were such that the weld throat was not significantly increased compared to welds made with cleaned surfaces. The increased melting did not contribute to increasing the strength of the welds; however, this increased absorptivity may be useful in working to increase welding speed. The coating of sheet surfaces with materials to increase the surface absorptivity is a promising possibility for use of the HPDL in industry.

Effects of Beam Presentation

Effect of Lateral Position and Incident Angle

For any fusion welding process producing fillet welds in lap joints, the positioning of the energy source in relation to the edge of the upper sheet has a major effect on weld bead shape and quality. For this reason, the weld shape and size with respect to beam presentation was examined. In this test series, all coupons for welding had the same surface preparation. For consistency, all sheets were sanded on all sides and cleaned with acetone before welding. Preliminary work had shown that small changes in working distance did not have a large effect on the bead cross section (Ref. 9). Therefore, in order to simplify the experimental matrix, the z position of the focal point was held constant at the center of the top sheet edge. The incident angle of the beam axis and its position in the x direction were varied, as shown in Fig. 11. Cross sections of the welds, as shown in Fig. 12, were examined and the weld throats were measured (Fig. 13).

When a suitable incident angle was used, a tolerance window of approximately 1 mm width was found for acceptable welds in terms of lateral positioning of the beam with respect to the edge of the top sheet. A noticeable trend in shape of the welds could be seen. As the beam moved from impinging mainly on the top sheet toward primarily heating the bottom sheet, the surface of the welds changed from being convex to concave, respectively. Incomplete fusion resulted when the beam was positioned too far in either direction from the edge of the top sheet. There were no strong trends in weld area or oxide tail length with change in beam presentation.

Effect of Beam Twist Angle

The effect of a beam twist angle, as illustrated in Fig. 14, was investigated. Beam twist angles of ±5 deg about the beam's z axis were used, while varying lateral position of the focal point. An incident angle of 20 deg was maintained for all tests, since this produced desirable results in previous experiments. The cross sections of those experiments that produced fused welds are shown in Fig. 15. Introducing twist angle de-

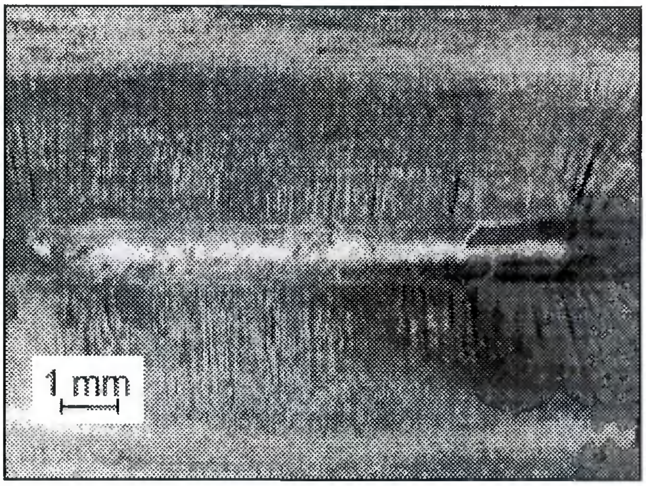


Fig. 7 — Surface of a bead-on-plate weld showing disruption of the oxide layer on the weld center.

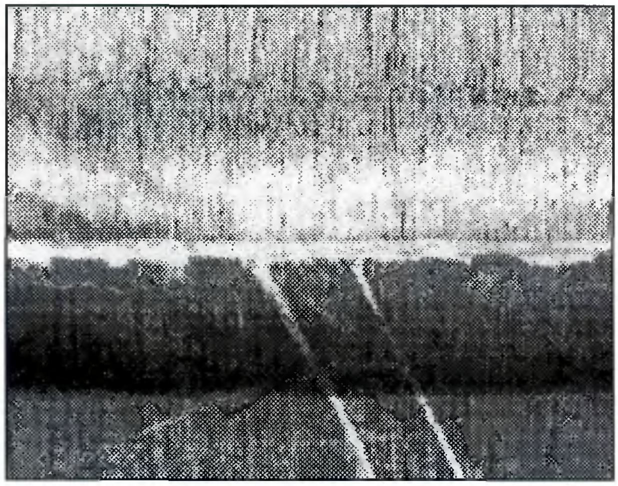


Fig. 8 — Surface of a fillet weld in lap joint with as-received surface condition, showing preservation of the native oxide layer on the bead surface, complete with original surface scratches and rolling texture.

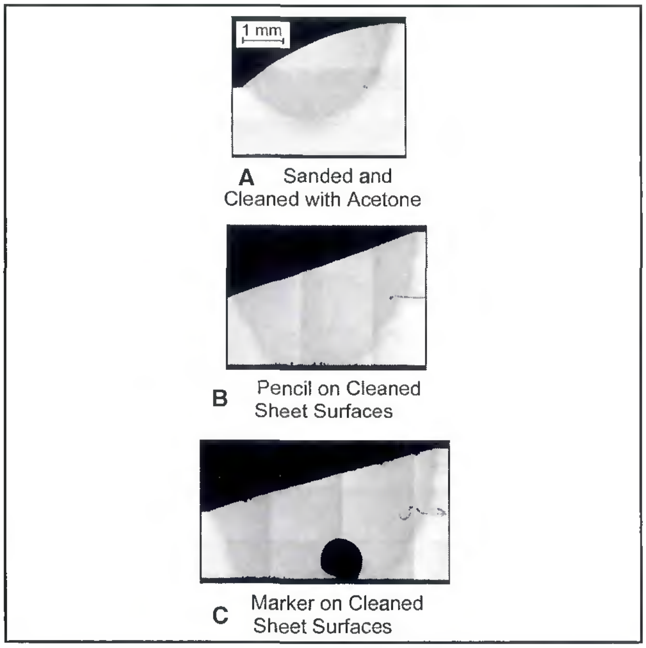


Fig. 9 — Effect of surface coatings on fillet welds in lap joints, 1.5-mm-thick aluminum Alloy 5182 at 1 m/min.

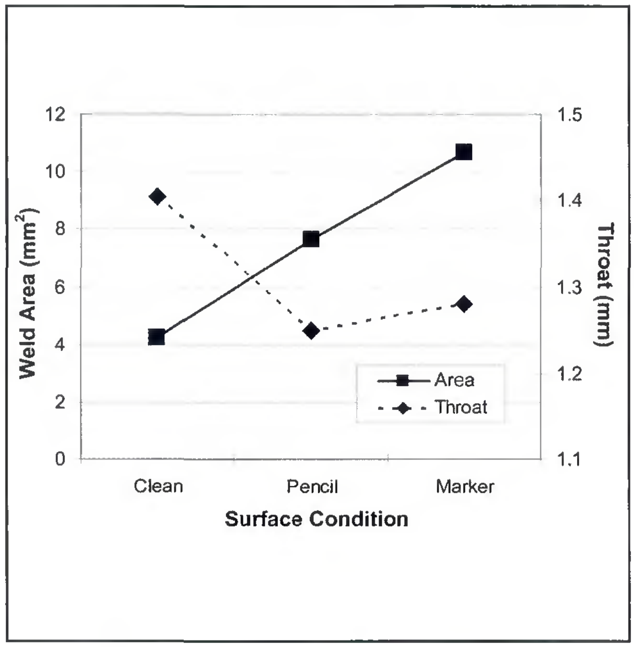


Fig. 10 — Effect of surface coatings on weld cross-sectional area and weld throat, 1.5-mm-thick aluminum Alloy 5182 at 1 m/min.

creased the process tolerance box, enhanced the shape change from convex to concave with change in lateral position, and reduced consistency and repeatability. In fact, of the welds shown in the array of Fig. 15, only the specimen made at –5 deg twist angle with centered lateral position achieved an acceptable throat thickness.

By twisting the rectangular beam of the HPDL, the distribution of the heat source was essentially widened. Eagar and Tsai (Ref. 20) have found that as the distribution of any welding heat source becomes more diffuse, the melting efficiency decreases, reducing the weld size for the same heat input. Alignment of the beam axis to the welded joint is, therefore, very important in HPDL welding.

Discussion

Absorptivity, Joint Geometry, and Weld Throat

Absorptivity is an important factor in laser welding processes, as greater absorptivity will have a strong influence on the process efficiency and weld cross-sectional area attainable at a given travel speed. Another important consideration, however, is the geometry of the fusion area. Since the weld throat is the smallest area through which a load is transferred through the joint, it is a more important geometrical measurement than weld area.

As absorptivity was increased in the case of fillet welds in lap joints (Fig. 9), the weld area subsequently increased significantly; however, the weld throat did not change considerably. In fact, increase of weld area without a corresponding increase in weld throat was expected to reduce the strength of the joint, since the increase of specific energy input that is implied by greater melted area could contribute to additional local strength loss, the amount dependent on the alloy and temper. Note that detrimental effects of

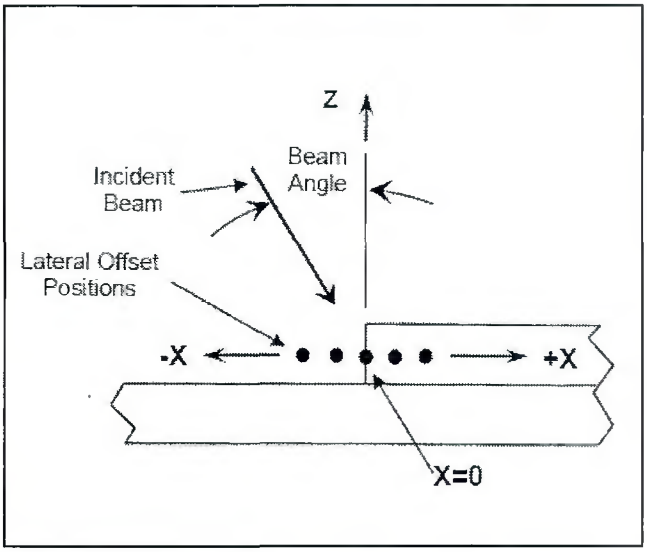


Fig. 11 — Sketch of beam presentation positions for lap-fillet welds with diode laser.

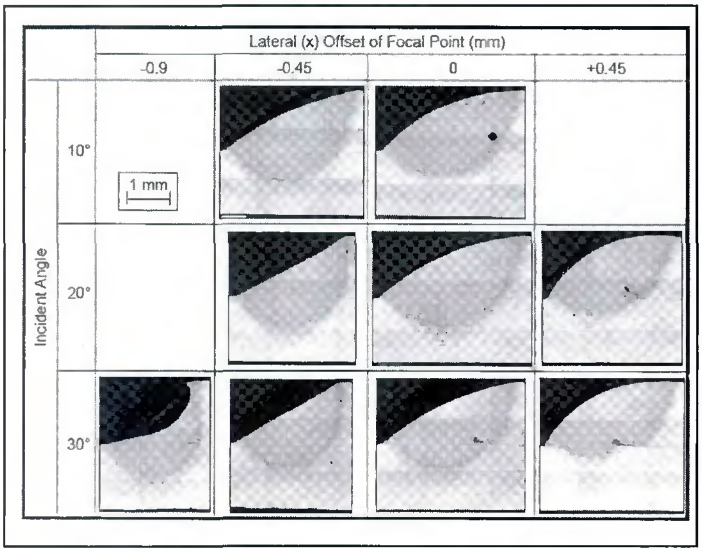


Fig. 12 — Effect of beam presentation on weld cross-sectional area, 1.5-mm-thick aluminum Alloy 5182 at 1 m/min.

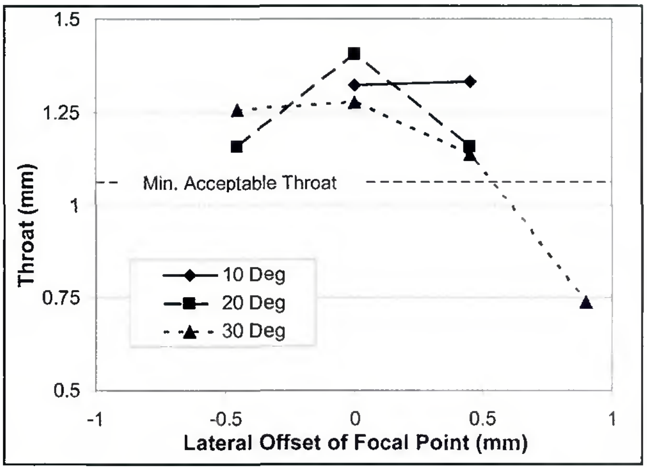


Fig. 13 — Effect of beam presentation on weld throat, 1.5-mm-thick aluminum Alloy 5182 at 1 m/min.

welding on the base metal would be amplified in heat treatable aluminum alloys. Therefore, increasing the absorptivity of the material by the addition of substances to the surface will not necessarily improve joint quality unless the energy can be directed in a manner that results in increased weld throat or can be used to increase welding speed to produce the same weld throat.

Further research on absorptivity and heat flow of diode laser welds in aluminum is underway at the University of Waterloo.

Mechanism of Weld Pool Development

An understanding of the mechanisms of weld bead formation is desirable to aid in the development of process improvements and future industrial procedure development.

In order to gain an understanding of the mechanism of weld bead formation, craters formed at weld termination were successively sectioned at increments of 3 mm from the first sign of melting at the leading edge of the weld pool. Since the leading end of the weld represents the front of the weld pool as it travels along the sheet edge, cross sections through the weld craters should give insight into the stages of weld pool development. Welds were made under different cleaning conditions, while maintaining an incident angle of 20 deg and focal point at the center of the edge of the top sheet.

Figure 16 shows a series of cross sections through the end of a weld with no cleaning, and cross sections of a weld made after sanding all surfaces and cleaning with acetone.

Investigation of the cross sections through weld craters showed that the sequence of weld pool development was quite different with varying cleaning conditions. This investigation has led to the following discussion on the mechanisms of weld pool development.

Cleaning of All Surfaces Prior to Welding

In the weld produced after sanding all surfaces and cleaning with acetone, melting was first seen on the top sheet edge, with no evidence of melting on the bottom sheet at the leading edge of the weld pool. The confinement of melting to the top sheet may have been a result of increased local absorptivity due to roughness remaining on the sheared edge. Once melting of both top and bottom sheets had begun, fusion into a combined weld pool was almost immediate. At 6 mm from the front of the weld pool, good fusion was already seen, with only small traces of oxide layer remaining. The thin oxide layer newly formed within a few minutes of sanding the surface appeared to be thin enough and weak enough to be easily broken and washed away by any fluid motion.

The section at 6 mm from the front of the weld bead exhibited pushing of the remaining oxide layer upward, as also seen in the weld without cleaning, thus suggesting that the fluid motion pattern likely behaved in a similar manner for both cleaning conditions. This fluid motion is further discussed in reference to the weld produced without prior cleaning.

After initial fusion, the surface gradually assumed the smooth convex shape; however, the depth and shape of penetration did not change significantly beyond 6 mm from the leading edge of the weld pool.

The proposed mechanism of bead formation with cleaned sheet surfaces is as follows:

1. Melting of the top sheet edge begins early in the beam interaction with little melting of the bottom sheet.

2. Once melting of top and bottom sheets is established, the thin oxide layer is easily broken due to fluid motion and fusion is almost immediately achieved. Any

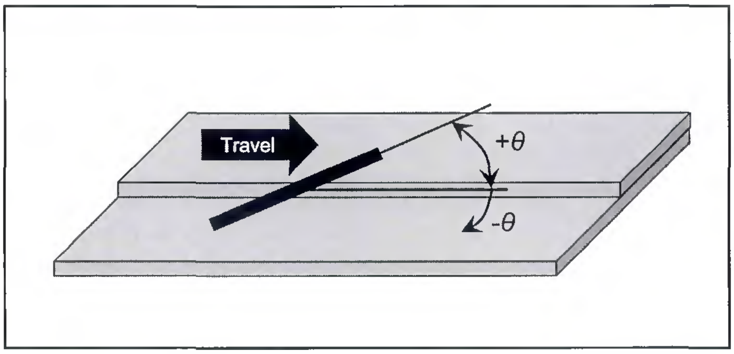


Fig. 14 — Sketch of beam twist angle in welding fillet welds in lap joints with diode laser.

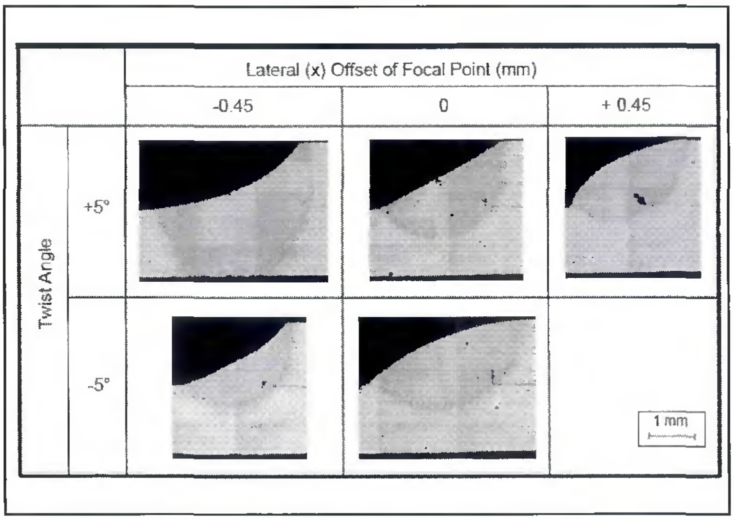


Fig. 15 — Effect of beam twist angle and lateral beam position on weld cross sections, 1.5-mm-thick aluminum Alloy 5182 at 1 m/min.

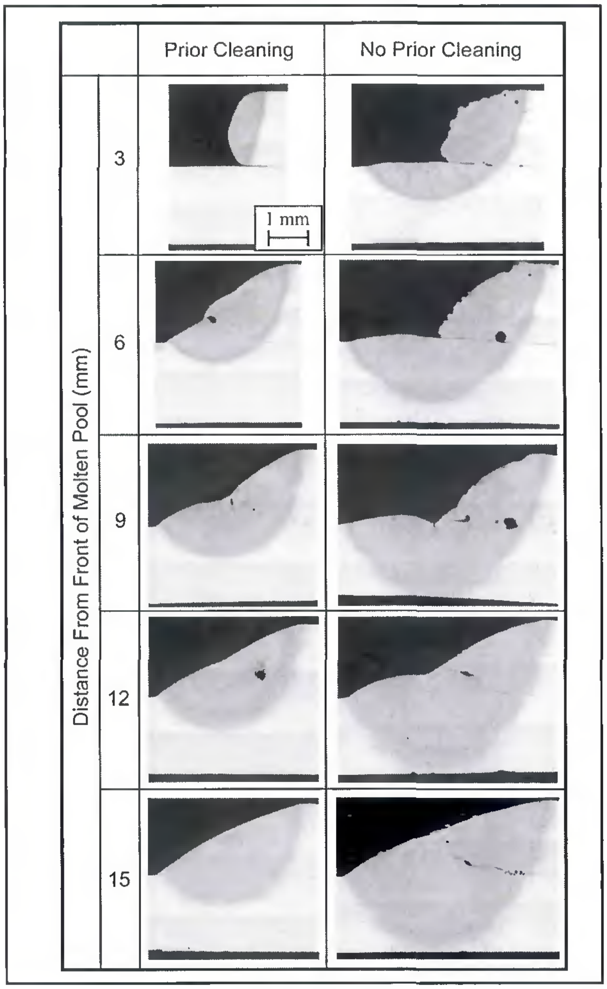


Fig. 16 — Cross sections through fillet weld in lap joint craters showing weld pool development, 1.5-mm-thick aluminum Alloy 5182 at 1 m/min.

remaining oxide layer is washed away.

3. The weld bead develops into a smooth convex shape.

No Cleaning Prior to Welding

When no cleaning of the aluminum sheets had been performed prior to welding, the sheet surfaces had a relatively thick oxide layer and significant presence of surface contaminants such as dirt and grease. In addition, the edge of the top sheet of the lap fillet weld was in the sheared condition with no further processing. Early in the beam interaction, melting of both the top and bottom sheets was observed; in fact, offset between beginning of melting on the top sheet and beginning of melting of the bottom sheet was about 3 mm in the uncleaned condition compared to 6 mm for welds made after sanding and cleaning with acetone. However, no fusion was seen for the first 6 mm of the weld bead in the uncleaned condition, as the thick oxide layer acted as a barrier to fusion.

At a distance of 9 mm into the weld bead, the oxide layer was broken, and fusion was achieved. Even after fusion, however, the thick oxide layer persistently remained in the weld bead, reducing the weld throat. The fusion observed at 9 mm from the front of the weld bead appeared to be due to gas bubbles formed at the oxide tail attempting to float out of the weld pool and disrupting the oxide tail as a result of the motion.

Prior to fusion, the weld pool of the bottom sheet was seen to be pushed upward. After fusion in this weld, the oxide tail was seen to be pushed upward as well. Thermal expansion of weld metal was likely a factor in the weld bead development. The extent to which other factors and 3-D fluid motion within the weld pool have influenced the bead development have not been quantified, but are recognized as potential factors.

The proposed mechanism for weld bead formation with no cleaning prior to welding is as follows:

1. Melting of the bottom sheet begins shortly after melting of the top sheet. However, the thick oxide layer envelop the molten metal of both sheet surfaces and acts as a barrier to fusion.

2. Some event must occur in order to disrupt the oxide layer to allow fusion. Often, gas evolves at the faying surfaces of the oxide layers as a result of heating of surface contaminants. Gas bubbles float toward the surface of the weld pool rupturing the oxide layer and allowing mixing of molten metal from the top and bottom sheets.

3. Without some disruption of the oxide layer, some of the oxide is removed near the surface of the weld pool likely due to high temperature near the point of laser impingement, while the majority of the oxide tail remains intact limiting the extent of fusion and the size of the weld throat.

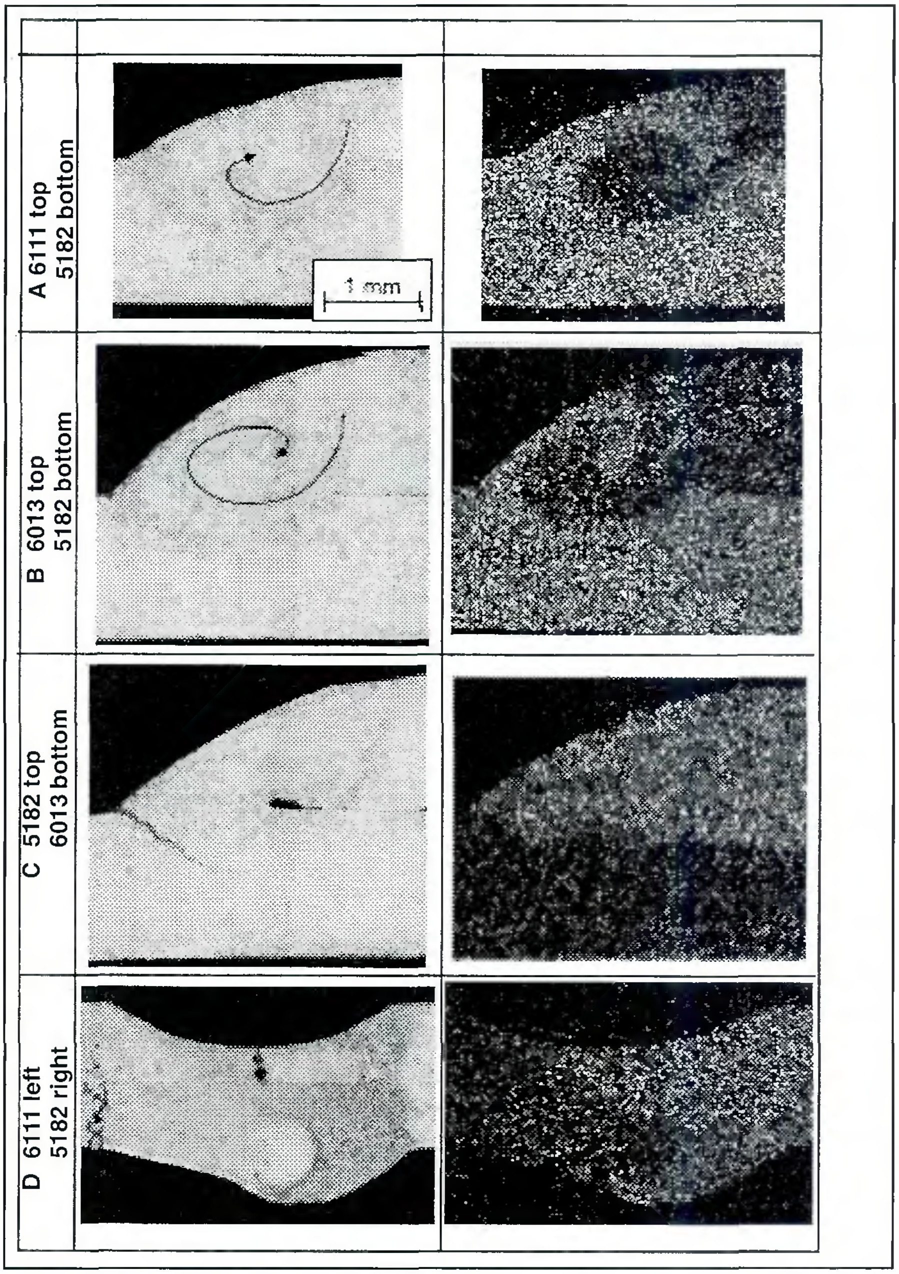


Fig. 17 — Fillet welds in lap joints and butt joint welds between 5xxx and 6xxx series aluminum alloys showing mixing in weld pools.

4. The weld bead develops into a smooth convex shape.

Fluid Flow in HPDL Welds of Aluminum

In order to further investigate the fluid motion in diode laser welds, some samples were made joining aluminum Alloy 5182 to aluminum Alloy 6111 or aluminum Alloy 6013. It can be seen in Table 1 that the most significant difference in alloy composition between the 5xxx and 6xxx series alloys is in the magnesium content. It is also significant that the 6xxx series alloys have higher density than the 5xxx series alloys.

Fillet welds in lap joints between 1.5-mm-thick aluminum Alloy 5182 and 1-mm-thick aluminum Alloy 6111 were made, as well as the same type of welds between 1.5-mm-thick aluminum Alloy 5182 and 1.5-mm-thick aluminum Alloy 6013. Fillet welds in lap joints were produced with the aluminum Alloy 5182 as the bottom sheet and 6xxx series alloy at the top sheet, and vice versa. Butt joint welds were produced between the aluminum Alloy 5182 and aluminum Alloy 6013 to further investigate the fluid flow in diode laser welds.

Magnesium concentration in the weld pools was used as an additional indicator of the mixing of the materials during welding by making energy-dispersive x-ray spectroscopic (EDS) concentration maps. Figure 17 shows optical micrographs of cross sections of the mixed alloy welds described above, as well as EDS maps of magnesium content of each cross section. Areas with a higher concentration of white pixels in the EDS maps indicated areas with higher magnesium content. Thus, areas associated with the aluminum Alloy 5182 appear brighter in the EDS maps.

As may be seen in Fig. 17A, B, when 6xxx series alloys (more dense) were used as a top sheet in a fillet weld in a lap joint, a gently swirled mixing pattern was generated. Arrows have been superimposed on the micrographs of Fig. 17A, B, to indicate the direction of the fluid flow. The EDS magnesium maps show distinct areas of high magnesium content in the fusion zone. This indicated that fluid motion in the weld pool was relatively slow and laminar, as material from the upper and lower sheets did not completely mix together.

When 6xxx series alloys were used as the bottom sheet in a fillet weld in a lap joint (Fig. 17C), no mixing at all was seen; since the more dense alloy was on the bottom, gravity did not induce the molten materials to mix. When aluminum Alloy 5182 and aluminum Alloy 6013 were joined in a butt configuration, the material of the aluminum Alloy 6013 sheet was seen to push the aluminum Alloy 5182 out of the way and upward (Fig. 17D). In the case of the butt joint, the denser 6013 alloy was influenced by gravity to flow downward and displace the less-dense 5182 alloy.

Liquation cracks were observed in the base metal of the 6xxx series alloy in the welds in Fig. 17C, D. 6xxx series alloys are highly susceptible to solidification and liquation cracks (Ref. 21), and since there was no filler metal added, the presence of cracks was not unexpected.

From this series of welds, it was clear that the fluid motion in the weld pool was influenced by small density differences in the alloys being joined. When a denser alloy was placed above a less-dense alloy in a weld joint, gravity influenced the denser alloy to flow downward in the molten weld pool, displacing the less-dense metal and resulting in a gently swirled mixing pattern. When the less-dense alloy was placed above a denser alloy, no mixing at all was seen. This sensitivity to small density differences indicated that forces other than gravitational acting on the weld pool in diode laser welding of aluminum alloys were very small. These results are consistent with fluid flow that is primarily buoyancy driven.

Discussion of Forces on the Weld Pool

The fluid motion in these diode laser welds of aluminum was very different from fluid motion that is often seen in keyhole-mode laser welding or arc welding processes (Refs. 3, 5, 22, 23). The moving keyhole in keyhole-mode laser welding processes forces liquid metal to flow rapidly around the keyhole (Ref. 22). Since the present experiments were based on conduction-mode welding, this rapid fluid motion and mixing did not occur in the diode laser welds.

Other forces that often act on arc weld pools include Lorentz forces, Marangoni forces, and buoyancy forces. Lorentz forces are present in arc welding processes where the current density gradients in the arc and weld pool interact with the magnetic field generated by the current to generate forces acting away from the surface of the weld pool (Ref. 22). Since there is no arc in laser welding processes, there is no Lorentz force.

Marangoni forces are due to surface tension gradients and act along the surface of a weld pool. Depending on the material properties and surface tension gradients, Marangoni forces can influence fluid to flow in various patterns in the weld pool (Ref. 22). No evidence of fluid flow due to Marangoni forces was observed in the diode laser welds of the present study, and this is not surprising since most of the "free" surface area of these welds was actually covered by an immobile, solid oxide film.

Buoyancy forces are due to density changes of the molten metal. In weld pools of uniform composition, liquid at higher temperatures becomes less dense and thus tends to flow upward, while cooler and therefore denser liquid flows downward. In these experiments, the density differences due to the different alloy compositions overcame buoyancy due to heating, and thus had a stronger influence on fluid motion. In other conduction-mode welding processes where Lorentz forces and Marangoni forces are present, gravity or buoyancy forces tend to be comparatively weak (Ref. 23). Lorentz forces are not expected to be present in diode laser welds, and the sensitivity of fluid motion to density indicated that Marangoni forces were also very weak in diode laser welds on aluminum alloys. Therefore, it was concluded that gravity was the most significant force acting on diode laser welds of aluminum.

Berkmanns et al. (Ref. 24) have found that in diode laser welding of steel, Marangoni forces are the dominant force on the melt pool, and combined with the effects of buoyancy, affect the direction of fluid flow in the weld pool. Fujii et al. (Ref. 19) studied the effects of gravity on fluid motion of weld pools and found that surface tension and buoyancy had the greatest effects on fluid motion in electron beam welds. However, when a solid oxide layer was present on the surface of the weld pool, such as in welding of aluminum, the Marangoni forces were greatly reduced.

Since there are no Lorentz forces in diode laser welding and Marangoni forces are expected to be very small if not nonexistent due to solid aluminum oxide layers on the weld surface, buoyancy forces were expected to be the dominant force in fluid motion in these welds. It has been found that these buoyancy forces are relatively weak and can easily be disrupted by composition differences between workpiece materials.

Summary

Work up to this point indicates that it is feasible to produce good-quality fillet welds in lap joints with the HPDL. Aggressive clamping and controlled cleaning conditions will be imperative to the success of such a process in an industrial application.

Investigation of the effect of surface conditions on welding revealed that absorptivity of the aluminum sheet is very sensitive to surface conditions. The weld cross-sectional area, which was measured as an indication of absorptivity, was reduced both by sanding and cleaning with acetone. Cleaning, however, reduced oxide tails in the welds. The effect of reducing oxide tails was more significant than the effect of reducing weld area, and thus cleaning was found to increase weld throat.

It was found that absorptivity could be increased significantly by applying dark substances to the surface. An important observation, however, was that increasing absorptivity would increase weld area, but not necessarily weld throat. Since weld throat is the important geometrical feature relating to strength, it became clear that increasing absorptivity alone did not immediately increase joint strength.

It was found that lap-fillet welds were best produced with an incident angle of 20 deg and focal point at the center of the edge of the top sheet. Welds with acceptable throat were produced with up to 0.5 mm (0.02 in.) of offset from the centerline in the lateral direction, resulting in a tolerance range of about 1 mm (0.04 in.) in the lateral direction. Introducing a twist angle about the beam axis resulted in wider distribution of heat to the workpiece and, therefore, reduced weld size.

The mechanisms of weld bead formation were investigated, and it was found that weld beads form differently under different cleaning conditions. In welds made with good cleaning, oxide layers were easily broken. In welds made without prior cleaning, thick oxide tails remained in the weld pool, reducing amount of fusion. The expulsion of gas bubbles appeared to be an important part of oxide removal in welds with no prior cleaning. The conduction-mode nature of the diode laser welds combined with lack of Lorentz forces and Marangoni forces resulted in quiescent weld pools with very little fluid motion. What little fluid motion did occur was found to be influenced mainly by buoyancy gradients in the molten weld pool. It was also suggested that 3-D fluid motion in the weld pools was present.

Cleaning prior to welding consistently produced welds with acceptable throat and quality, while welding on material with a thick oxide layer and other surface contaminants produced welds with unpredictable and large oxide-related defects. It is clear that controlling surface condition will be imperative to an industrial application of high-power diode laser welding of aluminum.

Acknowledgments

The authors would like to acknowledge the funding and support from Auto21, one of the Networks of Centres of Excellence supported by the Canadian Government; the Ontario Research and Development Challenge Fund; and Alcan Inc.

References

1. Zediker, M. 1999. Applications and Benefits of Direct Diode Lasers. *http://www.nuvonyx.com/slide%20show/index.htm.*

2. Zediker, M. S., Haake, J. M., and Cook, C. M. 2000. Laser diode material processing system. *Proc. ICALEO 2000, Laser Applications in the Automotive Industry*, Vol. 91, D1–D8. Eds. Hugel, H., Matsunawa, A., Mazumder, J., and DiPetro, F. Orlando, Fla.: Laser Institute of America.

3. Duley, W. W. 1999. *Laser Welding*. Toronto, Wiley Interscience.

4. Ki, H., Mohanty, P. S., and Mazumder, J. 2000. A self-consistent three dimensional laser keyhole welding model. *Proc. ICALEO 2000, Laser Applications in the Automotive Industry,* Vol. 91. D35–D43. Eds. Hugel, H., Matsunawa, A., Mazumder, J., and DiPetro, F. Orlando, Fla.: Laser Institute of America.

5. Zhao, H., White, D. R., and DebRoy, T. 1999. Current issues and problems in laser welding of automotive aluminum alloys. *International Materials Reviews* 44(6): 238–266.

6. Abe, N., Tsukamoto, M., Morikawa, A., Maeda, K., and Namba, K. 2002. Welding of aluminum alloy with high power direct diode laser. *Trans. JWRI* 31(2).

7. Clarke, J. A. 2001. Aluminum tailor-welded blanks. *Proc. ALAW 2001*, 42–80. Ed. Mazumder, J. Ann Arbor, Mich.: University of Michigan College of Engineering.

8. Herfurth, H. J., and Ehlers, B. 2000. Increased performance broadens processing capabilities of high power diode lasers. *Proc. ICALEO 2000, Laser Applications in the Automotive Industry*, Vol. 91, D9–D18. Eds. Hugel, H., Matsunawa, A., Mazumder, J., and DiPetro, F. Orlando, Fla.: Laser Institute of America.

9. Howard, K., Lawson, S., and Zhou, Y. 2003. Unpublished research, University of Waterloo.
10. *Aluminum for Automotive Body Sheet Panels*. 1998. The Aluminum Association. Publication AT3.
11. *Aluminum 6013 Composition Spec*. 2005. *http://www.matweb.com/search/SpecificMaterial.asp?bassnum=MA6013n*.
12. Forrest, M. G. 2003. Laser beam welding of automotive closure panel hems. *Welding Journal* 82(8): 30–35.
13. Gurney, T. R. 1979. *Fatigue of Welded Structures*, 2d ed. Cambridge, U.K.: Cambridge University Press, pp. 129–131.
14. Howard, K., Lawson, S., and Zhou, Y. 2004. Diode laser welding of aluminum. *Proc. AMT 2004*. Government of Canada Catalog No. NR15-70/2004E-MRC.
15. Xie, J., and Kar, A. 1999. Laser welding of thin sheet steel with surface oxidation. *Welding Journal* 78(10): 343-s to 348-s.
16. Xie, J., Kar, A., Rothenflue, J. A., and Latham, W. P. 1997. Temperature-dependent absorptivity and cutting capability of CO_2, Nd:YAG and chemical oxygen-iodine lasers. *Journal of Laser Applications* 9(2): 77–85.
17. Xie, J., and Kar, A. 1999. Melting and vaporization for large-area film removal with a chemical oxygen-iodine laser. *Journal of Applied Physics* 82(10): 4744–4751.
18. Ono, K., Adachi, K., Miyamoto, I., and Inoue, T. 2002. Influence of oxide film on weld characteristics of mild steel in CO_2 laser welding. *Journal of Laser Applications* 14(2): 73–77.
19. Fujii, H., Sumi, Y., Yamamoto, T., Kamai, M., and Nogi, K. 2001. Effect of gravity and surface tension on convection in molten pool. *Trans JWRI Special Issue HTC-2000*. Vol. 30: 523–528.
20. Eagar, T. W., and Tsai, N. S. 1983. Temperature fields produced by traveling distributed heat sources. *Welding Journal* 62(12): 346-s to 355-s.
21. Dickerson, P. B. 1993. Welding of aluminum alloys. *ASM Handbook*, Vol. 6, Welding, Brazing and Soldering, pp. 722–739. Materials Park, Ohio: ASM International.
22. Heiple, C. R., and Burgardt, P. 1993. Fluid flow phenomena during welding. *ASM Handbook*, Vol. 6, Welding, Brazing and Soldering, pp. 19–24. Materials Park, Ohio: ASM International.
23. Rohklin, S. I., and Guu, A. C. 1993. A study of arc force, pool depression, and weld penetration during gas tungsten arc welding. *Welding Journal* 72(8): 381-s to 390-s.
24. Berkmanns, J., Danzer, W., and Hartl, J. 2002. Influence of process gases in welding with diode lasers. *Proceedings ICALEO 2002*, 1413–1422. Ed. Yao, Y. L. Orlando, Fla.: Laser Institute of America.

Preparation of Manuscripts for Submission to the *Welding Journal* Research Supplement

All authors should address themselves to the following questions when writing papers for submission to the Welding Research Supplement:

- Why was the work done?
- What was done?
- What was found?
- What is the significance of your results?
- What are your most important conclusions?

With those questions in mind, most authors can logically organize their material along the following lines, using suitable headings and subheadings to divide the paper.

1) **Abstract.** A concise summary of the major elements of the presentation, not exceeding 200 words, to help the reader decide if the information is for him or her.

2) **Introduction.** A short statement giving relevant background, purpose, and scope to help orient the reader. Do not duplicate the abstract.

3) **Experimental Procedure, Materials, Equipment.**

4) **Results, Discussion.** The facts or data obtained and their evaluation.

5) **Conclusion.** An evaluation and interpretation of your results. Most often, this is what the readers remember.

6) **Acknowledgment, References and Appendix.**

Keep in mind that proper use of terms, abbreviations, and symbols are important considerations in processing a manuscript for publication. For welding terminology, the *Welding Journal* adheres to AWS A3.0:2001, *Standard Welding Terms and Definitions.*

Papers submitted for consideration in the Welding Research Supplement are required to undergo Peer Review before acceptance for publication. Submit an original and one copy (double-spaced, with 1-in. margins on 8 ½ x 11-in. or A4 paper) of the manuscript. A manuscript submission form should accompany the manuscript.

Tables and figures should be separate from the manuscript copy and only high-quality figures will be published. Figures should be original line art or glossy photos. Special instructions are required if figures are submitted by electronic means. To receive complete instructions and the manuscript submission form, please contact the Peer Review Coordinator, *Erin Adams*, at eadams@aws.org, (305) 443-9353, ext. 275; FAX 305-443-7404; or write to the American Welding Society, 550 NW LeJeune Rd., Miami, FL 33126.

Predictions of Microstructures when Welding Automotive Advanced High-Strength Steels

A combination of thermal and microstructural modeling can be used to estimate performance of welds in advanced high-strength steels

BY J. E. GOULD, S. P. KHURANA, AND T. LI

ABSTRACT. Weld strength, formability, and impact resistance for joints on automotive steels are dependent on the underlying microstructure. A martensitic weld area is often a precursor to reduced mechanical performance. In this paper, efforts are made to predict underlying joint microstructures for a range of processing approaches, steel types, and gauges. This was done first by calculating cooling rates for some typical automotive processes [resistance spot welding (RSW), resistance mash seam welding (RMSEW), laser beam welding (LBW), and gas metal arc welding (GMAW)]. Then, critical cooling rates for martensite formation were calculated for a range of automotive steels using available thermodynamically based phase transformation models. These were then used to define combinations of process type, steel type, and gauge where welds could be formed avoiding martensite in the weld area microstructure.

Introduction

Manufacturability, fuel economy, performance, and styling all continue to be major considerations in the design of next-generation vehicles. A major consideration in these improvements is material selection. To achieve these results in the body-in-white structure, automakers are increasingly turning to alternate materials. Materials under consideration include plastics, aluminum, and advanced high-strength steels (AHSS) (Ref. 1). In recent years, considerable interest has been placed on the use of Al sheet (Refs. 2, 3). However, material cost considerations have created renewed interest in the use of steels for advanced body construction (Ref. 4). Steels available today range from the highly formable interstitial-free (IF) grades to the range of AHSS materials. Interstitial-free grades of steel contain very low carbon contents, typically less than 0.010%. These materials offer both high R values (indicating resistance to sheet thinning during forming) and tensile ductilities in excess of 50%. Such materials have enabled complex forming operations, as well as reductions in forming-related scrap. Advanced high-strength steels are now available with tensile strengths ranging from 300 to 1500 MPa (Refs. 5, 6). Such steels employ a range of hardening mechanisms. The lower end of these strength ranges is typically solid-solution strengthened, particularly with phosphorus additions. Intermediate grades are generally made up of dual-phase (DP) steels, employing a fine grain structure and mixture of ferrite and martensite phases. More recent variants on such steels include the transformation-induced plasticity (TRIP) and complex-phase (CP) steels. The former uses a mixture of ferrite and austenite in the microstructure, while the CP grades employ mixtures of ferrite, bainite, and martensite. These steels largely offer improvements in vehicle weight through gauge reduction. Currently, body skin panels are on the order of 0.8 mm. Gauge reductions down to 0.6 mm are being considered for AHSS skins. In addition to direct replacement of skin panels, selectively placed AHSS offer potential for improved impact and fatigue performance, offering additional potential for vehicle weight reductions.

Efforts to implement these steels have, however, been accompanied by welding-related problems. Since the body-in-white is largely assembled by RSW, most problems have been associated with that joining approach. Recent work has related many of these welding problems to the formation of martensites in the weld nugget (Refs. 7, 8). Martensite, particularly with increasing carbon contents, results in weld zones with hardness levels sufficient to fail in a brittle manner on loading. Similar observations have been made when LBW these higher-strength grades of steel (Refs. 9, 10). The hardness achieved in these steels is directly associated with the cooling rates implicit in these processes. Cooling rates for many automotive welding methods are difficult to measure, largely related to the high processing speeds implied by these technologies (Ref. 11). These cooling rates have, however, been estimated by a range of modeling techniques. These include both closed form (Refs. 12–14) and numerical approaches (Refs. 15–17). These analyses have shown that such automotive processes can achieve cooling rates on the order of 10^5 °C/s. Assessment of microstructural changes at these cooling rates is difficult, particularly because accomplishing such cooling rates outside the processes themselves is difficult to nearly impossible. Recently, however, efforts to model austenite decomposition have offered new tools in predicting weld microstructures at these cooling rates. These approaches are both thermodynamically (Ref. 18) and phenomenologically (Ref. 19) based, and are capable of predicting continuous cooling transformation (CCT) diagrams for both a wide range of steels and cooling rates.

In this research, efforts have been made to predict cooling rates for a range of steel gauges welded with a number of automotive welding processes. These processes include RSW, RMSEW, LBW, and GMAW. Cooling rates are calculated using a range of closed-form solutions available in the literature for a range of

KEYWORDS

High-Strength Steels
Resistance Spot Welding
Resistance Mash Seam Welding
Laser Beam Welding
Gas Metal Arc Welding
Thermal Modeling
Microstructural Modeling

J. E. GOULD, S. P. KHURANA, and T. LI are with Edison Welding Institute, Columbus, Ohio.

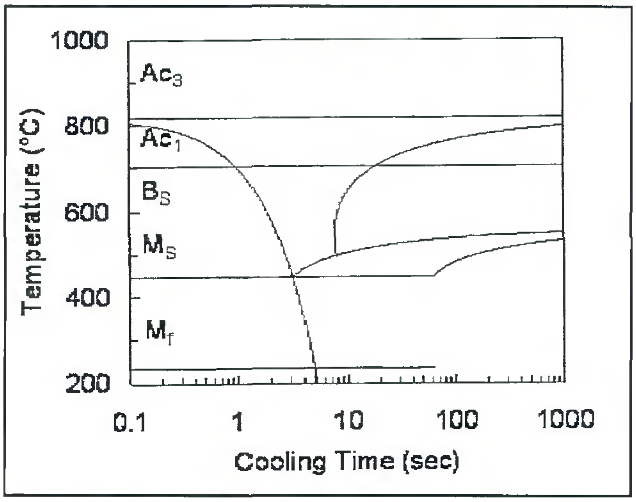


Fig. 1 — CCT diagram for a representative DP 600 steel based on the model developed by Li (Ref. 18).

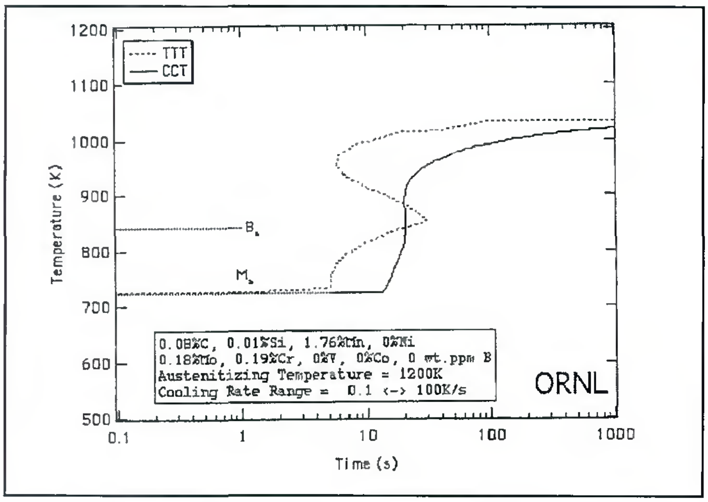


Fig. 2 — CCT/TTT diagram for a representative DP 600 steel based on the model developed by Bhadeshia (Ref. 19).

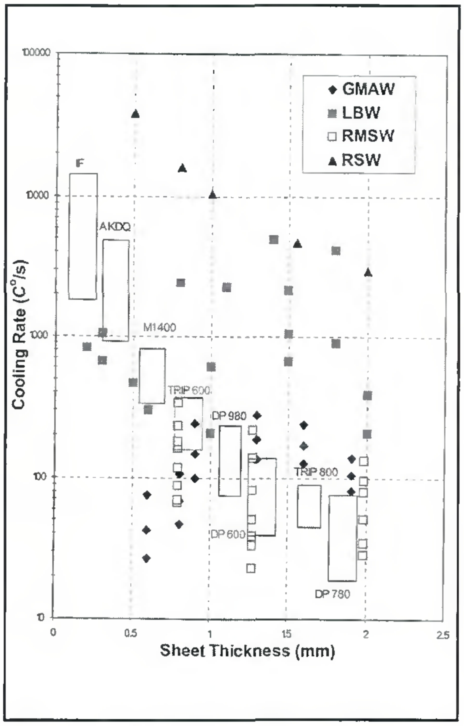


Fig. 3 — Cooling rates as a function of gauge for the RSW, RMSEW, LBW, and GMAW processes. [Also included are critical cooling rates for a number of automotive-type sheet steels. These critical cooling rates are presented as a range. The top of the range is taken from the model of Li (Ref. 18) and the bottom of the range is taken from Bhadeshia (Ref. 19).]

gauges of automotive interest. These results are then compared to critical cooling rates (for a martensite formation) for a number of new-generation automotive sheet steels. The comparison is then used to predict combinations of materials, gauges, and processes that might be problematic in automotive manufacture. Some microstructural evidence is also presented supporting the modeling results.

Table 1 — Definition of Terms for Predicting the Fractions of Constitutent Phases in the Final Microstructure

	Ferrite Formation	Pearlite Formation	Bainite Formation
ΔT	Ae_3-T	Ae_1-T	Bs-T
n	3	3	2
Q	27,500	27,500	27,500
F (Composition, G)	$F_{ferrite}/2^{0.41G}$	$F_{pearlite}/2^{0.32G}$	$F_{bainite}/2^{0.29G}$
F	[exp(1.00 + 6.31C + 1.78Mn +0.31Si +1.12Ni + 2.70Cr + 4.06Mo)]	[exp(– 4.25 + 4.12C + 4.36Mn +0.44Si +1.71Ni + 3.33Cr + 5.19√Mo)]	[exp(-10.23 + 10.18C + 0.85Mn + 0.55Ni + 0.90Cr + 0.36Mo)]

Analytical Models for Predicting Cooling Rates

Cooling rates during RSW have been calculated (Ref. 14) based on the following assumptions:

1. Heat flow during RSW is essentially one dimensional, from the workpiece into the electrodes.
2. The peak temperature distribution in the resistance spot weld can be described by a sine wave half period, with the peak at the center between the electrodes.
3. The welding electrodes are essentially straight sided.

Based on these observations, cooling rates during RSW can be estimated by the following equation:

$$\frac{\partial\Theta}{\partial t} = -\left(\frac{\alpha\pi^2}{4\Delta x^2}\right)\left(\frac{\Theta}{\Theta_P}\right)\left(\Theta_P - \frac{\Theta}{1+\left(\frac{2}{\pi}\right)\left(\frac{k_E}{k_S}\right)\left(\frac{\Delta x}{\Delta x_E}\right)\cos\left(\frac{\pi}{2\Delta x}x\right)}\right) \quad (1)$$

where Θ is the temperature, t is time, α is the thermal diffusivity, Δx and Δx_E are the sheet and electrode face thicknesses, respectively, Θ_p is the peak temperature in the spot weld, k_E and k_s are the thermal conductivities of the electrode material (Cu) and steel, respectively, and x is the position through the spot weld.

Similar equations can be obtained for the continuous processes (RMSEW, LBW, GMAW) based on the Rosenthal equations (Ref. 12). For automotive applications, the 2D approaches are the most appropriate. The basic equation, as modified by Adams (Ref. 13) to predict peak cooling rates, is as follows:

$$\frac{\partial\Theta}{\partial t} = -\frac{2\pi k_s^2}{\alpha}\left(\frac{v\Delta x}{\dot{Q}}\right)^2\left(\Theta-\Theta_o\right)^3 \quad (2)$$

where v is the travel speed, Q is the power input, and Θ_o original base metal temperature. Q for the LBW and GMAW processes can be calculated directly, and inserted into the equation. This equation has also been modified to estimate cooling rates during RMSEW (Ref. 20). In this case, the power input is estimated from the applied current and geometry of the lap. The resulting

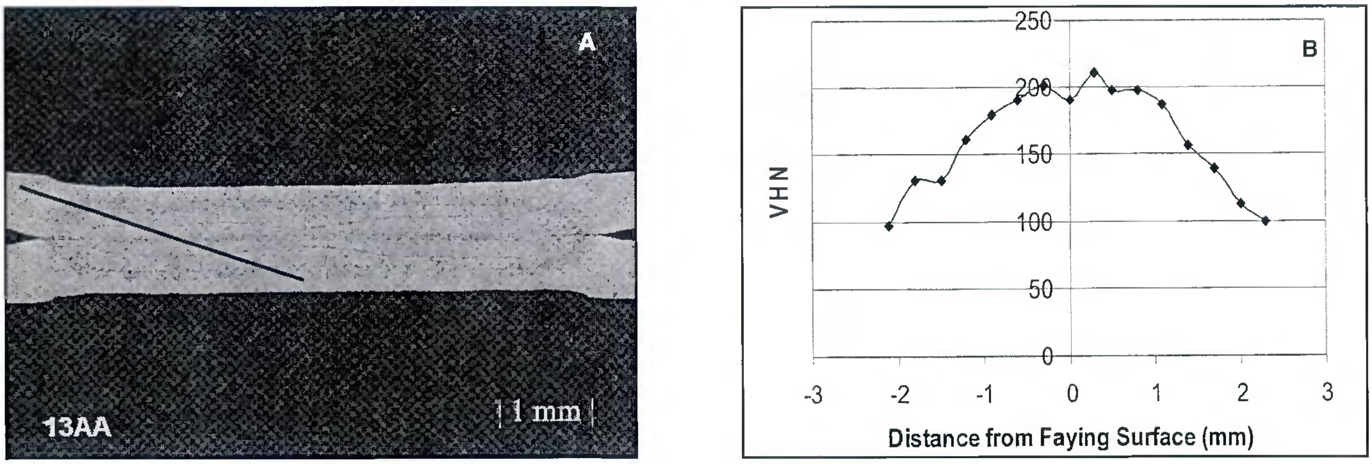


Fig. 4 — Macrostructure and hardness profile of a resistance spot weld on 0.8-mm IF (0.007% C, 0.14% Mn) steel. A — Macrostructure, hardness profile trace is shown as a dark line; B — hardness profile.

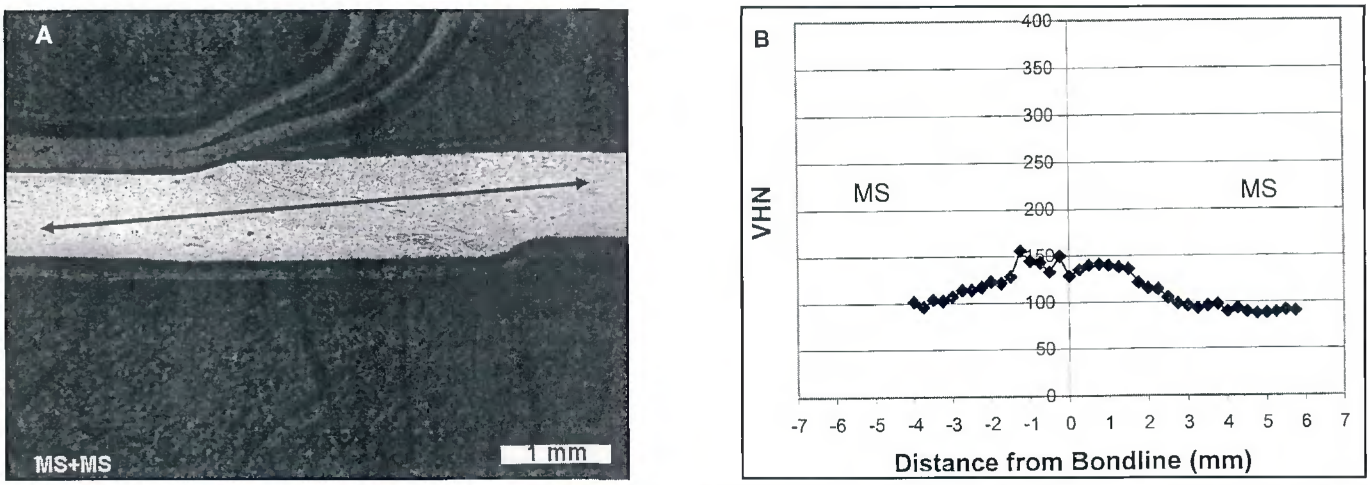


Fig. 5 — Macrostructure and hardness profile of a resistance mash seam weld on 0.8-mm AKDQ (0.03% C, 0.3% Mn) steel. A — Macrostructure, hardness profile trace is shown as a dark line; B — hardness profile.

equation is

$$\frac{\partial\Theta}{\partial t} = -\frac{2\pi k_s^2}{\alpha}\left[\frac{v}{\rho\left(\frac{I}{A}\right)^2 l y_o}\right]^2 \left(\Theta-\Theta_o\right)^3 \quad (3)$$

where ρ is the resistivity of steel, I is the welding current, A is the effective wheel contact area, l is the length of wheel contact, and y_o is the original overlap of the two sheets. These equations are now to be used to estimate cooling rates as a function of gauge for the range of welding technologies used in automotive manufacture today.

Prediction of Critical Cooling Rates for Martensite Formation

The critical cooling rates can be determined from CCT diagrams. As mentioned previously, mathematical models have been developed to define these CCT diagrams. These models generally consist of a thermodynamics portion, which determines the equilibrium temperatures, and an austenite decomposition reaction kinetics portion, which predicts the resultant microstructure. Two such models have been developed by Li (Ref. 18) and Bhadeshia (Ref. 19).

In the model developed by Li (Ref. 18), thermodynamic calculations are used to determine Ae_3 and Ae_1 temperatures. In addition, the thermodynamic conditions for the three-phase, α + γ + cementite, equlibria are also computed. The equations defining the transformation temperatures Ae_3 and Ae_1 are given in Table 1.

A reaction kinetics model can then be used to predict CCT diagrams. The reaction kinetics model (Ref. 18) is described by the following equations.

$$\tau\left(X,T\right) = \frac{F(Composition,G)}{\Delta T^n\, exp(-Q/RT)} S(X) \quad (4)$$

where τ(X,T) is the isothermal time taken to reach X amount of transformation at T temperature, ΔT is the undercooling, n is an empirical constant, Q is the activation energy, F is a function of steel composition, G is the prior austenite grain size in ASTM, and $S(X)$ is explained by the following equation.

$$S(X) = \int_0^x \frac{1}{X^{0.4(1-X)}\left(1-X\right)^{0.4X}} dX \quad (5)$$

Combining these equations and differentiating, we get the following:

$$\frac{dX}{dt} = \frac{\Delta T^n\, exp(-Q/RT) X^{0.4(1-X)}\left(1-X\right)^{0.4X}}{F\left(Composition,G\right)} \quad (6)$$

The individual terms of this equation are defined in Table 1.

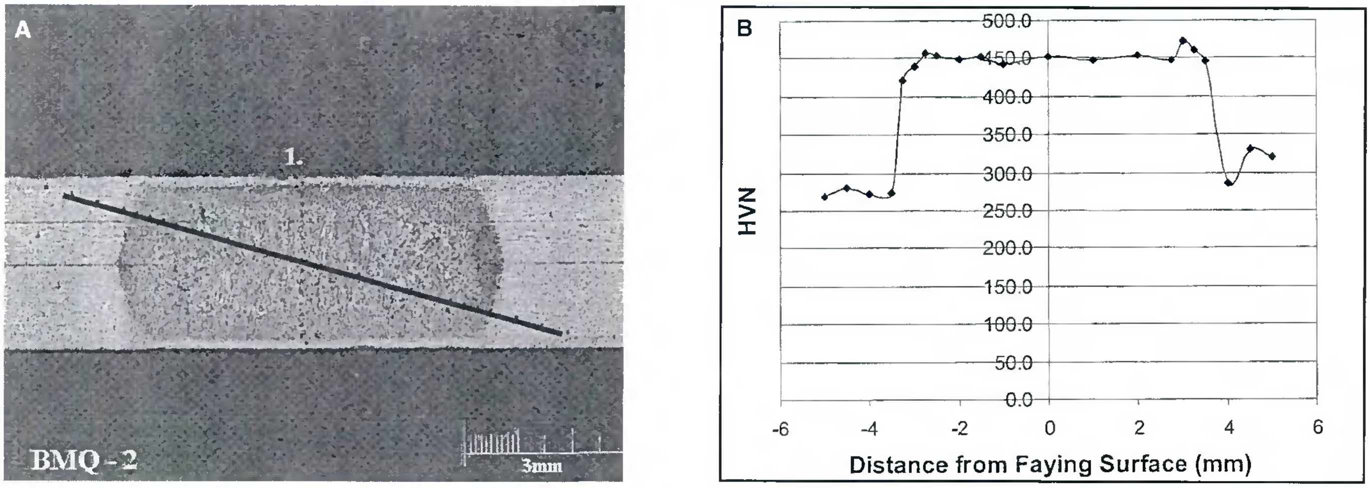


Fig. 6 — Macrostructure and hardness profile of a resistance spot weld on 1.6-mm DP980 (0.15% C, 1.4% Mn) steel. A — Macrostructure, hardness profile trace is shown as a dark line; B — hardness profile.

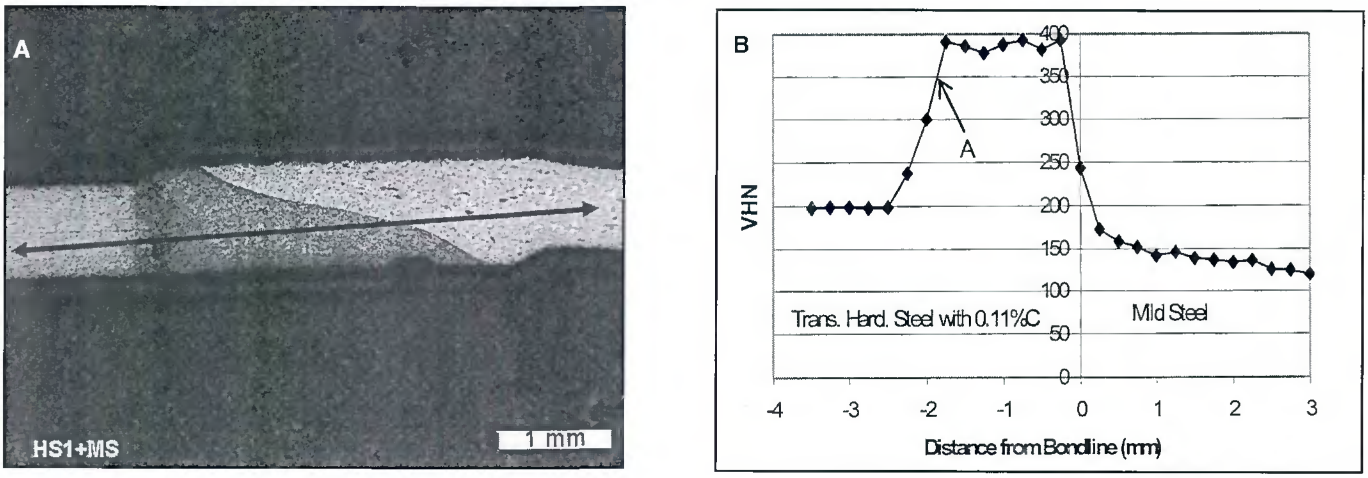


Fig. 7 — Macrostructure and hardness profile of a resistance mash seam weld between 0.8-mm DP980 and AKDQ steel.

The preceding equations can then be used to calculate the fractions of constituent phases as a function of time and temperature. This provides the basis for the appropriate CCT diagram. An example of a resulting predicted CCT/TTT diagram for a DP 600 steel is given in Fig. 1.

In the approach by Bhadeshia (Ref. 19), a thermodynamic method has been used to allow the prediction of phase transformation from the chemical composition of the steel concerned. In this case, the TTT diagram has been treated as composed of two overlapping C-curves. One C-curve represents the diffusional polygonal ferrite, the displacive Widmanstätten ferrite and pearlite transformations, and the other C-curve represents the bainite reactions. The correct prediction of the C-curves is based on estimating the shift in these curves as a function of alloying elements.

The time period before the detectable amount of a phase is formed at an isothermal temperature is used to detect this shift. This time period is dependent on the nucleation of the phase. The incubation period of a phase, τ, is defined in terms of time taken to establish a steady-state nucleation rate.

$$\tau \propto \frac{T}{\left(\Delta F_m^{v}\right)^p D} \tag{7}$$

where T is the absolute temperature, ΔF^{v}_m is the maximum volume free energy change accompanying the formulation of a nucleus in a large amount of matrix phase, P is a constant, and D is an effective diffusion coefficient defined as

$$D \propto exp\left(\frac{S}{R}\right) exp\left(-\frac{Q}{RT}\right) \tag{8}$$

where S is the activation entropy for diffusion, Q is the activation enthalpy for diffusion, and R is the gas constant.

Substituting Equation 8 in Equation 7,

$$\ln\left[\frac{\left(\Delta F_m\right)^p \tau}{T}\right] = \frac{Q}{RT} + C_1 \tag{9}$$

where ΔF_m is ΔF_m for 1 mol and C_1 is a constant.

Optimum values of p and Q are obtained by substituting experimental values of T, ΔF_m, and τ, and varying p until the equation balances.

Bhadeshia (Ref. 19) noticed that the graph of $\ln[(\Delta F_m)^p\tau/T]$ against $1/RT$ exhibited systemic curvature and did not have the strict linear form applied by Equation 9. This is attributed to the fact that activation enthalpy and entropy are temperature dependent. So Equation 9 was modified to the following form.

$$\ln\left[\frac{\Delta F_m^p \tau}{T^z}\right] = \frac{Q'}{RT} + C_4 \qquad (10)$$

where z, Q', and C_4 are constants.

This equation predicted better results. The correlation coefficients of Equation 10 were also better than that of Equation 9. The resulting CCT diagrams were used by Babu (Ref. 21) for predictions of microstructures in resistance spot welds, and can also be accessed online at the ORNL Web site (Ref. 22). A representative CCT/TTT curve based on this approach is presented in Fig. 2.

Comparisons of Process Cooling Rates and Critical Cooling Rates for Martensite Formation

The equations described above have been used here to calculate cooling rates over a range of automotive-related steel gauges. Welding parameters (e.g., power inputs, welding speeds) have been taken from available reference texts (Refs. 23–26). The resulting cooling rates, as a function of gauge, are shown collectively in Fig. 3. Of the processes, RSW shows the highest cooling rates. These rates range from over 100,000°C/s for gauges less than 0.5 mm, to roughly 2000°C/s at a 2.0-mm gauge. Of note, RSW is the only process examined here showing such a gauge effect. Cooling rates for LBW are somewhat less, ranging from 200° to 5000°C/s, depending on the specific parameters used. The scatter in the cooling rates here is an artifact of the recommended practices from the reference text (Ref. 25). Cooling rates for GMAW and RMSEW are similar, ranging from 20° to 300°C/s, again depending on the specific parameters used.

Critical cooling rates to achieve martensite formation for a range of automotive steels were taken from CCT diagrams determined using the two computational approaches described previously. Input to these models included the specific chemistry and grain size of each steel. Chemistries for the representative steels are given in Table 2. The resulting CCT curves were used to estimate the specific cooling rate(s) distinguishing 100% martensite formation. The characteristic cooling rates for each of these steels (using the respective models) are also provided in Table 2. It is first of note that depending on steel composition and the phase transformation model used, critical cooling rates range from 10^1 to 10^4 °C/s. In particular, it is noted that the model by Li (Ref. 18) predicts critical cooling rates 2 to 7 times that

Table 2 — Compositions and Critical Cooling Rates (for Martensite Formation) for the Steels of Interest in this Study

Composition/ CoolingRate (%)	Steel of Interest							
	IF	AKDQ	DP 600	DP 780	DP 980	M 1400	TRIP 600	TRIP 800
C	0.007	0.06	0.08	0.1	0.15	0.19	0.09	0.21
Mn	0.15	0.3	1.76	2.33	1.38	0.47	1.45	1.7
Si	—	—	0.01	0.23	0.29	0.02	1.47	1.66
Cr	—	—	0.19	0.03	0.03	—	0.05	0.03
Mo	—	—	0.18	0.02	0	—	0.1	0
Al	0.03	0.03	0.05	0.04	0.04	0.03	0.03	0.04
V	—	—	0	0.06	0	—	0.01	0
Ti	0.05	—	0	0	0.01	—	0.01	0.01
Crit. Cooling Rate (°C/s) based on Li(18)	13,500	5000	120	70	225	800	315	90
Crit. Cooling Rate (°C/s) based on Bhadeshia(19)	2000	1000	40	18	75	320	140	45

for similar steels by Bhadeshia (Ref. 19). In addition, the gap tends to widen for the leanest alloyed steels [IF and aluminum-killed drawing quality (AKDQ)]. The models do, however, bracket the regimes of critical cooling rates for each of the respective grades of steels.

These ranges of critical cooling rates for martensite formation are superimposed onto Fig. 3. These are shown as a series of boxes labeled for each respective steel. The top of the box represents the cooling rate predicted by the Li model, (Ref. 18) and the bottom that for the Bhadeshia model (Ref. 19). In Fig. 3, the cooling rates above that indicated by these respective levels (for the steel of interest) result in martensitic welds, while those below will result in a mixture of austenitic decomposition products. Effectively, processes with implied cooling rates above that indicated for the respective steel would contain predominantly martensite in the weld zone, and be susceptible to undesirable modes of failure. Those processes showing less than the critical cooling rate (for the respective steel) will result in tougher microstructures and improved performance.

From Fig. 3, it is clear that the critical cooling rates decrease with the increasing complexity of the steel (higher alloying content) and strength level. This is largely an artifact of the strengthening mechanisms employed in the higher-strength products. Higher-strength grades of steels generally employ larger volume fractions of second phases (bainite, martensite, austenite), typically accomplished by increases in austenite stabilizing additions. The most common of these are carbon and Mn, although high compositions of Si are present in the TRIP steels. These chemistry variations appear capable of suppressing the critical cooling rates to values near 10°–100°C/s, compared to the 1000°–5000°C/s values reported here for the common mild steel grades used in automotive production.

Figure 3 suggests the IF, AKDQ (mild steel), and even the martensite 1400 grades will decompose without martensitic transformation when joined with either the GMAW or RMSEW welding processes. The IF and AKDQ grades, alternately may or may not form martensite when joined with RSW or LBW, depending on the processing conditions used. For these steels, however, carbon contents are sufficiently low that martensite in the joint is not a precursor to unacceptable modes of failure.

Some examples of welds made on 0.8-mm IF and AKDQ grades of steels (Ref. 9) are presented in Figs. 4 and 5. Figure 4 shows a cross section of a resistance spot weld made on an IF grade of steel, as well as the associated hardness profile. The hardness profile is seen to progressively increase from the base metal to the center of the weld. Equation 1 suggests that cooling rates also will increase progressively from the electrode contact surface to the workpiece faying surface. This, in effect, shows that for this weld, cooling rate and hardness are related. This relationship suggests a lack of athermal martensite. With athermal martensite, hardness would be independent of cooling rate from an austenitic microstructure. Rather, the hardness variations observed are related to the scale of the microstructure and evolving constituent phases. This suggests that the IF steel welded here has a critical cooling rate for martensite formation greater than that provided by resistance welding. These results are more consistent with the model of Li than Bhadeshia. A microstructure and hardness profile of a RMSEW made between two pieces of AKDQ steel is shown in Fig. 5. The hardness profile for this weld peaks at the centerline, and is characteristic of the slower cooling rates inherent in this process.

Figure 3 suggests that the AHSS will all easily transform to martensite during RSW and for most LBW. In these cases, carbon levels are now sufficient such that the formed martensite can experience brittle fracture (Refs. 7, 8). For other welding processes (GMAW and RMSEW), the welds may or may not transform to martensite, depending on the processing conditions used and the specific chemistry of the steel. The most heavily alloyed steels (TRIP 800 and DP 780) do appear likely to form martensite in any of the automotive welding processes.

Some examples of welds made with a DP 980 grade of steel (Ref. 27) are presented in Figs. 6 and 7. Figure 6 shows a cross section and hardness profile for a resistance spot weld made on the 1.6-mm DP 980. The hardness profile of the weld shows a typical "top hat" morphology. This shows that for resistance spot welds made on this metal, hardness (for regions exceeding the austenization temperature) is largely independent of cooling rate, and consistent with athermal martensite formation. A similar cross section and hardness trace for a resistance mash seam weld made between 0.8-mm DP 980 and AKDQ steels are presented in Fig. 7. In this case, the DP 980 side of the joint shows the top hat hardness profile suggesting martensite formation. This again can be nominally predicted from either microstructrual model, depending on the weld processing employed. The AKDQ steel side of the weld shows hardness variations nearly identical to that described in Fig. 5.

One particular feature of note is variability in critical cooling rates for the different grades of AHSS, particularly that the DP 980 steel evaluated shows critical cooling rates higher than either the DP 600 or 780 grades. This variation in critical cooling rate largely is related to the relative carbon and Mn contents of the respective steels. Both are hardenability additions, and critical to the processing required in order to achieve desired mechanical properties. However, lower carbon contents (reducing both hardenability and martensite hardness) in the DP 600 and 780 steels are offset by substantially higher (nearly a factor of 2) Mn contents. This results in a higher hardenability for these steels, even though the actual design strengths are reduced. It also raises concern that differing formulations from different steel suppliers may result in a broad range of critical cooling rates for steels of a given grade. This suggests the possibility that steels of a given grade can actually vary in and out of conditions for forming martensite with a given process, resulting in intermittent weld failures on a production floor.

Conclusions

In this work, closed-form solutions were used to calculate cooling rates for a range of automotive-related welding processes (RSW, RMSEW, LBW, and GMAW) as a function of gauge. In addition, available microstructural models were used to predict critical cooling rates for a number of automotive-related sheet steel products. The results were used to investigate combinations of processes, steel types, and gauge ranges, which could result in detrimental martensite in the weld area. The results showed that highest cooling rates were associated with RSW, followed by LBW, and finally resistance seam welding (RSEW) and RMSEW. It was found that the IF and mild steels could form martensite during either RSW or LBW, but the martensite is of sufficiently low carbon levels to avoid undesirable modes of failure on destructive testing. The AHSS generally showed potential for martensite formation with the RSW and LBW processes. Here, carbon levels are sufficient that the formed martensites can be detrimental to such failure modes during destructive testing. The AHSS also showed potential for martensite formation during RMSEW and GMAW. For these steels and processes, sufficient variation exists in both steel chemistry and implied cooling rates for these processes to show intermittent martensite formation and loss of performance. It was also noted that susceptibility of martensite formation was less dependent on the grade of the AHSS and more on the specific chemistry used to achieve the strength levels required for the grade.

References

1. Dinda, S., and Diaz, R. 1995. The partnership for a new generation of vehicles (PNGV) and its impact on body engineering. *Proc. IBEC 95, Advanced Technologies and Processes*, pp. 5–8, IBEC Ltd.

2. Kurihara, Y. 1993. The role of aluminum in automotive weight reduction, Part 1. *Journal of Metals* 45(11): 32–33.

3. Tuler, F., Warren, A., Mariano, S., and Wheeler, M. 1994. Overall benefits and value of aluminum for an automobile body structure. *Proc. IBEC 94, Automotive Body Materials*, pp. 8–14, IBEC Ltd.

4. Crooks, M. J., and Miner, R. E. 1996. The ultralight steel auto body program completes phase 1. *Journal of Metals* 48(7): 13–15.

5. Davies, R. G., and Magee, C. L. 1979. Physical metallurgy of automotive high strength steels. *Structure and Properties of Dual Phase Steels*, eds. R. A. Kot and J. W. Morris, AIME.

6. Bleck, W. 1996. Cold rolled, high-strength sheet steels for auto applications. *Journal of Metals* 48(7): 26–30.

7. Gould, J. E., Lehman, L. R., and Holmes, S. 1996. A design of experiments evaluation of factors affecting the resistance spot weldability of high-strength steels. *Proc. Sheet Metal Welding Conference VII*, AWS Detroit Section.

8. Gould, J. E., and Workman, D. 1998. Fracture morphologies of resistance spot welds exhibiting hold time sensitivity behavior. *Proc. Sheet Metal Welding Conference VIII*, AWS Detroit Section.

9. Shao, H. 2000. Blank welding high strength steels, PhD dissertation. Columbus, Ohio, The Ohio State University.

10. Ream, S. L. 2003. Remote laser weld performance in advanced high strength steels. *Proc. ALAW 2003.* University of Michigan.

11. Gould, J. E. 1987. An examination of nugget development during spot welding using both experimental and analytical techniques. *Welding Journal* 67(1): 1-s to 10-s.

12. Rosenthal, D. 1941. Mathematical theory of heat distribution during welding and cutting. *Welding Journal* 20(5): 220-s to 234-s.

13. Adams, C. M. Jr. 1958. Cooling rates and peak temperatures in fusion welding. *Welding Journal* 37(5): 210-s to 215-s.

14. Chuko, W., and Gould, J. E. 2002. Development of appropriate resistance spot welding practice for transformation-hardened steels - phase 2: evaluation of post-weld cooling rate techniques. Report to the American Iron and Steel Institute.

15. Cho, H. S., and Cho, Y. J. 1989. A study of the thermal behavior in resistance spot welds. *Welding Journal* 68(6): 230-s to 244-s.

16. Xie, J. 2002. Weld morphology and thermal modeling in dual-beam laser welding. *Welding Journal* 81(12): 283-s to 290-s.

17. Kumar, S., and Bhaduri, S. C. 1994. Three-dimensional finite element modeling of gas metal-arc welding. *Metallurgical Transactions B* 25B(3): 435–441.

18. Li, M. V., Niebuhr, D. V., Meekisho, L. L., and Atteridge, D. G. 1998. A computational model for the prediction of steel hardenability. *Metallurgical and Materials Transactions B* 29B(6): 661–672.

19. Bhadeshia, H. K. D. H., and Svensson, L.-E. 1993. *Mathematical Modeling of Weld Phenomena*, eds. H. Cerjack and K. E. Easterling. Institute of Metals, London, pp. 109–180.

20. Gould, J. E. 2003. Theoretical analysis of bonding characteristics during resistance mash seam welding sheet steels. *Welding Journal* 82(10): 263-s to 267-s.

21. Babu, S. S., Reimer, B. W., Santella, M. L., and Feng, Z. 1998. Integrated thermal-microstructure model to predict the property gradients in resistance spot steel welds. *Proc. Sheet Metal Welding Conference VIII*, AWS Detroit Section.

22. *http://engm01.ms.ornl.gov*, Oak Ridge National Laboratory.

23. *Resistance Welding Manual*, 4th ed. Resistance Welding Manufacturing Alliance, George H. Buchanan Co. Philadelphia, Pa., pp. 7–16.

24. Funk, E. J., and Begeman, M. L. 1956. Electrical and metallurgical characteristics of mash seam welds. *Welding Journal* 35(6): 265-s to 274-s.

25. *LIA Handbook of Laser Materials Processing*. Ready, J. F., and Farson, D. F. (eds. in chief), pp. 381 and 399.

26. Cary, H. B. 1979. *Modern Welding Technology*. Englewood Cliffs, N.J. Prentice-Hall Inc., p. 706.

Use these convenient, postage-paid inquiry cards to request free information about the products or services advertised in this issue of *Welding Journal.*

For information about specific advertisements: Circle the key number on the card that matches the number on the bottom of the ad.

FREE INFORMATION • FREE INFORMATION

Please send literature on items circled at right:

May 2006 — Card void after November 1, 2006

Name ______________ Title ______________

Company ______________

Address ______________

City ______________ State ______ Zip ______

Phone: ______________ Fax: ______________

E-mail ______________

Please circle an entry for each category:

I. TYPE OF BUSINESS
1. Construction
2. Primary Metal Products
3. Fabricated Metal Products
4. Transportation
5. Petrochemical
6. Misc. Repair Services
7. Educational Services
8. Utilities
9. Other

II. JOB FUNCTION/TITLE
1. Corp. Management
2. Plant Mgmt.
3. Engineer
4. Welding or Cutting Oper.
5. Quality Control
6. Sales
7. Purchasing
8. Education
9. Other

III. PURCHASING AUTHORITY
1. Recommend
2. Specify
3. Approve

IV. NUMBER OF EMPLOYEES
1. Under
2. 50 to 99
3. 100 to 499
4. 500 to 999
5. 1000 to 2499
6. 2500 to more

V. ANNUAL DOLLAR VOLUME
1. Under $1 Million
2. $1 Million to 5 Million
3. Over $5 Million

VI. THIS INQUIRY IS FOR
1. Immediate Purchase
2. Future Project
3. General Information

1	35	69	103	137	171	205	239	273
2	36	70	104	138	172	206	240	274
3	37	71	105	139	173	207	241	275
4	38	72	106	140	174	208	242	276
5	39	73	107	141	175	209	243	277
6	40	74	108	142	176	210	244	278
7	41	75	109	143	177	211	245	279
8	42	76	110	144	178	212	246	280
9	43	77	111	145	179	213	247	281
10	44	78	112	146	180	214	248	282
11	45	79	113	147	181	215	249	283
12	46	80	114	148	182	216	250	284
13	47	81	115	149	183	217	251	285
14	48	82	116	150	184	218	252	286
15	49	83	117	151	185	219	253	287
16	50	84	118	152	186	220	254	288
17	51	85	119	153	187	221	255	289
18	52	86	120	154	188	222	256	290
19	53	87	121	155	189	223	257	291
20	54	88	122	156	190	224	258	292
21	55	89	123	157	191	225	259	293
22	56	90	124	158	192	226	260	294
23	57	91	125	159	193	227	261	295
24	58	92	126	160	194	228	262	296
25	59	93	127	161	195	229	263	297
26	60	94	128	162	196	230	264	298
27	61	95	129	163	197	231	265	299
28	62	96	130	164	198	232	266	300
29	63	97	131	165	199	233	267	301
30	64	98	132	166	200	234	268	302
31	65	99	133	167	201	235	269	303
32	66	100	134	168	202	236	270	304
33	67	101	135	169	203	237	271	
34	68	102	136	170	204	238	272	

Please mail:
- ❑ 305- List of AWS publications
- ❑ 306- Information on AWS Membership

NO POSTAGE NECESSARY IF MAILED IN THE UNITED STATES

BUSINESS REPLY MAIL
FIRST CLASS PERMIT NO. 11992 MIAMI, FL

POSTAGE WILL BE PAID BY ADDRESSEE

WELDING Journal
C/O CREATIVE DATA
519 E BRIARCLIFF RD
BOLINGBROOK IL 60440-9882

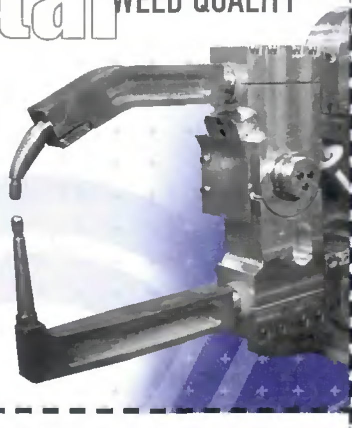
For faster processing, please FAX this card to (630) 739-9700.
Type or print the information and copy before faxing.
This fax number is for the service bureau only, not AWS.

NO POSTAGE NECESSARY IF MAILED IN THE UNITED STATES

BUSINESS REPLY MAIL
FIRST CLASS PERMIT NO. 11992 MIAMI, FL

POSTAGE WILL BE PAID BY ADDRESSEE

WELDING Journal
C/O CREATIVE DATA
519 E BRIARCLIFF RD
BOLINGBROOK IL 60440-9882



Use these convenient, postage-paid inquiry cards to request free information about the products or services advertised in this issue of *Welding Journal*.

For information about specific advertisements: Circle the key number on the card that matches the number on the bottom of the ad.

FREE INFORMATION • FREE INFORMATION

Please send literature on items circled at right:

May 2006 Card void after November 1, 2006

Name ________ Title ________

Company ________

Address ________

City ________ State ________ Zip ________

Phone: ________ Fax: ________

E-mail ________

Please circle an entry for each category:

I. TYPE OF BUSINESS
1. Construction
2. Primary Metal Products
3. Fabricated Metal Products
4. Transportation
5. Petrochemical
6. Misc. Repair Services
7. Educational Services
8. Utilities
9. Other

II. JOB FUNCTION/TITLE
1. Corp. Management
2. Plant Mgmt.
3. Engineer
4. Welding or Cutting Oper.
5. Quality Control
6. Sales
7. Purchasing
8. Education
9. Other

III. PURCHASING AUTHORITY
1. Recommend
2. Specify
3. Approve

IV. NUMBER OF EMPLOYEES
1. Under
2. 50 to 99
3. 100 to 499
4. 500 to 999
5. 1000 to 2499
6. 2500 to more

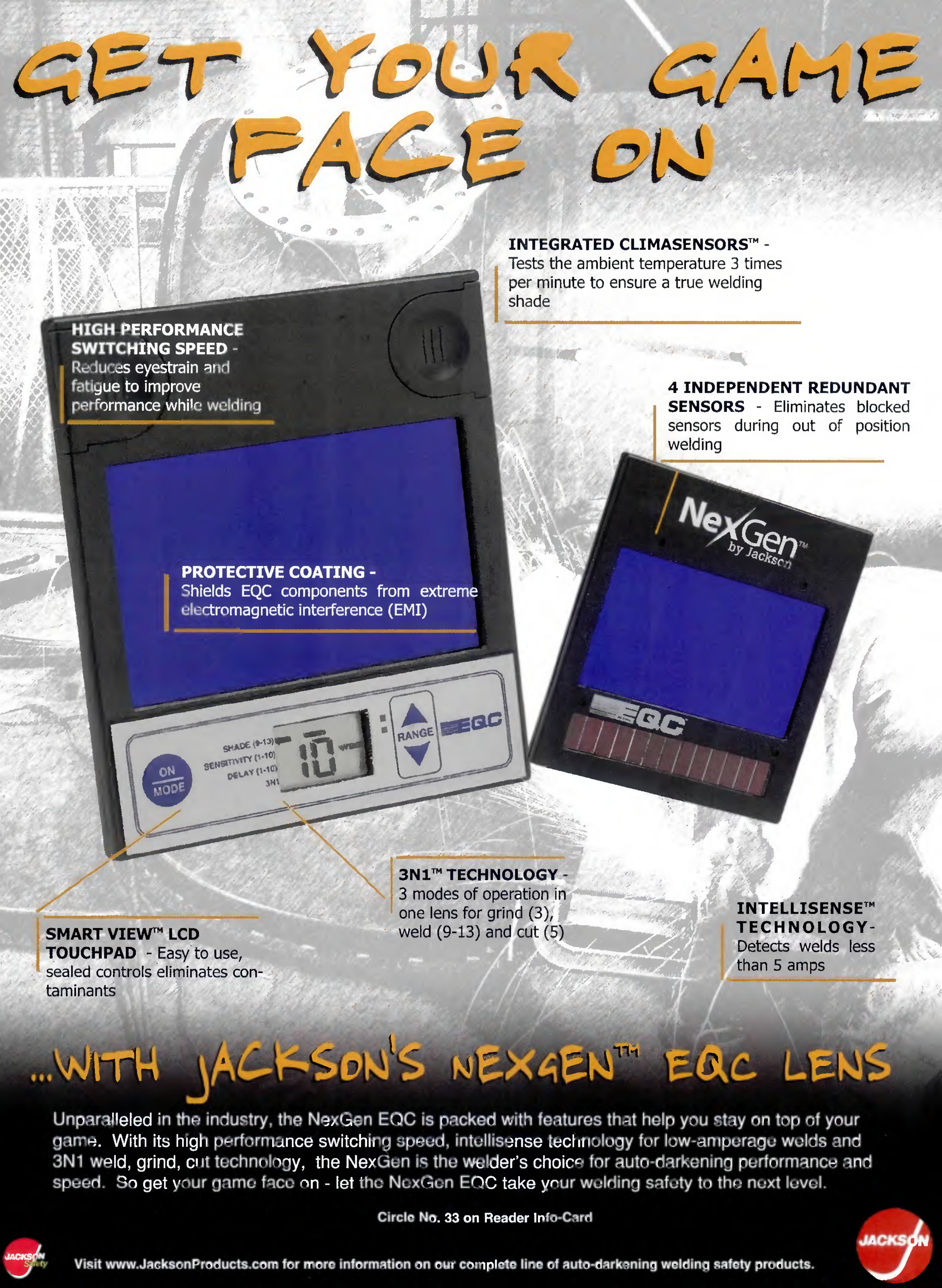
V. ANNUAL DOLLAR VOLUME
1. Under $1 Million
2. $1 Million to 5 Million
3. Over $5 Million

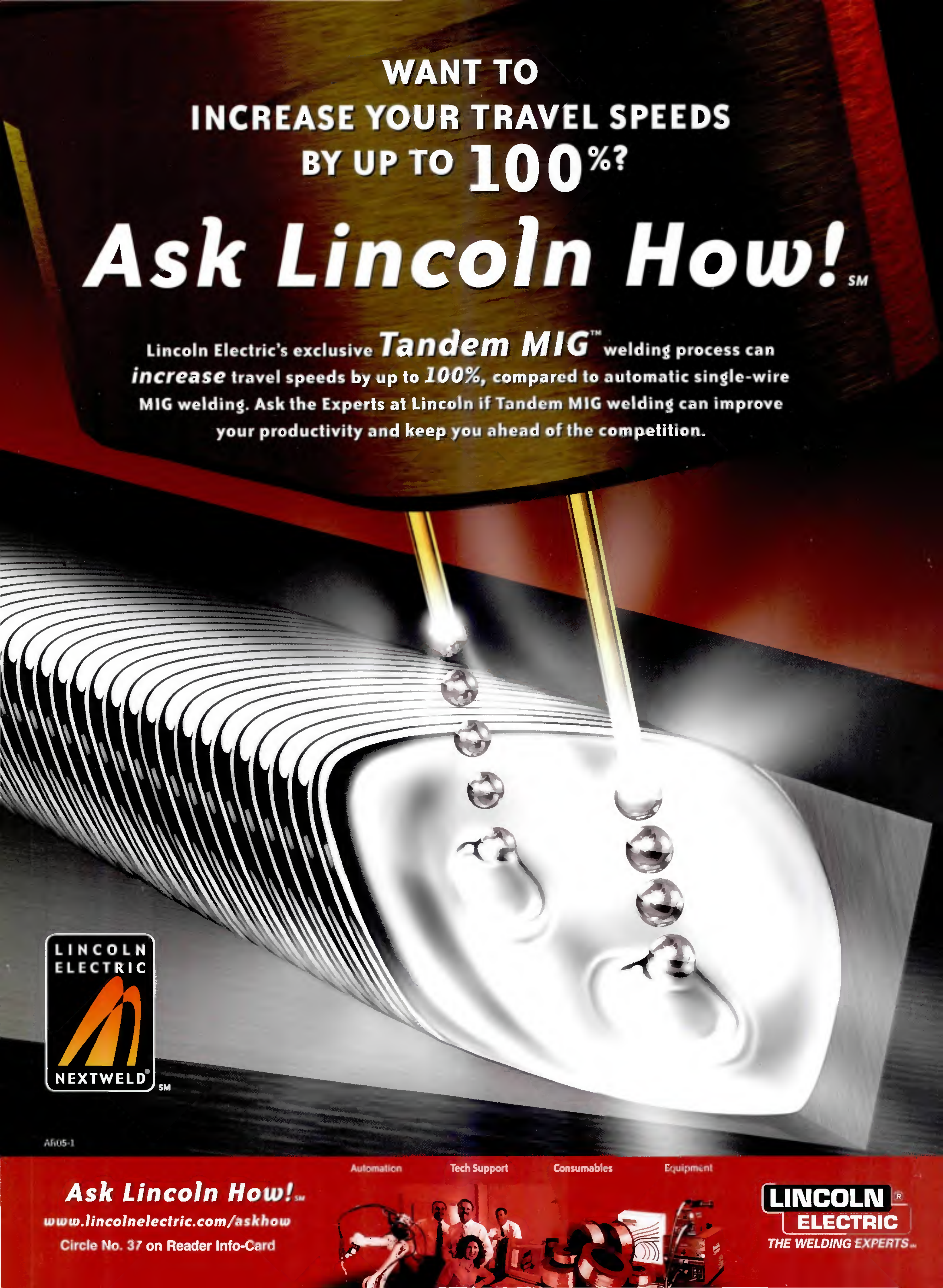
VI. THIS INQUIRY IS FOR
1. Immediate Purchase
2. Future Project
3. General Information

1	35	69	103	137	171	205	239	273
2	36	70	104	138	172	206	240	274
3	37	71	105	139	173	207	241	275
4	38	72	106	140	174	208	242	276
5	39	73	107	141	175	209	243	277
6	40	74	108	142	176	210	244	278
7	41	75	109	143	177	211	245	279
8	42	76	110	144	178	212	246	280
9	43	77	111	145	179	213	247	281
10	44	78	112	146	180	214	248	282
11	45	79	113	147	181	215	249	283
12	46	80	114	148	182	216	250	284
13	47	81	115	149	183	217	251	285
14	48	82	116	150	184	218	252	286
15	49	83	117	151	185	219	253	287
16	50	84	118	152	186	220	254	288
17	51	85	119	153	187	221	255	289
18	52	86	120	154	188	222	256	290
19	53	87	121	155	189	223	257	291
20	54	88	122	156	190	224	258	292
21	55	89	123	157	191	225	259	293
22	56	90	124	158	192	226	260	294
23	57	91	125	159	193	227	261	295
24	58	92	126	160	194	228	262	296
25	59	93	127	161	195	229	263	297
26	60	94	128	162	196	230	264	298
27	61	95	129	163	197	231	265	299
28	62	96	130	164	198	232	266	300
29	63	97	131	165	199	233	267	301
30	64	98	132	166	200	234	268	302
31	65	99	133	167	201	235	269	303
32	66	100	134	168	202	236	270	304
33	67	101	135	169	203	237	271	
34	68	102	136	170	204	238	272	

Please mail:
- ❑ 305- List of AWS publications
- ❑ 306- Information on AWS Membership

NOTE:
To speed the processing of your inquiry, please provide ALL the information requested on the card. This will make it easier for the companies to follow up on your request as soon as possible.


GET YOUR GAME FACE ON
INTEGRATED CLIMASENSORS™ - Tests the ambient temperature 3 times per minute to ensure a true welding shade
HIGH PERFORMANCE SWITCHING SPEED - Reduces eyestrain and fatigue to improve performance while welding
4 INDEPENDENT REDUNDANT SENSORS - Eliminates blocked sensors during out of position welding
NexGen™ by Jackson
PROTECTIVE COATING - Shields EQC components from extreme electromagnetic interference (EMI)
ON MODE
SHADE (9-13)
SENSITIVITY (1-10)
DELAY (1-10)
RANGE
EQC
3N1™ TECHNOLOGY - 3 modes of operation in one lens for grind (3), weld (9-13) and cut (5)
INTELLISENSE™ TECHNOLOGY - Detects welds less than 5 amps
SMART VIEW™ LCD TOUCHPAD - Easy to use, sealed controls eliminates contaminants
...WITH JACKSON'S NEXGEN™ EQC LENS
Unparalleled in the industry, the NexGen EQC is packed with features that help you stay on top of your game. With its high performance switching speed, intellisense technology for low-amperage welds and 3N1 weld, grind, cut technology, the NexGen is the welder's choice for auto-darkening performance and speed. So get your game face on - let the NexGen EQC take your welding safety to the next level.
Circle No. 33 on Reader Info-Card
JACKSON Safety
JACKSON
Visit www.JacksonProducts.com for more information on our complete line of auto-darkening welding safety products.


WANT TO
INCREASE YOUR TRAVEL SPEEDS
BY UP TO 100%?
Ask Lincoln How! SM
Lincoln Electric's exclusive Tandem MIG™ welding process can increase travel speeds by up to 100%, compared to automatic single-wire MIG welding. Ask the Experts at Lincoln if Tandem MIG welding can improve your productivity and keep you ahead of the competition.
LINCOLN ELECTRIC NEXTWELD® SM
Automation
Tech Support
Consumables
Equipment
Ask Lincoln How! SM
www.lincolnelectric.com/askhow
Circle No. 37 on Reader Info-Card
LINCOLN ELECTRIC®
THE WELDING EXPERTS SM