Offshore Pipe Welding

Critical Tube Repair

Weld Inspection
All the Muscle Needed for E71T-1 Welding

Select-Arc, Inc. offers a complete line of E71T-1 flux cored, gas-shielded, carbon steel electrodes including the proven Select 71T and the innovative Select 727.

Since Select-Arc commenced tubular welding electrode production in 1962, Select 71T has served as the mainstay of the product line. That is because Select 71T is an excellent general purpose electrode with outstanding welder appeal. It features a smooth, stable arc transfer with low spatter; emission and delivers better penetration than most “stick arc transfer” products.

Select 71T is a superb choice for general plate fabrication, structural steel welding and other applications where strength and toughness properties are primary requirements.

The new Select 727 is an exceptional all-position, lower fume version of Select 71T. Formulated to provide improved deposition rates and enhanced welder appeal, Select 727 offers significant reductions in fume emissions (KER204) and spatter levels with superior bead geometry compared to conventional E71T-1 electrodes.

Select 727 is well-suited for situations where welding occurs indoors in areas where reduced fumes are required. This electrode’s strength and toughness make it ideal for applications such as structural, steel, farm machinery, construction equipment, marine, railcar fabrication and shipbuilding.

For more information on the time-tested Select 71T and the new Select 727 electrodes, call Select-Arc at 503-391-5215 or contact:

SELECT ARC INC.

E.O. Box 259
Fort Laramie, WY 82072
Phone: (307) 295-5215
Fax: (307) 295-5217
www.select-arc.com

Circle No. 32 on Reader Info-Card
Performance you can see in Bright Sunlight...
...on a Vivid Color Display

The new USN 58L Ultrasonic Flaw Detector features a color transreflective display, fast 60 Hz single shot update rate, and high visibility in direct sunlight. The USN 58L replaces the popular USN 50L and USN 52L instruments.

- Rugged USN durability and dependability
- Fast “spin & set” rotating knob operation
- Trigonometric Flaw Location Calculations with curvature correction
- AWS D1.1 weld rating calculation
- .040” to 480” measurement range in steel
- 65 selectable material velocities and AutoCAL for quick setup

- Unique “persistence” freeze modes retain critical signals on the screen for up to 2 seconds
- Freeze reference echoes in different colors to compare live signal

For complete information on the USN 58L visit: AgfaNDT.com/100
When you make the world's best MIG wire, you can back it with the world's best guarantee.

Lincoln Electric's 100% Satisfaction MIG Guarantee.

The best reason yet to switch to the best MIG wire in the world.

Circle No. 33 on Reader Info-Card

www.lincolnelectric.com/superarc

22801 St. Clair Avenue • Cleveland Ohio 44117 • 216.481.8100
The ABCs of Eddy Current Weld Inspection
A process suited for detecting surface-breaking cracks is explained

Rocket Fuel Line Repair Depends on GTA Welding
Stringent welding procedures led to the successful repair of fuel line bellows in the Space Shuttle Atlantis. J. Goudy and J. Brook

Orbital Welding in the Friendly Skies
Stress cracks in a 2-in.-diameter titanium tube were repaired with orbital welding technology

Selecting Filler Metals for Offshore Piping
Filler metals are recommended for joining pipe that transports hydrocarbons containing carbon dioxide and hydrogen sulfide. J. R. Stil

Characteristics of Welding and Arc Signal in Narrow Groove Gas Metal Arc Welding Using Electromagnetic Arc Oscillation
Optimum welding parameters are sought to minimize incomplete fusion in a deep, narrow groove. Y. H. Kang et al.

A Mathematical Model of Wire Feeding Mechanisms in GMAW
A model that predicts friction between a welding wire and its liner was developed to help evaluate conditions of poor feedability. T. M. Padilla et al.

Analysis of Gamma Titanium Aluminide Welds Produced by Gas Tungsten Arc Welding
Good performance at elevated temperatures makes TiAl intermetallic alloys attractive, but welding them requires a careful selection of parameters. M. F. Arenas et al.

Influence of Welding Machine Mechanical Characteristics on the Resistance Spot Welding Process and Weld Quality
Machine stiffness, friction, and moving mass were systematically investigated to determine their relation to weld quality. H. Tang et al.
EWI to Help U.S. Army ‘Lose Weight’

The Edison Welding Institute (EWI), Columbus, Ohio, recently signed a five-year, $22 million contract with the U.S. Army to develop advanced materials joining technologies for a new series of ground vehicles, aircraft, and weapons systems. Plans call for the new systems to be as durable, lethal, and mobile as the Army’s heavy forces, but far lighter and more quickly transportable.

The key outcome of the 10-year transformation the Army calls “Objective Force” will be a combat vehicle that will be 70% lighter and 50% smaller than a tank. Since the vehicle will fit inside a C-130 transport plane, the Army will be able to field a brigade anywhere in the world in 96 hours and a division in 120 hours.

The contract is between EWI and the Army Research Lab in Aberdeen, Md. EWI will receive $2.25 million immediately and approximately $5 million per year for the next four years, according to EWI President Ted Ford.

EWI will work with the Army Research Lab to explore a range of advanced welding and joining technologies that will combine composites, aluminum, and titanium for more efficient structural designs with newer, lightweight materials unlike any commercially available. The new techniques, accompanied by improved process control and nondestructive examination methods, must meet performance requirements and reduce the unit costs of the Army’s weapons systems.

For more information, contact Heidi Wilson, marketing communications manager, at (614) 688-5130 or heidi_wilson@ewi.org or Matthew White, market leader for heavy manufacturing and government programs, at (614) 688-5241 or matt_white@ewi.org.

West Virginia University and Hobart Institute Establish Articulation Agreement

The Hobart Institute of Welding Technology (HIWT) and West Virginia University — Parkersburg (WVU-P) have established an articulation agreement whereby university students can transfer credits earned for classes taken at the Hobart Institute.

Basic, intermediate, and advanced courses in oxyacetylene, shielded metal arc, gas tungsten arc, gas metal arc, and flux cored arc welding, along with blueprint reading, welding safety, and inspection courses from HIWT are transferable with the approval of the WVU-P division chair for students wishing to pursue a certificate or degree program in welding-related fields.

“Articulation agreements are vital to both our program and the Hobart Institute, because it enables students to continue their education to receive a one-year certificate, a two-year associate degree in welding science in welding technology, or a two-year associate degree in applied science in welding management/technician,” said Carl Smith, welding instructor at WVU-P. “Upon completion of these courses, if the student is interested, he or she may go on for a four-year bachelor’s degree in applied technology. All the degrees have been approved by North Central accreditation.”

Ron Scott, vice president and general manager of the Hobart Institute, said many students travel from West Virginia to Troy to attend HIWT and the agreement will give them more choices for continuing their education when they return home.

Airgas Acquires 14 Locations in Florida, Georgia, and California

Airgas, Inc., Radnor, Pa., recently acquired 14 branches in Florida, Georgia, and California from Union Industrial Group (UIG). An independent distributor headquartered in Irving, Tex., UIG will retain its propylene business and about 30 branches, primarily in the Southwest.

The operations acquired include ten locations in Florida and Georgia doing business as Action Welding Supply and Equipment Sales Co. and four California locations doing business as Northwestern Equipment and Supply Co. The 14 locations have annual sales of more than $20 million in packaged gases and welding hardgoods.

Airgas will integrate the new acquisitions into 3 of its 12 regional companies: Airgas South, Airgas West, and Airgas Northern California and Nevada. The sites will all do business under the Airgas brand.
Bohler Stainless Steel
Flux-Cored Wires
Save You Money...

...in the cost of shielding gas.
Excellent arc characteristics with 100% CO₂ or 75% Ar + 25% CO₂

...in the cost of fabrication.
The self peeling slag and smooth weld finish minimize time of post weld clean-up.

...in the cost of rework.
The wide arc provides uniform, deep penetration with good side wall fusion and a smooth weld profile.

Save Time and Money With
BOHLER Flux-Cored Wires For Stainless Steel

BOHLER flux-cored wires are proven for production welding world wide.

Bohler stainless steel flux-cored wires are ideal for both heavy wall components and thin sheet metal fabrication applications. They produce excellent results with either 100% CO₂ or mixed shielding gas. And, for positional welding our T1 wires provide excellent operating characteristics as well as help reduce operator fatigue.

Our flux-cored wires provide a powerful, penetrating arc that deposits a smooth spatter free weld that is cost effective, with excellent overall wire performance, reliably and consistently.

Little post weld cleaning is required and temper coloration is minimized. There are also fewer defects caused by porosity, slag inclusions or lack of fusion.

7 Reasons To Specify Bohler FCAW Stainless Wire

- Reliable and Consistent Weld Quality
- Smooth Welding Characteristics
- Minimum Post Weld Clean Up
- Excellent Operator Appeal
- Significantly Reduced Welding Costs
- Bohler Welding Manufactures to ISO 9001 Quality Standards
- World Wide Leader in Welding Technology for Over 75 Years

Circle No. 14 on Reader Info-Card

Bohler Thyssen Welding USA, Inc.
P.O. Box 721678
Houston, Texas 77272-1678
Phone: (281) 499-1212
Fax: (281) 499-4347
www.btwusa.com • custsvc@btwusa.com

Bohler Thyssen Welding Canada, Ltd.
22 LePage Court
Downsview, ON M3J 1Z9
Phone: (416) 638-3253
Fax: (416) 638-4632
www.btwcan.com • custsvccdn@btwcan.com
Starting the Next Chapter

As my year as your president draws to a close, I want to tell you what an honor it has been to serve you. In these changing times, we will always be faced with challenges, but the AWS board of directors continually works to maintain a steady course for the Society. This year began with the board and me having to make some very difficult decisions that resulted in some changes to how the Society operates. The changes were made and they will help us achieve our strategic goals. We have turned the pages in the AWS history book and are starting a new chapter.

Before I share with you some of the American Welding Society’s accomplishments, let me offer my special thanks to Bill Rice for serving as interim executive director as this fiscal year started. We now have a new executive director, Ray Shook, and the staff has been restructured to operate more efficiently. Ray is empowering the AWS staff to generate new ideas and methods for performing their duties with more intensity. Presidential task groups are now in place to investigate tightening expenses across the board to provide a leaner, but more efficient, operation, and to study the changes that must take place for the AWS Welding Show to be more beneficial to attendees and exhibitors.

The Society is committed to the education and training of the next generation of welding professionals and continues to be the driving force in preparing individuals to serve our industry in a wide range of careers. AWS is exploring ways whereby parents, students, educators, engineers, business executives, and government agencies will form and maintain positive opinions about welding. These groups do not know the value welding adds to products that make life easier, protect our nation, and explore outer space, or that it provides a wide range of well-paying careers. The American Architectural Review has produced a feature story about the welding industry, the need for welding professionals, and the American Welding Society with Morley Safer as the host. The story supports this positive image of welding and will be aired on PBS television. While we know the Society enjoys a positive image among a majority of its members and peers, the general public and industry as a whole are virtually unaware of the role welding plays in the world today. The recent Impact of Welding Study showed welding contributes $34 billion per year to the U.S. gross domestic product.

Internationally, we have established new international cooperative agreements and reaffirmed earlier ones with our sister organizations and societies in China, Italy, and South Africa, just to name a few. AWS continues to enjoy solid relationships with our sister societies and counterpart organizations. This is very important to AWS in building a consensus on international standards and other industry activities.

It has been my responsibility as your president, along with the board of directors, to make sure the integrity, ethics, and financial well-being of the AWS are not being compromised. We have a very strong board of directors, a great staff, and are going forward to preparing the next generation of welding professionals for our great industry.

I want to say a special thanks to my family, Lockheed Martin, and the AWS board of directors and staff for all their support during this exciting and challenging year, and I look forward to this next chapter in the story of the American Welding Society.

Ernest D. Levert
AWS President
The movie industry has the Oscars.

The music industry has the Grammys.

The world has the Nobel Prize.

Us, well, we've got this chart.

<table>
<thead>
<tr>
<th>Product Quality</th>
<th>Quality Certification (ISO-Type)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low Price</td>
<td>Relationship with Sales Staff</td>
</tr>
<tr>
<td>R &amp; D Support</td>
<td>Technical Capability</td>
</tr>
<tr>
<td>Equipment Delivery Time</td>
<td>Warranty Length</td>
</tr>
</tbody>
</table>

While it may not seem like much to look at, we're proud of what it says. And now that we are one company, we've combined our strengths to make sure we're on top again next year. Because our goal is to continue to give you a superior product and excellent service at a reasonable price. So give us a call at (800) 547-1527 or visit www.ajaxtocco.com to get a copy of the poll, and discuss how we can put you at the top of our list.
Site Details Safety Equipment and Programs

International Safety Equipment Association (ISEA). This organization, based in Arlington, Va., is the trade association for U.S. companies that manufacture safety equipment. Included in the association are products for head, eye and face, respiratory, hearing, hand, and fall protection; environmental monitoring instruments; safety warning signs and symbols; emergency eyewash and shower; first aid kits, clean room garments, and safety wearing apparel. According to the association's Web site, ISEA "provides the forum through which its members can work to promote the standardization of safety equipment; represent the industry's interests before government bodies and interpret government actions to the industry; collect and disseminate information about the industry; maintain links to other organizations in the safety industry worldwide; and promote the proper use of personal protective equipment as essential to worker safety and health."

While some pages of the site are restricted to members only, it offers plenty of information that is available to any visitor. The site's "Safety Equipment Standards, Certification, and Regulation" section gives detailed information on what standards are, how they are developed, the roles of the American National Standards Institute (ANSI) and Occupational Safety and Health Administration (OSHA), and links to standards-developing bodies including the American Welding Society.

Visitors can search the "Buyers' Guide" by product category. Contact information and links are provided for each member company listed. The "Product Guides" section details ISEA's use and selection guides for nonpowered air purifying particulate respirators, personal fall protection equipment, and high-visibility products.

Links are provided to ISEA's Partnership for Worker Protection Web site, which provides information on ISEA's programs to prevent injuries and save lives in road construction. That site includes Protection Update newsletters, product guides, links to partner organizations, and other information.

Government activities can be found in the "Public Affairs" section, a "Calendar of Events" is available, and ISEA standards and other publications can be purchased through the Web site.

www.safetyequipment.org

Interests of U.S. Businesses Highlighted

U.S. Chamber of Commerce. The Web site for this Washington, D.C., based organization provides news, commentary, and information from the perspective of U.S. business. While not the parent organization of the local and state chambers of commerce, local chambers can become members, as can businesses and associations. Visitors can locate a local chamber through this site by either clicking on a map of the United States or typing in the name or location of the chamber they are interested in.

Much of the site focuses on governmental issues. The "Government and Legal" section provides background and contact information on members of Congress and other elected officials, including their committee assignments and voting records. Visitors can also check the status of legislation by typing in keywords or the bill number and check on litigation the chamber is interested in or is a party to. The "Issues Index" states background information and the chamber's position for a long list of government-related issues.

The "News and Events" section provides links to that day's industry-related news articles from newspapers around the country. It also provides press releases, and the text of speeches and letters to Capitol Hill.

In addition, the site lists member benefits and provides information on its Statistics and Research Center.

www.uschamber.com

Site Features Robotic Welding and Cutting Systems

Genesis Systems Group. This integrator of robotic welding and cutting systems based in Davenport, Iowa, recently redesigned its Web site. The site now provides 360-deg virtual views of the company's Versa-System work cells. A "News and Events" section provides a trade show schedule and press releases covering new products, services, and industry-related topics.

Visitors can request information online and download product brochures in PDF format using Adobe® Acrobat® Reader™. The company's training services as well as its own employment opportunities are also featured.

www.genesis-systems.com

Cylinder Sales and Service Showcased

Cyl-Tec, Inc. This Aurora, Ill., company sells new and reconditioned compressed gas cylinders and related products. Services include portable cryogenic cylinder repair, high-pressure cylinder testing and maintenance, and aluminum cylinder polishing. The Web site provides detailed information regarding sales and service, a company history, and contact information.

www.cyl-tec.com
Speed, Safety and Performance—All In One Package!

The Jackson NexGen™ EQC®.
Truly the next generation of auto-darkening for the welding specialist. The NexGen offers the flexibility of digital technology with the stability of analog to make the smartest auto-darkening filter on the market!

Controls protected inside the helmet
Four staggered sensors eliminate blocking and flickering
Intelli sense technology: allows unit to detect welds less than 5 amps

Replaceable lithium batteries
Versatile cartridge fits in most 4” x 5” vertical windows
Low battery indicator
Soft touch control panel eliminates contaminants

Smart View™ LCD for fingertip control information

Circle No. 29 on Reader Info-Card

Jackson Products—The Only Auto Darkening Filters Made in the USA
Army Student Completes S.E.N.S.E. Program and Achieves AWS Certification

BY E. C. STARNES, U.S. Army Ordnance Corps

He is the first. And the accomplishment will follow him throughout his career, whether it’s in the military or in civilian industry.

Private Nathan L. Henderson, Globe, Ariz., became the first student at the Ordnance Mechanical Maintenance School (OMMS) at Aberdeen Proving Ground, Md., to meet the AWS S.E.N.S.E. (Schools Excelling through National Skill Standards) Program standards and be certified by AWS.

Major Gen. Mitchell Stevenson, the Army’s Chief of Ordnance, joined Henderson’s fellow students, cadre, and instructors in honoring his achievement at an informal ceremony at Aberdeen Proving Ground.

Chief Warrant Officer 3 Michael Trzeciak, chief of the Metalworking Services Department, noted, “This program is a tough, realistic enhancement to our training. It has raised the standards for both the students and the instructors. Those students [like Henderson] that have prior experience or training now have something to challenge them.”

Stevenson explained that the AWS accreditation and certification program is just one of many programs completed or in the works to provide Ordnance soldiers with professional recognition from civilian industry.

Henderson explained he had some welding experience and training prior to coming to OMMS. In addition to training from his father, he had studied welding for three years in high school and two years in college. Prior to enlisting in the Army, he worked for Bowen Construction and Phelps Dodge Miami Mining in his home state of Arizona.

Henderson said he undertook the S.E.N.S.E. program because “It was a new challenge and I knew it could only benefit me. Later on in my career, it will be an advantage for me and help me secure a position in the metalworking field.”

Trzeciak explained Henderson worked hard to achieve success. “He was given a drawing and without assistance required to fabricate and weld the assembly. He completed both horizon-

Every Blue box is built with guts and wired with soul.

A welder is a welder is a welder. Unless it’s Blue. Strip away the cover, copper wire and controls, and you’ll find the most dedicated, passionate and skilled people in the world. Empowered by a common sense of purpose — your success — Miller people take their work seriously. While you may never meet line reps Lori and Larry, or need an applications engineer like Kevan, one thing’s for sure: there are 1,200 other folks just like them who Bleed blue just for you. To learn more, visit MillerWelds.com or call 1-800-4-A-MILLER. And experience The Power of Blue for yourself.
Henderson said it took about three weeks to complete the program. He recommends it to his fellow soldiers. "Anything you can do and learn from is worth doing and doing right." He also praised his Army training. "I learned a lot about myself and gained a newfound respect."

Trzeciak explained that there are four other soldiers currently attempting certification. He said the process challenges the students "by raising the standards and produces better quality soldiers. Additionally, it will make our soldiers more marketable upon leaving the military."

Henderson graduated from the Metalworker course (military occupational specialty 44B) on March 19 and is headed to Fort Hood, Tex., for his first assignment.

In addition to the AWS certificate, Henderson received a Chief of Ordnance coin from Stevenson and a 16th Ordnance Battalion Certificate of Achievement from Lt. Col. Thomas Keegan, battalion commander.

The training for 44B includes inspecting, installing, modifying, and maintaining the metal body components, radiators, fuel tanks, hulls, and accessories of Army watercraft and amphibians. Entry-level training includes welding ferrous and nonferrous metals using oxyacetylene and arc welding equipment.

**Speed Channel Show to Feature Welding of Aluminum**

Sam Memmolo and Dave Bowman, hosts of *Two Guys Garage* on Speed Channel, will demonstrate aluminum gas metal arc welding with a Lincoln Electric SP-135 Plus power source. The
Let Phoenix show you how to protect your welding profits!

NEW - DryRod® Portable Welding Electrode Stabilizing Ovens

• Protects welding rods from hydrogen-producing moisture
• Four capacities available: 10 lbs. (5kg), 20 lbs. (10 kg), 50 lbs. (25kg), and 150 lbs. (70kg)
• Wire wrap heating element assures superior heating performance
• Adjustable thermostat, thermometer, and indicator light standard (except T1)
• Available through your local welding distributor

www.phx-international.com

Phoenix International, Inc.
6151 N. 64th Street • Milwaukee, WI 53218
Ph: (414) 431-2620 • Fax: (414) 438-0238

Circle No. 37 on Reader Info-Card

show will run Sunday, June 1, at 11:00 a.m.

Memmolo and Bowman, along with Joe Kolasa from Lincoln Electric, will cover topics such as wire and shielding gas selection, changing the gun liner, setting the wire tension, and welding techniques. The equipment will be used to build an aluminum engine stand.

In addition, Kolasa will discuss gas tungsten arc welding (GTAW) for jobs that require more precise welding. GTAW demonstrations will include work on aluminum radiator fittings and valve cover air intakes.

Welder Honors Veterans with Handcrafted Replica U.S. Flags

Visitors to the AWS Show in Detroit in April got the chance to see firsthand one of the American flags Tony Golda welds together and gives free-of-charge to U.S. veterans and others who serve their country. Golda displayed a large-sized flag, which measures 3 ft x 5 ft and weighs approximately 70 lb. The small-sized flags he gives away weigh about 4 lb.

Currently disabled, Golda formerly worked as a welding machine repairman. The Sterling Heights, Mich., resident began using his welding skills to manufacture the flags about five years ago. He got the idea for making the flags when his family received a flag from the U.S. government after his father's death. “My dad didn't get a flag until he died,” Golda said. “I felt veterans should get a flag during their lifetime.”

While he has concentrated on giving the flags to World War II and Korean War vets, Golda said, “I have given them to cops, firemen, and a guy from the Federal Aviation Administration who investigates plane crashes. I always sign the back of them ‘thanks for serving our country!’ He has fabricated and given
Tony Golda of Sterling Heights, Mich., thanks veterans for their service by giving them handmade replica U.S. flags.

away several hundred flags so far and always carries one with him just in case he meets a veteran who would like a flag.

Golda uses a plasma arc cutting machine to cut out the stripes and gas metal arc welding and some rivets to put the flags together. They are made from sheet metal he recycles from old police lockers. A blue painted surface serves as background for stars made from metal washers. The stripes are painted red and white.

Delphi Develops Tube Welding Process

Delphi Technologies, Inc., Troy, Mich., a subsidiary of Delphi Corp., recently introduced a method for welding metal tubes to solids, sheet metal, and other tubes that it calls Annular Deformation Resistance Welding (ADRW). According to the company, the process allows for increased design flexibility while reducing cost, investment, and weight.

The process utilizes commonly used lean resistance welding equipment. It has a wide weld schedule tolerance and welds parts that do not need close dimensional tolerancing. The process creates joints through the deformation and displacement of nugget material at the interface. It creates leak-tight joints with uniform circumferential weld strength.

Further information is available at www.delphi.com/dti.

GSI Lumonics Moves All Laser Sources to Rugby, England

GSI Lumonics, Inc., Farmington Hills, Mich., recently consolidated the design and manufacturing of its laser products into its 100,000-sq-ft facility in Rugby, England. This includes all of its lamp and diode-pumped solid-state lasers, as well as excimer and CO2 laser sources. The move does not impact the company's components products and systems manufacturing.

The company has made an investment in training, improved clean rooms, and extended manufacturing facilities at the Rugby facility. By consolidating its laser sources portfolio under one
ECONOMICALLY PRICED TUNGSTEN GRINDER

SAFETY: Enclosed diamond wheel grinding area
WELD QUALITY: 20 Ra finish improves tungsten life, starting & arc stability
PRODUCTIVITY: Longitudinal diamond grind your tungsten under 30 seconds
VALUE: Diamond flat, grind & cut your tungsten economically

DIAMOND GROUND PRODUCTS, INC.
2550 Azurite Circle Newbury Park CA 91320
Phone (805) 498-3837 • FAX (805) 498-9347
Email: sales@diamonground.com
Visit our website: www.diamonground.com

NADCAP Reaccredits HiTech Aero

HiTech Aero (HTA), a HI TecMetal Group member company located in Eastlake, Ohio, successfully completed a six-month reaccreditation audit recently and maintained its National Aerospace and Defense Contractors Accreditation Program (NADCAP) accreditation from the Performance Review Institute. The company was reaccredited for the heat treating of beryllium copper, nickel and cobalt alloys, stainless and pH stainless steels, and titanium alloys (stress relief only). HiTech Aero was also approved for the following heat treating processes: vacuum heat treating, furnace brazing, and cryogenic treatments. The facility was also audited and reaccredited for hardness testing.

Industry Notes

Northrop Grumman Corp. was recently awarded a $23 million contract for dry docking work on the nuclear-powered submarine USS Minneapolis-St Paul. The work will be performed at the Newport News sector in Newport News, Va. Work to be done includes replacement of the tail shaft, removal and overhaul of the main and auxiliary sea valves, inspection and repair of all external and internal tanks, miscellaneous repairs to torpedo systems, and inspection and repairs to the sail, pressure, and nonpressure hulls. Work is scheduled for completion in mid-June.

COR-MET
MANUFACTURERS OF CORED WELDING WIRE AND STICK ELECTRODES

We have been told that we are the best-kept secret in the welding industry. In an effort to correct this situation we advise that:

WE MAKE

<table>
<thead>
<tr>
<th>Stainless</th>
<th>Cast Iron</th>
<th>Cobalt</th>
<th>AISI</th>
<th>Nickel</th>
</tr>
</thead>
<tbody>
<tr>
<td>410NiMo FC</td>
<td>33% Ni</td>
<td>1</td>
<td>4130</td>
<td>ENiCrFe-2</td>
</tr>
<tr>
<td>502 FC</td>
<td>55% Ni</td>
<td>6</td>
<td>4140</td>
<td>ENiCrFe-3</td>
</tr>
<tr>
<td>505 FC</td>
<td>99% Ni</td>
<td>12</td>
<td>4340</td>
<td>EniCrCoMo-1</td>
</tr>
<tr>
<td>E2553 FC</td>
<td>21</td>
<td></td>
<td></td>
<td>ERNiCrMo-3</td>
</tr>
<tr>
<td>E2209 FC</td>
<td></td>
<td></td>
<td></td>
<td>ERNiCr-3</td>
</tr>
<tr>
<td>E630 FC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>904L FC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

THE ABOVE ARE JUST A FEW OF THE CORED WIRES THAT WE MAKE. FOR MORE INFORMATION CALL:

COR-MET, INC. • 12500 EAST GRAND RIVER • BRIGHTON, MI 48116

Circle No. 52 on Reader Info-Card

Circle No. 20 on Reader Info-Card
Wind River Systems, Inc., Alameda, Calif., a provider of software and related services, recently awarded ABB Robotics its Cool Customer Design Award for the IRB 6600 industrial robot. The robot is equipped with a “bending backwards” flexible arm that enables it to complete multiple tasks in real-time, including upper arm extension and a selection of wrist movements. The robot’s control system, which was built on Wind River’s VxWorks® real-time operating system, allows users to customize the robot to control different tasks. ABB also used Wind River’s networking technology to build a service information system into the robot that allows users to remotely monitor the robot’s motion and load.

Joining Technologies, East Granby, Conn., a precision welding job shop, was recently named the primary North American distributor of the TRUMPF PowerWeld laser workstation. The workstation was specifically designed for welding operations in the mold and toolmaking industry. It can be used to repair worn or broken tools or modify tools requiring design changes or the addition of complex geometries. The PowerWeld can be equipped with different pulsed Nd:YAG lasers in average outputs from 40 to 200 W. The laser beam is guided to the workstation via a flexible fiber-optic cable, allowing the laser unit and workstation to be set up at any location.

Kobe Steel, Ltd., and Infra, S.A. de C.V., a unit of Mexico’s Infra Group, are collaborating to expand the marketing of Kobelco welding materials in Central and South America. As part of the agreement, Infra will sell Kobe’s flux cored welding wire and Kobelco Welding of America Inc. will provideInfra and its customers with product support and technical services. Infra is Mexico’s leading manufacturer of welding equipment, consumables, and gas.

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.

The faces behind Stoody hardfacing

They may not be pretty faces, but these experienced Stoody specialists and product engineers have the answer to any hardfacing challenge you may have. For 80 years, Stoody has specialized in developing and refining some of the best-known hardfacing products in the business: Dynamang®, Nicromang®, Borkum®, Thermaclad®, Brilliant®, Stoodite®, BTS, 100H, 100HC, 101HC and Super 20. Recent additions to Stoody’s market leading products include CF2000, Stoody 160 and Stoody 140.

For the name of the Stoody distributor or factory specialist nearest you, call (800) 227-9333 or www.stoody.com.
Q: We are attempting to qualify a submerged arc cladding of 309L stainless on mild steel. To do so, we must pass a 2T bend test of a cross section of the cladding and base metal. We keep failing the bend test with brittle cracks in the first layer of cladding. The cladding seems to have excessive dilution because the chemical composition of the first layer seems very lean (i.e., 12% Cr and 6% Ni), and because we find martensite in the cladding. We have seen several references (e.g., Welding Handbook, Vol. 4, 8th ed. page 399) that state lower dilution is obtained with direct current electrode negative (DCEN) polarity than with the direct current electrode positive (DCEP) polarity we had been using. So we tried DCEN, but with no better results — the bend tests still failed in a brittle manner. And the DCEN first layer has about the same composition we saw with DCEP. Why doesn’t DCEN reduce the dilution? And what can we do to produce cladding that will pass the bend test?

A: There are two levels of excessive dilution in cladding mild steel with ER309L, regardless of the welding process you use. In the more severe level of dilution, as you are experiencing, the chromium and nickel from the stainless filler metal are diluted to such an extent that the austenite formed at high temperature is unstable and transforms to martensite during cooling. The martensite is brittle and cracks during bending. If you succeed in reducing the dilution somewhat, you can easily end up with a deposit that is stable austenite at room temperature but contains no ferrite. In that case, it is likely to form hot cracks during solidification, and you will fail the bend test despite the stable austenite, because the hot cracks will open up during bending. So you have to make at major reduction in dilution, not a minor reduction.

The conventional wisdom that DCEN produces lower dilution than DCEP in submerged arc welding (SAW) is only part of the solution to your problem. There are two other parts. The first part of the solution is the ER309L filler metal itself. Its composition needs to be balanced by the producer so that it does more than just satisfy the composition limits of ER309L in the AWS A5.9 standard. The filler metal composition needs to be further restricted...
so that, when it is plotted on the WRC-1992 diagram, the diagram will predict a high Ferrite Number for the filler metal, at least 10 FN. Steel mills do not like to produce heats of steel for drawing into welding wire that are so high in predicted FN because their yield in reducing the as-cast steel into rod suitable for wire drawing is lower with higher FN. They prefer to produce what I refer to as "generic" 309L with low FN, but this does not make good welding filler metal because it has little tolerance for dilution from mild steel without hot cracking. The filler metal supplier has to demand, from the steel mill, high ferrite 309L for processing into wire, and you have to insist on getting high ferrite ER309L.

The second part of the solution is in your choice of the other welding conditions besides polarity. The same page of the Welding Handbook that you cited also indicates that increasing the welding current increases the dilution. Or, conversely, reducing the welding current reduces the dilution. And on the same page it notes that increasing contact-tip-to-work distance reduces dilution, and decreasing the pitch or step-over between beads in a layer will reduce dilution. The degree to which you can reduce dilution by increasing contact-tip-to-work distance and/or by decreasing step-over is greatly affected by your ability to consistently place the welding electrode in a straight line. As a result, while some reduction in dilution is possible, major improvements are not usually available by these two avenues.

Welding current is the most important way of reducing dilution in DCEN overlay with submerged arc. Welding current is largely controlled by wire feed speed, which also sets the deposition rate. So there is a tendency to run higher wire feed speeds (WFS) to obtain higher deposition rates, but this is exactly the wrong direction to go to for reducing dilution. Figure 1 shows four single-pass deposits of stainless on 1-in. (25-mm) mild steel made using DCEN and ½-in. (1.2-mm) diameter wire. The welding is done at progressively higher wire feed speed and current, with progressively higher travel speed to obtain consistent deposit cross-sectional area above the plate surface.

Figure 1 shows that consistent cross-sectional area of deposit above the plate surface was obtained for all four deposits, but the penetration into the plate is vastly different, increasing with increasing wire feed speed (current). By comparing the cross-sectional area above and below the plate surface, you can see that the deposit made with 60 in./min WFS has less than 20% dilution, while that made with 180 in./min WFS has about 50% dilution. With 309L filler metal of at least 10 FN, less than 20% dilution will produce a deposit composition that is stable austenite with a little ferrite.

Once the first layer of low dilution cladding is successfully deposited, the deposition of subsequent layers, if needed, can be done with higher productivity procedures. But it is essential for the first layer to be deposited under low dilution conditions to obtain a crack-free overlay that will consistently pass a 2T bend test.

DAMIAN J. KOTECKI is Technical Director for Stainless and High-Alloy Product Development for The Lincoln Electric Co., Cleveland, Ohio. He is a member of the AWS A5D Subcommittee on Stainless Steel Filler Metals; AWS D1 Structural Welding Committee, 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. Questions may be sent to Mr. Kotecki c/o Welding Journal, 550 NW LeJeune Rd., Miami, Fl. 33126 or via e-mail at Damian_Kotecki@lincolnelectric.com.

The patented 1Torch™ from Thermal Dynamics, with innovative Advanced Torch Connection (ATC™), is the first plasma cutting torch designed to operate with virtually any plasma cutting system. As a replacement torch for both hand and mechanized models, the 1Torch delivers top performance and low cost of operation across a wide range of cutting systems from 20-105 amps. 1Torch’s ergonomic handle and lighter leads provide operator comfort and ease of use without compromising rugged reliability. And an innovative new technology makes 1Torch available for all your plasma systems.

For more details on the revolutionary 1Torch, contact your local distributor or call (800) 752-7621 or visit www.thermal-dynamics.com.
**NEW PRODUCTS**

**Orbital Weld Head Joins Pipes Elbow to Elbow**

The Model 83 mounts on 14-in. elbows from 42.5 to 199 deg with wall thicknesses up to 1.375 in. The weld head features a 300-A water-cooled torch, and can weld one short-radius elbow to another in tight spaces.

Arc Machines, Inc. 100
1050 Orbital Way, Pacoima, CA 91331

**Box Furnace Heat-Treats for Various Applications**

The No. 908 heavy-duty box furnace performs commercial heat treatment up to 2000°F. The unit is powered by natural gas, with workspace dimensions of 48 × 48 × 48 in. The unit features a digital temperature controller and includes safety equipment to meet IRI, FM, and NFPA standards.

The Grieve Corporation 101
590 Hart Rd., Round Lake, IL 60073

**Wire Brushes Clean Pipes and Tubes**

The company's power and manual tube brushes can be used for cleaning, deburring, and finishing crossholes, keyways, grooves, threads, pipes, and tubes.
Join the tens of thousands of engineers who turn to The American Society of Mechanical Engineers for expert training in the application of the Section IX Welding & Brazing Qualification and other codes.

Visit www.asme.org/weldtraining for complete details of the following courses available throughout the year at sites across the country...

- ASME Section IX Welding & Brazing Qualifications – also available in Spanish
- Practical Welding Technology
- Blueprint Reading and Graphic Symbols including ASME B16.25

While earning CEUs, you trade experiences with fellow engineers grappling with the same problems that you face.

For more information including the most convenient locations and dates, visit: www.asme.org/weldtraining

Brush fill materials include high-tensile steel, Type 302 stainless, brass, nylon, and Nylox® (nylon abrasive) filaments. Brush sizes range from ¼ to 2½ in. diameter.

Weiler Corporation
One Wildwood Dr., Cresco, PA 18326

Comfort and Color Encourage Ear Protection Compliance

Z-Series™ Disposable Earplugz provide 29 to 31 NRR (noise reduction rat-

---

Drink to Keep Your Jobsite Cool

Circle No. 5 on Reader Info-Card

800-733-4043
hi-click.com/wharris.com
Find a Distributor: www.siliconbrazing.com

Circle No. 29 on Reader Info-Card
Is your current cutting and beveling method outdated, labor intensive or causing you to miss deliveries? Discover our complete line of innovative cold cutting, flame cutting and beveling machines. Mathey Dearman's precision equipment produces a good-looking, accurate, quality cut requiring little or no grinding.

Have a clamping application that is causing you to lose sleep at night? Put the fun back into your life! We offer several advanced methods of achieving, quick and accurate alignment or reforming of pipes, elbows, tees and other fittings, while providing the maximum amount of safety for the welder.

Does the pipe or plate job that you are working on require precise job alignment? Discover our sensational line of Pipeflter's Tools to help you achieve and check the alignment that is required.

Need to keep or rebake welding electrodes or flux? Our proven line of small or large Keeping and Flux Ovens are known throughout the WORLD for their quality and craftsmanship.

The company's welding gas cylinders are equipped with Scandina™ caps, which offer valve protection and maneuverability. They also feature new chrome pressure values that help prevent backflow of gases that could contaminate the cylinder and reduce welding quality.

The DualARM System™ allows two ARC Mate welding robots and a position by coating them with ZRC Cold Galvanizing Compound. Only ZRC has an industry-leading 95% zinc content to provide true galvanic protection. Available in brush on, spray on or aerosol application.
er to be controlled by one controller and a single teach pendant at a lower cost than two single-arm systems. The system is optimized for such work as welding automobile axles and chassis.

FANUC Robotics America
3900 W. Hamlin Rd., Rochester Hills, MI 48309-3253

Pump Can Handle Dirty Water with Solid Debris

The T-30H submersible trash pump moves 338 gallons/min of water, which

OUR PLEDGE

IN THE FOLLOWING STICK ELECTRODE CATEGORIES WE OFFER NOT ONLY THE VERY HIGHEST PERFORMANCE CHARACTERISTICS BUT ALSO THE LOWEST PRICES AS COMPARED TO BOTH DOMESTIC AND IMPORTED BRANDS

- NICKEL CAST IRON ELECTRODES
- ALUMINUM STICK ELECTRODES
- COBALT STICK ELECTRODES
- ½" TUBULAR HARDFACING

AS A MID-SIZE 20 YEAR OLD SPECIALTY ELECTRODE MANUFACTURER, SELECTRODE INDUSTRIES HAS EVOLVED INTO A SUPPLIER THAT MANY RESELLERS HAVE RELIED ON HEAVILY FOR PRODUCT PERFORMANCE AND RAPID DELIVERY. THIS UNPARALLELED RECOGNITION OF OUR CAPABILITIES HAS ENABLED US AS AN AMERICAN MANUFACTURER TO MAKE THE ABOVE, UNPRECEDENTED COMMITMENT.

SELECTRODE® INDUSTRIES, INC.
230 Broadway
Huntington Station, New York 11746
Ph: 631-547-5470
Fax: 631-547-5475
email: info@selectrode.com
Website: www.selectrode.com

The commercial diving industry wants qualified underwater wet welders. The College of Oceaneering offers all the education you need for a solid career in inland and offshore wet welding technology. We offer unparalleled certifications that you can't get anywhere else. Plus, take advantage of our lifetime career placement assistance.

Circle No. 39 on Reader Info-Card

Just add water

COLLEGE OF OCEANEERING
PORT OF LOS ANGELES ° SAN DIEGO
www.cos.edu

Circle No. 18 on Reader Info-Card
can include solid debris up to 1 in. diameter. The self-priming pump is powered by an 8-horsepower Honda GX-240 engine.

STOW Mfg.
18910 Wilmington Ave., Carson, CA 90746

Ergonomic Metallurgical Microscope Magnifies User Comfort

The LX-31 inverted metallurgical microscope features an ergonomic arrangement of controls and stage handles for user comfort and efficiency. Standard objective magnifications are 5X, 10X, 20X, and 50X, with a 10X eyepiece. The unit also features a trinocular video port.

LECO Corporation
3000 Lakeview Ave., St. Joseph, MI 49085

Welding Generator Reaches New Heights

The Big Blue® Turbo welding generator operates at altitudes greater than 3 miles (5000 m) with no loss of output.
Powered by a turbo-charged Deutz 2001 diesel engine, the generator creates a welding output of 45 to 750 A for SMAW and 20 to 500 A for GMAW. The unit is Mine Safety Health Administration-approved for use in underground coal mines.

Miller Electric Mfg. Co.
F.O. Box 1079, Appleton, WI 54912

Face Shield Provides Purified Air Protection

The ClearVisor with Adflo® system combines full face protection with a lightweight respirator. The rechargeable battery-powered respirator includes a particle filter that can be enhanced with additional cartridges to protect from specific hazards, such as organic vapors, sulfur dioxide, and chlorine fumes.

Hurnell, Inc.
2374 Edison Blvd., Twinsburg, OH 44087

Laser Helps Straighten Out Production Processes

The PL-100 alignment laser produces a bright red beam for adjusting equipment, aligning production parts, positioning conveyors, and other industrial setup tasks. The laser is 1 in. diameter x 5 in.

Less handling, easier positioning, faster and cleaner welds.

Atlas Pipemate and Idler Rolls
- Unit with idler rolls supports balanced loads up to 1000 lb.
- Rotates pipe and tube up to 17" dia.
- Portable, low profile for shop or field
- Dual speed 0 to 30 in/min or 0 to 60 in/min
- High frequency filter prevents interference with GTA welding

Atlas Rotary Table Positioners
- Three models: 9" table, 100 lb. capacity, 10° tilt table, 200 lb. capacity, 14" table, 500 lb. capacity
- Heavy duty grounding circuit for stick electrode, MIG or TIG welding
- Low profile for bench mounting
- Foot switch for feathering speed and on/off control
- Front panel speed and rotation controls

Other handling and welding aids... Atlas Pipe Supports, Atlas Roller Stands, Atlas Pipe Dollies

ATLAS WELDING ACCESSORIES, INC.
Troy, MI 48099
800-962-9353
WWW: atlasweld.com E-Mail: atlaswelding@ameritech.net

Circle No. 6 on Reader Info-Card
INCONEL® alloy 22 is a modified version of INCONEL alloy 622, with a composition optimized to resist corrosion by a wide range of both oxidizing and reducing acid media. The alloy is nickel-based, containing 21.5% Cr, 13.6% Mo, and 3% W. The company also provides approved welding consumables for the alloy.

Special Metals Corp.
3300 Riverside Dr., Huntington, WV 25705

Flux Core Wire Designed for High Argon Mixtures

Tri-Mark® TM-910™ is a gas-shielded flux core wire designed especially for argon gas mixtures of up to 95%. High argon mixtures can provide desired welding results with less smoke, fumes, and spatter. The wire is available in 0.045, 0.052, and ¼ in. diameters.

ITW Hobart Brothers Company
400 Trade Square E, Troy, OH 45373

Rotating Pallet Leveler Automatically Adjusts Height for Changing Loads

The P3™ Pneumatic Leveler uses spring-reinforced heavy-duty pneumatics to automatically adjust its height as pallets or boxes totalling as much as 4500 lb are added or removed. The unit features a turntable on antifriction bearings for manual work rotation.

Presto Lifts Inc.
21 Park St., Attleboro, MA 02703

THE ANSWER FOR INDEPENDENT WELDING SHOPS!

AWS AFFILIATE COMPANY MEMBERSHIP

MEMBER BENEFITS:

• Priceless exposure of your shop with free publicity on AWS’s 40,000-visitors-a-month website.
• $50 OFF a job posting on AWS JobFind www.aws.org/jobfind, your connection to hundreds of welders, inspectors and other job seekers!
• An AWS Individual Membership ($75 value), which includes need-to-know technical information through a FREE monthly subscription to the Welding Journal. WJ covers the latest trends, events, news and products guaranteed to make your job easier.

AWS AFFILIATE COMPANY

AFFILIATE COMPANY MEMBER

To join, or for more information call: (800) 443-9353, ext. 480 or (305) 443-9353, ext. 480 Visit us on-line at www.aws.org

Real-world business solutions for welding and fabricating shops

Circle No. 10 on Reader Info-Card

• Exclusive usage of the AWS Affiliate Company Member logo on your business card and promotional material for a competitive edge.
• Wall plaque to show your company’s affiliation with the world’s premier welding association.
• Window decal to display on your shop’s storefront.
• Free passes to the AWS Welding Show for you and your shop’s best employees.
• Unmatched networking opportunities at local Section Meetings, the annual AWS Welding Show, as well as at AWS-sponsored educational events.
• Professional development via discounts on world-renowned and industry-wide AWS Certification programs, conferences and workshops.
• Technical information through a 25% Members-only discount on 300+ industry-specific AWS Publications and technical standards.
Sonar® 1000 Series
Ultrasonic Flaw Detector / Thickness Gauge

- Fast 60 Hz update rate for shear wave weld inspection
- Customer-Interchangeable displays
  - Color Liquid Crystal
  - Monochrome Backlit Liquid Crystal
  - Hi-Brite Electroluminescent
- Trigonometric and curved surface calculations included
- FlawMaster™ software for custom documentation

- Simplicity of operation
- Wide range of industry accepted transducers - custom, off-the-shelf, and PVDF film
- VGA outputs for heads up display

Guaranteed free instrument loaner should your instrument ever need repair!

Circle No. 54 on Reader Info-Card
The

of Eddy Weld
The advantages of eddy current inspection include its effectiveness in detecting surface-breaking flaws and ability to be used on wet surfaces.
Currently, several nondestructive examination (NDE) techniques are used to inspect welds for defects: magnetic particle inspection (MP), liquid penetrant inspection (LP), ultrasonic testing (UT), X-ray testing (RT), and eddy current testing (ET). All have their advantages and disadvantages.

- Magnetic particle is straightforward and relatively easy to use but is not good for welds that have coatings or wet surfaces (surfaces must be dried first).
- Ultrasonic testing is good for finding subsurface defects but is operator dependent.
- Dye penetrant is good for surface cracks, but it also requires a dry surface and is operator dependent.
- X-ray is good for subsurface defects, but the radiation hazard requires additional safety considerations not necessary for other techniques.
- Eddy current is good for detecting surface-breaking defects, can detect these defects through fairly thick coatings (up to 2 mm), and can be used on wet surfaces (even underwater), but several scans of an individual weld must be performed to ensure a defect is not missed. Eddy current is also an operator-dependent technique.

As eddy current is best used for detecting surface-breaking cracks, its most practical applications relate to the in-service inspection of welded structures that are subject to a cyclical loading that can lead to fatigue crack propagation in critical welded areas.

How Eddy Current Works

In eddy current testing, a sinusoidal AC voltage is applied across the eddy current probe or inspection coil — Fig. 1. This coil creates an electromagnetic field, which in turn causes current flow in the surface of the material being inspected. (The circular nature of these currents has been compared to the eddies in a stream or river, hence the term “eddy current.”) When the coil or probe is scanned across the material surface, changes in the material's physical properties, i.e., geometry, temperature, conductivity, material type, flaws, etc., affect the current flow generated by the electromagnetic field induced in the material by the probe. These changes reflect back to the probe. If the voltage response of the eddy current probe is monitored, then changes in voltage amplitude and phase angle shift can be used to show changes in material properties. These changes in magnitude and phase angle are displayed on what is known as an impedance plane display.

Figures 2A and B show typical results from a simple absolute probe (single-winding coil) as it is scanned over surface-breaking flaws in a conductive material. The increasing magnitude of the signal relates to deeper flaws. The lift-off signal is associated with the signal generated by lifting the probe from the material. Simple absolute coils can be limited by the orientation of the flaw.

Flaws are most detectable when the eddy current path is crossed at right angles by the flaw — Fig. 3. Special probes designed for weld inspection help limit this problem.

Figure 4 shows the lift-off response of various thicknesses of nonconductive coatings on a ferrous test block. A clear relationship between the magnitude of the shift of the balance point and the coating thickness can be seen. This allows for assessment of the coating thickness on the actual structure to be inspected, which enables the operator to adjust the instrument gain level to normalize flaw signal re-
This, in turn, allows use of alarm gates for go/no go testing and flaw sizing between structures with different coating thicknesses.

Figure 5 shows the typical impedance plane display flaw indications in a Hooking WeldScan™ test block. The positive y-axis indications are generated with the probe in one orientation. The negative y-axis indications occur when the probe is rotated 90 deg. The indications are greater in magnitude for deeper flaws. (Note: Hooking WeldScan™ probes are differential probes with two orthogonal coils. This design also acts to eliminate signals associated with changes in the material properties in the heat-affected zone as well as minimizing the lift-off effect encountered when inspecting rough welds.) Normally, crack depth can be assessed to approximately 4.5 mm in depth. Beyond that, the signals level out. Crack length can also affect the response if the crack length is smaller than the probe's electromagnetic field area. Crack branching can give an indication the crack is deeper than it actually is.

Practical Applications

There are many practical applications of weld inspection using eddy current techniques. These include the following:

Offshore structures. By far the widest use of eddy current weld inspection occurs in the offshore industry. Offshore structures such as drilling platforms are subjected to cyclical loads twice daily (tides) and, more unpredictably, by severe weather. Fatigue crack propagation can occur topside or underwater and periodic inspection of critical weld areas is required. Frequently, topside inspections are only possible by rope access. Underwater inspections and repairs are often done by divers at acceptable depths and in acceptable water environments. At more extreme depths in cold water areas, remote operated vehicles (ROVs) have been developed to carry out surface preparation, eddy current weld inspection, weld repair, and repair inspection in one unit.

Ships. Ships are subject to bending and torsional moments in day-to-day use. Extreme weather conditions, shifting loads, and grounding can lead to extreme loading of the superstructure and overstress critical welded joints.

Submarines. Eddy current is often used in the inspection of new welds and for the detection of fatigue cracks in welded joints. Submarines are subject to the same loading as surface ships plus have the added stress of the cyclical loading that accompanies pressure changes associated with submersed operations.

Amusement park rides. Another relatively recent application is the inspection of amusement park rides. Again, these rides are subject to the same cyclical loading as bridges and cranes. Due to public demand, theme parks in warmer climates are often required to be in operation 364 days a year. Every day a ride is unavailable due to maintenance closure a negative public reaction is encountered, even if the closure is for safety-critical inspection and maintenance. Eddy current techniques for the inspection of track and cars represent a significant reduction in manpower and downtime, resulting in more cost-effective and higher quality maintenance and inspection along with more paying hours of operational attractions.

Law enforcement. Among the more unconventional uses for eddy current weld inspection are law enforcement applications. The technique can be used to identify welded joints in automobiles where you would not expect to find them. So-called "cut and shut" welds across a vehicle's chassis can easily be detected using eddy current technology as well as the welded area surrounding false VIN plates. This can be done without damage to the paintwork on the vehicle being inspected. Also, specially designed probes have been used to detect the removal of material from prison bars in penal institutions. However well the cut is hidden with dirt, shoe polish, or paint, the eddy current technique will ignore the filler material and detect the cut in the bar.

Rotary eddy current techniques. Special rotary probes were developed to aid in the inspection of welded steel engineering structures after the Kobe earthquake to allow construction engineers to evaluate structures that were under construction during the quake. Rotary techniques can detect flaws in any orientation, allowing the contractor to assess quickly whether cracks in the welds had occurred and to effect repair or demolition as necessary.
Crack parallel to eddy currents - not detected

Crack interrupts eddy currents - detected

Fig. 3 — A flaw is easiest to detect when it crosses the eddy current path at right angles.

Fig. 4 — Lift-off response of various thicknesses of nonconductive coatings on a ferrous test block.

Fig. 5 — Typical impedance plane display of flaw indications in a test block.

Summary of Benefits

Eddy current inspection offers several benefits over competing NDE inspection techniques. Traditionally, a suspect weld is stripped, cleaned, and a magnetic particle or liquid penetrant inspection is performed to detect any surface-breaking cracks. Beyond offering effective surface-breaking flaw detection for various welded structures, the eddy current technique offers a higher flaw detection “hit rate,” reduced costs and down time, lower inspection consumables cost, minimal or no surface preparation, and the capability to be done underwater. In many applications MP or LP inspection can be done to confirm eddy current results to give more confidence to operators new to the eddy current technique. Additionally, developments in ceramic and stainless steel probe tip design have greatly increased the wear resistance of eddy current probes, significantly enhancing the cost effectiveness of the eddy current technique. Special probe designs for aluminum and nonferritic stainless steel have also extended the usefulness of eddy current inspection to applications where magnetic particle inspection is not an option. Lastly, water-cooled probe designs have been developed for use in the inspection of welds in high-temperature piping and vessels, eliminating the need to take them off-line in order to perform the inspection.

Attention CWIs. Are you versatile enough for today’s NDT workforce? Do you or your company need to work to the European Union’s new Pressure Equipment Directive? If you answer “yes” to either of these questions, then check out how you may qualify for ASNT Central Certification Program Level II credential through the Transitioning Process until 30 September 2003. To find out more contact The American Society for Nondestructive Testing at (800) 222-2768 or visit online at www.asnt.org.
BETTER WELDS BEGIN AND FINISH WITH PFERD AND PFERD MILWAUKEE BRUSH
One Manufacturer for the Total Package of Quality Pipe Welding Hand Tools

PIPELINE WELD INTEGRITY IS CRITICAL.
You need the best tools to get the best welds. When it comes to weld preparation, root pass cleaning and weld finishing, we are the single source manufacturer for the best tools.

PREPARATION- PFERD pipeliner wheels grind a bevel around pipe edges quickly, and clean your root pass with the same fast action.

CLEANING- Milwaukee stringer bead brushes clean each weld thoroughly. They eliminate potential porosity and ensure better results for successive welds. PFERD also makes pipeliner files specially designed for pipe welding work.

FINISHING- Milwaukee cup brushes and full cable knot wheels with tempered steel or encapsulated wire give a consistent, stiff cleaning action to finish off your final weld surface.

YOUR NEAREST PFERD or PFERD MILWAUKEE Brush distributor is your best source for all these weld cleaning, surface conditioning and abrasive tools.

CALL, FAX OR E-MAIL us today for free copies of our latest catalogs. They show all sizes, types and wire styles you need, along with helpful application tips. Please specify print or CD-ROM version.

NEW! You can make your purchase on line through an authorized distributor. Go to www.WeldersMall.com
ROCKET FUEL LINE REPAIR DEPENDS ON GTA WELDING

BY JERRY GOUUDY
AND JIM BROOK

JERRY GOUUDY is lead flight welder, United Space Alliance, Kennedy Space Center, Cape Canaveral, Fla.
JIM BROOK is product manager, Miller Electric Mfg. Co., Appleton, Wis.
"Their hearts were full of enthusiasm, pride in country, faith in their God, and a willingness to accept risk in the pursuit of knowledge — knowledge that might improve the quality of life for all mankind. Although we grieve deeply, as do the families of Apollo 1 and Challenger before us, the bold exploration of space must go on." — From a statement from the families of Columbia, Feb. 3, 2003

"And while we grieve the loss of these astronauts, the cause in which they died will continue. America's journey into space will go on." — President George W. Bush

Chilled to –423°F, liquid hydrogen thunders through the Space Shuttle Atlantis' 12-in.-diameter fuel lines at a rate of 300 gallons per second. It is ignited, producing a cumulative thrust of 37 million horsepower. A spacecraft with a lift-off weight of 4.5 million lb (Fig. 1) has accelerated from zero to 17,400 miles per hour in 8.5 minutes.

The 26th successful flight of Atlantis last October would not have been possible without the use of gas tungsten arc welding (GTAW) to restore integrity to a hydrogen fuel line component. This may have been the most important and famous act in the history of welding maintenance repair and operation. Florida Senator Bill Nelson certainly thought so. He entered this welding achievement into the Congressional Record.

Prime Contractor Finds the Flaw

United Space Alliance (USA, Houston) is NASA's prime contractor for day-to-day operations of the space shuttle system. This includes mission design and planning, flight operations, astronaut and flight controller training, and vehicle processing, launch, and recovery. After every mission, USA performs extensive checks and verifies equipment performance.

In the course of normal operations, USA quality inspector David Strait noticed a small crack in Atlantis' fuel line bellows shield. Subsequent investigation uncovered a total of 11 cracks in all shuttles. No crack was longer than 0.6 in. Engineers ultimately determined they had probably existed for several missions, but following USA's "safety first" motto, every employee has the right to call a "time-out" that halts the normal flow of operations. This was one of those cases, and NASA and USA backed Strait.

The next day, a team of USA and NASA engineers, technicians, and welding operators from Kennedy Space Flight Center (Cape Canaveral, Fla.), Johnson Space Center (Houston), and Marshall Space Flight Center (Huntsville, Ala.) came together to put safety first and restore integrity to the fuel liners.

Finding a Needle in a Haystack

To allow for articulation and thermal expansion and contraction in the fuel lines, each line incorporates three metal bellows. From the side, these bellows resemble and function like the bendable portion of a drinking straw. To protect them from direct impingement by the fuel, each bellows has an
upstream and downstream flow liner made from 0.05-in.-thick 718 Inconel®, an alloy with high strength and resistance to extreme temperature ranges.

The flow liners have a series of 1-in.-long, oval-shaped slots that equalize the pressure on either side of the flow liner. The slots also facilitate cleaning, acting as drain holes for any cleaning solution and drainage of fuel prior to main engine shutdown during flight. It is at the slots closest to the space shuttle main engines that quality inspector Strait found the cracking.

![Fig. 2 — Schematic of stages of weld repair.](image)

**GTAW Is Best, Fastest Solution**

USA and NASA examined a number of different repair techniques. This included GTAW repair, stop drilling, mandrel expansion, and/or microplasma transferred arc. Microplasma transferred arc was discarded because it could not ensure penetration on the 0.050-in. liner material. Stop drilling and mandrel expansion were discarded because they didn't return the flow liner to its original configuration and presented other operational uncertainties.

Repair techniques that did not restore the liner's original integrity may have required reconfiguring the engine test stand and "hot firing" the engines to ensure proper function. This would have taken up to eight months, crippling the schedule for the International Space Station (a critical delivery of water was scheduled, along with delivery of a 45-ft-long, 15-ton part for expanding the station's backbone).

Of all the techniques examined, GTAW repair offered the most benefits and the lowest risk. By controlling amperage with a foot control, welders can precisely control the heat input. They can add more heat to ensure 100% joint penetration to the flow liner — a repair requirement — yet control the heat to prevent melting through the liner or leaving debris on the backside where access is extremely limited. Cleanliness is important because the liquid hydrogen lines require a 400 µm cleanliness level — no particles bigger than 400 µm (0.016 in.) can be observed in the line after the repair process.

**GTAW Details**

The contractor selected an AC/DC squarewave GTAW power source that allowed its welders to strike and maintain a steady arc through its entire amperage range (1 to 400 A). In this instance, the welding operator needed a power source that would let him quickly establish the weld pool and quickly react to changing weld pool conditions during the repair process. Representatives from the GTAW power source manufacturer worked with USA to ensure flawless performance in this critical application.

A 0.035-in. filler metal and a 0.040-in.-diameter, 2% thoriated tungsten electrode sharpened to a fine point and polished smooth were used. Pure argon was used as a shielding gas and to purge the weld area. Argon was taken to its maximum purity. By industry standards, "extremely dry" argon has no more than 2 parts per million (ppm) of water. The contractor reduced that to approximately 0.5 ppm with a system of its own design. Before the argon reaches the torch and purge line, it goes through two half-micron filters, a tube of desiccant, a heater, and two more half-micron filters. This is necessary because oxygen, hydrogen, other atmospheric gases, or water can contaminate the molten weld pool and lead to cracking. When welding 718 Inconel, the naked eye cannot see the effects of contamination. Under 500X or greater magnification, tiny cracks are apparent.

To minimize gas turbulence (turbulence can pull in atmospheric contaminants), the GTAW torch included a gas diffuser. To ensure good shielding gas coverage, the power source was set for 20 seconds of gas "pre-flow" and 45 seconds of postflow. Good post-flow also helped cool the weld pool, which was critical.

With the purge, all the flow liner slots, except the one to be welded, were covered with welding purge tape. The argon tube was inserted into the bottom of the flow liner and an oxygen sensor installed at the top. Because argon is heavier than air, it sinks. When the sensor does not pick up any oxygen, the argon has forced all the air out of the flow liner. A second oxygen sensor was placed next to the weld to verify no oxygen was in the immediate area during welding.

**Rapid Prototype**

Within 24 to 30 hours of discovering the cracks, the USA and NASA team at Marshall Space Flight Center used in-house design and manufacturing capabilities to pro-
were then subjected to six different GTAW repair approaches and placed back into the testing machine to recreate the cracks.

In the chosen weld repair technique, the characteristics of life for the repaired part were equal to or better than the "as stamped" original configuration. Come launch time, the crew of the Atlantis would be assured of a sound craft.

The chosen repair technique (Fig. 2) for Atlantis involved seven steps as follows:

1) Apply light edge preparation (approximately 0.002 grind with a fluted carbide cutting tool)
2) Apply weld repair (details below)
3) Autogenous "feather pass" with GTAW torch to minimize stress concentration at toes of the weld. This pass penetrates about 0.015 in. deep; the tungsten is held approximately 0.002 to 0.003 in. away from the part.
4) Grind weld crown flush with carbide cutting tool
5) Radius slot end, if required, to restore initial radius (approximately 0.125 in.)
6) Apply autogenous heat pass to slot radius
7) Polish slot radius with hard rubber sander to remove oxide and any sharp discontinuities.

**Nothing about This Job Was Easy**

Because the cracks could not be seen with the naked eye (most were 0.001 in. wide; a human hair is 0.003 in.), eddy current inspection was used to plot the path of the cracks. With this technique, an electrical current is sent through material and read on a screen. Cracks cause electrical discontinuities, which appear on the screen.

To remove surface oxides before welding (oxides would contaminate the weld pool), the operator set the machine to DC electrode positive. The welding current, flowing from the part to the tungsten, would "lift off" any surface oxides. The operator then switched to electrode negative to make the weld.

Normally, an operator would start the repair weld at an edge and weld into the part. This uses the mass of the part to dissipate the heat. On 718 Inconel, unfortunately, the contraction of the weld pool as it cools stresses the metal. This causes the weld to crack at the edge of the slot.

The challenge for the welding operator was to maintain penetration throughout the length of the weld without melting through as they reached the edge. Their technique involved striking the arc just past the start of the crack, then ramping up to about 15 A of heat to establish the weld pool. At this point, filler metal is added intermittently. As the operator approaches the edge of the slot, he reduces heat input to close to 1 A but starts adding filler metal constantly. Capillary action pulls the filler metal into the crack for 100% joint penetration, and the filler metal absorbs heat. Maintaining the filler metal in the weld pool at the end of the weld also absorbs more heat, and it produces an even contour without undercutting.

All of this hand-eye coordination and superb timing takes place over an average weld length just three-tenths of an inch long, and often out of position — Fig. 3.

**Technique Propagation**

After weld repair, the part went through a five-point nondestructive test inspection:

1) 4-mm boroscope (a visual inspection with up to 50X magnification)
2) Ultrasonic testing
3) Eddy current testing
4) X-ray testing
5) Cleaning and visual inspection.

Through careful planning, training, and just plain operator skill, these tests proved the weld cracks were successfully repaired. USA hopes the weld repair techniques developed for the orbiter can migrate into other aspects of military and commercial aviation, as well as other machines that use similar metals. ☢
Repair firm strengthens crack-prone Ti-alloy tubes from more than 1500 jet engines

When the entire North American fleet of General Electric CFM56 jet engines needed a titanium-alloy vent tube reengineered, Propulsion Technology, LLC, sought an automated orbital welding solution. The FAA-certified aviation repair and engineering services firm had a lot of CFM56 engines — commonly found on DC 8 and Boeing 737 aircraft — to modify quickly.

The problem with the CFM56 was vibration. Oil puddles would build up on the rotating turbine shaft and cause the engine to vibrate. The culprit was oil vapor leaking from a 5-ft-long, 2-in.-diameter “center vent tube” adjacent to the shaft.

“The tube had a resonant frequency that coincided with the natural frequency of the engine during operation,” said Juan Mendez, director of engineering for Propulsion Technology, based in Miami, Fla. “The excitations created a high stress on the thin-walled tube and caused it to crack.”

The titanium-alloy vent tubes had been produced using orbital welding, so the French manufacturer of the tubes suggested using orbital welding for the necessary modification.

“It was a relatively easy fix based on an engineering solution,” said Mendez. The 0.03-in.-thick center section of the vent tube had to be removed, and a 0.05-in.-thick section needed to be welded in its place.

The company acquired an automated PTW orbital tube welding system made by Liburdi Dimetrics and equipped it with Liburdi’s Model 3004 clamp-on style weld head, capable of joining up to 4-in.-diameter tube. Liburdi’s support staff helped the engineers at Propulsion Technology develop custom fixtures and weld schedules using test pieces of representative tubes until quality welds were obtained.

The complete center vent tube engine modification requires about two weeks, but the welding operation takes 30 min, with just 5 min to perform the actual welds. First, the welding surfaces are cleaned with an etching solution, and are handled with lint-free gloves. The replacement tube section and a consumable ring that acts as a weld wire are fitted tightly between the tube ends on a welding lathe. A thoriated-tungsten electrode is installed in the weld head, which is rigidly mounted to the workpiece assembly and closed to provide a tight chamber for the inert gas (usually argon) atmosphere. The proper weld schedule is retrieved from the computer, and the gas flow is turned for 2 min. on to purge the weld head. The operator provides the startup command with a remote pendant control. The weld is automatic, starting with a gradual ramp-up to a steady power while the electrode revolves around the tube’s circumference. A power rampdown provides a smooth, flared end to the weld. Mendez said the resulting weld is “very cold, even to the touch.”

Since the tubes are critical to the safety of passenger aircraft engines, strict FAA standards require the welds be checked by certified inspectors, who use visual inspection, fluorescent dye penetrants, and X-ray examination to confirm the required weld penetration and ensure there are no voids, missed joints, or cracks.

“Very seldom do we have to go back and redo it,” said Mendez.

Propulsion Technology also uses its orbital welding equipment and expertise to modify larger, 10-ft-long vent tubes from General Electric CF6 engines, and performs orbital welding repairs to helicopter engines and aviation instrumentation.

Based on a story from Liburdi Dimetrics, Davidson, N.C., (702) 892-8872.
SELECTING FILLER METALS FOR OFFSHORE PIPING

Welding consumables used for joining piping in offshore sweet and sour environments must be corrosion resistant.

BY J. R. STILL

Welding of process piping offshore is limited to shielded metal arc welding (SMAW), gas tungsten arc welding (GTAW), or a combination of the two. Consumables selected for joining pipe materials for handling hydrocarbons must be capable of resisting or limiting the effects of corrosion or corrosion-assisted cracking. While it is not the intention of this article to describe all aspects of the corrosion process, as this subject has been adequately covered (Refs. 1, 2), a brief description of corrosion and corrosion-assisted cracking is outlined in Table 1. Instead, this article is intended to provide an overview of the materials used and, more importantly, the selection of welding consumables for handling hydrocarbons containing carbon dioxide ($\text{CO}_2$), hydrogen sulfide ($\text{H}_2\text{S}$), and other compounds at various concentrations.

*J. R. STILL* is a Consultant Welding Materials Engineer in Aberdeen, Scotland.
Facilitation and Welding of Process System Pipework

Materials Selection

Facilities for processing hydrocarbons offshore involve separators linked by piping systems (Fig. 1) that operate at various temperatures and pressures. Figure 2 shows the process facilities and piping system on a recently constructed floating production storage and offloading vessel.

Carbon dioxide and hydrogen sulfide in the presence of water are the main contributors to corrosion and corrosion assisted cracking. Table 2 lists examples of materials and weld metals selected for systems designed for processing various concentrations of CO₂ and H₂S at specified temperatures and pressures (Ref. 3).

Details of chemical composition for materials selected for process systems are listed in Table 3.

Welding Consumables

Selection of welding consumables for joining process piping uses the same criteria as for pipe materials. Weld metal composition differs from that of the pipe materials and, within a susceptible environment, can influence the corrosion properties of either the weld metal or heat-affected zone (HAZ), e.g., preferential weld metal corrosion. Table 4 lists both SMAW and GTAW electrode types commonly used offshore for the welding materials listed in Table 2. In addition to the above, gas shielded flux cored arc welding (FCAW-G) has had some use offshore.

Welding Processes and Procedures

Development of suitable welding procedures for process piping is based on the criteria listed within the NACE requirement MR 01-75 (Ref. 4).

Control of the essential variables during welding is crucial, irrespective of material type, and failure to adhere to the welding procedure can influence the mechanical and corrosion properties of both the weld and the HAZ microstructure.
Table 1 — Corrosion Failures Associated with Sweet and Sour Environments

<table>
<thead>
<tr>
<th>Failure Types</th>
<th>Weight Loss Corrosion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight loss corrosion resulting in uniform or localized attack, such as pitting.</td>
<td></td>
</tr>
</tbody>
</table>

Environmental Cracking is the result of applied mechanical stress such as thermal processing, manufacturing deficiencies and residual stress on a metallic material within a corrosive aqueous H₂S environment with a low pH results in dissociation of H₂S into atomic hydrogen. Cracking Associated with an H₂S Environment

The failure mechanism involves the movement of hydrogen atoms through the microstructure. On encountering discontinuities within the microstructure, e.g., nonmetallic inclusions, hydrogen atoms combine to form molecular hydrogen. Pressure increases, resulting in cracking or blistering. A number of factors such as pH, volume of hydrogen diffused, volume fraction, and shape of inclusions present and surrounding microstructure influence the process. Stress in this instance is not as critical compared with SCC and SSC.

Table 2 — Selection of Material for Process Piping

<table>
<thead>
<tr>
<th>Installation Type</th>
<th>Process System</th>
<th>H₂S (ppm)</th>
<th>CO₂ (mole %)</th>
<th>Material Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed platform</td>
<td>Pipework from 1st stage separator</td>
<td>Trace</td>
<td>3</td>
<td>A106 Grade B</td>
</tr>
<tr>
<td></td>
<td>Produced water from separators</td>
<td>Zero</td>
<td>6</td>
<td>Duplex SS 25% Cr</td>
</tr>
<tr>
<td>Fixed Platform</td>
<td>Pipework from 1st stage separator</td>
<td>Zero</td>
<td>6</td>
<td>Duplex SS 25% Cr</td>
</tr>
<tr>
<td></td>
<td>produced from 2nd or 3rd stage separator</td>
<td>Zero</td>
<td>6</td>
<td>Duplex SS 25% Cr</td>
</tr>
<tr>
<td>Fixed Platform</td>
<td>Pipework from 1st stage separator</td>
<td>Trace</td>
<td>3</td>
<td>A106 Grade B</td>
</tr>
<tr>
<td></td>
<td>Water injection</td>
<td>Trace</td>
<td>3</td>
<td>A106 Grade B</td>
</tr>
<tr>
<td>Fixed Platform</td>
<td>Pipework from 1st stage separator</td>
<td>Zero</td>
<td>6</td>
<td>Duplex SS 25% Cr</td>
</tr>
<tr>
<td></td>
<td>produced from 2nd or 3rd stage separator</td>
<td>Zero</td>
<td>6</td>
<td>Duplex SS 25% Cr</td>
</tr>
<tr>
<td>Fixed Platform</td>
<td>Pipework from 1st stage separator</td>
<td>Trace</td>
<td>3</td>
<td>A106 Grade B</td>
</tr>
<tr>
<td></td>
<td>produced from 2nd or 3rd stage separator</td>
<td>Trace</td>
<td>3</td>
<td>A106 Grade B</td>
</tr>
<tr>
<td>FPSO Vessel (3 Reservoirs)</td>
<td>Pipework from 1st stage separator</td>
<td>Trace</td>
<td>0.33</td>
<td>ASTM A333 Grade 6</td>
</tr>
<tr>
<td></td>
<td>produced from 2nd or 3rd stage separator</td>
<td>Trace</td>
<td>0.33</td>
<td>ASTM A333 Grade 6</td>
</tr>
<tr>
<td>Subsea Tie Back to Fixed Platform</td>
<td>Pipework from 1st stage separator</td>
<td>Trace</td>
<td>1.78</td>
<td>ASTM A333 Grade 6</td>
</tr>
<tr>
<td></td>
<td>produced from 2nd or 3rd stage separator</td>
<td>Trace</td>
<td>1.78</td>
<td>ASTM A333 Grade 6</td>
</tr>
</tbody>
</table>

(a) 254 SMO is a Registered Trade Name of AvestaPolarit.
(b) Incoloy and Inconel are Registered Trade Names of the Special Metals Group of Companies.

Carbon and Carbon-Manganese Steels

Carbon and carbon-manganese steels comprise the majority of offshore process piping. Current welding practice involves depositing weld beads in a multirun sequence where the weave size is restricted to 2.5 times the rod diameter. This technique is standard practice for achieving the proper weld metal toughness properties. However, welds deposited with a restricted weave size are considered the norm, immaterial of toughness requirements. Use of a multipass, wide weave technique for welding materials such as A106 Grade B (Ref. 5) is acceptable, provided the welder has had adequate training to achieve the desired quality.

Parameters applied for welding the materials listed in Table 2 are similar, with identical, in most cases. However, preheat and interpass temperatures are influenced by chemistry, material thickness, and heat input.

The most common welding consumables used for welding materials such as A106 Grade B process piping are AWS E7016 (Ref. 6) and AWS 7018 (Ref. 7). One U.K. operator (Ref. 8) allowed AWS E6016 electrodes (Ref. 9) to be used offshore. The technique applied in that case involved depositing a wide weave with a shallow deposit; however, the practice was eventually rescinded due to standardization of low-hydrogen welding consumables offshore.

When the partial pressure H₂S of carbon and carbon-manganese steels exceeds 0.05 lb/in² (psia) (Ref. 3), both weld metals and HAZs are susceptible to sulfide stress corrosion cracking (SSCC) when the hardness level exceeds 22 HRC. The hardness of 22 HRC is linked to the microstructure, and control of the microstructure is dependent on material composition, selecting the correct consumable, applying the appropriate welding parameters, and preheat and interpass temperatures. Depending on the composition of both the material and weld metal, postweld heat treatment (PWHT) may also be required to achieve 22 HRC.

Welding of piping systems for offshore applications is carried out in accordance with ASME B31.3, section 330 (Ref. 10). Preheat temperatures for carbon, carbon-manganese, and low-alloy steels are stated in ASME B31.3. Table 330.11 of that document recommends preheat temperatures for materials of various P numbers based on composition and thickness. Although preheat temperature is critical in achieving the desired NACE hardness levels, interpass temperatures must be controlled to ensure that, both the weld metal and HAZ, mechanical and corrosion properties are not impaired.

When selecting new welding consumables for a carbon or carbon-manganese piping system, the corrosion resistance of the deposited weld metal for a given fluid or gas composition must be established by applying the applicable NACE corrosion tests (Refs. 4, 11).

Preferential weld metal corrosion in seawater injection piping is a result of galvanic coupling, whereby the weld metal is anodic and the base material is cathodic (Refs. 12, 13). To avoid preferential weld corrosion, the weld deposit must behave cathodically with respect to the pipe. Several types of SMAW consumables have been used for water injection pipe welds, the most common being AWS E8018G1 (1% Ni maximum) (Ref. 14). It has also been reported that preferential weld corrosion has occurred in process piping containing production fluids where the welding consumable used contains less than 1% nickel. Until further work has been carried out to establish the corrosion mechanism, one can only assume the presence of nickel must influence the process.
Table 3 — Examples of Piping Material Used for Process Systems

<table>
<thead>
<tr>
<th>UNS Number</th>
<th>Grade</th>
<th>C</th>
<th>Si</th>
<th>S</th>
<th>P</th>
<th>Mn</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>Cu</th>
<th>V</th>
<th>Ob</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>K09306</td>
<td>A106 Gr B</td>
<td>0.14</td>
<td>0.17</td>
<td>0.03</td>
<td>0.022</td>
<td>0.72</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specification</td>
<td>0.30 max</td>
<td>0.10 min</td>
<td>0.035 max</td>
<td>0.055 max</td>
<td>0.29-1.06</td>
<td>0.40 max*</td>
<td>0.40 max*</td>
<td>0.15 max*</td>
<td>0.40 max*</td>
<td>0.09 max*</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K09306</td>
<td>A333 Gr 6</td>
<td>0.15</td>
<td>0.2</td>
<td>0.028</td>
<td>0.012</td>
<td>1.02</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specification</td>
<td>0.30 max</td>
<td>0.10 min</td>
<td>0.025 max</td>
<td>0.025 min</td>
<td>0.29-1.06</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>API 5L X60</td>
<td>0.16</td>
<td>0.19</td>
<td>0.018</td>
<td>0.016</td>
<td>1.32</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specification</td>
<td>0.26 max</td>
<td>0.03 max</td>
<td>0.33 max</td>
<td>0.03 max</td>
<td>1.35 max</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Note: *not to exceed 1%

Austenitic, Superaustenitic, and Duplex Stainless Steel

<table>
<thead>
<tr>
<th>UNS Number</th>
<th>Grade</th>
<th>C</th>
<th>Si</th>
<th>S</th>
<th>P</th>
<th>Mn</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>Cu</th>
<th>W</th>
<th>Nitrogen</th>
<th>PRE</th>
</tr>
</thead>
<tbody>
<tr>
<td>S31603</td>
<td>A316L</td>
<td>0.015</td>
<td>0.38</td>
<td>0.011</td>
<td>0.023</td>
<td>1.64</td>
<td>12.51</td>
<td>17.12</td>
<td>2.24</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specification</td>
<td>0.03 max</td>
<td>1.0 max</td>
<td>0.45 max</td>
<td>0.45 max</td>
<td>2.0 max</td>
<td>18.04</td>
<td>16.18</td>
<td>2.3</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S31254</td>
<td>254 Mo</td>
<td>0.012</td>
<td>0.2</td>
<td>0.001</td>
<td>0.022</td>
<td>0.42</td>
<td>17.89</td>
<td>19.98</td>
<td>6.08</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specification</td>
<td>0.02 max</td>
<td>0.01 max</td>
<td>0.01 max</td>
<td>0.01 max</td>
<td>0.01 max</td>
<td>0.01 max</td>
<td>0.01 max</td>
<td>0.01 max</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S31803</td>
<td>22% Cr</td>
<td>0.012</td>
<td>0.54</td>
<td>0.004</td>
<td>0.018</td>
<td>0.82</td>
<td>17.92</td>
<td>22.22</td>
<td>3.12</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specification</td>
<td>0.03 max</td>
<td>1.0 max</td>
<td>0.03 max</td>
<td>0.02 max</td>
<td>2.0 max</td>
<td>4.55</td>
<td>21.5</td>
<td>25.35</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>S32760</td>
<td>25% Cr</td>
<td>0.022</td>
<td>0.26</td>
<td>0.001</td>
<td>0.016</td>
<td>0.58</td>
<td>7.34</td>
<td>25.65</td>
<td>3.71</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specification</td>
<td>0.03 max</td>
<td>0.75 max</td>
<td>0.01 max</td>
<td>0.01 max</td>
<td>0.02 max</td>
<td>0.2 min</td>
<td>24.26</td>
<td>3.24</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Nickel Alloys

<table>
<thead>
<tr>
<th>UNS Number</th>
<th>Grade</th>
<th>C</th>
<th>Si</th>
<th>S</th>
<th>P</th>
<th>Mn</th>
<th>Ni</th>
<th>Cr</th>
<th>Mo</th>
<th>Cu</th>
<th>W</th>
<th>Nitrogen</th>
<th>PRE</th>
</tr>
</thead>
<tbody>
<tr>
<td>N08825</td>
<td>B423/925</td>
<td>0.03</td>
<td>0.15</td>
<td>0.001</td>
<td>0.047</td>
<td>41.39</td>
<td>30.21</td>
<td>6.06</td>
<td>2.18</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Specification</td>
<td>0.03 max</td>
<td>0.5 max</td>
<td>0.03 max</td>
<td>1.0 max</td>
<td>38.46</td>
<td>19.5</td>
<td>23.3</td>
<td>2.5-3.5</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N06625</td>
<td>G25</td>
<td>0.10</td>
<td>0.50</td>
<td>0.015 max</td>
<td>0.015 max</td>
<td>0.015 max</td>
<td>0.15 max</td>
<td>30 min</td>
<td>20-23</td>
<td>80-100</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Preheat temperature and interpass temperature must be controlled between 10 and 20°C (50 and 68°F) and 120 and 150°C (248 and 302°F), respectively. It is recommended (Ref. 21) that the shielding gas used for GTAW contain between 2.5 and 3% nitrogen. This addition is to prevent nitrogen loss during welding, which would reduce the volume fraction of austenite and influence the corrosion properties. It is essential the ideal phase balance be achieved. It is common practice within the offshore industry for engineering specifications to quote a ferrite range from 30 to 70%.

Other factors associated with welding thin-wall pipe material, such as heat input, heat sink, and preheat temperature, will influence the interpass temperature and, subsequently, the transformation. Failure to control the transformation time for both weld and HAZ through the temperature range At 1000/500 will result in the formation of intermetallic precipitates (Ref. 16).

To prevent the formation of intermetallic precipitates, it is recommended the time to cool through the critical temperature range be less than 10 s. Figure 3 illustrates an example of sigma, which has an adverse effect on corrosion resistance and mechanical properties of duplex stainless steels, weld metals, and HAZs. Therefore, to avoid formation of intermetallic precipitates, strict control over

![Fig. 3 — A typical duplex stainless weld metal microstructure. The arrows identify sigma intermetallic phases.](image_url)

Austenitic Stainless Steels

The use of austenitic stainless steels (Ref. 3) in process systems is limited to superaustenitic stainless steels for produced water systems. When welding superaustenitic stainless steels, precautions must be taken to ensure welding is carried out in accordance with the weld procedure to prevent the possibility of sigma precipitation (Ref. 15). The use of matching consumables is not recommended because of alloy segregation, and it is advisable (Ref. 16) to select an overmatched welding consumable containing 8-10% Mo such as AWS A5.11 EN Cr Mo-3 (Ref. 17).

Duplex Stainless Steels

Duplex stainless steels fall into several categories, the most common of which involve UNS 31803 (Ref. 19) and UNS 32760 (Ref. 20).

Wall thicknesses of piping systems used offshore range from 3 to 10 mm (0.12-0.45 in.) and, in exceptional circumstances, from 16 to 45 mm (0.64-1.8 in).
Table 4 — Examples of Welding Consumables Suitable for Process Piping (AWS Classification and Consumable Trade Name Where Applicable)

<table>
<thead>
<tr>
<th>Material</th>
<th>Wire</th>
<th>Root and Hot Pass Gas</th>
<th>GTAW Wire</th>
<th>Fill Gas</th>
<th>SMAW Root and Hot Pass</th>
<th>Fill</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTM A106 Grade B</td>
<td>A5.18:ER70S-2</td>
<td>99.996% Argon</td>
<td>A5.18:ER70S-2</td>
<td>99.996% Argon</td>
<td>A5.1: E7016-1</td>
<td></td>
</tr>
<tr>
<td>ASTM A333 Grade 6</td>
<td>A5.28:ER80S-G</td>
<td>99.996% Argon</td>
<td>A5.28:ER80S-G</td>
<td>99.996% Argon</td>
<td>A5.5: E8018-G</td>
<td></td>
</tr>
<tr>
<td>22% Cr duplex SS</td>
<td>A5.9:ER2209</td>
<td>99.996% Argon</td>
<td>A5.9:ER2209</td>
<td>99.996% Argon</td>
<td>A5.4: E2553-15</td>
<td></td>
</tr>
<tr>
<td>25% Cr super duplex stainless steel</td>
<td>A5.9:ER2553</td>
<td>99.996% Argon</td>
<td>A5.9:ER2553</td>
<td>99.996% Argon</td>
<td>A5.4: E2553-15</td>
<td></td>
</tr>
<tr>
<td>22% Cr duplex stainless steel (SDSS)</td>
<td>UNG 32550, UNG 32760</td>
<td></td>
<td>A5.4-92: E2553</td>
<td>99.996% Argon</td>
<td>A5.11: ENiCrMo-3</td>
<td></td>
</tr>
<tr>
<td>22% Cr DSS</td>
<td></td>
<td></td>
<td>A5.9-93: ER2209</td>
<td>99.996% Argon</td>
<td>A5.11: ENiCrMo-3</td>
<td></td>
</tr>
</tbody>
</table>

Note: Depending on the application, i.e., processing of hydrocarbons, produced water, and seawater injection, the selection of piping materials is dependent on the fluid/gas composition and process parameters. Examples of the duplex steels available involve Zeron (Weirs Materials), SAF 2205 and 2507 (AB Sandvik Steel).

(1) 254 SMO is a Registered Trade Name of AvestaPolarit.
(b) Incoloy and Inconel are Registered Trade Names of the Special Metals Group of Companies.

Left, Fig. 4 — Welding consumables used offshore for welding process piping at various concentrations of CO₂ and H₂S.

The welding procedure is essential. Shielding gas used with GTAW has to be controlled to ensure the oxygen level is reduced below 0.5% to prevent surface oxidation (Ref. 16). This also applies to the root weld if corrosion is to be avoided.

Owing to the metallurgical differences that occur during welding between weld metals and HAZs, duplex and super duplex stainless process piping systems are more susceptible to localized corrosion.

Nickel Alloys

Nickel alloys used for offshore process piping systems have involved UNS N08825 (Ref. 22) and N06625 (Ref. 23). The welding consumable selected for the nickel alloys is AWS A5.11 EN Cr Mo-3 (Ref. 18).

Welding of nickel alloys requires fewer controls than for carbon and duplex steels, although the weld metal is sluggish and can be difficult to deposit (Ref. 24). As mentioned in the section on super-austenitic stainless steels, it is necessary to increase the weld preparation included angle to allow the welder sufficient access.
Table 5A — Process Piping — Ferous Materials, Filler Metals, and Weld Metal Microstructures

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Material</th>
<th>Welding Process</th>
<th>Welding Consumable</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>A106 Grade B</td>
<td>GTAW</td>
<td>A5.18:ER70S-6</td>
<td>As Welded</td>
</tr>
<tr>
<td>B</td>
<td>A106 Grade B</td>
<td>SMAW</td>
<td>A5.1:E6013</td>
<td>As Welded</td>
</tr>
<tr>
<td>C</td>
<td>A106 Grade B</td>
<td>SMAW</td>
<td>A5.1:E7016-1</td>
<td>As Welded</td>
</tr>
<tr>
<td>D</td>
<td>A333 Grade 6</td>
<td>SMAW</td>
<td>A5.1:E8018-G</td>
<td>As Welded</td>
</tr>
</tbody>
</table>

Weld Metal Microstructures

The following provides an insight into weld metal microstructures when exposed to a hydrocarbon environment containing CO₂ and H₂S:

A literature review (Ref. 25) did not identify any reference to SSC cracking in carbon and carbon-manganese weld metals used for offshore process systems. However, it has been reported (Refs. 25, 26) SSC readily occurs in the HAZ if the hardness level exceeds 22 HRC. It has also been reported that stress corrosion cracks were identified within pipeline submerged arc welds (Ref. 26). These cracks were located within hard spots or martensitic microphases within the weld metal (Ref. 27). The cracks failed to propagate because the surrounding softer weld metal microstructure prevented propagation of the crack.

Carbon and carbon-manganese weld metal microstructures are influenced by weld composition and the time it takes to cool through the transformation temperature range. Welding parameters and pipe thickness influence the transformation temperature range, e.g., heat input, interpass temperature, and preheat. The microstructures produced by carbon and carbon-manganese weld metals of various compositions consist primarily of ferrite in different morphologies.

Corrosion of carbon and carbon-manganese weld metals within a CO₂ environment is similar to that experienced in process piping and generally appears as pitting or, in some instances, depending on the flow characteristics, grooving, resulting in thinning of the pipe wall and weight loss.

The weld metal microstructure of duplex stainless steel comprises a ferrite/austenite matrix, whereas super-austenitic stainless steel and nickel alloys consist primarily of austenite. Figure 4 (Ref. 28) has been modified to identify the most suitable welding consumable (AWS classification) for materials within a range of CO₂ and H₂S partial pressures. The consumables quoted can be used for higher partial pressures of CO₂ and H₂S provided the offshore operator has successfully carried out the appropriate NACE corrosion tests (Refs. 3, 10).

Tables 5A and B illustrate the relevant weld metal microstructures for the consumables listed in Fig. 4. The microstructures illustrated in Tables 5A and B provide an insight into the differences between carbon, carbon-manganese, and corrosion-resistant alloy weld metals and
Table 5B — Process Piping — Corrosion Resistant Alloys, Filler Metals, and Weld Metal Microstructure

<table>
<thead>
<tr>
<th>Specimen</th>
<th>Material</th>
<th>Welding Process</th>
<th>Welding Consumable</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>E</td>
<td>Inconel 625™</td>
<td>GTAW</td>
<td>A5.14: ERNiCrMo-3</td>
<td>As Welded</td>
</tr>
<tr>
<td></td>
<td>22% Cr DSS</td>
<td>GTAW</td>
<td>A5.9: ER2209</td>
<td>As Welded</td>
</tr>
<tr>
<td>G</td>
<td>22% Cr DSS</td>
<td>SMAW</td>
<td>A5.4: E2209-15</td>
<td>As Welded</td>
</tr>
<tr>
<td>H</td>
<td>25% Cr Super DSS</td>
<td>GTAW</td>
<td>A5.18: ER2553</td>
<td>As Welded</td>
</tr>
<tr>
<td>I</td>
<td>25% Cr Super DSS</td>
<td>SMAW</td>
<td>A5.4</td>
<td>As Welded</td>
</tr>
</tbody>
</table>

(a) Inconel and Inconel are Registered Trade Names of the Special Metals Group of Companies.

the influence nickel, chromium, and molybdenum have had on developing the microstructure.

Summary

Use of materials such as duplex stainless steels and nickel alloys on new or existing offshore installations is now common practice. Continual development of welding consumables and processes by electrode manufacturers is essential to ensure the best possible consumable is available to meet not only the physical properties but also the corrosion properties of weld deposits. Factors that influence corrosion of process systems can be demonstrated by listing the essential elements on a cause and effect diagram.

Acknowledgments

The author would like to thank David Baille for commenting on the preparation of this paper and Bruce Winton and Kevin Simpson of OIS Aberdeen for use of the metallurgical facilities.

References

9. AWS A5.1-91, Specification for


Welding Low-Carbon Steel Pipe

Common low-carbon pipe steels are A53, A106, A135, A179, A524, A587, and API5L. They can be welded with the shielded metal arc, gas tungsten arc, gas metal arc, and oxyacetylene welding processes.

Cleanliness is important in the welding of pipe. Care must be taken to ensure both members of the joint are properly cleaned. Each side of a weld joint should be mechanically cleaned of all paint, scale, rust, or dirt for a distance of approximately 1 in. from the end of the bevel. The grinding and cleaning should be done just prior to joint alignment. Improper or insufficient cleaning can result in discontinuities such as porosity, undercut, incomplete fusion, and cracks.

Preheating normally is not required for the above pipe steels. However, if normal contributors to cracking are present, such as low base metal temperature or high restraint, preheating should be considered.

Welding procedures and joint preparation require the use of specific terminology. Figure 1 is an example of standard terminology for a butt joint. More information about terminology can be obtained from AWS A3.0, Standard Welding Terms and Definitions.

Commercial lineup clamps are made to hold virtually any type of pipe joint. The use of clamps to secure proper alignment is highly recommended. External clamps with cross bars will not provide access to welding the full circumference — Fig. 2. Therefore, tack welds must be made at locations between the cross bars. Tack welds must be of sufficient size to hold the pipe together after the clamp is released and before the root pass is completed. If the shape and size of the tack welds prevent them from being incorporated into the root pass without running the risk of incomplete fusion or incomplete root penetration, they should be ground to a contour that will permit complete fusion and penetration.

Pipe can be welded in all positions. Welders can become qualified in one or more of the positions shown in Fig. 3. The G stands for groove.

Fig. 1 — Terminology for butt joint.

Fig. 2 — External pipe clamps.

Fig. 3 — Welding test positions for groove welds in pipe.

Teachers, Counselors and Instructors — a complete guide of classroom or lab projects stressing math and science skills; available to you at no cost!

For more information on how to obtain your free booklet, please contact the AWS Foundation at 1-800-443-9353 ext. 688 or email us at found@aws.org.
NJC Developing Fabrication Techniques for the XM777 Howitzer

The Navy Joining Center (NJC) and Edison Welding Institute (EWI) are currently working with the Joint Project Management Office (JPMAO), Picatinny Arsenal, N.J., and BAE Systems on the development of the XM777 Howitzer — Fig. 1. The efforts in this project are directed at improving the productivity of the welding processes for fabrication of the howitzer. This howitzer will fire 15-mm projectiles and is to be transportable by a wide variety of NATO helicopters. Thus, the howitzer is designed to be portable, lightweight, and strong. To meet these requirements, the structure has been designed with Grade 5 titanium alloy (Ti6Al4V), a lightweight material with a very good strength to weight ratio. This is the first large-scale application of titanium for ground-based artillery systems. The design of the XM777 is based on fabrication of a series of large, complex space frames made from both cast and wrought titanium components. These frames require many feet of welds, currently produced by manual gas tungsten arc welding (GTAW). Manual welding requires highly skilled welders to achieve the necessary quality. Fabrication of these space frame assemblies also involves welding several unique joint configurations. One of these joint types is a tang-and-slot joint that aids productivity by reducing setup time and enables the use of simple tooling and fixturing. Complete joint penetration welds are required in most of the weld joints. In addition, weld bead sizes and profiles must be controlled to ensure the fatigue life of the assembly.

Project activity is directed at automated or mechanized welding procedures and tooling to improve productivity, standardize quality, increase weld process robustness, reduce distortion, and minimize repair. Special consumable titanium inserts were developed for V-grooves in tang-and-slot joints based on previous experience using inserts. These inserts were evaluated by both EWI and BAE and were found to greatly facilitate the use of mechanized welding for the space frame assembly. Operating parameters were developed for mechanized welding using the new inserts. These procedures are tolerant of variable root openings and fitup while producing consistent weld penetration and bead profiles. Welding procedures have been established and validated by fatigue tests of weld joints in both wrought and cast Grade 5 titanium alloy. The developed data supplements fatigue design rules for as-welded and stress-relieved welds in Grade 5 alloy joints that were established early in the project.

The development activities in this project demonstrated areas of continuous improvement for welding the XM777 Howitzer. Weld joint designs and the use of new titanium consumable inserts led to mechanized GTA welding for improved productivity and first time quality with less demand upon welding operators. With the insert concept proven, the project has moved on to develop custom inserts for other unique joint details. These "mechanization friendly" insert techniques are now being transitioned to production.

For further details, please contact John Lawmon, principal engineer, Arc Welding & Automation Group, at EWI at (614) 688-5054; e-mail: John_Lawmon@ewi.org.

Mark Your Calendars

- Date: October 14–15
- Workshop: Friction Stir Welding Technology for Defense Applications, hosted by Concurrent Technologies and the National Center for Excellence in Metalworking Technology (NCEMT)
- Location: University of Pittsburgh at Johnstown, Living/Learning Center, Johnstown, Pa.
- Organized jointly by National Center for Excellence in Metalworking Technology and the Navy Joining Center
- Objective: To update industry and Department of Defense (DoD) organizations on ongoing advances in friction stir welding technology; to obtain their input on the direction to be taken in developing this technology and removing barriers to full-scale implementation of these technologies for defense applications

For more information, contact Tricia Wright, (814) 269-2567, Fax: (814) 269-6800, or e-mail to wright@ctcgsc.
Demand more than just a hotsheet

Industrial Tradesman magazine

So much more

Along with the Construction Job Hotsheet we bring you industry information, news and features. Our job is to keep you informed about the issues, each and every month.

$95/year 12 issues

116 Bryan Road Wilmington, NC 28412
910.793.0580 www.industrialtradesman.com

Circle No. 26 on Reader Info-Card
Over the years, it has been said no single company does more arc welding than Caterpillar, Inc., but Caterpillar is just one of many manufacturers that build various types of tractors used in road construction and in farming. When it comes to welding, this industry is on the verge of a giant change. Where welders used to swarm around large components on the plant floors, robots now handle those same jobs. What will happen next? Will it be laser welding?

Attendees will hear a leading expert discuss fatigue design and another expert explain the results of a $20-million NIST program aimed at intelligent and synergistic materials processing. The conference will also feature presentations on cutting and hardfacing. Attendees will come away informed about the most cost-effective processes for their plants and will be able to decide where to go next.

Learn how advances in computer technology could allow your company to automate key processes, improve repeatability and quality, and operate more efficiently.

Chose from among 28 peer-reviewed presentations organized into the following parallel sessions:

- Modeling - Large Structures
- Modeling - Weld Pool and Solidification
- Modeling - General Topics 1
- Modeling - General Topics 2
- Real-Time Control - Weld Pool and Arc
- Weld Data Flow
- Computers and Automation
- Databases and Data Generation.

It all started during World War II when U.S. shipyards went wild fabricating welded ships for the war effort. A small number of these ships experienced cracks in their welds, and the newspapers and radio stations let the country know what was going on in some of these yards. Was the news blown out of proportion? Perhaps. But welding researchers looked into the matter with intensity, and much useful information was accumulated.

Those days of mass-produced ships are over, but the phenomena involving weld cracking are still apparent to some degree in many job shops, on pipelines, in pressure vessels, in offshore platforms, in aircraft engines, on truck chassis, in skyscrapers—wherever welds are used to hold components together. Modern science is helping industry test for these cracks and introduce a host of preventive cures.

One of the strongest segments of the U.S. economy is the energy industry, which is best exemplified by oil and natural gas. The pressure upon industry is intense to deliver these fuels to the marketplace as efficiently and economically as possible. Welding plays an extremely important role in this scenario. Therefore, the pressure is also on the welding industry to keep the cross-country pipelines in continuous operation, to make sure badly needed fuels are retrieved from offshore sources, and to maintain adequate production from the refineries.

For further information, contact Conferences, American Welding Society, 550 NW LeJeune Rd., Miami, FL 33126. Telephone: (800) 443-9353 ext. 449 or (305) 443-9353 ext. 449; FAX: (305) 648-1655. Visit the Conference Department homepage, www.aws.org, for upcoming conferences and registration information.
WeldAcademy is a convenient and cost-effective way to learn about welding technology and gain the knowledge you need to become a Certified Welding Inspector through web-based courseware. WeldAcademy is a 10-module course developed by the American Welding Society and Impart Knowledge based on the AWS’s popular "Welding Inspection Technology" seminar.

WeldAcademy provides:
- Study at your own pace, where you want, when you want
- Over 40 hours of instruction for one low price
- Videos and animations highlight key points
- Pre- and post-test questions help you truly prepare

Choose from the following ten modules:
- Welding Inspection and Certification
- Safe Practices for Welding Personnel
- Metal Cutting and Joining Processes
- Weld Joint Geometry and Welding Symbols
- Documents Governing Welding Inspection and Qualification
- Metal Properties and Destructive Testing
- Metric Practice for Welding Personnel
- Welding Metallurgy for Welding Personnel
- Weld and Base Metal Discontinuities
- Visual Inspection and Other NDE Symbols

Call Impart Knowledge today to learn more about this exciting new training course for the welding industry.

1-888-488-5669
8:30am - 5:00pm (CST)

Visit us online at www.weldacademy.com
Conferences and Exhibitions


Laser Technologies in Welding and Materials Processing. May 19–23, The House of Scientists of the NAS Ukraine, Katsiveli, Ukraine. Sponsored by the E. O. Paton Electric Welding Institute of the National Academy of Sciences of Ukraine and the Laser Technology Research Institute of the National Technical University of Ukraine, Kiev Polytechnic Institute, International Association Welding. Contact: Dr. I. Krivtsun or Dr. A. Zakharchenko, E. O. Paton Electric Welding Institute, 11 Bozhehno St., Kiev, 03680, Ukraine, (380) (44) 227 6757, FAX: (380) (44) 268 0486 or 274 0277, e-mail: journal@paton.kiev.ua or kovinvst@sovarnua.com; http://center.nas.gov.ua/pwj/ltwrnpO3.htm.


JOM-11, Eleventh International Conference on the Joining of Materials. May 25–28, Helsingør, Denmark. Contact: JOM Institute, Gilleleje Strandvej 28, DK-3250 Gilleleje, Denmark, (45) 4835 5458, FAX: (45) 4835 5457, e-mail: jom_aws@post10.tele.dk.

Third Phased Array Inspection Conference. June 9–11, The Mayflower Park Hotel, Seattle, Wash. Contact: Brent Lancaster, (704) 547-6017, e-mail: blancast@epri.com; http://intersectioncentral.com/events/cssi/search_results.asp?cid=epri&pid=2&tid=104265557355&postingForm=calendar.asp&bFromCalendar=1&event_schedule_id=1575.

ASME TURBO EXPO 2003: Power for Land, Sea, and Air and International Joint Power Generation Conference. June 16–19, Georgia World Congress Center, Atlanta, Ga. The two conferences will host a joint exposition. For more information, visit www.asme.org.


22nd EPRI Steam Generator NDE Workshop. June 30–July 2, Hilton Head Marriott Beach and Golf Resort, Hilton Head Island, S.C. Contact: Brent Lancaster, (704) 547-6017, e-mail:
13th Annual EPRI NDE Issues Meeting. July 23-25, Wild Dunes Resort, Isle of Palms, S.C. Contacts: Sue Glenn, (704) 547-6078, e-mail: sueglenn@epri.com or Chris Laundon, (704) 547-6194, e-mail: claundon@epri.com; http://inter.viewcentral.com/events/cust/search_results.asp?cid=epri&pid=2&lid=2&ts =amp=1037660165490&postingForm=calendar.asp&amp;FromCalendar=1&amp;event_schedule_id=1575.

13th Annual EPRI NDE Issues Meeting. July 23-25, Wild Dunes Resort, Isle of Palms, S.C. Contacts: Sue Glenn, (704) 547-6078, e-mail: sueglenn@epri.com or Chris Laundon, (704) 547-6194, e-mail: claundon@epri.com; http://inter.viewcentral.com/events/cust/search_results.asp?cid=epri&pid=2&lid=2&ts =amp=1037660165490&postingForm=calendar.asp&amp;FromCalendar=1&amp;event_schedule_id=1575.

13th Annual EPRI NDE Issues Meeting. July 23-25, Wild Dunes Resort, Isle of Palms, S.C. Contacts: Sue Glenn, (704) 547-6078, e-mail: sueglenn@epri.com or Chris Laundon, (704) 547-6194, e-mail: claundon@epri.com; http://inter.viewcentral.com/events/cust/search_results.asp?cid=epri&pid=2&lid=2&ts =amp=1037660165490&postingForm=calendar.asp&amp;FromCalendar=1&amp;event_schedule_id=1575.

13th Annual EPRI NDE Issues Meeting. July 23-25, Wild Dunes Resort, Isle of Palms, S.C. Contacts: Sue Glenn, (704) 547-6078, e-mail: sueglenn@epri.com or Chris Laundon, (704) 547-6194, e-mail: claundon@epri.com; http://inter.viewcentral.com/events/cust/search_results.asp?cid=epri&pid=2&lid=2&ts =amp=1037660165490&postingForm=calendar.asp&amp;FromCalendar=1&amp;event_schedule_id=1575.

13th Annual EPRI NDE Issues Meeting. July 23-25, Wild Dunes Resort, Isle of Palms, S.C. Contacts: Sue Glenn, (704) 547-6078, e-mail: sueglenn@epri.com or Chris Laundon, (704) 547-6194, e-mail: claundon@epri.com; http://inter.viewcentral.com/events/cust/search_results.asp?cid=epri&pid=2&lid=2&ts =amp=1037660165490&postingForm=calendar.asp&amp;FromCalendar=1&amp;event_schedule_id=1575.

Welding Korea 2003. August 27–30, Indian Hall, COEX, Seoul, Korea. Organized by the Korea Welding Industry Cooperative and COEX. Contact: Welding Korea 2003 Secretariat, COEX World Trade Center, Samsung-dong, Gangnam-gu, Seoul, 135-731, Korea. (02) 6000-1055, 1056, FAX: (02) 6000-1309, e-mail: kbc@coex.co.kr or donhan@coex.co.kr; www.weldingshow.co.kr.


Educational Opportunities
ASME Continuing Education Institute Short Courses on Welding. ASME Section IX, Welding and Brazing Qualifications, May 5–7, Houston, Tex. Practical Welding Technology, June 2–4, Pittsburgh, Pa. Contact: (800) THE-ASME.
The Nissen Feltip Paint Markers are as convenient, clean, and easy-to-use as a conventional felt tip marker, but they mark with the permanence of fast-drying enamel paint. You can mark on almost any material, even on wet or oily surfaces. The marks are permanent; they won't chip, peel, fade or rub off. They will withstand heat and weathering under adverse conditions. The Feltip Paint Markers are available in Standard and Fine-Line versions, and in nine high-gloss, lead-free colors: white, yellow, red, black, blue, green, orange, silver and gold.


EPRI NDE Training Seminars. EPRI offers NDE technical skills training in Visual Examination, Ultrasonic Examination, ASME Section XI, UT Operator Training, and more. For specific information, contact Sherryl Stogner, (704) 547-6174, e-mail: sstogner@epri.com.


The Fabricators & Manufacturers Association, International (FMA), and the Tube and Pipe Association, International (TPA) Courses. A course schedule is available by calling (815) 399-8775; e-mail: info@fmametalfab.org; www.fmametalfab.org.

Malcom Plastic Welding School. A comprehensive two-day, hands-on course that leads to certification in accordance with the latest European DVS-approved plastic welding standards for hot gas and extrusion welding techniques. Contact: Sheila Carpenter, Administration, Malcom Hot Air Systems, 1676 E. Main Rd., Portsmouth, RI 02871, (888) 807-4030, FAX: (401) 682-1904, e-mail: info@malcom.com; www.plasticweldingtools.com.

Symex Star-Trac II Automatic Gouging System

☆ Designed for continuous gouging of long seams in the manufacture of ships, pressure vessel tanks, bridges, etc.

☆ High resolution voltage control capability regulates accurate gouging depth to a machine-like tolerance of ±0.015" (0.4mm) even over warped plate.

☆ Total weight (less travel system) is 20 lbs.

☆ Use with Symex 3/8" - 5/8" "Secur-Fit" Jointed Gouging Electrodes up to 1200 Amps.

☆ Suited for out-of-position work due to its light weight.
### Educational Opportunities

**AWS Schedule — CWI/CWE Prep Courses and Exams**

Exam application must be submitted six weeks before exam date. For exam information and an application, contact the AWS Certification Dept., (800) 443-9353 ext. 273. For exam prep course information, contact the AWS Education Dept., (800) 443-9353 ext. 229.

<table>
<thead>
<tr>
<th>Cities</th>
<th>Exam Prep Courses</th>
<th>CWI/CWE Exams</th>
</tr>
</thead>
<tbody>
<tr>
<td>Albuquerque, N.Mex.</td>
<td>August 3–8</td>
<td>August 9</td>
</tr>
<tr>
<td></td>
<td>(API 1104 Clinic also offered)</td>
<td></td>
</tr>
<tr>
<td>Atlanta, Ga.</td>
<td>May 4–9</td>
<td>May 10</td>
</tr>
<tr>
<td></td>
<td>(API 1104 Clinic also offered)</td>
<td></td>
</tr>
<tr>
<td>Baton Rouge, La.</td>
<td>July 13–18</td>
<td>July 19</td>
</tr>
<tr>
<td></td>
<td>(API 1104 Clinic also offered)</td>
<td></td>
</tr>
<tr>
<td>Beaumont, Tex.</td>
<td>June 8–13</td>
<td>June 14</td>
</tr>
<tr>
<td></td>
<td>(API 1104 Clinic also offered)</td>
<td></td>
</tr>
<tr>
<td>Birmingham, Ala.</td>
<td>EXAM ONLY</td>
<td>May 24</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Boston, Mass.</td>
<td>EXAM ONLY</td>
<td>June 7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Chicago, Ill.</td>
<td>June 22–27</td>
<td>June 28</td>
</tr>
<tr>
<td></td>
<td>(API 1104 Clinic also offered)</td>
<td></td>
</tr>
<tr>
<td>Cincinnati, Ohio</td>
<td>EXAM ONLY</td>
<td>June 7</td>
</tr>
<tr>
<td></td>
<td>(API 1104 Clinic also offered)</td>
<td></td>
</tr>
<tr>
<td>Columbus, Ohio</td>
<td>May 12–16</td>
<td>May 17</td>
</tr>
<tr>
<td></td>
<td>(API 1104 Clinic also offered)</td>
<td></td>
</tr>
<tr>
<td>Corpus Christi, Tex.</td>
<td>EXAM ONLY</td>
<td>May 3</td>
</tr>
<tr>
<td></td>
<td>(API 1104 Clinic also offered)</td>
<td></td>
</tr>
<tr>
<td>Denver, Colo.</td>
<td>June 22–27</td>
<td>June 28</td>
</tr>
<tr>
<td></td>
<td>(API 1104 Clinic also offered)</td>
<td></td>
</tr>
<tr>
<td>Houston, Tex.</td>
<td>May 19–24</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9-YEAR RECERTIFICATION COURSE</td>
<td></td>
</tr>
<tr>
<td>Idaho Falls, Idaho</td>
<td>EXAM ONLY</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(API 1104 Clinic also offered)</td>
<td></td>
</tr>
<tr>
<td>Kansas City, Mo.</td>
<td>July 27–August 1</td>
<td>August 2</td>
</tr>
<tr>
<td></td>
<td>(API 1104 Clinic also offered)</td>
<td></td>
</tr>
<tr>
<td>Kansas City, Mo.</td>
<td>August 4–9</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9-YEAR RECERTIFICATION COURSE</td>
<td></td>
</tr>
<tr>
<td>Long Beach, Calif.</td>
<td>EXAM ONLY</td>
<td>July 26</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Louisville, Ky.</td>
<td>May 18–23</td>
<td>May 24</td>
</tr>
<tr>
<td></td>
<td>(API 1104 Clinic also offered)</td>
<td></td>
</tr>
<tr>
<td>Miami, Fla.</td>
<td>EXAM ONLY</td>
<td>May 15</td>
</tr>
<tr>
<td></td>
<td>(API 1104 Clinic also offered)</td>
<td></td>
</tr>
<tr>
<td>Miami, Fla.</td>
<td>EXAM ONLY</td>
<td>June 19</td>
</tr>
<tr>
<td></td>
<td>(API 1104 Clinic also offered)</td>
<td></td>
</tr>
<tr>
<td>Miami, Fla.</td>
<td>EXAM ONLY</td>
<td>July 17</td>
</tr>
<tr>
<td></td>
<td>(API 1104 Clinic also offered)</td>
<td></td>
</tr>
<tr>
<td>Miami, Fla.</td>
<td>EXAM ONLY</td>
<td>August 14</td>
</tr>
<tr>
<td></td>
<td>(API 1104 Clinic also offered)</td>
<td></td>
</tr>
<tr>
<td>Milwaukee, Wis.</td>
<td>May 18–23</td>
<td>May 24</td>
</tr>
<tr>
<td></td>
<td>(API 1104 Clinic also offered)</td>
<td></td>
</tr>
<tr>
<td>Mobile, Ala.</td>
<td>EXAM ONLY</td>
<td>July 19</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orlando, Fla.</td>
<td>June 5–11</td>
<td>July 12</td>
</tr>
<tr>
<td></td>
<td>(API 1104 Clinic also offered)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(API 1104 Clinic also offered)</td>
<td></td>
</tr>
<tr>
<td>Pittsburgh, Pa.</td>
<td>June 8–13</td>
<td>June 14</td>
</tr>
<tr>
<td></td>
<td>(API 1104 Clinic also offered)</td>
<td></td>
</tr>
<tr>
<td>Pittsburgh, Pa.</td>
<td>June 23–28</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9-YEAR RECERTIFICATION COURSE</td>
<td></td>
</tr>
<tr>
<td>Sacramento, Calif.</td>
<td>June 8–13</td>
<td>June 14</td>
</tr>
<tr>
<td></td>
<td>(API 1104 Clinic also offered)</td>
<td></td>
</tr>
<tr>
<td>Sacramento, Calif.</td>
<td>August 10–15</td>
<td>August 16</td>
</tr>
<tr>
<td></td>
<td>(API 1104 Clinic also offered)</td>
<td></td>
</tr>
<tr>
<td>Salt Lake City, Utah</td>
<td>July 13–18</td>
<td>July 19</td>
</tr>
<tr>
<td></td>
<td>(API 1104 Clinic also offered)</td>
<td></td>
</tr>
<tr>
<td>San Diego, Calif.</td>
<td>May 4–9</td>
<td>May 10</td>
</tr>
<tr>
<td></td>
<td>(API 1104 Clinic also offered)</td>
<td></td>
</tr>
<tr>
<td>Seattle, Wash.</td>
<td>July 27–August 1</td>
<td>August 2</td>
</tr>
<tr>
<td></td>
<td>(API 1104 Clinic also offered)</td>
<td></td>
</tr>
</tbody>
</table>

---

**Image Management from LECO**

**Efficient Acquisition and Storage of Digital Images/Data for Welding Quality Control**

LECO offers the **SZX12 Stereo Microscope** and the **PAX-it™ Image Management System** for efficient acquisition and storage of digital images and data. Capable of measuring, pre-testing, and documenting welds, this system is the ideal solution for your welding-related image management needs.

- Flexibility and modularity
- Quick set-up with Windows®-based operating software
- Ideal for welding and area fraction applications

*For more information, visit [www.leco.com/le849r2.htm](http://www.leco.com/le849r2.htm)*

LECO Corporation  
3000 Lakeview Avenue • St. Joseph, MI 49085-2396 • Phone: 800-292-6141 • Fax: 269-982-8977
info@leco.com • www.leco.com • ISO-9001 • No. FM 24045 • LECO is a registered trademark of LECO Corporation.
Circle No. 32 on Reader Info-Card
NEW!
AWS WELDING DISTRIBUTOR MEMBERSHIP...

Put your company on the Map!

AWS Welding Distributor Members enjoy:

- $375 in Individual AWS Memberships (25% off) offering each of your employees or customers:
  - Complimentary subscription to the award-winning Welding Journal magazine.
  - The American Welder, a special section of the Welding Journal designed for front-line welders.
  - A popular AWS Publication (188 value) for only $25.
- 25% Members-only discount on any AWS Publication – choose from among 30+ titles by calling (800) 83-WELD.
- Professional Development via Members'-only discounts on world-renowned AWS Certification programs, dozens of topical conferences, seminars and home-study courses.
- Complimentary VIP Passes to the AWS Welding Show – distribute as perks to your best customers.
- 25% discount on any AWS Publication, i.e., Welding Handbook, and opportunity to resell them for a profit.
- 70% off subscription to Welding Journal direct to your end-users.
- 70% Discount on Welding Journal gift subscriptions mailed directly to end-users use your company's name on the shipping bag – use WJ as gifts to your loyal customers and promote your company name at the same time.
- A professional-looking AWS Welding Distributor wall plaque to display your company’s affiliation with the Society.
- 50% off shipping charges with Yellow Transportation, Inc. – an extra 5% off your freight bill.
- Access to AWS JobFind (<www.aws.org/jobfind>), a full-featured online career recruitment service that is housed on the AWS Website and provides companies a vehicle to post job openings and to search a resume database for qualified candidates.

For more information or an application for becoming an AWS Welding Distributor Member, please call (800) 443-9353, ext. 253, or (305) 443-9353. Or, go on-line at www.aws.org/membership.
AWS Elects National and District Officers at Its Annual Meeting

The American Welding Society elected a new slate of national officers on April 7 at the AWS Annual Meeting in Detroit, Mich. The new officers will assume office on June 1.

- **Thomas M. Mustaleski** was elected president of the Society. He is a research staff member in the Development Division of BWXT-Y12 (formerly Lockheed Martin Energy Systems, Inc.), Oak Ridge, Tenn. Mustaleski received his undergraduate degree in metallurgical engineering from Rensselaer Polytechnic Institute and has done subsequent graduate work at the University of Wisconsin-Milwaukee and the University of Tennessee.

- **James E. Greer** was elected to his third term as vice president. He is a professor and coordinator of the welding program at Moraine Valley Community College and president of Techno-Weld Welding Consultants. Greer received his A.S. degree from Moraine Valley Community College, his B.S. from Northern Illinois University, and his M.S. from Chicago State University.

- **Damian J. Kotecki** was elected to his second term as vice president of the Society. He is technical director for stainless and high-alloy product development at The Lincoln Electric Co., Cleveland, Ohio. Kotecki received his B.S., M.S., and Ph.D. degrees in mechanical engineering.
2003–2004
AWS Officers

from the University of Wisconsin-Madison.

- Gerald D. Uttrachi was elected to his first term as vice president. He is president of WA Technology, LLC. Uttrachi holds bachelor's and master's degrees in mechanical engineering and a master's of science degree in management from New Jersey Institute of Technology.

Incoming President Mustaleski and Vice Presidents Greer, Kotecki, and Uttrachi will also serve on the Society's board of directors. Also added to the board are the following elected officers.

- Scott C. Chapple was elected director-at-large. He is a welding consultant in Rockwood, Mich.

- Harvey R. Castner was elected director-at-large. He currently directs the Government Programs Office at Edison Welding Institute in Columbus, Ohio.

- Russell L. Norris was elected District 1 director. He is branch manager for Merriam Graves Corp. in Portsmouth, N.H.

- Theodore R. Alberts was elected District 4 director. He is an associate professor and coordinator of the welding technology program at New River Community College, Dublin, Va.

- Robert J. Tabernick was reelected District 7 director. He is district manager in Columbus, Ohio, for The Lincoln Electric Co.

- Victor Y. Matthews was reelected District 10 director. He is employed at The Lincoln Electric Co. and is currently assigned responsibility for Cleveland-manufactured consumable products worldwide.

- Efthios Siradakis was elected District 11 director. He has been with Airgas Great Lakes, a regional Airgas Inc. company, for 21 years.

- Jesse L. Hunter was reelected District 13 director. He is senior staff engineer in quality control at The Lincoln Electric Co. and is currently assigned responsibility for Cleveland-manufactured consumable products worldwide.

- Robert J. Tabernick was reelected District 19 director. He is QA manager for both Brooklyn Iron Works and Brooklyn Industrial Coatings.

- Kent S. Baucher was elected District 22 director. He is a partner in Technicon Engineering Services, Inc., a testing and inspection laboratory he and a business partner began in 1989.


NASA Names Computer for AWS Member

NASA recently honored American Welding Society (AWS) member Edmund F. Rybicki, who serves as chairman of the mechanical engineering department at the University of Tulsa (UT), by naming a computer for him, citing him for his "contributions to the field of fracture mechanics."

The computer, named RYBICKI, is used at the Langley Research Center in Virginia to help design spacecraft and materials research. The computer is also used by researchers to study the fracture and failure of metal and composite materials.

Prior to joining UT in 1979, Rybicki studied the causes of failures of composite materials at Battelle Memorial Institute, Columbus, Ohio, where he and a coworker developed a method of predicting failures. It is this method that NASA uses in its computer analysis software.

Rybicki, who is UT's F. W. Murphy Professor of Mechanical Engineering, is chair of the AWS Committee on Thermal Spraying and Subcommittee of Mechanical Properties of Thermal Spraying, vice chair of the AWS Subcommittee on Conference and Show, and is a member of the AWS Technical Activities Committee, the SSPC/NACE/AWS Tri-Society Thermal Spray Committee on the Corrosion Protection of Steel, and the ASTM/AWS Joint Task Group on Thermal Spray Equipment.
AWS Publications

Guide for Estimating Welding Emissions

AWS has published AWS F1.6:2003, Guide for Estimating Welding Emissions for EPA and Ventilation Permit Reporting. The intent of this guide is to assist companies in estimating emissions from welding processes for Environmental Protection Agency (EPA) reporting purposes.

This ANSI-approved guide is concise, easily understandable, and outlines methods of estimating airborne emissions from the arc welding process. It was developed by the AWS Safety and Health Subcommittee for Fumes and Gases with assistance from manufacturers and users of welding equipment and consumables.


Two Specifications for Thermal Spray Equipment Inspection and Application Released

The AWS Thermal Spray Committee has released two new standards to answer the welding industry's call for information on thermal spray equipment inspection and thermal spray coatings to protect steel against corrosion.


The specification is 30 pages and contains five tables. Inspection reports are also provided. C2.21M/C2.21:2003 is $36 for AWS members and $48 for nonmembers.

Covered as industrial processes for the application of thermal spray coatings on steel in AWS C2.22M/C2.22:2003, Specification for the Application of Thermal Spray Coatings (Metallizing) of Aluminum, Zinc, and Their Alloys and Composites for the Corrosion Protection of Steel, are safety, job reference standards, equipment, and surface setup and preparation, as well as aluminum and zinc application, sealer, and topcoat.

The specification is 71 pages, contains five tables, and has nine figures. The price of C2.22M/C2.22:2003 is $36 for AWS members and $48 for nonmembers.

Independent Shop's Guide to Welding Safety and Health

The American Welding Society has released The Independent Shop's Guide to Welding Safety and Health. Through the use of visual text and help boxes, the guide presents an easily understood, straightforward safety reference for independent welding shops. From management responsibilities to protection from and prevention of welding hazards, this comprehensive guide addresses the issues faced by welding shops without the overhead to implement compliance/training programs and safety officers.

Author J. D. Jennings writes with the authority earned during his years as manager of technical publications for Miller Electric Mfg. Co. He acknowledges that a loss of manpower can be devastating to the operations of smaller shops, so to help managers avoid this type of crisis, Jennings, with help from authoritative reviewers, has compiled an impressive list of both print and Internet information sources and resources, many of which are free to users.

The Independent Shop's Guide to Welding Safety and Health is 38 pages and includes one table, three figures, and a MSDS/HCP glossary. The guide is $33 for AWS members and $44 for nonmembers.

Specification for Shielded Metal Arc Welding Electrodes

The American Welding Society has published a new specification to establish the requirements for the classification of carbon steel electrodes for shielded metal arc welding. Requirements include the mechanical properties of the weld metal, weld metal soundness, and the usability of the electrodes. A guide for the use of the standard is included as well as guidelines for the preparation of technical inquiries.

AWS A5.1/A5.1M:2003, Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding, supersedes ANSI/AWS A5.1-91. It incorporates both U.S. Customary and SI units. Classification E6018 (E4318) has been included in this new edition.

Specification for Carbon Steel Electrodes for Shielded Metal Arc Welding is 64 pages long. The price for AWS members is $33; $44 for nonmembers.

Guide for Joining Wrought Nickel-Based Alloys

The American Welding Society has released AWS G2.1M/G2.1:2002, Guide for the Joining of Wrought Nickel-Based Alloys. The guide is the result of the work of the AWS G2 Committee on Joining Metals and Alloys to meet industry's demand for information on welding metals and alloys not covered by other documents and committees.

This ANSI-approved standard describes the welding of different wrought nickel-based alloys, including solid-solution and precipitation-hardening alloys. A safety section is also included.

AWS G2.1M/G2.1:2002, Guide for the Joining of Wrought Nickel-Based Alloys, is 48 pages in length. The cost is $36 for AWS members and $48 for nonmembers.

Ordering AWS Publications

To order AWS publications, call Global Engineering Documents at (800) 854-7179 or, outside the United States, (303) 397-7956 or visit the AWS Web site at www.aws.org.

Student Chapters, Send Us Your News

Student Chapters are encouraged to send reports of their meetings, activities and events, along with photographs, for publication in the Welding Journal's Student Activities department.

Send your meeting/event reports to Susan Campbell, Associate Editor, Welding Journal, 550 NW LeJeune Rd., Miami, FL 33126.

Reports can also be e-mailed to campbell@aws.org or faxed to (305) 443-4704.
Indiana Library Dedicated to AWS Member David Via

During Student Night on November 18, 2002, the Bernard K. McKenzie Career Center in Indianapolis, Ind., dedicated the Welding Lab Library to the memory of AWS member David Via. Via, who passed away on July 3, 2002, conducted field training throughout the world for the Hobart Institute of Welding.

During the presentation naming the library, McKenzie Center Welding Instructor William E. “Ed” Wyatt said, “David was passionate about welding and about teaching people how to weld. His passion for life and his love for people were reflected in the students that he mentored and in the many people, like me, who cherished his friendship.”

A plaque in honor of naming the library for Via was presented by AWS President Ernest Levert to Via’s widow, Madonna; daughter, Natalie; and son, Nathan.

AWS Baton Rouge Member’s Students Build a Gazebo for Their Town

American Welding Society Baton Rouge member Davis Raborn oversaw the construction of a gazebo for the town of Zachary, La., by his welding students from Zachary High School.

Materials to build the gazebo were provided by the mayor of Zachary. Raborn’s students primarily used the shield metal arc welding process to fabricate the gazebo.

The gazebo is located next the town’s Historical Village and will be used by students on field trips, for holiday activities, and other events.

AWS North Texas Chairman Promotes Welding in Garland, Texas, Schools

American Welding Society North Texas Section Chairman J. Jones recently attended the Garland Independent School District’s (GISD) Appreciation Breakfast, which is given to thank volunteers from industry who generously donate their time to speak on behalf of their industry to students in the school district.

J. Jones, a training specialist for Victor Equipment Co., works with the GISD in Garland, Tex., to promote welding as a profession. He gives safety presentations for and hands-on demonstrations of gas apparatus to welding classes. He furnishes training literature to the schools and passes out stickers and wearable items to students who correctly answer questions during his presentations.

Jones has worked with the district for many years, involving both the AWS North Texas Section and his employer, in trying to promote careers in the welding industry and to better prepare students for the challenges those careers will bring. Jones said, “I speak to the school board concerning the importance of skilled technology classes [such as welding classes] for our youth. There’s seldom a day that goes by that one’s life isn’t affected by the welding industry, and we need people out there calling attention to it.”

JOM to Host Eleventh International Conference on the Joining of Materials

The Institute for the Joining of Materials (JOM) will host the Eleventh International Conference on the Joining of Materials from May 25 through 28 in Helsingør, Denmark. For further information on the conference, contact: JOM Institute, Gilleleje Strandvej 28, DK-3250 Gilleleje, Denmark, (45) 4835 5458, FAX: (45) 4835 5457, e-mail: jomaws@post10.tele.dk.
AWS Welcomes New Affiliate Member Companies

Alaska Ship & Dry Dock
P.O. Box 9470
Ketchikan, AK 99901

Carotek, Inc.
700 Sam Newell Rd.
Matthews, NC 28106

Combs Welding Design
503 Dundee Rd.
Dundee, FL 33838

D & L Fabricating, Inc.
1422 S. 21st Dr.
Phoenix, AZ 85009

Hackett's Welding
1033 Palin Farm Rd.
Derby, VT 05829

Leitner Fabrikation Corp.
88 Beacon Street
Buffalo, NY 14220

McFarlane Mfg. Co., Inc.
1330 Dallas Street
Sauk City, WI 53583

Rowen Welding & Underwater Construction Ltd.
Units 11 & 12 Silverdale Business Court
Silverdale Rd.
Newcastle-Under-Lyme
ST5 6EH Staffordshire
England

Skinner Fabricating & Welding
19706 Progress Dr.
Strongsville, OH 44159

Steve's Welding
7901 S.R. 73 N.
Hillsboro, OH 45133

T & M Manufacturing, Inc.
P.O. Box 307
Tremonton, UT 84337

Westeel Ltd. (Olds Branch)
5812 48th Ave.
Olds T4H 1V1 Alberta
Canada

Western Press
985 Elmsford
Troy, MI 48083

Sustaining Member Companies

Superheat FGH Services, Inc., is a world leader in on-site heat-treatment services and temperature control. The company utilizes a proprietary software program to remotely control heat-treatment systems.

Services provided by Superheat FGH include postweld heat-treatment, welding preheat, heatshrink/expansion, coating cures, hydrogen bake out, refractory dry out, warming systems, and line thaw.

Innovative Welding Accessories LLC is a manufacturer of safety and convenience accessories for portable welding machines. The company features the Cable Catcher, a cable protection system designed to allow free movement of a portable welding machine by preventing the machine's wheels from becoming entangled with cables and hoses lying on the floor.

AWS Welcomes New Supporting Companies

New Educational Institutions

Commercial Diving Academy
8137 N. Main St.
Jacksonville, FL 32208

Franklin Technology Center
MSSC Campus
3950 Newman Rd.
Joplin, MO 64804

Nelson County Area Technology Center
1060 Bloomfield Rd.
Bardstown, KY 40004

New Supporting Companies

M. W. Technologies, Inc.
71 Midland Ave.
Elmwood Park, NJ 07407

Valero Ardmore Refinery
East Highway 142 and
Cameron Rd.
Ardmore, OK 73401

Visit AWS on the Web

The world of AWS is as close as a click of your mouse. While visiting the American Welding Society’s Web site, you can renew your membership, buy books and standards, and even look for a new job. To see what's on the Web site for you, just visit www.aws.org.

CS Unitek, Inc.
22 Harbor Ave.
Norwalk, CT 06850

In 1991, CS Unitek, Inc., invented the first pneumatic portable hand saw. In subsequent years, the company has added to its list of industry firsts with the widest range of portable magnetic drills, annular cutting machines, portable saws, pipe sanders, surface finishing machines, tube rolling motors, and electric and pneumatic motors for special driving and turning applications.

AWS Membership

Member Grades As of April 1, 2003

Sustaining Companies 431
Supporting Companies 262
Educational Institutions 314
Affiliate Companies 97

Total Corporate Members 1,104
Individual Members 44,078
Student Members 4,236

Total Members 48,314
DISTRICT 1
Director: Geoffrey H. Putnam
Phone: (802) 439-5916

Dale Powell, foreground, during his presentation to the Boston Section.

Ron Coulstring instructing a Boston Section member during hands-on demonstrations at the November meeting.

BOSTON
OCTOBER 7, 2002
Speaker: Dale Powell, northeast regional manager.
Affiliation: Copper Development Association.
Topic: Joining copper and copper alloys with an emphasis on large-diameter tubing.

NOVEMBER 11, 2002
Speaker: Steve Flowers, welding instructor.
Affiliation: Southeastern Technical School, Southeastern, Mass.
Topic: Pipe welding.
Activity: Welding instructor Ron Coulstring demonstrated various welding and cutting processes on pipe and plate. Steve Flowers was honored with the 2002 District Educator Award.

Boston Chairman Tom Ferri, right, presenting a speaker's award to Bruce Richardson.

Boston Section Program Chairman Jim Reid, left, and Chairman Tom Ferri, right, presenting guest speaker Matt O'Keefe with a speaker's gift.

JANUARY 13
Speaker: Bruce Richardson, plant supervisor.
Affiliation: Bird Machine Co.
Activity: Members toured the Bird Machine Co. plant. Welding techniques for duplex and austenitic stainless steels were emphasized.

FEBRUARY 3
Speaker: Neil Mansfield, welding instructor.
Topic: Blacksmithing.

MARCH 10
Speaker: Matt O'Keefe, CEO.
Affiliation: Seven Cycles.
Activity: The Section toured the Seven Cycles plant, featuring the fabrication and welding of titanium and steel bicycle frames.

GREEN & WHITE MOUNTAIN
FEBRUARY 13
Speaker: Brian Sullivan, district manager.
Topic: Theory of multiprocess welding machines.
Activity: Members had the opportunity to operate Lincoln's new 300-A multiprocess welding machine.

CONNECTICUT
FEBRUARY 18
Speaker: Ken Ludue, technical specialist.
Affiliation: Magnatech Corp., East Granby, Conn.
Topic: Orbital, GMA, and GTA welding equipment.
Activity: Members toured the Magnatech facility and watched demonstrations of orbital welding on copper-nickel, stainless steel, and carbon steel pipe.

DISTRICT 2
Director: Alfred F. Fleury
Phone: (732) 868-0768

New York Chairman Dominic Colasanto, left, with guest speaker Marc Vargas during the November meeting.

NEW YORK
NOVEMBER 25, 2002
Speaker: Marc Vargas, compliance officer.
Guest speaker Albert J. Moore, Jr., left, with New York Section Chairman Dominick Colasanto.

Affiliation: OSHA, Manhattan area.
Topic: Structural steel erection roles, Subpart R.

FEBRUARY 24
Speaker: Albert J. Moore, Jr., owner.
Affiliation: Marion Testing and Inspection, Canton, Conn.
Topic: Horror stories about preengineered buildings.

DISTRICT 3
Director: Alan J. Badeaux, Sr.
Phone: (301) 449-4800, ext. 286

Lehigh Valley Section members, from left, Dan Moyer, Ernest Dengler, and Brad Brandmeir at the National Vocational-Technical Honor Society’s induction ceremony.

LEHIGH VALLEY
JANUARY 16
Activity: Section members attended the National Vocational-Technical Honor Society induction ceremony at the Lehigh Career and Technical Institute, where three of the five students inducted were AWS members.

JANUARY 29
Activity: The Section held its annual SkillsUSA/VICA Student Welding Contest awards ceremony. First place was won by Kyle Weiss, Career Institute of Technology; second place went to Ernest Dengler, Lehigh Career and Technical Institute; and in third place was Josh Staples, Monroe County Area Vocational Technical School.

FEBRUARY 11
Speaker: Bob Wiswesser, president.
Topic: Filler metals.

LANCASTER and YORk-CENTRAL PENNSYLVANIA
MARCH 7
Activity: AWS President Ernest Levert spent the day working with York County School of Technology students in the welding lab and then gave a presentation. He also visited Thaddeus Stevens College, where, after a tour of the campus, he gave a presentation to the freshman welding class. That evening, Levert made a presentation at the Section’s meeting, which was also Awards Night. Chairman George Bottenfield presented Mike Bunnell with the Section Meritorious Award; Levert awarded Bottenfield with the District Meritorious Award; Past District 3 Director/Section Secretary Claudia Buttenfield pre-
York-Central Pennsylvania Award winners Mike Bunnell, left, and Section Chairman George Bottenfield, right, with Past District 3 Director/Section Secretary Claudia Bottenfield.

Presented Mike Bunnell, Mike Fink (not present), and George Bottenfield with the District 3 Director Award.

DISTRICT 4
Director: Roy C. Lanier
Phone: (252) 321-4285

Members of the Southwest Virginia Section during their March meeting.

Fred Ciampi during his presentation to the Southwest Virginia Section.

SOUTHWEST VIRGINIA
January 16
Speaker: Fred Ciampi, district sales manager.
Affiliation: National-Standard Co.
Topic: History of welding.

February 19
Speaker: John Abbitt, district business manager.
Affiliation: Thermadyne.
Topic: History and use of the modern plasma cutting process, and how to increase the life of consumables.

March 12
Speaker: Frank Armao, group leader nonferrous applications.
Affiliation: The Lincoln Electric Co., Cleveland, Ohio.
Topic: Nonferrous applications.

Southwest Virginia Section Secretary Bill Rhodes, right, with guest speaker John Abbitt at the Section's February meeting.

SYRACUSE
March 12
Speakers: Bob and Bill Davis, owners.
Affiliation: Davis Inspection Agency.
Topic: Visual and dyed penetrant inspection.

DISTRICT 7
Director: Robert J. Tabernik
Phone: (614) 488-7913

Pittsburgh Section Student Day award recipients David Jobe, left, who won first place in the Postsecondary Student Weld-off, and Instructor Don Kowalski, who accepted an award for Triangle Tech.

DISTRICT 5
Director: Wayne J. Engeron
Phone: (404) 501-9185

Pittsburgh Section Chairman George Harris, left, presenting guest speakers Glen Hergenrather and Robert Blauser with speakers' gifts.

SOUTH CAROLINA
February 20
Speaker: Marvin Tallent, assistant QA/QC manager.
Affiliation: Palmetto Bridge Constructors.
Topic: Joining reinforcing steel.

March 7
Speaker: Kerry Sabo.
Affiliation: The Lincoln Electric Co.
Topic: How being multitalented helps meet the demanding requirements of today's job market.
Activity: The Section held Student Day.

March 11
Speaker: Glen Hergenrather, frame resident engineer, and Robert Blauser, manufacturing engineer, welding and fabrication.
Affiliation: Harley-Davidson Motor Company.
Topic: Design and fabrication of motorcycle frames and various plant locations and test facilities.

SOUTH CAROLINA
March 13
Speaker: Rajesh Talwar.
Affiliation: Boeing's Phantom Works.
Topic: Friction stir welding at Boeing and around the world.

COLUMBUS
March 13
Speaker: Rajesh Talwar.
Affiliation: Boeing's Phantom Works.
Topic: Friction stir welding at Boeing and around the world.

PITTSBURGH
March 7
Speaker: Kerry Sabo.
Affiliation: The Lincoln Electric Co.
Topic: How being multitalented helps meet the demanding requirements of today's job market.
Activity: The Section held Student Day.

March 11
Speaker: Glen Hergenrather, frame resident engineer, and Robert Blauser, manufacturing engineer, welding and fabrication.
Affiliation: Harley-Davidson Motor Company.
Topic: Design and fabrication of motorcycle frames and various plant locations and test facilities.

NORTHERN NEW YORK
March 4
Speaker: Neal Chapman, site welding engineer and AWS District 6 director.
Affiliation: Entergy Nuclear Northeast.
Topic: Nuclear welding program — issues, challenges, and the future.
SPECIAL OFFER (See reverse) — IT'S EASIER THAN EVER TO RECRUIT NEW AWS INDIVIDUAL MEMBERS

THE AWS ADVANTAGE
The 2002-2003
AWS Member-Get-A-Member Campaign

AWS is nearly 50,000 members strong. Imagine how much stronger we would be if each of our members took just a few minutes to encourage one of their colleagues to join AWS. We could potentially boost a membership of nearly 55,000 — making us one of the largest associations in the world... and giving you the resources necessary to expand your business as an AWS Member. Referrals are our most successful member recruitment tool. Our Members know firsthand how useful AWS Membership is. Why not take the time to encourage someone to join us?

Top Ten Reasons to be an AWS Member:
10. To encourage the next generation with AWS Scholarships awarded through the AWS Foundation and discounted student memberships.
9. To have a voice in a global community that promotes and takes pride in the materials joining industry.
8. For Members-only discounts on car rentals, insurance, and more!
7. To obtain valuable technical knowledge with 300+ publications available.
6. To experience the wave of the future through the world's largest materials joining show by attending the AWS Welding Show.
5. For on-going training through AWS seminars and conferences.
4. To save hundreds of dollars with Members-only discounts on all AWS publications, conferences, seminars and certification programs.
3. Because your FREE annual subscription to the Welding Journal will provide you with valuable information to keep you at the forefront of the materials joining industry.
2. For career advancement through networking opportunities at local Section Meetings and by utilizing the AWS Website which includes AWS JobFind.

The #1 reason to become an AWS Member...
...Because of the savings, knowledge and prestige you'll receive from the premier Society for materials joining professionals.

PRIZE CATEGORIES

President's Honor Roll:
Recruit 1-5 new Individual Members and receive an American Welder™ T-shirt.

President's Club:
Recruit 6-10 new Individual Members and receive an American Welder™ polo shirt.

President's Roundtable:
Recruit 11-19 new Individual Members and receive an American Welder™ watch.

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

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

SPECIAL PRIZES
Participants will also be eligible to win prizes in specialized categories. Prizes will be awarded at the close of the campaign (June 2003).

Sponsor of the Year:
The individual who sponsors the greatest number of new Individual Members during the campaign will receive a plaque and a trip to the 2004 AWS Welding Show, and recognition at the AWS Awards Luncheon at the AWS Welding Show.

Student Sponsor Prize:
AWS Members who sponsor two or more Student Members will receive an American Welder™ T-shirt.

The AWS Member who sponsors the most Student Members will receive a free one-year AWS Membership and an American Welder™ polo shirt.

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

LUCK OF THE DRAW
For every new member you sponsor, your name is entered into a quarterly drawing. The more new members you sponsor, the greater your chances of winning. Prizes will be awarded in November 2002, as well as in February and June 2003.

Prizes Include:
- American Welder™ T-shirt
- Complimentary AWS Membership renewal
- American Welder™ polo shirt
- American Welder™ baseball cap

SUPER SECTION CHALLENGE
The AWS Section in each District that achieves the highest net percentage increase in new Individual Members before the June 2003 deadline will receive special recognition in the Welding Journal and a District Membership Award.

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

American Welding Society
550 N.W. LeJeune Rd. • Miami, FL 33126
Visit our website http://www.aws.org
Second-place winner of the Holston Valley Section's student welding competition Abel Lopez, left, assisting first-place winner Robert Sass with his prize.

NORTHEAST MISSISSIPPI
FEBRUARY 20
Activity: Members toured the Holley Performance Products plant.

HOLSTON VALLEY
MARCH 4
Activity: The Section held Student Night along with a welding competition, which was conducted by Vaughn and Jabin Stroup. The first-place winner was Robert Sass of the Tennessee Technology Center. Second place was captured by Abel Lopez, a student at Unicoi County High School. Prizes were donated by John Deere Power Products, Holston Gases, Lincoln representative Denny Davis, the Tennessee Technology Center, Airgas, and Industrial Marching Repair.

DISTRICT 9
Director: John Bruskotter
Phone: (504) 367-0603

Showing off their plaques at the New Orleans Section's February meeting are, from left, guest speaker Jonathan Davis, Executive Committee member Mike Skiles, guest speaker Gene Roy, and meeting host Ken Ashworth.

DISTRICT 10
Director: Victor Y. Matthews
Phone: (216) 383-2638

Central Michigan Chairman Jeff Grossman, left, accepting a speaker's gift from Detroit Section's Marty Deaseel.

DISTRICT 11
Director: Scott C. Chapple
Phone: (586) 772-1514

Central Michigan Section Chairman Greg Koprowitz presenting Barbara Estes with a speaker's plaque.

NEW ORLEANS
FEBRUARY 18

MOBILE
FEBRUARY 20
Speaker: Barbara Estes, president. Affiliation: Associated Builders and Contractors, Mid Gulf Chapter. Topic: Is Mobile really ready to commit to work force development? Activity: It was Ladies' Night. Chairman Greg Koprowitz gave all ladies in attendance a long stem rose and Past Chairman Robert Wells presented the ladies with Mardi Gras beads.

DISTRICT 10
Director: Victor Y. Matthews
Phone: (216) 383-2638

DISTRICT 11
Director: Scott C. Chapple
Phone: (586) 772-1514

CENTRAL MICHIGAN
JANUARY 21

FEBRUARY 18
Speaker: Lyle Birchman.
Affiliation: General Motors Lansing Car Assembly Body Plant. Topic: Robotic resistance welding of car body assemblies. Activity: Members toured the plant and saw body assembly and welding of the Oldsmobile Alero and Pontiac Grand Am.

NORTHERN MICHIGAN
MARCH 3

DETOUR
MARCH 13
Speaker: Don Henry, N.A. market segment manager - UT.
Topic: Nondestructive examination of welds by ultrasound.
Activity: Old Timers’ Night was held. Phillip Temple, James Goode, Fredrick Ellilcott, and Richard Donovan were presented with AWS Life Member Awards. Receiving the AWS Silver Award were Richard Frank, Gerald Rosenthal, Richard Mollick, John Cunningham, Michael Faitel, John Ludwig, Paul Palleschi, Scott Rainey, Thomas VanLoon, Conran Fisher, Edwin Rimpley, Raymond Roberts, John Bonnier, Don Snyder, Jr., Thomas Czarnecki, Ben Delecke, Stephen Jezierski, and Les Okreglak.

DISTRICT 12
Director: Michael D. Kersey
Phone: (262) 650-9364

Milwaukee Section Chairman Bob Schuster, second from right, with guest speakers, from left, Jeffrey Noruk, Jim Meyers, Joseph Campbell, Sr., and Jay Haynes.

MILWAUKEE
FEBRUARY 20
Speakers: Joseph Campbell, Sr., Jeffrey Noruk, Jim Meyers, and Jay Haynes.
Affiliations: Machinery and Welder Corp., Servo Robotic Corp., Ataco Steel Products, and ABB Flexible Automation, respectively.
Topic: The evolution of robotics to the present and beyond.

DISTRICT 13
Director: J. L. Hunter
Phone: (309) 888-8956

ILLINOIS VALLEY
FEBRUARY 20
Speaker: Chuck Hundley, production manager.
Affiliation: Unytec, Inc., Peru, Ill.
Activities: A plant tour was provided to members. District 13 Director Jesse Hunter presented Section Awards to B. Plotrowski and J. Flanagan.

Lexington Section members during their tour of the Progressive Welding Robotics plant.

Mississippi Valley Secretary Roger Geyer, right, and Rocky McRaeighn, center, presenting a speaker’s gift to Bill Monti.

Speakers: Cathy Hynes and Sam Willard.
Topic: Cryogenic heat exchangers.
Activity: Members toured the Good Times Productions facility in Arkansas City, Kan.

MISSISSIPPI VALLEY
FEBRUARY 19
Speaker: Bill Monti, welding productivity manager, CWI.
Affiliation: Praxair, Inc., St. Louis, Mo.
Topic: How to become a certified welder.
**LEXINGTON**  
**FEBRUARY 27**  
Activity: Section members and guests toured the Progressive Welding Robotics plant.

**ST. LOUIS**  
**FEBRUARY 27**  
Speaker: Ernest Levert, senior staff engineer and AWS president.  
Affiliation: Lockheed Martin Missiles and Fire Control.  
Topic: Career opportunities in the welding industry.  
Activity: Student Night. Four students were awarded $500 Section scholarships.

**DISTRICT 15**  
**Director: J. D. Heikkinen**  
**Phone: (218) 741-9693**

**NORTHWEST**  
**FEBRUARY 18**  
Activity: The Section held its Annual Behind-the-Mask Contest. There were 58 competitors and 13 helpers, field judges, and weld inspectors to help the contest run smoothly. Contestants had a choice of welding with either the GTAW or GMAW process. Winners in the GTAW portion of the contest were Joey Miller in first place, Mike Herzog in second, and Jason Hellickson in third. The winners in the GMAW competition were Josh Ruka in first, Eric Nelson in second, and Randy Wente in third. Dwight Affeldt and Pam Lese-  

**DISTRICT 16**  
**Director: C. F. Burg**  
**Phone: (515) 294-5428**

**DISTRICT 17**  
**Director: Oren P. Reich**  
**Phone: (254) 867-2203**

Guest speaker Robert Warke addressing members of the East Texas Section.

**CENTRAL ARKANSAS**  
**JANUARY 21**  
Activity: A business meeting was held.

**FEBRUARY 20**  
Speakers: Ron Settimi and Bob Ellig.  
Affiliation: Demmeler Welding Systems.  
Topic: Modular welding fixtures.

**EAST TEXAS**  
**FEBRUARY 20**  
Speaker: Robert Warke, professor.  
Affiliation: LeTourneau University.  
Topic: Weld failure analysis.

**DISTRICT 18**  
**Director: John Mendoza**  
**Phone: (210) 860-2592**

Students and faculty advisor of Lamar University’s mini-Baja racer at the Sabine Section meeting

**SABINE**  
**FEBRUARY 18**  
Activity: The Section-sponsored mechanical engineering student group from Lamar University brought the mini-Baja car they designed to the meeting. They will race the car in a national competition in May at Brigham Young University, Provo, Utah.

**DISTRICT 19**  
**Director: Phil Zammit**  
**Phone: (509) 468-2310 ext. 120**

Guest speaker Peter Cortina with Northern Alberta Section Chairman Firdosh Mehta.

**NORTHERN ALBERTA**  
**MARCH 12**  
Speaker: Peter Cortina, manager of business development.  
Affiliation: Hobart Brothers.  
Topic: Strategies for improving welding productivity.

**DISTRICT 20**  
**Director: Jesse A. Grantham**  
**Phone: (303) 451-6759**

**SOUTHERN COLORADO**  
**FEBRUARY 1**  
Speaker: Emilio Gonzales.  
Affiliation: Pueblo Community College.  
Activity: Members toured the college’s welding lab, which, after three moves, is finally in place.

**DISTRICT 21**  
**Director: Les Bennett**  
**Phone: (805) 929-2356**

Lake Charles Section Chairman Tac Edwards, right, presenting a guest speaker's plaque to Chuck Meadows.
District 22
Director: Mark Bell
Phone: (209) 367-1398

District 22 Director Mark Bell, left, congratulating Incoming District 22 Director Kent Baucher on his election to the position.

Sacramento Valley Chairman Rob Purvis, right, thanking First Vice Chairman Dale Flood, second from right, for his presentation as, from left, Dennis Bercsa and Emmanuel Ezenwa look on.

SACRAMENTO VALLEY
MARCH 19
Speaker: Dale Flood.
Affiliation: Tri Tool, Inc.

INTERNATIONAL SECTION

INDIA
JANUARY 23
Activity: The Section held a seminar on ASME Boiler and Pressure Vessel Code in association with Hartford Steam Boiler International GmbH.

Guest speakers at the India Section's January seminar.

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 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. A draft copy may be obtained by contacting Rosalinda O'Neill at AWS, Technical Services Business Unit, 550 NW LeJeune Rd., Miami, FL 33126; telephone: (800) 443-9353, ext. 451 or outside the United States, (305) 443-9353, ext. 451; e-mail: roneill@aws.org.


ISO Draft Standards for Public Review

Copies of the following Draft International Standards are available for review and comment through your national standards body, which in the United States is ANSI, 25 West 43rd St., Fourth Fl., New York, NY 10036; telephone (212) 642-4900. Any comments regarding ISO documents should be sent to your national standards body.

In the United States, if you wish to participate in the development of International Standards for welding, contact Andrew Davis at AWS, 550 NW LeJeune Rd., Miami, FL 33126; telephone (305) 443-9353 ext. 466, e-mail: adavis@aws.org. Otherwise, contact your national standards body.


ISO/DIS 16432, Resistance welding — Procedure for projection welding of uncoated and coated low carbon steels using embossed projection(s).

ISO/DIS 16433, Resistance welding — Procedure for seam welding of coated and uncoated low carbon steels.

Reaffirmed Standards Approved by ANSI


Submit Your Technical Committee Reports

Committee Chairmen — We want to recognize the efforts of your committee and inform our readers of its accomplishments. Send a brief profile of its activities and recent accomplishments, along with a member roster and contact numbers, and we will publish it in the Welding Journal's Society News section.

Send your submissions to Susan Campbell, Associate Editor, American Welding Society, 550 NW LeJeune Rd., Miami, FL 33126, Telephone: (305) 443-9353 ext. 244, FAX: (305) 443-7404, e-mail: campbell@aws.org.
**2002–2003 Member-Get-A-Member Campaign**

Listed below are the people participating in the 2002–2003 Member-Get-A-Member Campaign. For campaign rules and a prize list, please see page 65 of this Welding Journal.

If you have any questions regarding your member proposer points, please call the Membership Department at (800) 443-9353 ext. 480.

---

**Winner's Circle**  
(AWS Members sponsoring 20 or more new Individual Members, per year, since June 1, 1999.)

| J. Compton, San Fernando Valley*** | S. McGill, Northeast Tennessee — 20 |

---

**President's Guild**  
(AWS Members sponsoring 20 or more new Individual Members between June 1, 2002, and May 31, 2003.)

| J. Compton, San Fernando Valley — 31 |

---

**President's Round Table**  
(AWS Members sponsoring 11–19 new Individual Members between June 1, 2002, and May 31, 2003.)

| G. Fairbanks, Jr., Baton Rouge — 13 |

---

**President's Club**  
(AWS members sponsoring 6–10 new Individual Members between June 1, 2002, and May 31, 2003.)

| B. McGuire, East Texas — 9 |

---

**Student Sponsors**  
(AWS members sponsoring 3 or more new AWS Student Members between June 1, 2002, and May 31, 2003.)

| J. Carney, Western Michigan — 5 |

---

*Denotes the number of times an Individual Member has achieved Winner's Circle status. Status will be awarded at the close of each membership campaign year.

---

---
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 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 are to send a letter stating which particular office they are seeking, 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 Richard L. Arn, Chairman, National Nominating Committee, American Welding Society, 550 NW LeJeune Rd., Miami, FL 33126.

The next meeting of the National Nominating Committee is currently scheduled for April 2004. The terms of office for candidates nominated at this meeting will commence June 1, 2005.

Honorary-Meritorious Awards

The Honorary-Meritorious Awards Committee has the duty to make recommendations regarding nominees presented for Honorary Membership, National Meritorious Certificate, William Irgang Memorial, and the George E. Willis Awards. These awards are presented in conjunction with the AWS Exposition and Convention held each spring. The descriptions of these awards follow, and the submission deadline for consideration is July 1 prior to the year of presentation. All candidate material should be sent to the attention of John J. McLaughlin, Secretary, Honorary-Meritorious Awards Committee, 550 NW LeJeune Rd., Miami, FL 33126.

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 Irgang Memorial Award: This award is administered by the American Welding Society and sponsored by The Lincoln Electric Co. to honor the late William Irgang. 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 award's luncheon or at another time as appropriate in conjunction with the AWS President's travel itinerary, and, if appropriate, a one-year membership to AWS.

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.
A 16-page catalog describes more than 200 textbooks, videos, manuals, standards, and other publications about powder metallurgy and particulate materials.

Metal Powder Industries Federation
105 College Rd. E., Princeton, NJ 08540

DIN Pipeline Handbook Published in English

The second edition of DIN Handbook 141 (Steel Pipelines) has been translated into English. It contains 624 pages and includes European standards for water supply systems, site drainage, sewerage systems, and valves. Pipe work welding and corrosion standards are also included.

Beuth Verlag GmbH
D-10772, Berlin, Germany

Guide to Automated Deburring Released

A 12-page educational brochure about automated deburring includes parameters for matching wire and synthetic brushes of various types to different classifications of burrs.

Weiler Corporation
One Wildwood Dr., Cresco, PA 18326

Spec Sheet Describes Cylinder Delivery Truck Bodies

The company’s literature features EW Series delivery truck bodies for gas cylinder delivery routes. The bodies, equipped with hydraulic lifts, are designed to pro-
vide easy loading of heavy cylinder loads. They have DOT-specified mounting and safety features and range from 10 to 20 ft in length.

H&H Equipment Company
16339 Lima Rd., Huntertown, IN 46748

Catalog Features Air-Powered Finishing Tools

A 12-page full-color catalog includes a variety of right-angle tools powered by 1-hp air motors. Finishing tools, disc Sanders, depressed center wheel grinders, buffer/polishers, and accessories are featured, along with technical tips.

Dynabrade, Inc.
8989 Sheridan Dr., Clarence, NY 14031

Safety Sign Catalog
Includes More than 23,000 Products

The company's 2003 catalog features health and safety signs, security and property identification, regulatory markings, electrical maintenance and lockout/tagout products, and other safety graphic products.

Brady Corporation
P.O. Box 571, Milwaukee, WI 53201-0571

COR-MET®
SPECIALTY CORED WIRE
AND COATED ELECTRODES
(810) 227-3251 FAX: (810) 227-9266
www.cor-met.com

Circle No. 19 on Reader Info-Card

THE WAIT IS OVER

Traditional Viewing
Extended Viewing

Auto-Darkening Welding Filter
"There Ain't Nothing Bigger"
20 Sq. Inch Viewing Area

Circle No. 4 on Reader Info-Card
WELDHUGGER COVER GAS DISTRIBUTION SYSTEMS

- Flows gas evenly over and behind the weld pool.
- Reduces oxidation and discolorization.
- Designed for trailing shield and a variety of other applications.
- 316L Stainless steel nozzles and manifolds.

They're Bendable!

Basic Kit
$249

Snake Kit
$349

WELDHUGGER, Inc.
Toll Free: (877) WELDHUG (877) 935-3447 Fax: (480) 940-9366
Visit our website at: www.weldhugger.com

Circle No. 50 on Reader Info-Card

Catalog Features Pipe Cutting Products

The company's 2003 parts catalog displays pipe cutting and beveling equipment, including the Model C adjustable torch holder, saddle-type and band-type beveling machines, and shape-cutting attachments.

H&M Pipe Beveling Machine Co.
120
311 East Third St., Tulsa, OK 74120

“LOOKING FOR A CWI?”
Your search just got easier. AWS JobFind @ www.aws.org/jobfind

Find Certified Welding Inspectors, Level II NDT, Welders, Welding Managers, Engineers and more...

COMPANIES CAN:
- post, edit and manage your job listings easily and effectively, any day or time
- have immediate access to an entire resume database of qualified candidates
- look for candidates who match your employment needs: full-time, part-time or contract employees
- receive and respond to resumes, cover letters, etc. via e-mail
- use two efficient job posting options; 30-day or unlimited monthly postings

INDIVIDUALS CAN:
- enjoy free access to job listings specific to the materials joining industry
- post a public or confidential resume in a searchable database
- apply directly online for open positions with prospective employers
- manage your job search any day or time; update your profile, edit your resume and review all jobs that you applied for
- upload additional resources for free

American Welding Society
Founded in 1919: Advance the Science, Technology and Application of Welding

www.aws.org/jobfind
Northrop Grumman Announces CEO

Northrop Grumman Corp., Los Angeles, Calif., has announced that Ronald D. Sugar, the company's president and COO, was elected CEO. In addition to his election as CEO, he will retain the position of president. As CEO, Sugar succeeds Kent Kresa, who was also chairman and will continue in the position of nonemployee chairman until October 1.

Prior to joining the company in 2001, Sugar served as Litton Industries' president and COO. Previously, he was president and COO of TRW Aerospace and Information Systems. Sugar holds a B.S. from the University of California at Los Angeles and master's and doctoral degrees, all in electrical engineering.

PFERD Announces Management Changes

PFERD, Inc., Leominster, Mass., the U.S. subsidiary of August Rüggeberg GmbH of Marienheide, Germany, has announced the retirement of Frank Langs [AWS] as president after 19 years in the position. He will remain president of PFERD Milwaukee Brush Co. of Menomonee Falls, Wis. Named to succeed Langs as president of PFERD, Inc., was Gene Huegin [AWS]. Huegin, who holds a B.S. degree from California State University, came to the company from Cooper Tools, where he was director of channel marketing.

In addition, the company has promoted James Moro [AWS] to vice president of sales for its U.S. operations. He most recently served as sales manager of special products at the company. Moro joined the company in 1998 from Tyrolit North America, Grafton, Mass., where he was regional sales manager.

Multiquip Names Director

Multiquip, Carson, Calif., has named Mike Ferguson director of sales for the company's General Construction Equipment Unit. Ferguson, who spent 19 years with the company before leaving last year to pursue other interests, previously served as district sales manager covering Tennessee, Mississippi, and Alabama.

Lincoln Appoints Manager

Lincoln Electric Holdings, Inc., Cleveland, Ohio, has appointed Steven Sumner global product manager. He previously served as manager of product development, a position he had held since 1999. Sumner joined the company in 1987 as a mechanical designer in the Research and Development Department and was promoted to a series of positions of increasing responsibility. He is a graduate of Cornell University with a B.S. in mechanical engineering and holds an M.B.A. in marketing from the Weatherhead School of Management at Case Western Reserve University.

Magnatech Hires Sales Manager

Magnatech Ltd. Partnership, East Granby, Conn., has hired Don Brown
HI TecMetal Announces New Appointments

HI TecMetal Group (HTG), Cleveland, Ohio, announced the following new appointments.

Brent Davis was named Strategic Business Unit manager at Brite Brazing. Davis joined the company in 1987 as a quality technician.

Bruce Dulin [AWS] has joined HTG Cincinnati as senior processing coatings engineer. Dulin, who attended The Ohio State University, has more than twenty years of thermal spray, brazing, and heat-treating experience for a wide variety of industries.

JW Harris Names Manager

JW Harris Co., Inc., Kings Mountain, N.C., has named Jack Valentine national welding sales manager. Valentine has served as regional sales manager in the upper Midwest for the Harris Weldco division of the company. He is a member of AWS and has served as chairman of the AWS Northwest Section.

Obituaries

Joseph A. Cunningham, Sr.

Joseph A. Cunningham, Sr. [AWS], a Life Member of AWS, passed away on March 1 at his home in Mooretown, N.J. Cunningham, a graduate of Villanova University in electrical engineering, founded J. A. Cunningham Equipment in 1946. The company eventually grew to be one of the largest independent welding supply distributors on the East Coast.

Karl Graff was honored with the Columbus Technology Council's Technology Hall of Fame Award on January 23.

Graff received his Ph.D. from Cornell University in the field of theoretical and applied mechanics after earning his B.S. and M.S. degrees from Purdue University. He served on the faculty of The Ohio State University (OSU) for a number of years and chaired two academic departments, including the Department of Welding Engineering. While presiding over the welding engineering department, the program was greatly expanded and a Ph.D. degree curriculum was established. In 1984, Graff led the effort to establish the Edison Welding Institute (EWI) and served on its board of trustees. In 1987, he left OSU to head EWI, overseeing its growth to one of the leading welding research organizations in the world. From 1987 until his retirement in 2000, Graff built EWI from a consulting organization operating from a converted warehouse into the largest industrially driven engineering and consulting organization in North America dedicated to materials joining technology. Under his leadership, EWI was selected by the U.S. Navy to operate its national Center of Excellence in welding and joining. In 1995, he also led the development and construction of EWI's 132,000-sq-ft technical center on the OSU research campus.

Graff retired as EWI's executive director in September 2000. He then became a part-time EWI principal engineer. In his current role, he works with EWI engineers and member companies to advance the application of high-power ultrasonics to joining of metals and plastics.

Recognizing the need for a unified central Ohio technology strategy, Graff played an active role in the creation of the Industry and Technology Council (ITC), a forerunner to the Columbus Technology Council (CTC). For many years, he served on the board of the ITC.

The Columbus Technology Council is a membership led, nonprofit organization of technology-based companies in the central Ohio region. The leadership is provided by a board of trustees that is representative of technology businesses in central Ohio. CTC is focused on assisting member companies to develop into high-performance organizations and/or provide products and services to such organizations.

James Philip Kirk

James Philip Kirk [AWS], a Life Member of AWS, died on March 16 in Fairway, Kans.

Kirk, who attended the University of Illinois, was the owner and cofounder of Kirk Welding Supply, Inc., headquartered in Kansas City, Mo. Kirk was also a founder of Airgas. In addition to membership in AWS, Kirk was also active in the National Welding Supply Association and the International Oxygen Manufacturers Association. He was also active in his community, serving as the cofounder of the Southtown Y, the YMCA Foundation, and the Kansas City City of Fountains campaign. He was also active in the Rotary Club, the United Way, and the Boy Scouts of America.

Kirk is survived by his wife of 67 years, Elizabeth; a sister, Helen Young; three sons, J. Philip and his wife Judy, Frank and his wife Nancy, and Michael and his wife Julie; grandchildren David Kirk and his wife Molly, Melinda Sanders and her husband Bob, Natalie Kirk, Andrew Kirk, James Kirk, and Kristin Kirk; and four great-grandchildren.
Learn how advances in computer technology could allow your company to automate key processes, improve repeatability and quality, and operate more efficiently.

Choose among 26 peer-reviewed presentations, organized into the following parallel sessions:

A1 Modeling – Large Structures
A2 Modeling – Weld Pool and Solidification
A3 Modeling – General Topics 1
A4 Modeling – General Topics 2
B1 Real-time Control – Weld Pool and Arc
B2 Weld Data Flow
B3 Computers and Automation
B4 Databases and Data Generation

We hope you will join us for this innovative and educational conference. To learn more about this or other AWS conferences, you can log onto our website at: www.aws.org. Or, call the conferences department at: 1-800-443-9353, ext. 449.
R&D Engineer
Prefer Ph.D. in metallurgy, materials science, or similar field. Experience in brazing, heat treating, organic coatings, or polymer chemistry. Ten years experience in research, technology development, or technology teams. Abilities to design experiments, interpret results. Proven expertise in developing new products/processes. E-mail resumes and cover letters to: csimpson@conformaclad.com. Company located in Louisville, KY area. EOE.

GEA RAINEY CORPORATION
Port of Catoosa, Tulsa, Oklahoma
Welding Technician/Inspector
Experience with ASME Section II, V, VIII, & Sect. IX, AWS D1.1, API 661, and air-cooled heat exchangers is preferred. Applicant must have good computer knowledge. CWI with NDE experience preferred. Please send resume to:
GEA RAINEY CORPORATION
Human Resources
5202 West Channel Road
Catoosa, OK 74015-3017
posten@gearainey.com

EMPLOYMENT OPPORTUNITY
www.grantweb@tampabay.rr.com
Fax: 941-351-1596

Get Real Training in 2003
Real Educational Services, Inc.

CWI PREPARATORY
Guarantee - Pass or Repeat FREE!
SAT-FRI COURSE (7 DAYS)
TAKE THIS COURSE IF YOU NEED A HEAD START!
Pascagoula, MS June 14-20 • Aug. 16-22
Houma, LA Sept. 13-19
MON-FRI COURSE (5 DAYS)
GET READY - RAPID FIRE INSTRUCTION!
Pascagoula, MS June 16-20 • Aug. 18-22
Houston, TX July 14-18
Houma, LA Sept. 15-19
Test follows on Saturday at same facility
FURTHER YOUR TRAINING WITH OUR COMPREHENSIVE COURSES:
Applications of Visual Inspection
Welding Procedure Fundamentals
Advanced Visual Inspection
RT Film Interpretation
ASME Quality Control
Welding Processes
MT/PT/RT/UT
For our entire class schedule, call or email:
1-800-489-2890
info@realeducational.com

ATTENTION
Welding Engineering Professional Engineers (PE)
If you possess a current PE license in welding engineering, you may be eligible to receive the IIW International Welding Engineer diploma.
For more information, contact Jeff Hufsey at hufsey@aws.org.

Services
Cover Gas Problems?
www.weld-huffer.com
USED, RECONDITIONED WELDING MACHINERY

JUST IN! Koike-Aronson head/tailstocks 6 to 20 tons. C-1000 & 2000 Uni-Balance positioners. Manipulators up to 12 x 15 ft. on cars. "1998" Pandjiris 2 head, seam-tracked, 14 ft. box beam fab system. More than 100 positioners up to 75 tons. Turntables up to 60 tons. Longitudinal seamers from 12 in. to 18 ft., turning rolls up to 400 tons, circular weld systems, welding lathes, arc machines, and other orbital welding machines. Everything else for Arc Welding!

WELDING-RELATED MACHINERY IS OUR ONLY BUSINESS
TALK TO US — WE KNOW WELDING
Web site: www.weldplus.com e-mail: jack@weldplus.com
WELD PLUS, INC., CINCINNATI, OHIO
800-288-9414 Jack, Pete, Paul, or Dennis
Fax: 513-467-3585
Join an elite group of over 400 AWS Sustaining Company Members and enjoy:

- Your choice of one of these money-saving benefits:
  1. AWS Standards Library ($6,500 value)
  2. Discount Promotional Package - save on Welding Journal advertising and booth space at the AWS WELDING SHOW (save thousands)
  3. 10 additional AWS Individual Memberships ($570 value)

- Plus...
  1. 10 AWS Individual Memberships ($570 value); each Individual Membership includes a FREE subscription to the Welding Journal, up to an 87% discount on an AWS publication, Members-only discounts and much more
  2. Free company publicity - give your company a global presence in the Welding Journal, on the AWS Website, and at the AWS WELDING SHOW
  3. Exclusive usage of the AWS Sustaining Company logo on your company's letterhead and on promotional materials for a competitive edge
  4. An attractive AWS Sustaining Company wall plaque
  5. Free hyperlink from AWS's 40,000-visitor-a-month website to your company's website
  6. Complimentary VIP passes to the AWS WELDING SHOW
  7. An additional 5% discount off the already-reduced member price of any AWS conference or seminar registration
  8. Up to 62% off Yellow Freight shipping charges, outbound or inbound, short or long haul

AND MUCH MORE...

Also available AWS Supporting Company Membership.
AWS Welding Distributor Membership and AWS Educational Institution Membership

For more information on AWS Corporate Membership, call (800) 443-9353, ext. 253 or 260. E-mail: service@aws.org for an application.

American Welding Society
550 N.W. LeJeune Rd.
Miami, Florida 33126
Visit our website at www.aws.org

Your organization needs solutions. AWS means answers.
Characteristics of Welding and Arc Signal in Narrow Groove Gas Metal Arc Welding Using Electromagnetic Arc Oscillation

Experiments produce optimum parameters for obtaining uniform and sufficient groove face penetration

BY Y. H. KANG AND S. J. NA

ABSTRACT: Narrow groove welding is an important technique for increasing productivity in the manufacture of thick-walled components. The nature of the process demands an automated approach and precise control to ensure consistently high weld quality. The most important objective of narrow groove welding is to maintain uniform and sufficient penetration at both groove faces. Several different approaches, such as wire bending technique and wire rotating method, have been adopted in an attempt to minimize the incomplete fusion in the narrow groove GMAW process. In this study, a welding system using electromagnetic arc oscillation was developed for narrow groove welding. The electromagnet for applying a magnetic field to the welding arc was designed from the electromagnetic analysis results. This paper shows the arc and head characteristics in narrow groove GMAW using electromagnetic arc oscillation. Based on the results, the appropriate welding and oscillation conditions were selected to satisfy high weld quality. Consequently, magnetic arc oscillation resulted in uniform and sufficient penetration to both groove faces. Arc signal characteristics for automatic joint tracking were also investigated. The periodic change of welding current in electromagnetic arc oscillation was examined by experiments and numerical analysis. To establish the mathematical model of the arc sensor, some assumptions were needed to calculate the arc length. Analytical results using these assumptions showed good agreement with experimental ones. The periodic signal was adopted to develop an automatic joint tracking system in narrow groove GMAW.

Introduction

A magnetic field externally applied to a welding arc deflects the arc by electromagnetic force (Lorentz force) in the plane normal to the field lines. The magnetic field exerts the force on the electrons and ions within the arc, which causes the arc to be deflected away from the normal arc path. The welding arc can be deflected forward, backward, or sideways with respect to electrode and welding direction, depending upon the direction of the external magnetic field. A transverse magnetic field deflects the arc in the welding direction, whereas a longitudinal magnetic field deflects the arc perpendicular to the bead. If a unidirectional magnetic field is applied to an AC arc, or an alternating field is applied to a DC arc, then the arc can be oscillated in the position normal to the direction of welding, and this has been used to improve the arcs with both gas tungsten arc welding (GTAW) and gas metal arc welding (GMAW) (Ref. 1). Oscillating the arc sideways with respect to the welding direction could be used for strip cladding and welding of materials that are sensitive to hot cracking because this gives a wide bead and uniform and shallow penetration (Refs. 2, 3). Subjecting the welding arc to transverse magnetic fields increases the welding speed several times, at which rate undercut-free and no-porosity welds can be made (Ref. 4). Also, magnetic arc oscillation could be applied to high-speed joint tracking because the magnetically oscillating arc possesses virtually no inertia (Ref. 5).

Narrow groove welding is an important technique for increasing productivity in the manufacture of thick-walled components. Narrow groove welding has many advantages such as high productivity and quality, minimal distortion, and all-position capability. But incomplete fusion into groove faces is the most frequent defect in narrow groove GMAW due to the low heat input and small molten weld pool. In order to improve the weld quality, an arc weaving technique has to be used. Arc length control and weld joint tracking are also needed because the weld quality is sensitive to any disturbance of the arc. Therefore, the nature of the process demands an automated approach and precise control to ensure consistently high weld quality. The most important objective of narrow groove welding is to maintain uniform and sufficient penetration at both groove faces. Several different approaches have been adopted in an attempt to minimize the incomplete fusion in the narrow groove GMAW process (Refs. 6–9). To improve the groove face fusion, the electrode may be oscillated by adopting a wire bending technique in which the bending direction is periodically changed.
or alternatively (Ref. 6), a wire rotating method in which an eccentric contact tip is rotated (Ref. 7). These systems are effective on penetration at both groove faces, but the former system is relatively complex: the number of oscillations is limited, and the wear resistance of the contact tip is low. In the case of the latter, the minimum root opening is often limited by the need to rotate the whole welding head, and the rotation of the eccentric contact tip may cause the welding head to vibrate, especially in deep groove welding.

In this study, a welding system using electromagnetic arc oscillation was developed for narrow groove welding. The welding arc was periodically oscillated by the electromagnetic force in the plane normal to the magnetic field lines when an alternating magnetic field is applied. With the magnetic arc oscillation method, it is easy to control the weaving width and frequency by controlling the magnitude and frequency of current applied to the electromagnet. The frequency of oscillation is the same as that of the controlling magnetic field. This paper shows the arc and bead characteristics in narrow groove GMAW using electromagnetic arc oscillation. Arc signal characteristics for automatic joint tracking were also investigated. The periodic change of welding current with electromagnetic arc oscillation was examined by experiments and numerical analysis and adapted to develop an automatic joint tracking system in narrow groove GMAW.

Development of Welding Head and Electromagnet

A schematic diagram of electromagnetic arc oscillation in narrow groove welding is shown in Fig. 1. The magnetic field is applied to the welding arc in parallel to the welding direction and the arc is deflected sideways with respect to the welding direction. If an alternating field is applied to the arc, it can be oscillated over the weld pool in a position normal to the direction of welding. The width of arc oscillation is dependent upon the flux density of the applied magnetic field, the arc current, and the arc length (Refs. 4, 10).

Electromagnetic analysis was performed for the design of electromagnets used in narrow groove GMAW. Figure 2 shows the FEM model of the electromagnet composed of core, coil, yoke, and magnetic pole. The required maximum magnetic flux density in the welding area is about 200 gauss because flux density loss occurs in narrow groove welding of ferromagnetic materials such as mild steel. Figure 3 shows the analysis results under conditions of 450 coil turns and 1.2 A current on the coil. The magnetic flux lines are shown in Fig. 3A and the distribution of magnetic flux density in the welding area is shown in Fig. 3B. The magnitude of magnetic flux occurs at the side of the core because the distance between both cores is almost the same as that of both magnetic poles. But the density at the center of the welding area is more than 300 gauss (0.03 tesla), which is enough for arc oscillation, as shown in Fig. 3B. The electromagnet used in narrow groove welding could be designed from these results.

The narrow groove GMA welding head is shown in Fig. 4. The electromagnet is built into the welding head. The welding head is 6 mm thick, and the surface of the welding tip is coated with ceramic. Consequently, the body is insulated from the welding tip. The length and width of the welding head are 160 mm and 60 mm, respectively, while the length is dependent on the thickness of material welded. A welding tip made of copper with high thermal conductivity is cooled by forced water flow to prevent its temperature from rising above its melting temperature. Shielding gas is also supplied through side holes. The magnetic arc oscillation controller controls oscillation frequency and width.

Welding Characteristics of Electromagnetic Arc Oscillation

One feature of magnetic arc oscillation is the decentralized physical effects of the arc, which provides a wide bead and uniform and shallow penetration. This can also be obtained by mechanically rotating the arc. Therefore, uniform and sufficient penetration to both groove faces was obtained with this narrow groove welding process.

Arc Images

The magnitude of magnetic arc deflection was measured with a high-speed video camera. The welding experiments were made in a square-groove butt joint with a 10-mm root opening under the following conditions: a welding current of 280 A, welding voltage of 31 V, travel speed 22 cm/min, contact tip-to-workpiece distance 15 mm, and arc oscillation frequency 30 Hz. Figure 5 shows the images of the arc column during narrow groove welding at magnetic flux densities of 25 gauss, 50 gauss, and 75 gauss. Assuming oscillation width as the offset of the arc centerline, the oscillation width increases with in-
increasing flux density. The oscillation width was small at a density of 25 gauss, and oscillation effect could not be expected. At 75 gauss, the width was too large and undercut at the groove face could be expected. The deflected arc is directed toward the corner between the weld material and the backing plate at a density of 50 gauss.

Figure 6 shows images of the arc column for root openings of 8 and 10 mm. Despite operating under the same welding conditions and with the same magnetic flux density, the arc shape and oscillation width are very different from each other if the root opening decreases from 10 to 8 mm. In the 8-mm root opening, the deflected arc occurred between wire tip and groove wall.

Formation of Weld Bead

The influence of welding parameters on weld bead formation using electromagnetic arc oscillation was investigated. The examined parameters were oscillation frequency and magnetic flux density (or oscillation width) applied in the welding area. Macrosections of weld beads under various oscillation frequencies from 0 to 50 Hz are shown in Fig. 7. The figure clearly indicates the side penetration $P$ with arc oscillation is deeper than without oscillation. Side penetration $P$ slightly increased and the penetration $H$ decreased with increased arc oscillation frequency.

The relationship between magnetic flux density and bead formation was investigated. The density was varied from 0 to 75 gauss by changing current applied to the electromagnet. The oscillation frequency was fixed at 30 Hz, and the other welding conditions were the same as in previous experiments. Macrosections obtained from this experiment are shown in Fig. 8. Increased density caused increased oscillation width, as mentioned previously. The penetration to groove faces, therefore, increased with increased magnetic flux density. In conventional straight welding without magnetic arc oscillation, the side penetration $P$ was especially small, while the penetration $H$ was very large. But at a density of 75 gauss, undercut occurred at both groove faces. The maximum magnetic flux density would be limited to 50 gauss under the welding conditions in this experiment with a 10-mm
root opening for a square groove weld. The same results could be obtained by investigating the images of the arc column — Fig. 5.

Figure 9 shows a macrosection of a thick plate. The thickness of the plate is 22 mm with a 10-mm root opening. A deposition of 4-5 mm per pass was obtained at 280 A, 31 V, and 22-cm/min welding speed. An average depth of side penetration was about 1.7 mm. A stable uniform penetration into the groove faces was secured by using magnetic arc oscillation.

Arc Signal Characteristics for Automatic Joint Tracking

In narrow groove welding, the deviation of the welding wire from the center line of the deep groove directly affects the weld quality. Since the arc sensor system does not need any external sensing device and senses the position of the arc itself, it is preferable for narrow groove welding.

Magnetic arc oscillation leads to a change of arc length, which in turn periodically changes the welding current and voltage. An alternating parallel magnetic field causes the arc to oscillate in a position normal to the direction of welding, which has an effect like mechanical weaving. Welding current variation was investigated during narrow groove GMA welding using magnetic arc oscillation.

Numerical analysis of the arc sensor in narrow groove GMAW was carried out for theoretical prediction. A conventional welding power source can generally be considered equivalent to a constant source with an output resistance $R_s$ and inductance $L_s$. The welding cable is also characterized by its resistance $R_c$ and inductance $L_c$. The arc voltage, $U_a$, consists of voltage drops in the anodic zone, cathodic zone, and arc column. Based on the experimental results, it is characterized by a constant component $U_{ao}$, resistance $R_a$, and the electric field intensity $E_a(=E_{al}+E_{ai})$ of the arc column. $E_{al}$ and $E_{ai}$ represent a constant component of $E_a$ and the component proportional to current, respectively. Thus, the voltage equations for the whole loop of the welding circuit can be written as follows (Ref. 11):

$$\frac{dI}{dt} = \frac{U_a - U_{ao}}{L_a + L_c}$$
$$\frac{L_a + L_c}{K_s + R_a + R_e + R_c} I + \frac{E_{al} + E_{ai}}{L_a + L_c}$$

where $I$ is the welding current, $L_a$ is the arc length, and $R_e$ the electric resistance of the welding wire extension. The dynamic melt-
The melting model of the welding wire is as follows:

\[
\frac{dL_e}{dt} = \frac{V_f - Al}{1 - BJ_e} \tag{2}
\]

where \( V_f \) is the wire feed rate, \( A \) and \( B \) the coefficients in the wire melting model, and \( J_e \) the quantity of Joule heat at the wire tip, as shown in Equation 3.

\[
J_e = \int_{t_1}^{t_2} \frac{I^2}{r} \, dt \tag{3}
\]

As shown in Fig. 10, the arc length \( L_a \) is expressed by the geometrical relationship of the deflection angle \( \theta \), the contact tip to workpiece distance \( L_p \), the wire extension length \( L_e \), and the distance between the electrode wire and groove face \( W \). Thus, the arc length \( L_a \) can be written as follows:

\[
(L_t - L_e) \tan \theta \leq W \rightarrow L_a = \frac{L_t - L_e}{\cos \theta} \tag{4}
\]

\[
(L_t - L_e) \tan \theta > W \rightarrow L_a = \frac{L_t - L_e - W}{\cos \theta} \frac{(L_t - L_e) \tan \theta - W}{\sin \theta} \tag{5}
\]

The arc shape and oscillation width vary depending on the root opening width, as mentioned before. Consequently, the arc length changes according to the width. Therefore, the following assumptions were used for calculating the arc length:

a. \( W \leq W_c \)
   1. \( L_a > W \rightarrow \text{Arc length} = W \)
   2. \( L_a \leq W \rightarrow \text{Arc length} = \) Equations 4 or 5

b. \( W > W_c \rightarrow \text{Arc length} = \) Equations 4 or 5

where \( W_c \) is the critical root opening width.

The critical root opening width was introduced to calculate the arc length change according to the applied root opening width. The critical width is the critical value that decides whether the arc is influenced by the groove face or the backing plate.

If the distance between the welding wire and groove face \( W \) is less than the critical width \( W_c \) and if the calculated arc length \( L_a \) is longer than \( W \), the arc occurs between the wire tip and groove wall. If the calculated arc length is smaller than \( W \), however, the arc length is determined by Equations 4 or 5. If \( W \) is longer than \( W_c \), the arc length is determined also by Equations 4 or 5.

Waveforms of the welding current were monitored to investigate the relation with the distance between the welding wire and groove faces. Experiments were carried out on a specimen with a single groove face at the right side, as shown in Fig. 11, where the applied magnetic flux density was 50 gauss. In this case, the critical width \( W_c \) was determined to be between 4 and 5 mm from the simulation and the experimental results. The peak-to-peak values of welding current increased with decreased distance \( W \) because the shortest length of the arc during oscillation was the same as the distance \( W \). If \( W \) is less than \( W_c \) and the arc is deflected toward the groove face, it is assumed to occur between the wire tip and the groove face. Therefore, flat parts in welding current waveforms were observed at the distance \( W \) of 3 and 4 mm. The magnitudes as well as waveforms of welding current in simulation showed a fairly good agreement with the experimental results. In the case of 75 gauss, the simulation results were also similar to experimental ones, as shown in Fig. 12.
From the previous experimental and simulation results, it is dearly indicated that by increasing $W$, the peak-to-peak value of welding current decreased rapidly, up to a distance of 5 mm in 50 gauss and 6 mm in 75 gauss, as shown in Fig. 13. This implies the welding current is seriously affected by the groove face at distances less than the critical width. At 25 gauss, the groove face has almost no effect on the variation of welding current.

The experiments were carried out on a specimen with both groove faces, as shown in Fig. 14. The waveforms of the welding current were monitored under magnetic flux density of 50 gauss and arc oscillation frequency of 5 Hz with a 10-mm root opening for a square-groove weld. Figure 14A shows a welding current waveform for no deviation between the welding head and groove center. Figure 14B shows a waveform that indicates a deviation of the welding head to the right side by about 1 mm. A waveform frequency of 10 Hz showed no deviation. Two similar waveforms of welding current were obtained in one period of arc oscillation. The waveform frequency was 5 Hz for the 1-mm deviation. This periodic change of welding current can be used as the output signal for an arc sensor for automatic joint tracking in narrow groove GMA welding.

**Conclusions**

Arc shape and bead formation in narrow groove GMA welding were investigated. Based on the results, appropriate welding and oscillation conditions were selected to maintain high weld quality. Magnetic arc oscillation resulted in sufficient penetration to the groove face. The penetration increased slightly with increased arc oscillation frequency. Increased magnetic flux density applied in the welding area caused increased oscillation width. The penetration to the groove face also increased with increased magnetic flux density. But at a density of 75 gauss, undercut occurred at both groove faces. Consequently, the magnetic flux density was limited to 50 gauss under the welding conditions used in this experiment, which included a 10-mm root opening for a square-groove weld.

Magnetic arc oscillation resulted in a change of arc length, which in turn caused the welding current signals to change periodically. Although the signals included...
the high-frequency noise of the welding power source, the welding current fluctuation — the basic signal component — produced by magnetic arc oscillation was clearly shown. Basic signal components can be used as the output signal of the arc sensor for automatic joint tracking in narrow groove GMA welding.

Numerical analysis of the arc sensor was also carried out for theoretical prediction. The arc shape and oscillation width varied depending on the root opening width. Some assumptions in establishing the mathematical model of the arc sensor were needed to calculate the arc length. Analytical results using these assumptions showed fairly good agreement with experimental ones.

Acknowledgment

This work was supported in part by the Brain Korea 21 Project. The authors would like to thank the POSCO Research Institute for providing matching funds for this project.

References

A Mathematical Model of Wire Feeding Mechanisms in GMAW

Investigations into both aluminum and steel welding wire focus on elements that contribute to poor feedability

BY T. M. PADILLA, T. P. QUINN, D. R. MUNOZ, AND R. A. L. RORRER

ABSTRACT. A Hertzian-based contact model of the friction between the welding wire and the wire liner has been developed to predict the wire pulling force for gas metal arc welding (GMAW). The model predicts a 2.5:1 exponential increase in wire pulling force as the bend angle between the welding wire and the wire liner is varied from 0 to 180 deg. A one-dimensional force transducer recorded the wire pulling force, while a linear actuator pulled the welding wire through various wire liners at constant wire feed speeds ranging from 10 to 18 m/min (400 to 700 in./min). Results indicate model agreement to within ±0.60 N (0.14 lbf) RMS when using aluminum welding wires ranging from 0.8 to 1.6 mm (0.030 to 0.0625 in.) in diameter. Extension of the model to applications feeding steel welding wires exhibits agreement to within ±0.50 N (0.11 lbf) RMS when using 1.1-mm-diameter (0.045-in.) welding wires and a spiral-wound steel wire liner. Statistical analyses show an independence of wire pulling force from wire feed speed over the interval of speeds ranging from 10 to 18 m/min (400 to 700 in./min).

Introduction

A key factor in the performance of gas metal arc welding (GMAW) is the feedability of the welding wire through the wire liner. For aluminum electrodes, fluctuations in the wire feed speed (WFS) of even 1% can lead to irregular arc lengths, oscillatory voltage and current levels, and degradation of the overall weld quality (Ref. 1). In part, variations in the target WFS are caused by adverse conditions during welding (Refs. 2-4). These include damaging effects such as "stick-slip" motion of the welding wire, premature wear of the contact tube and, in general, uncontrolled movement of the hose package during welding. A considerable amount of effort (Refs. 5-9) has been spent to develop microprocessor-based wire delivery systems and specialized components that are capable of reducing velocity variations to within 0.5 to 1.0% of the target value. Here, these specialized components and processes allow for controlled feeding at distances of up to 60 m (200 ft) between the wire spool and the workpiece. However, the use of such systems is an expensive and nontrivial option when compared to conventional means of wire delivery (Ref. 10), thereby leaving room for more practical and cost-effective solutions.

At present, a limited amount of published research has been conducted to understand and separate the various elements that contribute to poor wire feeding performance. One important factor that controls wire feedability is friction between the welding wire and the wire liner. Large or irregular wire feeding forces have been shown (Refs. 3 and 4) to cause pronounced fluctuations in the WFS and wire buckling. These problems are more readily manifested when feeding aluminum and other difficult-to-feed alloys (Ref. 11). Studies have been conducted (Refs. 6 and 12) to measure the wire feeding force during welding, but a limited amount of detail has been given to model the source of friction. This paper presents a Hertzian-based contact model of the welding wire-to-wire liner friction as the welding wire is pulled through various wire liners at constant velocity.

Model

Movement of the welding wire through the wire liner is similar to "belt-on-drum" applications — Fig. 1. Historically, this situation has been treated using Euler's equation (Ref. 13) for rope friction given by

\[ T_2 = T_1 e^{\mu \theta} \]  

where \( T_1 \) refers to the slack-side tension, \( T_2 \) the tight-side tension, \( \mu \) the wire-to-liner coefficient of friction, and \( \theta \) the wire-to-liner contact angle.

Predictions of the wire-to-liner friction force using Euler's equation rely on the use of known values for the coefficient of friction. Even when the formulations of the welding wire and wire liner materials are known (most are proprietary), little data exists for the coefficient of friction in the context of a wire sliding on a stationary surface. Predictions can be made using the coefficient of friction from similar materials, but these predictions do not adequately fit the experimental results and either overestimate or underestimate the true functional form of the data (Ref. 14).

An alternative model utilizing aspects of Hertzian contact mechanics and friction theory has been developed to better predict the wire-to-liner friction using only basic information about the welding wire and the wire liner. The alternative model is based upon experimentally determining the shear strength at the welding wire and wire liner interface. As a result, there is no need to rely on tabulated data for the co-

**KEY WORDS**

- Aluminum Wire Feeding
- Friction Model
- GMAW Wire Feeding
- Hertzian Contact
- Mechanics
- Steel Wire Feeding
- Wire Feeding Force
- Wire Friction
efficient of friction since an actual interface parameter can be computed for any welding wire and wire liner pair. The following details this development.

According to Hertzian contact theory, when two rough surfaces come in contact with each other, the surfaces distort locally and make contact at discrete points (Ref. 15). In the case of the welding wire and the wire liner, the combination can be modeled as a pair of axially aligned cylinders that make contact under constant curvature $R$, and with a specified "wrap" or contact angle $\theta$ -- Fig. 2.

If a differential element of the welding wire is pulled with applied tensions $T_1$ and $T_2$ (Fig. 3) at steady-state conditions (with assumed constant velocities and negligible accelerations) over constant curvature $R$ and through a fixed contact angle $\theta$, the distributed load $w$ acting per unit length over the segment of welding wire can be formulated from a static force balance. Considering the arbitrary orientation of a differential segment of the welding wire (Fig. 3), the equations of equilibrium can be written as

\[ \Sigma F_x = 0; \]
\[ T \sin(\theta) + wR \theta \cos\left(\theta + \frac{d\theta}{2}\right) + F \sin\left(\theta + \frac{d\theta}{2}\right) - T + dT = 0 \]
\[ \Sigma F_y = 0; \]
\[ -T \cos(\theta) + wR \theta \sin\left(\theta + \frac{d\theta}{2}\right) - F \cos\left(\theta + \frac{d\theta}{2}\right) + (T + dT) \cos(\theta + d\theta) = 0 \]
\[ \Sigma M_{\theta} = 0; \]
\[ FR + TR - (T + dT)R = 0. \]  

Here, the angle $\theta$ refers to the initial start position of curvature as measured from the abscissa, $d\theta$ refers to subtended angle of the differential element, $T$ the applied welding wire tension, $dT$ the additional
tension due to the tangential resistive force $F$, $R$ the constant bend radius of curvature, and $w$ the distributed loading acting over the differential element of the welding wire.

By small angle theory (Ref. 16), as the value of $d\theta$ approaches zero, the sine and cosine terms containing the $d\theta$ argument behave as

\[
\lim_{d\theta \to 0} \sin(d\theta) = d\theta \\
\lim_{d\theta \to 0} \cos(d\theta) = 1.
\]  

Using Equation 5 with Equations 2-4 and simplifying to include only first order terms results in equilibrium equations of the form

\[
wRd\theta \cos(\theta)
\]

\[+ F \left[ \sin(\theta) + \cos(\theta) \left( \frac{d\theta}{2} \right) \right] - Td\theta \cos(\theta) - dT \sin(\theta) = 0
\]  

\[
wRd\theta \sin(\theta)
\]

\[+ F \left[ \cos(\theta) - \sin(\theta) \left( \frac{d\theta}{2} \right) \right] - Td\theta \sin(\theta) + dT \cos(\theta) = 0
\]  

\[F - dT = 0.
\]

Adding Equation 6 to Equation 7 and substituting Equation 8 upon simplification to retain first order terms yields

\[
wR \sin(\theta) + wR \cos(\theta)
\]

\[- T \cos(\theta) - T \sin(\theta) = 0.
\]

Gathering like terms to solve for the distributed loading $w$ acting over the differential element provides

\[w = \frac{T}{R}.
\]

where the tension $T$ is a function of the...
contact angle $\theta$ and the bend radius $R$ is assumed constant over the entire contact angle range. According to Hertzian contact theory, the applied loading and subsequent surface deformation of bodies in contact create an area of contact $A_c$ that can be expressed in terms of the semi-infinite half-width $a$ and the wire-to-liner contact length $L$ (Ref. 17) as

$$A_c = 2aL.$$  \hspace{1cm} (11)

In this expression, $L$ is taken as the segment length of the differential element through the subtended angle $d\theta$. Assuming the radius of curvature $R$ for the differential element is constant, the segment length $L$ can be written as

$$L = Rd\theta.$$  \hspace{1cm} (12)

For axially aligned, conformal cylinders, the Hertzian-based semi-infinite half-width $a$ of Equation 11 is defined (Ref. 17) as

$$a = \sqrt{\frac{4wR^*}{\pi E^*}},$$  \hspace{1cm} (13)

where $R^*$ and $E^*$ refer, respectively, to the reduced radius of curvature and the effective surface modulus of the mating bodies. In this expression, $w$ is the applied uniform distributed loading acting along the body-to-body contact length of the differential element calculated earlier in Equation 10.

The quantities $R^*$ (adjusted with a negative sign to account for conformal bodies) and $E^*$ of Equation 13 can be formulated in terms of the material properties designated by Poisson's ratio $v$, Young's modulus $E$, and the nominal welding wire and wire liner radii of curvature $r$. Using the indices "w" and "l" to designate nominal properties associated with the welding wire and the wire liner, respectively, $E^*$ and $R^*$ (Ref. 17) can be expressed as

$$E^* = \left(\frac{1-\nu^2}{E_w} + \frac{1-\nu^2}{E_l}\right)^{-1},$$  \hspace{1cm} (14)

$$R^* = \left(\frac{1}{r_w} + \frac{1}{r_l}\right)^{-1}.$$  \hspace{1cm} (15)

By Amontons' Law (Ref. 17) for friction, the measure of resistance to motion (i.e., $\mu$ the coefficient of friction) is normally defined to be independent of the apparent contact area and in terms of the normal force $N$ and tangential resistive force $F$, such that

$$\mu = \frac{F}{N}.$$  \hspace{1cm} (16)

However, since real surfaces are known to contain irregularities in their surface topology, the theoretical coefficient of friction can be shown (Refs. 15, 17-19) to be dependent on the "real" contact area caused by surface distortion and asperity-to-asperity contact. Accordingly, Equation 16 can be re-expressed as a function of the real contact area $A_c$ to give

$$\mu = \mu(A_c).$$  \hspace{1cm} (17)

For the welding wire to wire liner contact, the normal load $N$ of Equation 16 is a quantity that depends only on the applied tension and is independent of the body-to-body contact area. This leaves the tangential resistive force $F$ as the term responsible for the area dependency in the coefficient of friction observed in Equation 17. Elementary friction theory further suggests the total resistance to motion for rough surfaces can be summed over all asperity-to-asperity contacts (essentially the mating contact area $A_c$, if statistical variations are ignored) provided the interfacial shear strength between the mating materials remains constant (Refs. 15, 17-19). Hence, the tangential resistive force $F$ acting between the welding wire and the wire liner can be written in terms of the real contact area $A_c$ and the wire-to-liner interfacial shear strength $\tau$ as

$$F = A_c \tau.$$  \hspace{1cm} (18)

By the simplified equations of equilibrium given in Equations 6-8, the tangential resistive force $F$ is equivalent to the change

![Diagram](image-url)
Table 1 — Summary of the Values and Conditions Used in Case Studies

<table>
<thead>
<tr>
<th>Item</th>
<th>Case No. 1</th>
<th>Case No. 2</th>
<th>Case No. 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Test Summary</strong></td>
<td>Manufacturer Matched Aluminum-on-Teflon</td>
<td>Manufacturer Matched Aluminum-on-Teflon</td>
<td>Manufacturer Matched Steel-on-Steel</td>
</tr>
<tr>
<td><strong>Welding Wire</strong></td>
<td>Solid-Core Aluminum ER5356</td>
<td>Solid-Core Aluminum ER5356</td>
<td>Solid-Core Copper-Clad ER70S6</td>
</tr>
<tr>
<td><strong>Nominal Diameter</strong></td>
<td>0.8 mm (0.030 in.)</td>
<td>1.6 mm (0.0625 in.)</td>
<td>1.1 mm (0.045 in.)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Nominal Internal Diameter</strong></th>
<th>Teflon Impregnated</th>
<th>Teflon Impregnated</th>
<th>Mild Steel, Sprialally Wound</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Wire Liner L.D. to Welding Wire O.D. Ratio</strong></td>
<td>1.7:1</td>
<td>1.6:1</td>
<td>1.4:1</td>
</tr>
<tr>
<td><strong>Wire Feed Speed</strong></td>
<td>10 to 18 m/min @ 700 in./min (400 to 2500 l/min)</td>
<td>10 to 18 m/min @ 700 in./min (400 to 2500 l/min)</td>
<td>10 to 18 m/min @ 700 in./min (400 to 2500 l/min)</td>
</tr>
<tr>
<td><strong>Contact Angle</strong></td>
<td>0 to 180 deg in 10 deg increments</td>
<td>0 to 180 deg in 10 deg increments</td>
<td>0 to 180 deg in 10 deg increments</td>
</tr>
<tr>
<td><strong>Applied Backtension</strong></td>
<td>5 N (1.1 lbf)</td>
<td>5 N (1.1 lbf)</td>
<td>10 N (2.2 lbf)</td>
</tr>
<tr>
<td><strong>Wire-To-Liner Sliding Condition</strong></td>
<td>Dry, as manufactured</td>
<td>Dry, as manufactured</td>
<td>Dry, as manufactured</td>
</tr>
</tbody>
</table>

Substituting the expression for the contact area \( A_c \) and the following terms \( L, a, R', \) and \( \omega \) as developed earlier, results in

\[
dT = 4\tau \sqrt{\frac{TRR'}{\pi E^*}} \, d\theta.
\]  

(20)

Dividing Equation 21 by the quantity \( d\theta \) produces a first order nonlinear homogeneous ordinary differential equation of

\[
dT = 4\tau \sqrt{\frac{TRR'}{\pi E^*}} = 0.
\]  

(21)

Solving Equation 21 by separation of variables and integrating over the differential element, as shown in Fig. 3, results in the following relationship between the applied backtension \( T_2 \), the applied force tension \( T_1 \), and the interfacial shear strength \( \tau \).

\[
T_2 = \left[ T_1^{1/2} + 2\tau \left( \theta_1 - \theta_2 \right) \right] \frac{RR'}{\pi E^*}.
\]  

(22)

Here, the quantities \( T_1, R, \theta_1, \theta_2, R', \) and \( E^* \) can either be obtained directly or computed from the initial wire-to-liner setup, thereby leaving \( \tau \) as an unknown parameter that can be determined empirically. The end result is an alternative model to the Euler rope friction equation that is independent of the nominal coefficient of friction and that is capable of predicting the wire pulling force given only basic information about the welding wire and wire liner system.

**Experiments**

Full-scale tests were conducted to determine the validity of the contact model developed in this research. The welding wire and the welder liner were wrapped around a variable-angle jig (Fig. 4) to simulate a combination of bends typically found in the wire-feeding hose package. One end of the welding wire was attached to a pulley and mass system to create a uniform backtension on the welding wire, thereby simulating the drag normally associated with the wire spool. The uniform backtension also helps ensure complete contact of the welding wire with the wire liner.

Travel speed of the welding wire through the wire liner is controlled using a computer-driven linear actuator that is capable of providing a stroke of 3 m (10 ft) at velocities ranging from 0.01 to 30.5 m/min (0.5 to 1200 in./min) to within ±0.5% absolute. Once a particular combination of the welding wire, wire liner, wire feed speed, and bend curvature was selected, the linear actuator was initiated and triggered a data-acquisition system to record the wire pulling force. The force transducer used in this application is capable of measuring up to 110 N (25 lbf) with an uncertainty of ±0.05% full-scale as computed from a static calibration. Following a force measurement, the wire jig was reset to a new contact angle and the experiment was repeated.

In this study, three individual cases were considered to determine the accuracy of the contact model in predicting the wire pulling force when using various combinations of readily available welding wires and wire liners. In each case study, the welding wire was initially unspooled with a wire cast radius of approximately 50 mm (2 in.) and subsequently straightened to a cast radius of approximately 1.2 m (48 in.). Helix in the welding wire was measured to be less than 13 mm (0.5 in.) and was considered to be negligible. The surface of the welding wire and the wire liner was dry, un lubricated, and used in the as-manufactured condition. Replication measurements (shown as data error bars in attached figures) were taken for statistical analysis at wire-to-liner contact angles equal to 0, 60, 120, 140, 160, and 180 deg, respectively. Each case is outlined as follows and is summarized in Table 1 for clarity.

**Case No. 1 — Matched-Size Aluminum Welding Wire Dry-Sliding on a Teflon® Wire Liner**

An aluminum welding wire was used with a matched size (as recommended by the manufacturer) polymer-based Teflon® impregnated wire liner. Experiments were

1. "Cast" refers to the amount of natural curl in the welding wire due to the way of the wire onto the spool. "Helix" refers to the amount of natural coil in the welding wire caused by the lateral wrap of the wire from one side of the drum to another.

2. Trade names contained herein are used only to generically identify the material used in this research. Actual welding wire and wire liner compositions are proprietary and hence unknown. Such identification does not constitute recommendation or endorsement of these materials.
Fig. 9 — Comparison of the interfacial shear strength values as a function of WFS for a 0.8-mm (0.030-in.) ER5356 solid-core aluminum welding wire dry-sliding on a 1.3-mm (0.052-in.) internal diameter Teflon wire liner.

Fig. 10 — Experimental and theoretical comparison using pooled data results for a 0.8-mm (0.030-in.) ER5356 solid-core aluminum welding wire dry-sliding on a 1.3-mm (0.052-in.) internal diameter wire liner. Uncertainty in the model is shown as dashed lines and represents one standard deviation in the estimate of the interfacial shear strength. The data shown have been normalized for a 5-N (1.1-lbf) uniform backtension to show a nonzero force value at zero contact angle representing static friction.

Fig. 11 — Experimental and theoretical comparison using a 1.6-mm (0.0625-in.) ER5356 solid-core aluminum welding wire dry-sliding on a 2.5-mm (0.100-in.) internal diameter Nylon wire liner. Uncertainty in the model is shown as dashed lines and represents one standard deviation in the estimate of the interfacial shear strength. The data shown have been normalized for a 5-N (1.1-lbf) uniform backtension to show a nonzero force value at zero contact angle representing static friction.

Fig. 12 — Wire pulling force for WFS = 10 to 18 m/min (400 to 700 in./min) with a 1.1-mm (0.045-in.) ES70S6 solid-core copper-clad steel welding wire dry-sliding on a 1.7-mm (0.065-in.) internal diameter spiral wound steel wire liner. The data shown have been normalized for a 10-N (2.2-lbf) uniform backtension to show a nonzero force value at zero contact angle representing static friction.
conducted using a 0.8-mm (0.030-in.) ER5356 solid-core aluminum welding wire spooled onto a standard 1-kg (2-lb) drum. A 2.5 m (8 ft) length of 1.3-mm (0.052-in.) internal diameter “Teflon” wire liner was used and had the manufacturer’s rating for use with welding wires ranging from 0.8 to 0.9 mm (0.030 to 0.035 in.) in diameter. This particular combination of welding wire and wire liner provided a diameter ratio of 1.7:1.

Wire feed speeds were varied from 10 to 18 m/min (400 to 700 in./min) in 2.5 m/min (100 in./min) increments to represent the middle range of wire feed rates used during typical aluminum GMAW. Bends in the hose package were simulated by varying the contact angle between the welding wire and the wire liner from 0 to 180 deg in 10-deg increments. A 5-N (1.1-lbf) uniform backtension was applied to the welding wire with the pulley and mass setup to ensure complete contact of the welding wire with the wire liner and to simulate drag normally associated with the wire spool.

3. “Teflon” and “Nylon” have been used as a shorthand notation to refer to the polymer-based, Teflon-impregnated wire liners and the polymer-based, Nylon-impregnated wire liners used in this study.

**Case No. 2 — Matched-Size Aluminum Welding Wire Electrode Dry-Sliding on a Nylon Wire Liner**

Case No. 2 tested the applicability of the contact model to a larger diameter (= 2X larger diameter than that for Case No. 1) aluminum welding wire and polymer-based, Nylon-impregnated wire liner. This study was also conducted to determine whether there was an improvement or degradation in the overall wire feeding performance when using the “Nylon” wire liner.

Experiments were conducted using a 1.6-mm (0.0625-in.) ER5356 solid-core aluminum welding wire spooled onto a standard 1-kg (2-lb) spool. The welding wire was guided through a 2.5 m (8 ft) length of 2.5-mm (0.100-in.) internal diameter Nylon wire liner. This particular size of wire liner was recommended exclusively for use with the 1.6-mm-diameter welding wires and provided a diameter ratio of 1.6:1. An intermediate constant-valued WFS of 14 m/min (550 in./min) was selected. This single constant-valued wire feed speed was selected to give a uniform metric of comparison in determining whether there was an increase or decrease in wire pulling force performance when using the Nylon wire liner. The contact angle between the welding wire and the wire liner was similarly varied from 0 to 180 deg in 10-deg increments. A 5-N (1.1-lbf) uniform backtension was again applied to the welding wire.

**Case No. 3 — Matched-Size Copper-Clad Steel Welding Wire Dry-Sliding on a Steel Wire Liner**

Case No. 3 was conducted to determine the applicability of the contact model to steel-on-steel GMAW applications when feeding steel welding wires of intermediate diameter through a spiral-wound steel wire liner. Experiments were performed using a 1.1-mm (0.045-in.) ER70S-6 solid-core copper-clad steel welding wire spooled onto a standard 0.5-kg (1-lb) drum. A 2.5 m (8 ft) length of 1.7-mm (0.065-in.) internal diameter spiral-wound steel wire liner was used. This particular liner was recommended for use with welding wires ranging from 0.9 to 1.1 mm (0.035 to 0.045 in.) in diameter and provided a diameter ratio of 1.4:1. Wire feed speeds were similarly varied from 10 to 18 m/min (400 to 700 in./min) in 2.5-m/min (100-in./min) increments, while bends in the hose package were again varied from 0 to 180 deg in 10-deg increments. The uniform backtension on the welding wire was increased to 10 N (2.2 lbf) to compensate for the relatively stiffer steel welding wire.
Results and Discussion

Case Study No. 1 — Matched-Size Aluminum Welding Wire Dry-Sliding on a Teflon Wire Liner

The wire pulling force data (Fig. 5) indicate there is an approximate 2.5:1 exponential increase in wire pulling force as the contact angle between the welding wire and the wire liner is increased from 0 to 180 deg. The severity of the bend in the hose package (i.e., an increase in the angular sum of bend) increases the mean wire pulling force. This corroborates previous research (Ref. 12) that the configuration of the hose package plays a significant role in wire feedability. Normalizing the data set with respect to the applied backtension, the nonzero force value observed at zero contact angle is believed to represent the minimum static friction in the wire-to-liner system. It is believed the static friction component of force is due to self-weight of the welding wire acting against the wire liner and, more predominately, the entry/exit effects of the welding wire passing through the wire liner.

If the data are directly compared against Euler's equation for rope friction (Equation 1) using a representative range of coefficient of friction values (μ = 0.2 to μ = 0.4), the measured wire pulling force can be greatly underestimated or overestimated — Fig. 6.

Here, the representative coefficient of friction values are typical (Refs. 17, 18, 20) and include pairs similar to the tested wire and liner system, such as polymer-on-steel, aluminum-on-Teflon, aluminum-on-Nylon, and Flexiglass-on-steel. A problem with using typical coefficient of friction data is compounded by the wide range of coefficient of friction values that depend on whether the system is lubricated or unlubricated. As a result, it is not clear which coefficient of friction value adequately represents the true welding wire and wire liner system under consideration.

In order to compare the experimental results with the contact model, while avoiding the coefficient of friction ambiguity, the “Bootstrap” method (Ref. 21) was used to determine the specific interfacial shear strength (ISS) τ for the tested aluminum-on-Teflon system. In brief, the Bootstrap algorithm is an n-iteration method of determining the average value and uncertainty of an unknown model parameter (see flowchart, Fig. 7). The algorithm uses an initial least-squares estimate of the unknown parameter, followed by iteration to generate a secondary guess of the unknown parameter. The secondary guess is based upon a fuzzy data set that has randomly been assigned a residual error computed from the first run. The process is repeated n times to give n estimates of the unknown parameter, from which a sample average and standard deviation can be computed — Fig. 8. This provides a measurable way of determining the uncertainty in the model. In this case study, 5000 iterations of the Bootstrap algorithm were performed to determine τ and its uncertainty at each of the four wire-feed speeds — Fig. 9.

As indicated in Fig. 9, the value τ is grouped around a central value of 0.9 MPa (130 lbf/in.²), prompting a null hypothesis to suggest the interfacial shear strength values (each for a different WFS) originate from the same population, thereby indicating an independence of wire pulling force from wire feed speed. A Chi-Squared goodness-of-fit test was conducted with the interfacial shear strength values using a 95% confidence interval (v = 3, α = 0.05) to yield a computed statistic of 0.262 compared to a critical statistic of 5.991.

Accordingly, the null hypothesis is considered true and indicates the wire pulling force is independent of wire feed speed over the range from 10 to 18 m/min (400 to 700 in/min). As a result, the wire pulling force data of Fig. 5 were pooled as one data set and passed through the Bootstrap algorithm (with n = 5000) to generate a new estimate of the interfacial shear strength equal to 0.9 MPa ± 0.1 MPa (130 lbf/in.²) for the composite data set.

The interfacial shear strength estimate was subsequently used to compare the pooled data set with the contact model — Fig. 10. Here, the solid line indicates the mean wire pulling force (mean estimate of τ) and the dashed lines indicate the uncertainty in the model based upon the uncertainty in the estimate of the interfacial shear strength. As shown, the contact model is within ± 0.60 N (0.14 lbf) RMS of the measured values and matches the 2.5:1 exponential increase in wire pulling force for all contact angles ranging from 0 to 180 deg.

Case No. 2 — Matched-Size Aluminum Welding Wire Dry-Sliding on a Nylon Wire Liner

Since the results for the aluminum-on-Teflon study indicated the wire pulling...
force was independent of wire feed speed. we assumed the same conditions would hold true when testing aluminum-on-Nylon. As a result, a single constant wire feed speed of 14 m/min (550 in./min) was selected for this study to give a uniform metric of comparison of wire pulling force performance when using the Nylon wire liner.

To compare the values of the measured wire pulling force, the aluminum-on-Nylon data were similarly passed through the Bootstrap algorithm to generate a mean interfacial shear strength of 0.5 MPa ± 0.1 MPa (73 lb/in.² ± 15 lb/in.²). Substituting this computed value of τ into the contact model results in a similar 2.7:1 exponential increase in pulling force when using the 2X larger-diameter welding wire and Nylon wire liner - Fig. 11. The comparison again indicates the severity of the bend (i.e., an increase in the total angular sum of bends) in the hose package plays a significant role toward increasing the overall wire pulling force. In general, the model predicts the wire pulling force to within ± 1.31 N (0.30 lbf) RMS of the measured value. Likewise, the non-zero force component at zero contact angle is again believed to represent the static friction in the wire-to-liner system. In this case, the static friction contribution is twice as large as that of the aluminum-on-Teflon system.

When predicting the wire-to-liner friction, the contact model provides a breadth of distribution that is 50% greater in predicting the wire pulling force when using the welding wire of larger diameter (Fig. 10 vs. Fig. 11). The cause of the larger variation is not known. Despite the increase in uncertainty, the predicted and measured force values for either of the two wire liners (Nylon or Teflon) lie within 20% of each other, with the Nylon wire liner producing the overall larger wire pulling forces for similar contact angles.

**Case #3 — Matched-Size Copper-Clad Steel Welding Wire Dry-Sliding on a Steel Wire Liner**

Since many of the same aluminum GMAW wire feeding problems are experienced in steel GMAW, Case No. 3 was conducted to assess the contact model in predicting the wire pulling force when using a copper-clad steel welding wire and a spiral-wound steel wire liner. The wire pulling force for a copper-clad steel wire dry-sliding on a steel wire liner is again seen (Fig. 12) to increase as a function of contact angle, but does so nearly linearly (R² = 0.96) at a rate of 2:1. Again, the data indicate that tighter bends in the hose package increase the wire pulling force. The Chi-Squared goodness-of-fit test was repeated with the steel-on-steel data sets to again show mathematically (with 95% confidence) that the computed values of interfacial shear strength for each wire feed speed (Fig. 13) originate from the same population as evidenced by a computed Chi-Squared statistic of 3.891 vs. a critical statistic of 5.991. As a result, the wire pulling force for steel-on-steel applications is also shown to be mathematically independent of wire feed speed over the interval of speeds ranging from 10 to 18 m/min (400 to 700 in./min), despite a 10% increase from one wire feed speed to another. Using the pooled data set for steel-on-steel, the mean interfacial shear strength was computed to be 3.9 MPa ± 0.4 MPa (566 lbf/in.² ± 58 lbf/in.²).

The wire pulling force data were similarly pooled and directly compared with the contact model predictions - Fig. 14. As indicated, the contact model predicts an increase in wire pulling force with increasing contact angle and again suggests that tighter bends in the hose package increase the mean wire pulling force. Likewise, the static friction in the wire and liner system is observed to be similar to that of the aluminum welding wire sliding through the Nylon wire liner.

The increase in wire pulling force in the case of steel-on-steel is observed to increase more linearly than was previously exhibited during the test of aluminum-on-Teflon and aluminum-on-Nylon. Despite this difference, the measured and predicted quantities are within ± 0.80 N (0.18 lbf) RMS of each other. In general, the steel-on-steel results produce mean wire pulling forces that are up to 10% larger that for either of the two previous aluminum tests. We speculate that the difference in the observed behavior of the steel and aluminum can be attributed to the nature of the contact between the welding wire and the wire liner. Since Young’s modulus of the steel welding wire (E_al = 70 GPa (10 Mpsi)) is approximately three times that of the aluminum welding wire (E_al = 73 GPa (10 Mpsi)), under identical applied tensions of T₁ and T₂, welding wires of nominally identical diameter may fail to make complete contact or only make partial contact with the wire liner - Fig. 15. As a result, the loading distribution development (Equation 10) and the resulting governing differential equation (Equation 21) would undoubtedly differ for steel and aluminum conditions, and may account for the observed exponential and linear difference in the data.

We also speculate that the interface between the welding wire and the wire liner plays a significant role in determining the wire pulling force. In all case studies, the computed interfacial shear strength is lower than theoretically expected. Microscopically, the interface between the welding wire and the wire liner can be considered to consist of mixed asperity-to-asperity contacts - Fig. 16. As a result, one of several or a combination of potential shear zones define the true interfacial shear strength.

Although the contact model is developed to account for an “average” interfacial shear strength value over the entire contact region, the theoretical basis of this model only accounts for “bulk” values of the welding wire and the wire liner. Consequently, the contact model does not account for additional intricacies contributed by interactions caused by the oxide layer (if present), lubricant (if present), or any other higher-order factors such as “composite” material values or third-body debris.

**Conclusions**

1) The welding wire and the wire liner can be modeled as two axially aligned cylinders utilizing aspects of Hertzian contact mechanics and friction theory to compute the interfacial shear strength at the wire/liner interface. The contact model incorporates the bend angle and radius of curvature between the welding wire and the wire liner, as well as nominal diameters and moduli of the welding wire and wire liner.

2) The contact model accurately predicts the wire pulling force for aluminum and steel GMAW applications to within ± 0.60 N (0.14 lbf) RMS and ± 0.80 N (0.18 lbf) RMS, respectively. A statistical analysis has shown with 95% confidence and regardless of liner composition, the wire-pulling force for aluminum-on-Teflon and steel-on-steel GMAW applications is independent of wire feed speed over the interval of speeds ranging from 10 to 18 m/min (400 to 700 in./min).

3) In all tests, the wire-to-liner friction force increases as the severity of the bend in the hose package is increased. This indicates tighter bends in the hose package require larger wire pulling forces to overcome the increased friction. Additionally, the non-zero force component at zero contact angle represents the static friction in the welding wire and wire liner system. When testing aluminum-on-Teflon and aluminum-on-Nylon wire/liner combination, the wire pulling force increased exponentially at a rate of 2.5:1 and 2.7:1, respectively. A 20% larger difference was observed between the mean wire pulling force values when using Nylon-impregnated vs. Teflon-impregnated wire liners. As well, under similar conditions, the wire pulling forces for steel-on-steel wire/liner combination were observed to increase more linearly at a rate of 2:1, and in general were up to 10% larger than either combination of aluminum welding wires.
Acknowledgments

The authors thank the American Welding Society’s Graduate Research Fellowship Program and the NIST Professional Research Experience Program (PREP) for project funding. The authors also extend their most sincere thanks to Dr. Tom Siewert of NIST and to Mr. John Hinrichs of Friction Stir Link, Inc., for their practical insight and advice into this research.

References

Careful selection of GTAW parameters is needed for successful joining of TiAl alloys

BY M. F. ARENAS AND V. L. ACOFF

ABSTRACT: This study examines the weldability of a cast gamma titanium aluminide (γ-TiAl) alloy using the autogenous gas tungsten arc welding process. Experimentation consisted of spot and butt joint welding of gamma titanium aluminides at welding current levels ranging from 50 to 150 A using no preheating. It was found that the welded microstructure exhibited columnar and equiaxed dendritic structures along with a small quantity of gamma grains. A closer examination of the dendritic grains showed that a fine lamellar structure consisting of alternating platelets of alpha-2 and gamma was observed within the dendrites. Other microstructural constituents in the fusion zone were a massive gamma structure and the alpha-2 phase. Crack-free welds were obtained for high welding currents. However, cracking was observed at lower welding currents, which corresponded to increased amounts of the alpha-2 phase. The hardness of the fusion zone increased relative to the base metal, resulting in a decrease in both room temperature ductility and tensile strength of the weld. Conclusively, very careful selection of welding parameters that result in decreased amounts of the alpha-2 phase is required for successful joining of TiAl alloys using gas tungsten arc welding.

Introduction

The low density, superior strength, and high stiffness at elevated temperatures of TiAl intermetallic alloys have attracted great deal of attention from the aerospace and automobile industries (Refs. 1–5). However, it is apparent that the ability to weld these materials to themselves and to other materials is the key to making them more attractive. It is particularly interesting to study the feasibility of using the gas tungsten arc welding (GTAW) technique, which promises to be an economical way to weld gamma titanium aluminides. Despite its importance, only a few papers have been published on the joining of gamma titanium aluminides using gas tungsten arc welding. For instance, L. C. Mallory et al. (Refs. 6, 7) investigated the evolution of the weld fusion zone and heat-affected zone (HAZ) microstructure in preheated GTA welds of a forged gamma Ti-48Al-2Cr-2Nb alloy. When preheating to 800°C was used, no cracking was detected. However, weld beads produced under identical welding conditions but without preheating all contained cracks. A microstructural analysis of the fusion zone showed cored dendritic solidification structures with single colonies of fine lamellar alpha-2/gamma (α/γ) constituent extending across the dendrites. The occasional presence of interdendritic gamma grains was also observed. Interestingly, the microhardness of the fusion zone and HAZ were significantly increased relative to the base metal.

T. J. Kelly (Ref. 8) studied the GTA weldability of a cast Ti-48Al-2Cr-2Nb gamma alloy. Prior to welding, all specimens underwent hot isostatic pressing (HIPing) and some were heat-treated after HIPing at 1300°C for 20 h. As-deposited weld metal exhibited a highly segregated solidification structure that consisted of the gamma phase, colonies of gamma plus alpha-2 (γ + α1) laminates, and the Laves phase. Solid-state cracking was observed in all welds of as-HIPed specimens even with preheats as high as 600°C. However, specimens heat-treated at 1300°C after HIPing did not crack even without preheating because heat-treating at 1300°C increased the ductility of the specimens. In another study, Bharani and Acoff (Ref. 9) used autogenous GTA spot welding to produce crack-free welds in cast alloy Ti-48Al-2Cr-2Nb and extruded alloy Ti-46Al-2Cr-2Nb-0.9Mo without the use of preheating. They showed it is possible to achieve crack-free welds by applying a post-stress relief treatment at 615°C. The crack length in the fusion zone decreased as a function of increasing current level, with no cracks observed for the highest current levels. Dendritic solidification structures were produced in the fusion zone of both alloys. Microhardness profiles also indicated an increase in hardness from the base metal to the fusion zone.

Although some success has been achieved, a comprehensive understanding of the weldability of these alloys is still lacking. The objective of the present study is to analyze GTA welding of the intermetallic γ-TiAl by examining the structure and mechanical properties of γ-TiAl welds for different welding currents. Characterization tools and techniques employed for this investigation consisted of light microscopy, X-ray diffraction, scanning electron microscopy, transmission electron microscopy, microhardness testing, and tensile testing.

Experimental Procedure

Materials and Sample Preparation

An alloy of nominal composition Ti-48Al-2Nb-2Cr (at.-%) was used in this study, with the actual composition shown in Table 1. The alloy was received in the form of 256-mm-long × 110-mm wide × 15-
WELDING RESEARCH

mm-thick cast plates from GE Aircraft Engines. The specimens were HIPed at 1185°C at 107 MPa for 3 h followed by a stabilization heat treatment at 1205°C for 2 h, which was all performed at GE. The cast plates were sectioned into 100-mm x 15-mm x 2-mm specimens for butt-joint welding and 20-mm x 15-mm x 2-mm specimens for spot welding (i.e., welding with the torch stationary at a single location for a fixed time) using electrical-discharge machining (EDM). The specimens were mechanically ground with 120-grit SiC paper then pickled in a solution composed of 400 mL H2O + 40 g KOH + 40 mL H2O2 in order to remove surface contaminants. Before welding, a pre-stress relief treatment was performed at 615°C for 2 h to relieve any stress produced during grinding of the re-cast EDM layer.

Experimental Apparatus

Autogenous GTA welds were produced using spot and butt-joint welding on coupons of γ-TiAl alloys. All welding experiments were performed using direct current electrode negative. A welding speed of 3 mm/s was used to make the butt-joint welds and a welding time of 2 s was employed for the spot welds. The welding equipment had a spot timer device that allowed precise control of the welding time. The welding currents used ranged from 50 to 150 A and the corresponding welding voltage was 14-18 V. Immediately after welding, the samples were visually checked to detect the presence of cracks. All welding was performed inside a welding chamber that was purged with argon for 10 min prior to welding.

Materials Characterization

The welded and as-received samples were sectioned into metallographic specimens. These metallographic samples were prepared using conventional metallographic procedures for titanium aluminides (Ref. 10). Microstructural details were revealed by a Kroll's modified etching solution comprised of 100 mL H2O + 35 mL H2O2 + 5 mL HNO3 + 10 mL HCl. Microstructural characterization was performed using light microscopy, scanning electron microscopy (SEM) equipped with energy dispersive X-ray spectrometry (EDS), and transmission electron microscopy (TEM). X-ray diffraction (XRD) was used for primary phase identification of the fusion zone and base metal. The weld specimens were prepared for XRD by carefully removing the fusion zone from the specimen using a precision saw. Measurement parameters for XRD were as follows: Cu Kα radiation, accelerating voltage 40 kV, and tube current 35 mA. Diffraction patterns were obtained in the step, 20 mode in the range of 20-90 deg.

Mechanical Testing

Microhardness data was obtained using a Knoop microhardness tester with a load of 500 g. The Knoop hardness number (KHN) was plotted as a function of distance across the welded specimen. Tensile tests were carried out on a universal testing machine at room temperature using a constant crosshead speed under a strain rate of 10^-4 s^-1. Two tensile specimens were evaluated; one that consisted of only the base metal and the other of only the fusion zone.

Results and Discussion

Microstructural Characterization of the Base Metal

The as-received condition of the alloy consisted primarily of a lamellar microstructure composed of alternating platelets of gamma and alpha-2 and some equiaxed gamma grains, as shown in Fig. 1. This microstructure is the result of the treatment for cast alloys developed by Austin et al. (Ref. 11), which involves HIPping of the as-cast alloy followed by heat treatment in the alpha + gamma field. The X-ray diffraction analysis of the base metal is shown in Fig. 2. In this XRD scan, peaks due to gamma and alpha-2 phases are identified. The prominent peak at about 39 deg corresponds to the gamma phase (Ref. 12) and it accounts for both the gamma lamellae and the equiaxed gamma grains observed. After solidification, cast gamma titanium aluminides are transformed into a lamellar structure with a preferred orientation of the lamellae -- Fig. 1. The lamellae are aligned parallel to the outer surface of the ingot, i.e., perpendicular to the heat flow during solidification. This texture is reflected in the XRD measurement showing a high-intensity peak in the (111) plane. The small peak at about 41 deg corresponds to the alpha-2 phase (Ref. 13), which is present in the base metal as alpha-2 lamellae. The weak intensity of the alpha-2 peak is probably due to the very thin alpha-2 lamellae, which is below the spatial resolution of the XRD technique, and the minimal presence of individual alpha-2 grains as shown in Fig. 1.

Fusion Zone Microstructures for Spot Welds

Figure 3 shows a light micrograph of a weld obtained by welding with an arc current of 50 A, where the evolution of microstructure from the base metal (left) to the fusion zone (right) is evident. This figure shows that the fusion zone microstructure is composed of columnar grains oriented perpendicular to the direction of the radial fusion boundary. This was expected, since during solidification, grains tend to grow in the direction perpendicular to the solid/liquid interface.
which is the direction of the maximum temperature gradient and thus the maximum driving force for solidification. Higher magnification micrographs of the columnar structure show lamellar grains and some amount of small blocky grains identified as the gamma phase — Fig. 4. A region of about 200 μm between the base metal and the fusion zone can be recognized as the heat-affected zone (HAZ) — Fig. 5. This region mainly consisted of equiaxed gamma grains. The center of the fusion zone showed a markedly different microstructure. This region, which experienced the highest temperatures, exhibited a dendritic structure — Fig. 6. The difference in microstructure between the weld centerline and the fusion boundary can be attributed to different temperature gradients and solidification rates between the two regions. As the welding current was increased, the volume fraction of lamellar structure increased while that for the equiaxed gamma grains decreased.

A high cracking susceptibility was observed for welding at 50 A. A typical crack that occurred is shown in Fig. 7. The cracks appeared either immediately after welding or several seconds after welding was performed. These cracks were identified as solidification cracks and occurred at the center of the fusion zone. For the spot welds, the center of the weld pool was highly susceptible to crack development and occasionally the cracks propagated into the base metal, as shown at the bottom of Fig. 7. Interestingly, SEM/EDS analysis found that the cracked surfaces were enriched with Al ranging from 51 to 54 at.-%, suggesting that the heavily segregated interdendritic regions were initiation sites for cracks.

Since the specimens were relatively small (2 mm thick) and there was little or no external stress exerted to the workpiece, it is believed the major contributing factor to the susceptibility to solidification cracking was thermal stresses. The thermal stresses developed from the difference in temperature across the fusion zone as a result of the metal at the fusion zone/base metal boundary solidifying much faster than the metal at the center of the fusion zone. The thermal stresses cannot be accommodated due to the lack of ductility of the fusion zone, which results from the increased volume fraction of the brittle alpha-2 phase compared to the base metal. Furthermore, severe solute segregation at the center of the fusion zone provides fracture initiation sites for the cracks. However, it is believed that decreasing the cooling rate (increasing the welding current), which in turn reduces both alpha-2 formation and interdendritic segregation, reduces the susceptibility for solidification cracking. Traditional hot cracking was not the operative mechanism since no evidence of grain boundary liquation or fracture features associated with the occurrence of subsolid liquid microconstituents was observed.

No cracks were observed for using welding currents equal to or greater than 75 A. This observation supports the belief that decreasing the cooling rate by increasing the welding current reduces the susceptibility for solidification cracking. Although the butt-joint welded specimens have a much higher heat input compared to spot welded specimens, it was consistently observed that the specimens spot welded at 50 A exhibited solidification cracking, whereas specimens spot welded
at currents greater than or equal to 75 A did not. Patterson et al. (Ref. 14) concluded there is a critical weld cooling rate (300 K/s) below which cracking does not occur for γ-TiAl welds. They observed from light microscopy that an increase in the acicular microconstituent occurred with increasing the weld cooling rate. For the present study, a change in the fusion zone microstructure with increased welding current (decreased cooling rate) was also observed. As the welding current was increased, the volume fraction of the brittle alpha-2 phase decreased. This microstructural observation was supported by the XRD results that are presented in the present study.

**Fusion Zone Microstructures for Butt-Joint Welds**

Butt-joint welds were obtained using three different welding currents: 55, 75, and 115 A. Figure 8 shows the fusion zone microstructure obtained for the 55-A heat input. Large columnar grains oriented in the welding direction were observed. Similar features were also obtained for the other two heat inputs. However, an increase in the grain size of the columnar structure was evident as the welding current increased. Figure 9 shows a higher magnification SEM micrograph of the fusion zone microstructure produced for a welding current of 55 A. This microstructure mainly consisted of fine lamellar grains, similar to those observed for the spot welded specimens. Large gamma grains located at lamellar grain boundaries were also observed. Interestingly, some dark, deeply etched gamma grains with a patchy morphology were observed — Fig. 9B. These grains were identified as massive gamma grains (γm), which result from the massive transformation from α to γ at relatively high cooling rates (Ref. 15). Also, some amount of alpha-2 phase, resolvable only by TEM analysis, is believed to be present due to the higher cooling rate — Fig. 10. Figure 10A is a bright-field TEM micrograph of the fusion zone showing an alpha-2 grain with a neighboring lamellar grain. The identification of the phase was confirmed with a selected area diffraction pattern in the (0001) orientation as shown in Fig. 10B. The diffraction pattern confirmed the hexagonal close-packed alpha-2 structure. Interestingly, the heat-affected zone was practically indistinguishable at the optical and SEM scale for the butt-joint welded specimens. The 55-A specimen exhibited a high proportion of cracks. The crack morphology was similar to that observed for the 30-A spot welded specimen.

Increasing the welding current to 75 A revealed that the lamellar structure was the main constituent. However, lesser amounts of massive gamma and supersaturated alpha-2 structures were observed compared to the microstructure obtained for 55 amps. A further increase in the welding current from 75 to 115 A produced a more extensive fusion zone with coarser grains.

**X-ray Diffraction Analysis of the Fusion Zone**

XRD was utilized to determine the different phases that developed in the fusion zone microstructure. Figure 11 shows the results for spot welds obtained at three different heat inputs: 50, 100, and 150 A. The XRD data in this figure indicates there was a significant increase in the alpha-2 phase compared to the base metal condition — Fig. 2. This was revealed by the stronger peaks of the alpha-2 phase, especially the main peak in the (201) plane. The increase in alpha-2 structure was the highest for the 50-A specimen. This suggests the cooling rate plays an important role in the microstructural control of the fusion zone. In GTA welding of gamma titanium aluminides, solid-state phase transformations are strongly affected by the cooling rates. At lower cooling rates, the lamellar structure is largely predominant. In this case, the alpha phase transforms into a well-defined alpha-2/γ lamellar structure (α → α + γ). Studies have shown this reaction occurs in the two-phase α+γ phase field of the TiAl phase diagram (Ref. 16) and exhibits characteristics of a nucleation and growth process, very likely involving diffusion (Ref. 17). At higher cooling rates, however, the decomposition of the alpha phase is suppressed in favor of the ordering of the alpha phase into the alpha-2 phase (α → α₂), resulting in an increased amount of alpha-two in the fusion zone. The present study suggests that welding of TiAl-based alloys should be conducted at cooling rates that will not suppress the decomposition of the alpha phase. In this work, the heat input or the applied welding current controlled the cooling rates. Moreover, the study of other variables that can also modify the cooling rates, such as welding speed and the use of preheating, was beyond the scope of this work.
Microhardness Measurements

A microhardness profile of the as-welded condition using a heat input of 75 A is shown in Fig. 12A. In this figure, the fusion zone microhardness increased dramatically relative to the base metal microhardness of 300 KHN. The microhardness increased on average by a factor of 1.5. The observed increase in fusion zone microhardness is in agreement with all previous reports on TiAl weldability. It is believed the increase in microhardness is due to the increased presence of alpha-2 structures that formed during welding. This microstructure is known to have a higher microhardness compared to other gamma-related microstructures. The microhardness profile for the weld produced at 115 A is illustrated in Fig. 12B. This figure shows an increase in microhardness from the base metal to the fusion zone that was similar to the 75-A specimen. However, the average fusion zone microhardness was slightly lower than that observed for the 75-A specimen, which corresponds with the decrease in alpha-2 phase that was observed as the welding current was increased — Fig. 11.

Tensile Testing

Figure 13 shows the room temperature stress-strain curves for the as-welded condition and the as-received condition (base metal). Results show there was a dramatic decrease in tensile strength and loss of ductility for the as-welded condition. Furthermore, the calculated elongations at failure were 0.1 and 0.5% for the as-welded condition and the base metal, respectively. The observed tensile behavior of the as-welded condition agrees with the increase in fusion zone microhardness discussed previously.

The reduction of mechanical properties can be partially explained by the microstructural changes that occurred during welding that resulted in a higher amount of the brittle alpha-2 phase in the fusion zone. SEM micrographs of the tensile test fracture surfaces for the as-received and as-welded specimens are shown in Fig. 14. For the welded specimen, fracture occurred in the weld fusion zone. The micrographs reveal that there are two distinct failure mechanisms for the base metal (Fig. 14A) and the as-welded condition (Fig. 14B). The base metal exhibited mainly translamellar fracture, which agrees with the great proportion of lamellar constituent in this material, as shown in Fig. 1. Translamellar fracture is associated with a greater degree of plastic deformation experienced at the crack tip and ligament formation, often yielding higher toughness. However, the as-welded condition exhibited transgranular cleavage fracture, which is common for brittle materials. The multifaceted surface, observed in Fig. 14B, is typical of cleavage in polycrystalline materials where each facet corresponds to a single grain. The "river patterns" on each face are also typical of cleavage fracture.
It is believed that fracture occurred in the planes with low cohesive strength. For TiAl, these planes have been identified as the (111) planes (Ref. 18).

Conclusions

Autogenous GTA welding has been used to produce crack-free welds in Ti-48Al-2Cr-2Nb without the use of preheating. A procedure for obtaining sound, crack-free welds consisted of pre-stress relief treatment of 615°C for 2 h and welding at arc currents equal to or greater than 75 A.

The γ-TiAl base metal microstructure consisted of a lamellar (γ/α) structure with some amount of gamma grains. However, the welded microstructure exhibited columnar and equiaxed dendritic structures. The columnar grains extended from the fusion boundary to the weld center, whereas the equiaxed structure developed at the center of the fusion zone. A closer examination of the dendritic grains showed they were composed of a considerably fine lamellar structure compared to that of the base metal. Other microstructural constituents observed in the fusion zone were supersaturated alpha-2 phases and massive gamma metastable structures. There were more of these structures present at the lower heat inputs. Less cracking was observed as the welding current increased, which corresponded with a decrease in the alpha-2 phase in the fusion zone.

Mechanical properties of the weld were decreased relative to the base metal, as was indicated by microhardness measurements and tensile testing. A significant increase in microhardness was observed in the fusion zone. Also, the as-welded condition showed a reduction in ductility and a decrease in tensile strength.

Acknowledgments

The authors gratefully acknowledge Tom J. Kelly and GE Aircraft Engines (Cincinnati, Ohio) for donating the alloy used in this study. Financial support for this work was provided by the National Science Foundation under grant number DMR-9702448.

References

Influence of Welding Machine Mechanical Characteristics on the Resistance Spot Welding Process and Weld Quality

How machine stiffness, friction, and moving mass can affect welding results

BY H. TANG, W. HOU, S. J. HU, H. Y. ZHANG, Z. FENG, AND M. KIMCHI

ABSTRACT: Mechanical characteristics of resistance spot welding machines, such as stiffness, friction, and moving mass, have complex influences on the resistance welding process and weld quality. In this paper, these influences are systematically investigated through experiments. The mechanisms of the influences are explored by analyzing process signatures, such as welding force and electrode displacement, and other process characteristics, such as electrode alignment. A better understanding of the influences is achieved through this analysis. This study shows machine stiffness and friction affect welding processes and weld quality. It also confirms the moving mass does not significantly affect the process and quality of resistance spot welding.

Introduction

A resistance spot welding (RSW) machine consists of two distinct subsystems: electrical and mechanical. The characteristics of the mechanical subsystem, such as machine stiffness, friction, and mass, play important roles in the functionality and performance of a welding machine, and subsequently influence welding process and weld quality.

According to published literature, research on the influence of welding machines started in the 1970s. Early work focused on the differences in machine types. For example, Gáspárová and Williams investigated the influence of machine type on electrode life for welding zinc-coated steels (Ref. 1). Kolder and Bosman studied the influence of equipment on the weld lobe diagrams of an HSLA steel at five sites (Ref. 2). Satoh and his coworkers concluded machine type was an important factor in weld performance based on their experiments on four types of welding machines (Refs. 3, 4).

More recently, researchers have addressed the effects of individual machine characteristics on various aspects of the welding process. Several studies were conducted on the influence of machine stiffness and electrode displacement. Hahn et al. (Ref. 5) found large displacement of electrodes resulted in defects of electrode contact and decrease of weld quality. Williams (Ref. 6) discovered an increase in throat depth and electrode stroke decreased electrode life. Similarly, Howe (Ref. 7) found electrode deflection significantly influenced electrode life. Dorn and Xu (Ref. 8) observed that the stiffness of a lower arm had an effect on the oscillation and the mean value of electrode force when electrodes were in contact with the workpiece.

The influence of machine friction, or the friction between the moving parts and the stationary parts in contact within a welding machine, has also been studied. Satoh et al. (Ref. 3) found that friction had effects on nugget diameter and sheet separation. They also noticed that weld expansion occurred mainly in a direction perpendicular to the electrode axis if the friction effects were significant. Dorn and Xu (Refs. 8, 9) concluded an increase in friction reduces oscillation of electrode force during touching. They further found that the increase in friction reduced the tension-shear force and torsion moment of welds.

The moving mass of RSW machines was found less important to weld quality than stiffness and friction. Satoh et al. (Refs. 3, 4) did not find much influence from moving mass on weld nugget formation. They stated that the optimal weight of the moving part existed for electrode life in relation to the natural frequency of a RSW machine. Dorn and Xu (Ref. 9) observed that the moving mass affects vibration at low friction with a rigid lower arm. However, they did not detect any clear influence of the mass on weld quality. Theoretical attempts were made by Gould and his coworkers on the dynamic behavior of moving parts of a welding machine (Refs. 9, 11). In a recent study, Tang et al. (Ref. 12) performed a systematic investigation of the dependence of electrode force on machine mechanical characteristics, welding process parameters, and materials.

In summary, these researchers have made valuable contributions to the understanding of the effects of machine characteristics on welding. However, several issues remain to be resolved in this research area. First, the results of the previous studies were mainly descriptive and lacked convincing explanations. Due to the complexity of RSW, it is difficult to obtain explicit expressions of the influences only from comparisons. Second, weld quality was not emphasized in their studies, although improving weld quality has been one of the main concerns in both academic research and industrial practice. In addition, important mechanical characteristics of a resistance welding machine have not been systematically studied in previous works.

It is desirable yet challenging to obtain a scientific and systematic relationship between machine characteristics and weld quality. This research attempts to address...
some aspects of the relationship and also to understand how weld quality is affected. Both experimental and process signature analysis techniques were utilized in this study. Changes in machine mechanical characteristics are usually directly reflected by various process signatures recorded during welding. Therefore, the influence of machine characteristics on weld quality can be explained by analyzing the process signatures.

The electrode force was chosen as the primary process signature in this study. The influence of machine characteristics on weld quality may be largely explained through the analysis of the force characteristics because other process parameters, such as welding current and time, are not directly related to machine mechanical characteristics. Electrode displacement during welding is also important because it reflects the expansion, melting, growth, and solidification processes. Thus, both force and displacement were studied in this investigation of the relationship between RSW machines and weld quality. In the context of this work, weld quality refers to the geometric characters of a weld such as indentation, the appearance of expulsion, and the tensile-shear strength (peak load) of a weld.

The new approach attempted in this study combines experimental investigation (as performed by previous investigators) and process signature analysis — Fig. 1. Experimental investigations were systematically designed and conducted. Weld quality was emphasized in the study. Based on the experimental results and on analytical and numerical studies, the relationship between the individual characteristics and weld quality was explored through process signature analysis.

**Experimental Investigation and Process Analysis**

This experimental investigation was carried out on welding machines with modified mechanical characteristics. Such characteristics were then linked to weld quality, and the relationship was established through process signature analysis. The focus was placed on the signals during...
welding, i.e., during the application of electric current. In addition, the hold stage was analyzed because it influences the solidification of liquid nuggets.

The majority of experiments were carried out on a 75-kVA pedestal welding machine. Some experiments were performed using a 42-kVA C-type gun and a 200-kVA pedestal welding machine. Truncated-cone electrodes were used in all experiments. Welding force, electric current, and thickness of metal sheets were chosen as experiment variables. To determine the welding current used in the experiments, weld lobe tests under various conditions were conducted first. The current profile when welding expulsion happened was recorded. The welding currents used for all following designed experiments were selected near the expulsion limits, or the minimum currents at which expulsion is observed. In order to ensure the reliability of experiments, five welds were made under each condition.

In the experiments, the process signals were recorded for subsequent analyses. The force was measured by a strain gauge-based load cell, while a linear variable differential transducer was used to measure the displacement. The current was also recorded in order to capture the exact welding stage duration.

Several measures were selected as criteria for evaluating weld quality. The tensile-shear strength was used as the primary index of quality. Weld indentation was also measured. Each of five specimens was measured three times for the indentation. Furthermore, metallurgical examinations were conducted on selected specimens. Materials used in the experiments are steel and aluminum sheets commonly used in automotive applications, and their specifications are listed in the individual sections.

The mechanical characteristics of the welding machines, i.e., machine stiffness, friction, and moving mass, were modified. In order to ensure the consistency of testing conditions, only one characteristic was modified at a time for specific experiments. Two levels of these individual characteristics were used in comparative experiments. The modifications of welding machines are briefly described in the following sections. Refer to an earlier paper (Ref. 12) for detailed descriptions.

Stiffness

The stiffness of welding machines reflects their ability to resist the deflection under loading. Since the upper structures of the welding machines used in this study are much stiffer than the lower structures, only the stiffness of the lower structures was considered and altered. The stiffness was modified in two ways. Reducing stiffness was realized by adding springs between the lower electrode and its support structure for the pedestal welding ma-
chines, while increasing stiffness was achieved by adding a supporting leg from the floor to the lower arm for the C-type gun. Therefore, two levels of stiffness were achieved on each machine: 4.3 kN/mm and 13.0 kN/mm for the gun; 8.8 kN/mm and 52.5 kN/mm for the 75-kVA pedestal welding machine.

**Friction**

Friction exists between two contact surfaces only when there is a relative movement or a moving tendency. For both the pedestal welding machines and the C-type gun used in this study, only the upper structure is movable during welding. A special device offering adjustable additional friction (Fig. 2) was designed and mounted on the pedestal welding machines in order to vary the friction force. In the experiments, two different friction situations were considered: the original setup and one with an additional 0.36-kN (80-lb) friction.

**Moving Mass**

Because some parts of the upper structures of the welding machines move during welding, a 20-kg weight was added on the movable parts to change their mass. Two levels of moving mass of the upper structures were considered for the pedestal welding machines: the original weight (about 40 kg) and the original weight plus additional weight.

**Influence of Machine Stiffness**

The investigation was conducted on both gun-type and pedestal-type welding machines. Three types of DS (drawing steel) steel specimens were used: 0.8-mm bare, 1.7-mm bare, and 0.8-mm galvanized. The welding time was 12 cycles for most experiments, and the welding current and force are listed in Figs. 3 and 4. Error bars are used in these and other figures to show the ranges of experimentally observed values, and solid dots and numerical values indicate the averages of the data. Expulsion, which has been proved undesirable (Ref. 14), and tensile-shear peak load (Ref. 15) are discussed in the following.

**Expulsion**

Tests were conducted first for the influence of machine stiffness on the expulsion limits and then for the selection of appropriate currents for subsequent experiments. In the tests, welding current was increased gradually while the force and time were unchanged. The experiment results show the expulsion limit rises with stiffness, as shown in Table 1. Because higher expulsion limits allow higher welding cur-

![Fig. 8 — Geometric model for axial misalignment and contact area.](image)

![Fig. 9 — FEA model of weld gun body.](image)

![Fig. 10 — FEA models for pressure analysis. A — Perfect alignment; B — misalignment.](image)

![Fig. 11 — Comparison of pressure distributions.](image)
rents, potentially larger welds can be made without expulsion.

Peak Load

A comparative experiment was conducted under identical conditions with various machine stiffnesses. As shown in Fig. 3, weld quality is improved in terms of tensile-shear strength (peak load) with machine stiffness. However, the improvement is not significant because only about a 3% difference exists and the data ranges overlap.

Similar experiments were performed using the 200-kVA pedestal welding machine. In these experiments, both steel and aluminum specimens were used: 0.8-mm and 1.7-mm bare steel, and 1-mm and 2-mm aluminum alloy (AA5754). The experiment results show the stiffness is slightly beneficial to weld quality in terms of tensile-shear strength — Fig. 4. However, the experiment data did not show the influence of machine stiffness on weld indentation. The experiment results of both gun-type and pedestal-type machines are consistent.

In summary, machine stiffness slightly improves weld quality in terms of weld strength under the same conditions and significantly raises welding expulsion limits. Further analysis was made on the influence of the machine stiffness on two aspects of the welding process: the characteristics of the welding force and electrode displacement, and electrode alignment.

Electrode Force

In welding steels using the pedestal welding machine, electrode force increases immediately after electrical current is applied — Fig. 5 (Ref. 12). The maximum increase of electrode force is about 5–10% of its preset value. The increase is due to thermal expansion of the weldment and the constraint imposed by machine stiffness. When a machine is stiff, the constraint is strong and results in a large force. The increased electrode force imposes a forging force on the nugget, which is beneficial to preventing welding expulsion.

Electrode Displacement

Electrode displacement may be the best indicator of nugget initiation and growth, and other characteristics (such as expulsion, etc.) during welding. Although the amount of electrode movement during welding varies according to the stiffness of the welding machine, similar displacement characteristics have been observed when welding with different machine stiffness, as shown in Fig. 6 where relative displacement between the upper and lower electrodes was plotted. It takes a similar amount of expansion (i.e., $d_1 = d_2$) for nuggets to grow, but with the stiffer machine it takes longer for expulsion to happen. This is because a stiffer machine provides a larger constraint or force, which delays expulsion according to Ref. 13. In the case of Fig. 6, welding time was set at 16 cycles and expulsion occurred at the fifth cycle (0.083 s) in the weld stage when the machine stiffness was low. However, expulsion happened almost at the end of welding when stiffness was high. If welding time had been set at 10 cycles, the expulsion would have not occurred under the higher stiffness, but still could have occurred under the lower stiffness. The amount of relative displacement of the electrodes of the stiffer welding machine is larger when expulsion happens, as shown in Fig. 6, as the machine asserts more squeezing force on the softened weld.
Electrode Alignment

Ideally, electrodes should be aligned during the RSW process because a misalignment induces unfavorable features to the process and weld quality. Misalignments, either axial or angular, may cause irregularly shaped welds and reduce weld size because misalignments result in asymmetrical distribution of force and current. A misalignment can result from machine deflection under an applied force, as shown by a finite element model (Fig. 7), even if the electrodes appear aligned under no loading or very low loading. Such misalignment is often ignored in practice. In this section, analytical and numerical (finite element modeling) analyses are conducted to provide a quantitative understanding of the reduction in contact area that affects the welding current density, and the effect on the pressure distribution due to deflection-induced misalignment.

Axial misalignment reduces the (overlapped) contact area between the sheets, as shown in Fig. 8. The actual contact area \((C_r)\), in percentage of electrode face area, can be approximated by Equation 1. It can be seen from the equation that the reduction in contact area is strongly correlated with the axial misalignment.

\[
C_r = \frac{2r^2 \arccos \left( \frac{b}{2r} \right) - 2b \sqrt{r^2 - \left( \frac{b}{2} \right)^2}}{\pi r^2}
\]

where \(r\) is the radius of electrode face; \(b\) is the axial misalignment.

A misalignment due to structural deflection can be quantified when the geometry and mechanical properties of a welding machine are known through theoretical or numerical analyses. Finite element analysis (FEA) is a convenient tool for evaluating the deflection and corresponding misalignment.

A 3-D FEA model was created for a gun body using ANSYS 5.4 — Fig. 9. In the model, the gun body was modeled by tetrahedral solid elements; the interface between sheets and electrodes was modeled by nonlinear contact elements. Under an electrode force of 2.67 kN (600 lb), the electrodes misalign 0.75 mm axially and 0.28 deg in angle. The electrode face diameter was assumed 6.4 mm, and the contact area was reduced to 85% of the electrode face area according to Equation 1. Therefore, a welding schedule designed on perfect alignment conditions may not be adequate, and weld strength may be reduced due to misalignment.

Furthermore, a contact pressure analysis was conducted based on the above misalignment information, i.e., 0.75-mm axial and 0.28-deg angular misalignment using a 2-D FEA model for the electrodes and workpieces — Fig. 10.

The pressure distribution on the faying surface under 2.67 kN (600 lb) of electrode force is shown in Fig. 11 and some data are listed in Table 2. The average pressure with perfect alignment on the faying face is 83.0 MPa. Under ideal alignment, high pressure always occurs around the electrode edge, which plays a role in containing the molten nugget and preventing possible welding expulsion. When the electrodes misalign, the pressure distribution asymmetically. Obviously, this asymmetrical pressure distribution is unfavorable in terms of expulsion prevention.
Influence of Machine Friction on Weld Strength and Microstructure

In the experiments, welding specimens were 0.8- and 1.7-mm bare steel and 1- and 2-mm aluminum sheets. The welding time was 12 cycles. The current was 7.1 kA for steel and 35 kA for aluminum. The force was set at two levels: 2.67 kN (600 lb) and 4.00 kN (900 lb) for steel; 3.56 kN (800 lb) and 5.34 kN (1200 lb) for aluminum.

Figures 12 and 13 show the comparisons of the joint strength, with data range bars, under different conditions. Based on the comparisons, it can be concluded that friction is unfavorable for both steel and aluminum welding. However, for some combinations of parameters, strength reduction is not statistically significant since the data ranges overlap. In general, the influence of friction varies with welding conditions.

In order to gain further understanding, the welded specimens were sectioned and examined through standard metallographic techniques. Typical cross sections are shown in Figs. 14-16. In the cross sections, it is easy to recognize there is incomplete fusion on the faying surface under higher friction condition.

For 0.8-mm steel (Fig. 14), incomplete fusion on the faying surface was observed when the machine had additional friction. This could be the reason for the reduction of weld strength. For 1.7-mm steel (Fig. 15), it is obvious the weld under greater friction has shrinkage porosity. A similar situation was observed in the weld of 2-mm aluminum - Fig. 16. However, the internal porosity may not affect the tensile-shear strength of the welds in some cases, as reported in Ref. 16 for aluminum welds.

(Ref. 13) and electrode life. Therefore, expulsion happens easily when electrode misalignment exists.

In addition, the analysis results show sheet thickness is another factor on pressure distribution. Thicker sheets can reduce the asymmetrical pressure on the faying surface, which partially explains why machine stiffness has less influence on welding expulsion for welding thicker sheets.

Fig. 17 — Comparison of electrode force with different friction.

Fig. 18 — Comparison of electrode displacement with different friction.

Fig. 19 — Influence of mass on weld strength (steel).

Fig. 20 — Influence of mass on weld strength (aluminum).
Therefore, machine friction adversely influences weld quality. Although the internal discontinuities in welds. With large machine friction, electrodes indent less into workpieces for aluminum welding.

Effect on Electrode Force

The friction in RSW machines contributes significantly to total electrode force. Under the same preset value, the actual force with larger friction is smaller than that with smaller friction — Fig. 17. When large friction exists, electrode movement is sluggish and cannot promptly follow the contraction. Thus, it is most likely internal discontinuities, such as porosity, appear in the nugget. The desired situation should be that the electrodes move freely in the welding and holding stages.

Effect on Electrode Displacement

Expansive information on weld indentation. An example of 2-mm aluminum welding under 3.56-kN force is shown in Fig. 18. The electrodes extrude less into the workpieces with larger friction. The difference in displacement was about 0.1 mm as electrodes were retracted. The initial impact of electrodes onto workpieces is also reduced by friction, which may be beneficial to electrode life.

In summary, machine friction influences welding process and weld quality. Therefore, the effect of moving mass of welding machines can be neglected in design.

Influence of Moving Mass on Weld Quality

Various experiments were conducted by altering the mass of the upper structure of the pedestal welding machines. The selected welding schedules were the same as used in the early parts of the experiments of this work. Some results are shown in Figs. 19 and 20. The results, in terms of the tensile-shear strength of welds and welding expulsion limits, do not show any significant influence of machine moving mass for both steel and aluminum welding. Therefore, the effect of moving mass of a welding machine can be neglected in design.

The insignificance of the effect of the moving mass was expected because of the small amount of motion of electrodes during welding. The effect of mass, in the form of dynamic force, can be significant only when weld volume thermally expands with a large acceleration. The dynamic force can be obtained if moving mass and the acceleration of electrode movement are known. The force \( F \) can be calculated by \( F = ma \) where \( m \) is the moving mass and \( a \) is acceleration, which can be approximated by the following differential equation:

\[
a = \frac{x(t+1) - 2x(t) + x(t-1)}{(\Delta t)^2}
\]

where \( x(t) \) is the measurement of electrode displacement during welding at the instant \( t \) and \( \Delta t \) is the sampling interval.

For 1.7-mm steel, welding with 6.8-kA current and 2.67-kN (600-lb) force, as an example, the calculated acceleration of weld expansion is shown in Fig. 21. From the calculated results, the largest acceler-
gular misalignment with 0.75-mm axial misalignment result in significant asymmetrical pressure distribution. Such a conclusion should be considered as a reference only because this calculation did not consider thermal-mechanical interaction occurring during welding. However, it indicates possible influence of machine stiffness on electrode alignment and possibly on weld quality. In practice, a certain amount of angular misalignment can be compensated by the fact that electrodes are usually slightly worn after a few welds, and by using dome-shaped electrodes. In general, establishing a tolerance of axial and angular misalignments for RSW machine design needs further FEA and experimental study. As discussed in previous sections, machine friction is generally unfavorable to weld quality. Friction should be kept as small as possible for this reason. There are several practical ways to minimize friction. For instance, the moving parts of RSW machines should be supported by a roller guide, such as ball screws, rather than by a sliding mechanism. A specific mechanism may be designed so that the friction is applied only during the hold stage to increase forging force.

According to this study, moving mass of RSW machines has no significant effect on weld quality. Therefore, the mass or weight should be minimized to reduce the impact at touching for improved electrode life and to improve gun portability for energy and ergonomic considerations. Further research is needed to obtain optimal machine and process design.

Summary
In this paper, the influence of RSW machine mechanical characteristics on welding process and weld quality was systematically investigated. Both experimental and analytical studies were performed to understand such influences. In general, machine stiffness has a positive influence on expulsion prevention and weld quality. Specifically, high stiffness can reduce electrode misalignment, increase expulsion limits, and provide forging effect. Thus, high stiffness is recommended. Machine friction should be reduced whenever possible because of its negative effects on weld quality, especially on internal discontinuities. Machine moving mass shows no influence on weld quality.

In addition to experimental investigations, a systematic approach is developed based on analyzing process information. From such analyses, new understanding of the influences of the machine mechanical characteristics can be obtained, and guidelines for the design of RSW machines can be developed.
ABICOR

Your solutions partner
Today, tomorrow...and tomorrow...

and tomorrow...

Circle No. 1 on Reader Info-Card

The World Leader

ABICOR BINZEL

MIG • TIG • ROBOTICS

800.542.4867

www.binzel-abicor.com
Built to **Last.**

Built to **Perform.**

Built for **Safety.**

What makes ESAB's OXWELD®, PUROX®, and PREST-O-LITE® gas equipment tops in quality, reliability and safety? Exclusive features like patented, built-in protection against cylinder fires in oxygen regulators. Torches designed for leak-free operation. Solid brass barstock regulator bodies. Operating features that simplify your job. Plus, superior product backing, including a Lifetime Warranty on all OXWELD® products. With the 99.9% customer satisfaction ranking earned by ESAB's gas equipment, there simply is no competition.

© Your Partner in Welding & Cutting

Circle No. 24 on Reader Info-Card

For more information call 1-800-ESAB-123 or visit www.esabna.com.

See ESAB's OXWELD® gas equipment in action on Discovery Channel's *Monster Garage.*