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Welding Research Supplement

197-S  Resistance Spot Welding of Aluminum Alloy to Steel with Transition Material — Part II: Finite Element Analyses of Nugget Growth
A cold-rolled transitional material was used to assist in the resistance welding of aluminum to steel
X. Sun and M. A. Khaleel

203-S  An Investigation on the Effects of Gases in GTA Welding of a Wrought AZ80 Magnesium Alloy
Various gases, some enriched with hydrogen, were tested to determine if penetration could be increased
M. Marya et al.

213-S  Fundamental Studies on the Effect of Distortion Control Plans on Angular Distortion in Fillet Welded T-Joints
Techniques were tested to control cumulative plastic strain
G. H. Jong and C. L. Tsai
Hoganas Sells Part of Powder Metal Operations

Swedish metal powder manufacturer Hoganas AB has sold part of the assets of the SCM Metal Products operation it acquired last year. The sale involves its U.S.-based powder product lines, which serve brazing, thermal spray, electrode, and flux applications, among others, as well as a manufacturing facility in Research Park, N.C. The purchaser was the Gibraltar Group of Buffalo, N.Y. The company's North American Hoganas High Alloys subsidiary will continue to produce noncopper powder products at its Johnstonstown, Pa., plant.

Alabama College Tries Free Welding Tuition

As a demonstration program, Bishop State Community College in Mobile, Ala., is training 40 welding students for free. Supported by a $250,000 grant from the state, the school's program aims to prove it can supply welders for three large local shipyards: Atlantic Marine, Austal USA, and Bender. The course is running eight hours a day, five days a week for eight weeks, and uses a facility that previously trained students for the aviation industry.

Factories Add and Subtract Jobs

A number of manufacturers have announced that they are adding jobs. Thomas Built Buses has opened a new $39.7 million school bus manufacturing plant in High Point, N.C., that will employ 192 workers and produce up to 22 buses per shift. The plant makes extensive use of robotics. Chrysler is investing $113 million in capital expenditures at its St. Louis South Assembly Plant in Fenton, Mo., to boost production of minivans with an innovative seat storage capability. Freightliner is adding a third shift and 593 new full-time jobs at its Cleveland, N.C., heavy-duty truck manufacturing plant. However, following the army’s cancellation of the $39 billion Comanche helicopter program, Sikorsky Aircraft is closing a large plant in Bridgeport, Conn., and has cut 175 workers.

Boom in LNG Terminals Seen

A study by Merrill Lynch reports that U.S. demand for natural gas has caught up with wellhead supply, as well as the storage and transportation infrastructure. Multibillion-dollar capital expenditures for storage, terminals, and pipelines are needed to keep natural gas supplies flowing over the next few years, the report concludes, or else the nation will have to rely on increased imports of liquefied natural gas (LNG) carried aboard ships.

Hoping to avoid government permitting hassles, a Tulsa company has signed an agreement with the Sipayik Indian tribe to develop a one-hundred-cubic-foot-capacity LNG terminal and storage facility on tribal land near the port of Eastport, Maine. Meanwhile, the Federal Energy Regulatory Commission has issued an environmental impact statement paving the way for development of an LNG terminal on the Texas Gulf coast, on Quintana Island near Freeport.

Harley-Davidson Hopes to Roar into China Market

Harley-Davidson has announced a relationship with China's Zongshen Motorcycle Group that the U.S. company hopes will pave the way for entry into the giant market. China has huge official and unofficial barriers against importing motorcycles, including a 50% import duty that, even if it drops to 30% next year as scheduled, Harley-Davidson considers onerous. The U.S. company will share technical and marketing knowledge with the Chinese firm, while gaining its own expertise in the new market. Unlike many companies with joint ventures in China, Harley-Davidson believes it can eventually export products made by American workers into China without manufacturing there.

‘Rosie the Riveters’ Convene

The National Rosie the Riveter Association’s annual conference was held in Baltimore in June. Hundreds of “Rosies” with World War II home-front manufacturing experience attended. Lockheed Martin, which employed many women workers during the war, was the main sponsor.
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MORE of What You Need in a Stick Electrode.

MORE CONTROL—Hot start tip. Square burnoff. Excellent restrikes. Superior puddle control.

MORE PROFITABILITY—High deposition rates. Low spatter levels. Easy slag removal. Excellent tie-ins.

MORE PEACE OF MIND—Conforms to AWS, ASME, ABS, Lloyds, DNV, BV, GL & CBA/GSA.

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Be an Active Member

On a recent Sunday afternoon, my wife Leslie hosted our church's annual Ladies' Spring Tea. This event resulted in approximately 50 women and girls of all ages — 4 to 84 — coming to our home for a traditional English tea complete with scones, and cucumber sandwiches. My role was to be available to assist those needing help on the stairs, but otherwise to keep a very low profile.

I confess to being a “people watcher.” While waiting for flights in airports or sitting on the sometimes too few husband benches in shopping malls, I watch the people walk the aisles. Large people, little people (those under 10 years of age), slow moving people, and those in too much of a hurry, they help pass the time as I wait. Although somewhat different, it was much the same that Sunday afternoon. Although personally unique in many ways, the women had the common bond of not only being the same gender, but also belonging to the church community. This connection enhanced the conversations, the genuine interest shown toward each other, and their optimism regarding future events.

I found a direct correlation to my personal experiences in AWS. During my 30 plus years of membership, I have been fortunate enough to travel to many places and to meet many AWS members. I can report that the people making up the welding community are a widely diverse group, with many different interests, yet they each possess one key mutual interest: welding and joining technology. Notwithstanding the diversity of the human species, this common interest results in our membership sharing a prized character trait of being supportive and helpful toward one another.

I can speak through firsthand experience of how many AWS members have helped me to solve the numerous welding issues I have faced. Many times a phone call to a friend or an acquaintance is all I’ve needed to guide me to a technically sound resolution. Without this assistance and support, I would have spent many unnecessary hours researching potential solutions, employing a trial-and-error approach on test welds, or otherwise delaying the shipyard production trades as I sought an answer. Yes, it is possible to simply look up names in a directory and start calling people, but the success rate in getting those busy people to take the time to help a total stranger will be much less than if they were asked to help someone they know, even if they’ve only met that person one time.

Our membership includes so many talented, brilliant, knowledgeable people that, taken collectively, no welding problem can go unsolved. For many of us in the industry, this is a priceless resource we can access. Unfortunately, however, many people may not be aware of the help their fellow AWS members can provide and are missing out on this valuable benefit of membership.

How can you tap into this talent pool? Participate in your Section activities, District conferences, committee meetings, and any of the many venues listed on the AWS calendar of events. By becoming an active, participating member, you can expand your personal base of contacts and networking opportunities. Only you can limit the advantages you have by being an AWS member. Don’t short-change yourself, become a more active member today.

Lee G. Kvidahl
AWS Past President (1993–1994)
and Chair, Membership Committee
services a wide variety of industries in the ENERGY SECTORS of hydro, petro chemical, atomic, gas, oil, wind, etc. in addition to those in heavy manufacturing, steel, pulp & paper, mining, marine, forestry, etc. Hodgson’s commitment to providing customers superior products and personalized professional service has earned itself a reputation for excellence, making the name HODGSON synonymous with “paramount quality and workmanship”.

Hodgson Custom Rolling Inc. is one of North America’s largest plate rolling, forming, section rolling and fabricating companies.

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Hodgson Custom Rolling has the expertise to roll curved structural sections into a wide range of shapes and sizes (angle, wide flange beam, I-beam, channel, bar, tee section, pipe, tubing, rail, etc.). We specialize in Spiral Staircase Stringers, flanges, support beams, gear blanks, etc.

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Lincoln Electric Names New CEO

Lincoln Electric Holdings, Inc., announced in early June that John M. Stropki, Jr., had been elected president and chief executive officer, succeeding Anthony A. Massaro, who held the position for eight years. Massaro had previously announced his intention to retire and will remain as chairman. Stropki, who began work in Lincoln Electric's Cleveland factory 35 years ago while attending college, is only the seventh CEO in the company's 109-year existence.

Robot Orders Jump in First Quarter

North American-based robotics manufacturers saw robot orders jump 17% in the first quarter of 2004 over the opening quarter of 2003, the best new order rate to start the year since the record-setting year of 1999. A total of 4101 robots valued at $226.5 million were ordered by North American manufacturing companies in the opening quarter. The revenue figure is 3% higher than in the first quarter of 2003. When sales to companies outside North America are added in, the totals are 4372 robots valued at $245.8 million, for gains of 20% in units and 6% in revenue. Among the applications posting the strongest gains in the first quarter were arc welding, material handling, and spot welding.

Industrial Gas Supplier Starts Distributor Council

Praxair, Inc., has formed a distributor council to advise the company in developing business strategies that benefit the company and its distributors with long-term, sustainable growth. The new council consists of representatives from Praxair's senior management and six independent distributors selected by the company.

NASA Project Leads to Portable Alloy Analysis Technology

Collaboration between NASA and KeyMaster Technologies of Kennewick, Wash., has resulted in development of a four-pound, handheld vacuum X-ray fluorescent analyzer that performs on-the-spot chemical analyses of alloys in materials such as welding electrodes—a task previously only possible in a chemical laboratory. The capability promises to be a boon to the aerospace industry, where NASA uses the device to verify the high-strength aluminum alloys used in the Space Shuttle propulsion system. The "chemistry lab in your hand" can detect elements such as silicon that can be detrimental to welding. It can also penetrate paint to detect corrosion.

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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>
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<tr>
<td>410NiMo FC</td>
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<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>4</td>
<td>2101</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>
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<tr>
<td>904L FC</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

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Technical Standard Published for Welding Fabrics

Auburn Manufacturing, Mechanic Falls, Maine, is the first company to have its heat-resistant fabrics tested and approved to a new safety standard aimed at reducing fire risks during hot work such as welding. An insurance company, FM Global, developed the technical standard, called FM Global Approval Standard 4950, for heat-resistant fabrics used in protective blankets, pads, and industrial curtains.

Deepwater Oil Production on the Rise

In its latest report, "Deepwater Gulf of Mexico 2004: America's Expanding Frontier," the U.S. Minerals Management Service says deepwater oil production rose more than 840% and deepwater gas production increased about 1600% from 1992 to 2002. Of the 7800 active oil and gas leases in the Gulf, 54% are in deep water.

Miniature Embedded Electrodes Detect Corrosion in Real Time

Engineers at the Southwest Research Institute in San Antonio, Tex., have developed a technology for electronic embedded corrosion sensors that can be incorporated into welded materials, such as pipelines, aircraft, military equipment, and offshore structures. The electrodes are composed of material identical to the material making up the component being monitored, but are connected to each other with tiny resistors to form an electronic array. Instruments can be used to detect changes in current through the array to analyze the rate of corrosion over any period of time.

Panel Warns of Engineer Shortages

The National Science Board, a nongovernmental body that advises the president and Congress on scientific and engineering matters, warns that the country's preeminence in science and technology is in jeopardy because the country is facing a shortage of scientists and engineers. American students are losing interest in the sciences, the study states, and the United States can no longer rely on foreigners to fill the gap, due to various restrictions on guest workers, and international competition for their skills.

Steel Price Fluctuations Lead to New Index

Dow Jones Newswires has launched the first transactions-based, U.S. steel-price indexes: the Dow Jones Monthly Hot Rolled Coil and Cold Rolled Coil Indexes. The two indexes will be published on the fifth business day of every month, reflecting prices for steel obtained through spot trades or contracts, and shipped during the previous month. The launch of the indexes comes at a time of heightened volatility in world steel prices.
amidst a growing interest among steel producers and consumers in financial instruments capable of reducing exposure to price swings.

Engineers Held in High Esteem

In a survey conducted on behalf of the American Association of Engineering Societies, engineering received a higher rating from adults as a career choice for their children than either accounting or the ministry. When asked to use a scale of one through ten to represent extremely displeased to extremely pleased if their child were to enter a particular profession, engineering and science both received a nine. The survey found that the average American is personally acquainted with six engineers, but only a third of those polled felt well informed about engineering, and only 40% were interested in learning more.

LNG Terminal Project Gets EPA Approval

The U.S. Environmental Protection Agency (EPA) has issued permits for the construction by ChevronTexaco of a deepwater LNG terminal 37 miles off the coast of Louisiana. The offshore location helps ease fears of safety impacts from terror attacks. There are presently only four active LNG terminals in the United States, and analysts say these cannot meet future demand for natural gas. But communities have resisted new onshore LNG projects, because sabotage could prove catastrophic to a wide geographic area.

Organization Calls for Plan on Auto Production

The chairman of the National Association of Manufacturers called on the U.S. auto industry to adopt an “action plan” to meet the challenges posed by unprecedented global competition. Richard E. Dauch said external overhead costs associated with taxes, regulations, rising energy prices, health care, pensions, and runaway litigation conservatively add 22.4% to the price of domestic production, creating what he called “an uneven playing field.”

Texas Welding Businesswoman Receives Recognition

Tracy Delce, a black woman who took over management of her brother’s Tin Man Welding shop a few years ago, has grown the firm dramatically and received the annual Entrepreneur Award from the mayor of Ft. Worth, Tex. By getting help from the Small Business Administration, and concentrating on public works projects, the firm doubled its business in its first year, 2002, and has continued to rocket in growth since.

Student’s Robot Does Paper-Folding Art

Devin Balkcom, a student at Carnegie Mellon University, was looking for a challenge when he decided to develop the world’s...
first origami-folding robot as the subject of his doctoral thesis. The robot uses a tiny suction cup attached to the arm to pick up a piece of paper, rotate it, and place it over a narrow gutter in a worktable. Then a ruler descends and presses the paper into the gutter to create a crease. The robot can make paper hats and airplanes. “Once you build a robot that can duplicate human tasks,” said Balkom, “you can learn more about human skills that we often take for granted.”

College Changes Designation of Welding Curriculum

LeTourneau University, Longview, Tex., has renamed its welding degree concentrations to “Materials Joining” to reflect increased emphasis on joining of polymers, ceramics, and composites. The school expects that over five years, its emphasis on metals and welding vs. nonmetals and joining will change from a 90/10 mix to a 70/30 mix.

Study Says Worker Shortage a Bigger Threat to Manufacturing than Outsourcing

The Detroit Regional Chamber, a southeastern Michigan business organization, has released a study on offshore outsourcing and its impact on job loss in the state. The study found that only 12% of lost jobs were due to job displacement from imports and outsourcing, and that increased manufacturing productivity is having a much greater impact. The report warns that a substantial worker shortage in the state ultimately poses the greatest threat to the future of manufacturing competitiveness.
Welding Supply Shops See Jump in Lens Sales from Solar Event

Stargazers who wanted to witness the transit of the planet Venus over the face of the sun flooded some welding supply shops in early June to purchase safety lenses. Suppliers around the country ran short of No. 14 lens plates, a heavier grade than most welders use. Shops have time to stock up before the next transit of Venus in the year 2012.

Lincoln's Sponsored Car Wins at Indy

Buddy Rice raced an IndyCar, partly sponsored by Lincoln Electric, to victory in the Indianapolis 500 on Memorial Day. The welding equipment manufacturer has been involved with the winning Rahal Letterman Racing team, co-owned by “Late Night” host David Letterman, for seven years as an equipment sponsor. This was the team’s first victory.

Welding Companies Team Up to Help Hospital Ship

The Caribbean Mercy, one of the fleet of three Mercy ships that provide health care and disaster relief to some of the world’s neediest people, was in drydock in Mobile, Ala., recently, when employees of Welding Equipment Supply Co. (WESCO), Pritchard, Ala., learned that the ship needed work on its operating room. The company contacted its colleagues at Air Products, Thermadyne, A-Welders & Medical Supply, and Western Enterprise, who all joined WESCO in donating products and labor to install and test an oxygen piping system. By working long hours, the project was finished in 3½ days, in time for the ship’s departure for a mercy mission to Honduras.

China’s Central Bank Warns that Its Metals Industries Are ‘Overheated’

The People’s Bank of China has published a monetary policy report warning that the country’s steel and aluminum industries have been receiving too much investment. China is the world’s largest manufacturer of steel and currently consumes more steel than it produces. However, its steel production capacity will exceed demand by the end of 2005, the central bank predicts, leading to overcapacity. The report also predicts that China’s aluminum manufacturing capacity will exceed its domestic demand by 50% by the end of 2005.

Industry Notes

- The National Equipment Museum in Bowling Green, Ohio, has broken ground on a library for the collection of manuals, photographs, and other archives relating to antique construction equipment dating back to the early 1800s.
- This month, the American Film Institute will hold a workshop for engineers on how to write screenplays for TV and movies. The workshop is funded by the U.S. Air Force.
- The National Park Service is developing a “Rosie the Riveter National Historical Park” in Richmond, Calif., and is seeking
A long day welding
300° pre-heated steel

The same job in a
ClimaTech Cooling Vest

Whether it’s the HeatShield™, with its synthetic ice core, or the AirVest™ that turns compressed air into your personal AC, ClimaTech’s patented cooling technology will change the way you work. And play. It’s like night and day. Or better yet, hot and cold. Leave work with energy to burn. Ask your favorite distributor, call 800-266-5440 or visit www.climatechsafety.com.

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International Briefs

- Boosted by manufacturing, Mexico’s economy expanded during the first quarter at its fastest rate (3.7%) in three years, the country’s finance ministry said.
- The Russian economic ministry reports that the country’s GDP will have grown 7.5% in the first half of 2004. Russia is running a foreign trade surplus.
- A company in Vietnam is the first there to produce flux cored welding wire. It has a contract to supply $10 million worth of welding wire to the British Welding Alloys Group.
- According to a study by Deloitte Research, U.S. manufacturing firms have cut overseas investment for the third year in a row. The study warns that by outsourcing to foreign firms rather than owning their own foreign manufacturing capacity, U.S. firms may be paying to create their own future competitors. Direct foreign investment by U.S. manufacturers in 2003 was 32% less than in 2000.
Q: I have to weld a 410 clevis to the end of a 316L rod. Several hundred such weldments are to be made. The rod is actually a 3-in.-diameter pipe with ½-in. wall thickness. The clevis is essentially an end cap for the pipe. It was purchased already hardened and tempered to 30 Rockwell C to provide wear resistance against the clevis pin. The joint is to be full penetration and will be subject to fatigue loading and possibly impact, so I feel I need to perform a postweld heat treatment (PWHT) to temper the HAZ of the 410. In the September 2000 Stainless Q&A column about welding 410 to 304L, filler metal Alloys 312, 309L, and 308L were all considered to be suitable for that joint, But nothing was said about PWHT. There will be 316L filler metal on the jobsite for other joints involving the 316L parts of the assembly. Assuming that 312, 309L, and 308L would be suitable filler metals, would 316L also be a suitable filler metal? And what PWHT can I use without damaging the hardness of the 410 clevis?

BY DAMIAN J. KOTECKI

Table 1 — Typical Compositions for 316L and 410 Base Metals and 316L Filler Metal, with Predicted FN from the WRC-1992 Diagram

<table>
<thead>
<tr>
<th>Component</th>
<th>C (%)</th>
<th>Mn (%)</th>
<th>Si (%)</th>
<th>Cr (%)</th>
<th>Ni (%)</th>
<th>Mo (%)</th>
<th>Cu (%)</th>
<th>N (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASTM A240 Type 316L</td>
<td>0.03*</td>
<td>2.0*</td>
<td>1.0*</td>
<td>16.0-18.0</td>
<td>10.0-14.0</td>
<td>2.0-3.0</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Typical 316L</td>
<td>0.02</td>
<td>1.5</td>
<td>0.4</td>
<td>17.0</td>
<td>12.0</td>
<td>2.2</td>
<td>0.2</td>
<td>0.03</td>
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<tr>
<td>ASTM A240 Type 410</td>
<td>0.15*</td>
<td>1.0*</td>
<td>1.0*</td>
<td>11.5-13.5</td>
<td>—</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Typical Type 410</td>
<td>0.11</td>
<td>0.5</td>
<td>0.4</td>
<td>12.5</td>
<td>0.1</td>
<td>0.05</td>
<td>0.05</td>
<td>0.01</td>
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<tr>
<td>AWS A5.4 E316L-XX</td>
<td>0.04*</td>
<td>0.5-2.5</td>
<td>0.9*</td>
<td>17.0-20.0</td>
<td>11.0-14.0</td>
<td>2.0-3.0</td>
<td>0.75*</td>
<td>—</td>
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<tr>
<td>Typical E316L-XX</td>
<td>0.03</td>
<td>1.5</td>
<td>0.4</td>
<td>19.0</td>
<td>12.0</td>
<td>2.2</td>
<td>0.2</td>
<td>0.06</td>
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<tr>
<td>AWS A5.9 ER316L</td>
<td>0.03*</td>
<td>1.0-2.5</td>
<td>0.30-0.65</td>
<td>18.0-20.0</td>
<td>11.0-14.0</td>
<td>2.0-3.0</td>
<td>0.75*</td>
<td>—</td>
</tr>
<tr>
<td>Typical ER316L</td>
<td>0.02</td>
<td>1.5</td>
<td>0.4</td>
<td>19.0</td>
<td>12.0</td>
<td>2.2</td>
<td>0.2</td>
<td>0.06</td>
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<td>AWS A5.22 E316LTX-X</td>
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<td>0.5-2.5</td>
<td>1.0*</td>
<td>17.0-20.0</td>
<td>11.0-14.0</td>
<td>2.0-3.0</td>
<td>0.75*</td>
<td>—</td>
</tr>
<tr>
<td>Typical E316LTX-X</td>
<td>0.02</td>
<td>1.5</td>
<td>0.4</td>
<td>19.0</td>
<td>12.0</td>
<td>2.2</td>
<td>0.2</td>
<td>0.06</td>
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</table>

* Maximum permitted by the specification

Table 2 — Calculated Chromium and Nickel Equivalents and Predicted FN for the Root Pass of 316L and 410 Base Metals Welded with E316L-XX SMAW Electrodes

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<tbody>
<tr>
<td>316L base metal</td>
<td>19.2</td>
<td>13.3</td>
<td>2.1</td>
</tr>
<tr>
<td>410 base metal</td>
<td>12.55</td>
<td>4.15</td>
<td>not applicable</td>
</tr>
<tr>
<td>Equal mix of base metals</td>
<td>15.88</td>
<td>8.73</td>
<td>not applicable</td>
</tr>
<tr>
<td>E316L-XX filler metal</td>
<td>21.2</td>
<td>14.25</td>
<td>6.0</td>
</tr>
<tr>
<td>Root pass</td>
<td>19.6</td>
<td>12.39</td>
<td>5.2</td>
</tr>
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A: I agree that PWHT seems prudent for the sake of tempering the HAZ of the 410. There is a concern about whether there will be a little ferrite in the root pass. If there is ferrite in the root pass, subsequent passes should also contain ferrite and be crack resistant. However, when PWHT comes into the picture, there is a new consideration — the possibility of forming sigma phase in the weld metal. Let’s work backward from the PWHT to the weld metal analysis, and then consider sigma phase.

Hardness of 30 Rockwell C indicates, from the tempering curves for 410 given in the ASM Heat Treater’s Guide, that tempering was accomplished at about 1050°F (565°C). Any PWHT you might perform, so long as it is at no higher temperature than the original tempering temperature, will not appreciably soften the 410. However, it will soften the HAZ of the 410, which could be as hard as 45 Rockwell C in the as-welded condition. The Heat Treater’s Guide recommends avoiding tempering in the range of 700°F to 1050°F (370 ° to 565°C) for parts requiring high toughness. Tempering in the range of 1050°F to 1125°F (565 ° to 605°C) is indicated for achieving 25 to 31 Rockwell C. Of course, the lower hardness would be achieved at the higher tempering temperature. So I would suggest that your PWHT be done at the low end of this latter temperature range — about 1050°F.

Since you would prefer to use 316L filler metal for your joint, the next thing to consider is whether 316L filler metal will provide some ferrite in the diluted root pass between 316L base metal and 410 base metal, so you won’t need to worry about solidification cracking.

Table 1 provides typical compositions for 410 and 316L base metals, and for 316L.
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<td>Welders Supply of Erie</td>
<td>PA</td>
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filler metals, so that prediction of root pass weld microstructure can be made using the WRC-1992 Diagram.

The 316L base metal is typically designed by the steel mill to solidify as primary ferrite, but, due to cost considerations, is generally relatively lean in composition. Since you didn't state which welding process you plan to use, Table 1 covers filler metals for all of the major welding processes. You will note that the filler metals tend to be richer in chromium content than the 316L base metal, so they tend to have higher ferrite content than the potential ferrite of the base metal.

You will also note that the typical compositions of the various forms of 316L filler metal are similar, even though there are differences in specific alloy limits for the different product forms. As a result, the various processes produce similar ferrite contents in the undiluted weld metal. So it is adequate to conduct the ferrite prediction using the SMAW E316L-XX composition, which generally tends to produce the lowest FN due to slightly higher carbon content than the other filler metals.

Table 2 lists the calculated chromium and nickel equivalents for the two base metals, the undiluted E316L-XX filler metal, and the typical 30% dilution root pass joining the two base metals. In calculating the root pass composition, the assumption is made that each base metal contributes equally to the dilution, i.e., 15% of the root pass composition comes from each base metal.

Figure 1 presents the ferrite prediction graphically. The synthetic base metal, composed of 50% 316L and 50% 410 lies at Point B on the diagram. The predicted weld metal composition, Point W at 5.1 FN, lies in the region of compositions that solidify as primary ferrite. Furthermore, if the dilution were to be significantly increased by using submerged arc welding, Fig. 1 indicates that more than 50% dilution would still provide about 4 FN and primary ferrite solidification. And even at higher dilution, the predicted root pass weld metal composition would lie in the region of primary ferrite solidification. Further, the root pass composition lies comfortably above the martensite boundary, so weld metal cold cracking will not be an issue. Of course, a preheat of about 300°F (150°C) is advisable to avoid cold cracking in the HAZ of the 410.

The last concern is the possibility of sigma phase transformation in the ferrite of the weld metal during PWHT at 1050°F (565°C). Experimental data for formation of sigma phase in 316L weld metal are shown in Welding Metallurgy of Stainless Steels by Erich Folkhard (published by Springer-Verlag). These data indicate that sigma phase formation is quite slow at 1050°F, showing little effect after ten hours at 600°C (1110°F). Even if it did form, there is not enough ferrite to transform to sigma to produce any significant embrittlement. So no difficulty with sigma phase is anticipated.

Accordingly, 316L filler metal is considered to be a quite satisfactory selection for your application.
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Airgas – Terry Jarvis Memorial Scholarship

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"It is a great honor to receive the Edward J. Brady Memorial Scholarship. I am very grateful to the American Welding Society and the Edward J. Brady Scholarship Committee for their dedication. I would like to recognize my parents and Professor Andrew Burke. Thank you to everyone."

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"It is an honor to be eligible for an AWS National scholarship, and even more of an honor to receive this scholarship. This scholarship will allow me to become more fully engrossed in my studies without having to worry about how my education will be paid for. It is not only an investment in me but an investment in the joining sciences."

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"I thank the AWS Foundation for the chance to continue my education. I work at Welding Engineering Supply Company, where I have been employed for the past five years. I am blessed to be involved with the welding industry, which offers so many opportunities to young people with the help and support of the American Welding Society."
Arc-Zone.com Available through Canadian Site

Arc-Zone.com (www.arc-zone.com) has contracted with Arczone.com of Canada (www.arczone.com) to share its front page. The move was made because the company’s customers often left out the hyphen when typing the Web address and ended up at a Web site in Canada, said Arc-Zone.com president Jim Watson.

Terry Trainor, the company’s director of Internet Services, worked out arrangements to share the front page with the Canadians, who weren’t actually using it at that time. Trainor designed a page that includes the Arc-Zone.com logo alongside the contact information for the Canadian company; therefore, customers who leave out the hyphen will still be able to locate the company’s gas metal arc, gas tungsten arc, and plasma arc welding and cutting products.

PMA Introduces Advocacy Web Site

The Precision Metalforming Association (PMA) recently developed a Web site dedicated to government advocacy in an effort to make it convenient for manufacturers to become involved with the association’s grassroots efforts. The site, www.metalformingadvocacy.com, allows visitors to follow current legislation that impacts the metalforming industry and send e-mails to members of Congress, the White House, and major executive departments, as well as view voting records for members of Congress.

The Precision Metalforming Association is the trade organization that represents the industry that creates precision metal products using stamping, fabricating, and other processes. It represents nearly 1300 member companies.

The site includes news items relevant to the industry, information about candidates in the 2004 elections, and allows users to register to vote. It also provides a media library in which metalformers can search for media outlets. Results will contain contact information for each media outlet, including lists of staff members, their positions, and e-mail addresses.

Downloadable Videos Show Water Jet Cutting Tools in Action

NLB Corp. If you’ve never seen a water jet cutting system in operation, you now can through this Web site. A five-minute aluminum cutting video is among the application videos that can be downloaded. The site also features an extensive “Applications” section that describes the most common uses of water jetting, offers product information, and provides downloadable application literature.

In addition, visitors interested in water jet pumps can scroll through diesel, electric, or convertible units. They can also enter their own specifications to see which unit best matches their needs and request a quotation. The site also provides information about renting the company’s equipment, as well as descriptions and specifications for hundreds of accessories. A credit application is also included.

Materials Handling Products Highlighted

FKI Logistex® White Systems. This site details the company’s automated material storage and retrieval systems. The company recently redesigned the site for easier navigation and to give visitors quick access to information. A menu system on the left side of every page guides visitors to where they want to go.

Besides a large amount of product information, the site includes an extensive library of videos that show the systems in action and details regarding customer service. High- and low-resolution versions of company literature can be downloaded. Also, a set of case studies is shown that can be searched by company, industry, or product.

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This latest edition of Dr. Kou’s textbook was obviously written as a supplement to a lecture course for his students in welding technology. Kou is a respected professor and chair of the Department of Materials Science and Engineering at the University of Wisconsin. This is a well-organized volume for basic instruction for students who are pursuing training that leads to a professional career in welding technology. In the preface, the author describes how this new edition revises his initial work published in 1987, and incorporates new understanding from recent research and greatly improved graphics.

The table of contents is well arranged into four major sections, each divided into logical chapters. The first, titled “Introduction,” consists of five chapters on the fundamentals of welding, the fusion processes (primarily arc welding), heat flow, chemical reactions, fluid flow in both the vapor and molten regions, and the mechanical stresses resulting from the heating and cooling effects of the joining processes. The author then proceeds to describe in six chapters of Part II, called “The Fusion Zone,” by reference to thermodynamic phase diagrams and micro and macro photos, the various morphologies found as welds solidify and subsequent microstructural changes during solid phase transformation. This section then describes sources of alloy segregation and various inhomogeneities encountered, including alloy segregation often associated with defects such as cracking or porosity. In a fascinating Part III, Kou describes the complicated structures found in what is termed “The Partially Melted Zone,” the region between the fusion and the unfused workpiece. Finally, Part IV deals with “The Heat-Affected Zone,” where the thermal effects of the welding process alter the microstructure of the workpiece, often with some sacrifice to the mechanical or other properties of the welded joint. For alloys where some of the problems are more frequently encountered, entire chapters are devoted to aluminum alloys, nickel-based alloys, low-alloy steels, and stainless steels.

Throughout the book many illustrations are provided, including schematic sketches, phase diagrams, and macro- and microstructures, allowing one to imagine attending the author’s lectures. Moreover, one cannot avoid the student’s possible dread for examinations of the course, as at the end of each chapter are listed problems to solve with no hints as to the answers, except by a more careful review of the principles. These make valuable class discussion topics, not only for college-level students, but in any postprofessional training seminars. Each chapter also provides a list of references cited, as well as a selected list, marked “Further Reading.”

In less than 500 pages, Kou has compressed knowledge found in the multivolume AWS Welding Handbook, and Volume 6 on welding in the ASM Handbook, and even the almost 1000-page classic AWS Fourth Edition of George E. Linnert’s Welding Metallurgy. Of even greater importance, he has incorporated references to recent sophisticated research in current problem areas; this makes it a valuable addition to any professional in welding technology. One should emphasize that this book is for a professional or would-be professional, for it deals with mathematical models and physical chemical concepts that might discourage those who may lack basic training in this field of engineering.

The index allows the reader to seek the sections that specifically address topics of interest. I turned to the topic “submerged arc welding,” and was directed to Chapter 1, where the welding processes were described, and to a figure illustrating the grain structure with and without the titanium carbide inoculation of a submerged arc weld. I was disappointed not to have found references to pages 83 to 92 where flux basicity is covered. I suggest that these valuable pages would not have been overlooked if the index searches had included the abbreviation SAW as well as submerged arc welding.

While on the subject of indexing, if I were an instructor in a welding course and were making use of this textbook, I would love to be referred by way of the index to the “Problems” that deal with specific subjects. For example, if I were to search the index for the valuable list of questions relating to stainless steels, I would have been directed to page 432 containing Table 18.1 giving references to several sections of the book where specific problems are detailed. However, none would have directed me to stainless steel questions that occur frequently at the end of many chapters, not only to the end of Chapter 18 on stainless steel. If Kou undertakes another revision, my suggestion for the index would include searching for the topics among the end of each chapter’s problems. As I mentioned before, I found these questions and problems one of its more important features, one not found in most reference volumes.

R. DAVID THOMAS, JR., is a Fellow of the American Welding Society, Miami, Fla.
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Miller Fall Protection
1345 15 St., Franklin, PA 16323

--- continued on page 91 ---
Welding in the Defense Industry
breakthrough welding information from
leading defense industry experts
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Leading defense industry experts to share results on overcoming weldability obstacles of aluminum, titanium, and stainless steels on an array of applications.

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To review the program and presenters, go to www.aws.org/conferences/defense.

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AWS D1.1 Code Week
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The AWS D1.1 Code Week is designed to provide an in-depth look at AWS D1.1/D1.1M: 2004, Structural Welding Code — Steel.

• Day 1 — D1.1 Road Map
• Day 2 — Design of Welded Connections
• Day 3 — Qualifications
• Day 4 — Fabrication
• Day 5 — Inspection

Register for the full week and receive your complimentary copy of AWS D1.1/D1.1M: 2004, Structural Welding Code — Steel. For more information, contact the AWS Conferences and Seminars Business Unit at (800) 443-9353 ext. 223, or visit our Web site at www.aws.org/w/s/conferences/d1.
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The many customers who have depended on Select-Arc's quality electrode products, superior service and most value-added can now enjoy the substantial benefits of specifying Select-Arc hardsurfacing electrodes. For more information on selecting Select Wear electrodes, call Jeff at 1-800-341-5215 or visit our website at www.select-arc.com.

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Friends and Colleagues:

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

For specifics on the nomination requirements, please contact Wendy Sue Reeve, at AWS headquarters in Miami, or simply follow the instructions on the Fellows nomination form in this issue of the *Welding Journal*. Please remember, we all benefit in the honoring of those who have made major contributions to our chosen profession and livelihood. The deadline for submission is February 1, 2005. The Committee looks forward to receiving numerous Fellow nominations for 2006 consideration.

Sincerely,

Dr. Alexander Lesnewich
Chairman, AWS Fellows Selection Committee
CLASS OF 2006
FELLOW NOMINATION FORM

DATE __________________________ NAME OF CANDIDATE __________________________

AWS MEMBER NO. __________________________ YEARS OF AWS MEMBERSHIP __________________________

HOME ADDRESS __________________________ __________________________ __________________________

CITY __________________________ STATE __________________________ ZIP CODE __________________________ PHONE __________________________

PRESENT COMPANY/INSTITUTION AFFILIATION __________________________ __________________________ __________________________

TITLE/POSITION __________________________ __________________________ __________________________

BUSINESS ADDRESS __________________________ __________________________ __________________________

CITY __________________________ STATE __________________________ ZIP CODE __________________________ PHONE __________________________

ACADEMIC BACKGROUND, AS APPLICABLE:

INSTITUTION __________________________ __________________________ __________________________

MAJOR & MINOR __________________________ __________________________ __________________________

DEGREES OR CERTIFICATES/YEAR __________________________ __________________________ __________________________

LICENSED PROFESSIONAL ENGINEER: YES __ NO __ STATE __________________________ __________________________

SIGNIFICANT WORK EXPERIENCE:

COMPANY/CITY/STATE __________________________ __________________________

POSITION __________________________ YEARS __________________________

COMPANY/CITY/STATE __________________________ __________________________

POSITION __________________________ YEARS __________________________

SUMMARIZE MAJOR CONTRIBUTIONS IN THESE POSITIONS: __________________________ __________________________ __________________________

_______________________________ ____________________________

SUGGESTED CITATION (50 TO 100 WORDS, USE SEPARATE SHEET) INDICATING WHY THE NOMINEE SHOULD BE SELECTED AS AN AWS FELLOW. IF NOMINEE IS SELECTED, THIS STATEMENT MAY BE INCORPORATED WITHIN THE CITATION CERTIFICATE.

SEE GUIDELINES ON REVERSE SIDE

SUBMITTED BY: PROPOSER __________________________ AWS Member No. __________________________

Print Name __________________________

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

NOMINATING MEMBER: __________________________ NOMINATING MEMBER: __________________________

Print Name __________________________ Print Name __________________________

AWS Member No. __________________________ AWS Member No. __________________________

NOMINATING MEMBER: __________________________ NOMINATING MEMBER: __________________________

Print Name __________________________ Print Name __________________________

AWS Member No. __________________________ AWS Member No. __________________________

SUBMISSION DEADLINE FEBRUARY 1, 2005
Fellow Description

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

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

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

NUMBER OF FELLOWS
Maximum of 10 Fellows selected each year.

AWS Fellow Application Guidelines

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

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

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

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

Return completed Fellow nomination package to:
Wendy S. Reeve
American Welding Society
550 N.W. LeJeune Road
Miami, FL 33126

Telephone: 800-443-9353, extension 293

SUBMISSION DEADLINE: February 1, 2005
Exhibiting at the AWS Welding Show 2005 is the most cost-effective way to gain broad exposure in a short time. As an AWS exhibitor, you will have the opportunity to meet those buyers who need your products. The AWS Welding Show has more to offer than any other show in the metal-fabricating and construction industries.

**Big benefits for exhibitors before, during, and after the Show.**

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- Use of the AWS Press Room.
- Discounts on freight, car rentals, and room rates, as well as free shuttle buses from AWS-sponsored hotels to the Show.

- On-site staff to assist you during the Show and to help provide a hassle-free exit at the end.
- AWS website, which is used as a year-round tool by manufacturers, distributors and end-users looking for products and services.
- A targeted demographic attendee list will be available from Show management.
- Our marketing staff will be available for consultation on lead follow-up and tracking.

To participate in any of the pavilions or for more information, please contact our Welding Show Exhibit Sales office at: 1-800-443-9353, ext. 295 or 242.

**Seven exciting Special Pavilions give attendees new reasons to come to the Show:**

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- Cutting and Grinding Products
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- Resistance Welding
- Laser Welding and Cutting
- Nondestructive Testing and Inspection
The use of P91 (9Cr-1Mo-V) chromium-molybdenum steel pipe has continued to increase since its introduction into power plant construction. With conventional single-V-groove pipe welds, the root bead for P91 material is deposited with the gas tungsten arc welding (GTAW) process with an inert gas purge (e.g., argon) in the pipe to prevent contamination of the root bead (i.e., formation of oxides or "sugaring"), improve wetting, and augment general bead appearance. The purging process can be extremely expensive and labor intensive for field-fabricated pipe since a minimum of five to six volume changes of gas are typically required to reduce the oxygen content inside the pipe to an acceptable level (usually 2% or less oxygen). A variety of techniques (e.g., soluble dams, collapsible disc dams, inflatable bladder dams, etc.) provide a reduction in the purge volume, which in turn, decreases the required volume of gas, resulting in reduced costs. However, in many instances, these techniques are not viable options, thus necessitating a purge of the entire piping system.

Fluor Corporation recently qualified and successfully completed the first production welds in North America using Böhler Thyssen's newly developed Thyssen Chromo T 91 E9018-B9-H4 electrode with the shielded metal arc welding (SMAW) process. According to the manufacturer, this low-hydrogen electrode was developed for uphill welding using either alternating current (AC) or direct current (DC), direct current electrode negative (DCEP) or direct current electrode positive (DCEP) polarity, and for depositing root beads using DC with excellent weldability.

Decision

Samples of the electrodes in \( \frac{3}{32} \) in. (2.4 mm) and \( \frac{1}{8} \) in. (3.2 mm) diameter were obtained and subsequently implemented in the welding of sample welds. The decision to proceed to procedural qualification was determined by the following criteria: visual appearance of the root bead’s interior surface, the short training time required, weldability, and the elimination of purge gas.

Procedure Qualification Data

Two pieces of SA-335:Grade P91, UNS Number K91560, ASME Section IX, P-Number 5B, Group 2, Schedule 80 (0.594-
in. (15.1-mm) wall thickness), 10 in. (254 mm) diameter were combined to form the test coupon. The specified weld parameters are presented in Table 1.

Weld joint fitup (i.e., root opening and internal alignment) was maintained by tack welding three carbon-steel flat bars equally spaced around the circumference of the pipe (Fig. 1), thus eliminating the need to place tack welds into the weld groove and avoiding potential defects associated with tie-ins at the tacks. Localized areas were preheated to 430°F (221°C) using a rose bud prior to welding the flat bars into place.

Following the welding of the flat bars and verification of the correct fitup and alignment, the complete weld joint was preheated and maintained at a minimum of 430°F (221°C) utilizing Miller's Induction Heating System. The completed root bead, after grinding, is shown in Fig. 2 with blankets and induction heating coil in place and the flat bars removed.

Metallurgical Testing for Procedure Qualification

The completed weld was transported to an independent metallurgical laboratory for testing in accordance with ASME Section IX and B31.1, along with additional requirements specified by Fluor. The performed tests and their corresponding results are listed in Table 2.

Welder Training and Qualification

Welder training was initiated using a ¾-in. (9.5-mm) thick plate possessing a 30-deg bevel angle, ½-in. (3.2-mm) root face, ½-in. (2.4-mm) (loose) root opening positioned at a 45-deg angle, ½-in. electrodes, and 75 A current — Fig. 3.

Once the welder demonstrated proficiency at welding the plate in the 45-deg angle position, the plate was replaced with a 6-in. (152-mm) diameter schedule 160 pipe coupon. The joint fitup tolerances and parameters previously noted were maintained during the remainder of the training. An additional six to eight hours of training using pipe coupons were typically required before the welder obtained proficiency to proceed to the welder qualification test. The qualification tests were performed on identical pipe coupons, joint tolerances, and parameters as used in training. All qualification tests successfully passed both a root and final visual inspection as well as a radiographic examination in accordance with ASME Section IX. In order to support the project's schedule, a total of six welders were trained and qualified as noted above.

Production Welding

On a cold February morning with the temperatures hovering in the single digits and a brisk wind blowing, preparations were quickly underway to fit up the first production P91 weld joint to be welded in North America with an electrode specifically designed for shielded metal arc root bead welding. The weld joint selected was a 12-in. (305-mm) diameter pipe welded...
Table 2 — Metallurgical Tests

<table>
<thead>
<tr>
<th>Dimensions (in.)</th>
<th>Area (in²)</th>
<th>GL (in.)</th>
<th>0.20%YS (psi)</th>
<th>UTS (psi)</th>
<th>%E1</th>
<th>Fracture Location/Type</th>
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<tbody>
<tr>
<td>0.7590 x 0.5500</td>
<td>0.4175</td>
<td>2.00</td>
<td>64,000</td>
<td>90,000</td>
<td>26.5</td>
<td>Weld/Ductile</td>
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<tr>
<td>(19.3 x 14 mm)</td>
<td>(26.9 x 14 mm)</td>
<td>(50.8 mm)</td>
<td>(441 MPa)</td>
<td>(626 MPa)</td>
<td></td>
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</tr>
<tr>
<td>0.7510 x 0.5520</td>
<td>0.4146</td>
<td>2.00</td>
<td>69,900</td>
<td>97,400</td>
<td>29.0</td>
<td>Base/Ductile</td>
</tr>
<tr>
<td>(19.1 x 14 mm)</td>
<td>(26.7 x 14 mm)</td>
<td>(50.8 mm)</td>
<td>(482 MPa)</td>
<td>(672 MPa)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Side Bends

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<tr>
<th>Dimensions (in.)</th>
<th>Bend Angle (deg)</th>
<th>Former Diameter (in.)</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>180</td>
<td>1.5 (38.1 mm)</td>
<td>Acceptable</td>
</tr>
</tbody>
</table>

Root Bends

<table>
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<tr>
<th>Dimensions (in.)</th>
<th>Bend Angle (deg)</th>
<th>Former Diameter (in.)</th>
<th>Results</th>
</tr>
</thead>
<tbody>
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<td>2</td>
<td>180</td>
<td>1.5 (38.1 mm)</td>
<td>Acceptable</td>
</tr>
</tbody>
</table>

Location

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<tr>
<th>Dimensions (mm)</th>
<th>Test Temp. (°F)</th>
<th>Energy Absorbed (ft lb)</th>
<th>% Shear</th>
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</thead>
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<tr>
<td>Weld</td>
<td>68 (20°C)</td>
<td>80 (109 J)</td>
<td>75</td>
</tr>
<tr>
<td>Weld</td>
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<td>72 (98 J)</td>
<td>70</td>
</tr>
<tr>
<td>Weld</td>
<td>68 (20°C)</td>
<td>54 (73 J)</td>
<td>60</td>
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<td>HAZ</td>
<td>68 (20°C)</td>
<td>101 (137 J)</td>
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<td>176 (239 J)</td>
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</tr>
<tr>
<td>HAZ</td>
<td>68 (20°C)</td>
<td>121 (164 J)</td>
<td>100</td>
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</tbody>
</table>

Charpy Test per ASTM E 23

<table>
<thead>
<tr>
<th>Number of Traverses</th>
<th>Maximum Hardness</th>
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</thead>
<tbody>
<tr>
<td>9</td>
<td>238</td>
</tr>
</tbody>
</table>

Hardness Survey per ASTM E 384

Vickers Microhardness Survey

Method Load (kg-f) Depth (in.) Number of Traverses Maximum Hardness

![Fig. 4](image1.png) — Fitup and alignment were maintained by using a section of P91 pipe with a carbon-steel handle.

![Fig. 5](image2.png) — Chris Pucci deposits the first SMAW P91 root bead in North America.

Chris Pucci is shown in Fig. 5 depositing the root bead with techniques and skills acquired through the training described herein. The root bead was deposited in opposite quarter sections with each start and stop ground to a taper to assist in a complete tie-in and smooth bead transition into the next section. A
technique was employed that allowed the amperage to be increased by approximately 10 A via a remote control, thus further augmenting successful tie-ins and transitions. This was accomplished by visually monitoring the progression of the root bead during welding through the root opening and subsequent “window” (short section of root bead approximately 2 in. [51 mm] long that was not welded), allowing the amperage to be increased at the appropriate time. Immediately following the tie-in location, the amperage was returned to the original setting. Following the deposition of the root bead, except for the window, the welder changed to an E9015-B9 electrode and deposited the second bead (hot pass). The ends of this bead were cascaded approximately ½ in. (19 mm) from the ends of the root bead on each side of the window. Visual examination through the window revealed that the heat from the hot pass resulted in approximately 95% of the slag on the interior of the root pass being detached. Following the visual examination, the welder changed electrodes and completed the remainder of the root bead using the techniques previously noted. Once the root bead was completed, the welder again changed electrodes and completed the “hot pass” and the remainder of the weld.

A total of 28 large-bore P91 welds with an average pipe diameter of 18 in. and an average wall thickness of 1.781 in. (45.2 mm) using Thyssen Chromo T 91 E9018-B9-H4 electrodes for the root bead followed by E9015-B9 filler metal were completed at the project. Each weld was radiographed in accordance with ASME/ANSI B31.1, which resulted in one weld being rejected for a root bead discontinuity (incomplete joint penetration at a window closure tie-in). A respectable project weld reject rate of 3% for field production welding using this welding technique was duly noted.

Cost Savings

Cost savings are difficult to approximate in field applications due to the project environment and the uniqueness of each weld. However, cost savings directly related to the 28 welds, after deducting costs associated with training and qualifications, were estimated at $56,560. The largest single cost savings was the elimination of work hours required to clean and install the purge dams inside the pipe. Other significant cost savings included the elimination of work hours waiting for the oxygen content of the purge to reach 2% as required by specification, cost of argon for both shielding and purge gas, and elimination of the time-consuming gas tungsten arc welding process.

Conclusion

Böhler Thyssen’s newly developed Thyssen Chromo T 91 E9018-B9-H14 electrode with the SMAW process has demonstrated that it is a viable option for welding radiograph-quality root heads in P91 during initial construction. This combination certainly has a future in operations and maintenance applications as well.

Acknowledgments

The authors gratefully acknowledge Böhler Thyssen for donating the filler metal for trial and PQR development, and Russell Fuchs, senior technical manager and welding engineer for Böhler Thyssen Welding USA, Inc., for his technical support. The authors thank Miller Electric Mfg. Co. for providing the Induction Heating System, and Gerald Miller, account manager for Miller Electric, for his technical support.
Weld Metal Properties of Reeled Pipelines

Construction method of offshore pipelines determines the characteristics of the welded joints

BY J. R. STILL

Methods for laying pipe offshore involve conventional lay barges, reel ships, and towing of pipe bundles. All of these methods rely on welding to join the pipes, either onshore or offshore. Pipe laying using a reel ship is an attractive option, as all pipe joints, with the exception of the offshore tie-ins, are welded onshore. This technique is considered to be one of the most reliable methods for laying a pipeline offshore. Welding trials are an essential part of the approval process where the weld joint properties must meet the requirements of the national standard, i.e., BS 4515-1 (Ref. 1), API 1104 (Ref. 2), plus any additional requirements requested by the client. This article describes the onshore production facilities, welding processes, and the properties achieved during welding procedure trials that include strain-aged Charpy impacts.

Construction of Pipelines for Reeling

The onshore fabrication of pipelines for reeling involves having a purpose-built workshop, laid out in such a way to ensure that the welding of pipe material and butt joints is carried out with the minimum of disruption. Also, contained within these facilities will be a radiographic and coating unit. Fabricated pipeline sections up to 1000 m

Fig. 1 — Onshore pipe-to-pipe welding using pulse gas metal arc welding.

Fig. 2 — An internal clamp with backing shoes is used for the root run.

J. R. STILL is a consultant welding and materials engineer, Aberdeen, Scotland.
(3280 ft) in length, referred to as pipe stalks, are transferred from the fabrication shop to an open holding area. Within the holding area, all weld repairs, tie-ins between pipe stalks, and coating and coating repairs are carried out, which are inspected on completion to ensure that the quality meets the client’s requirements.

The pipe stalks are eventually coiled onto the vessel reel. This can involve several pipe stalks joined by butt joint welding.

On location offshore, the reeled pipe is uncoiled and laid on the seabed. Depending on the length of the pipeline being laid, it may be necessary to tie-in the laid pipe with a section of the reeled pipe by butt joint welding. This operation is carried out on the reel vessel and, on completion of welding, nondestructive examination (NDE), and coating, pipe laying continues.

### Pipeline Welding

A 16-in. (406.4-mm) -diameter, API 5L X60 (Ref. 3) pipeline, manufactured through a quenched and tempered route, was recently laid in the U.K. sector of the North Sea. Chemical composition and mechanical properties are outlined in Tables 1 and 2.

Construction of the 16-in. (406.4-mm) -diameter pipeline involved the following welding procedures:

**Pipe-to-Pipe Mainline Onshore.** The method used for the mainline butt joint welds consisted of an automatic pulsed gas metal arc welding (GMAW-P), an example of which is illustrated in Fig. 1. Details of the welding procedure, which was carried out in the 5G position, is outlined in Table 3. Weld preparation consisted of a narrow gap bevel with zero gap between root faces. An internal clamp with copper backing shoes (Fig. 2) is used for the root run and hot pass. Preheat temperature was 100°C with interpass temperature controlled at 300°C maximum.

**Complete Penetration Repair to Mainline Weld Onshore.** Repairs to the mainline welds are carried out in the pipe stalks’ holding area, and welding is carried out in an all-weather habitat. The process used for repairing original mainline welds consists of shielded metal arc welding (SMAW). Details of the weld procedure carried out in the 5G position are outlined in Table 4. Welding in this instance is carried out in the uphill position using a preheat temperature of 150°C and an interpass temperature controlled at 300°C maximum.

### Table 1 — Pipe Metal Chemical Analysis

<table>
<thead>
<tr>
<th>Element</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>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>0.11</td>
<td>0.25</td>
<td>0.003</td>
<td>0.12</td>
<td>1.10</td>
<td>0.11</td>
<td>0.08</td>
<td>0.11</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Element</th>
<th>V</th>
<th>Cu</th>
<th>Al</th>
<th>Nb</th>
<th>N</th>
<th>B</th>
<th>Ca</th>
<th>Ti</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>0.05</td>
<td>0.14</td>
<td>0.025</td>
<td>0.022</td>
<td>0.0082</td>
<td>0.002</td>
<td>0.0017</td>
<td>0.003</td>
</tr>
</tbody>
</table>

Carbon Equivalent: 0.36

### Table 2 — Pipe Metal Mechanical Properties

<table>
<thead>
<tr>
<th>Test Type</th>
<th>Tensile Tests</th>
<th>Charpy Impact Tests</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tensile Strength N/mm²</td>
<td>-40°C</td>
</tr>
<tr>
<td></td>
<td>Elongation (%)</td>
<td>Inside</td>
</tr>
<tr>
<td></td>
<td>Charpy Impact Tests</td>
<td>252, 252, 258, Av 254</td>
</tr>
<tr>
<td></td>
<td>Test Temperature</td>
<td>Impact Properties Joules</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Inside</td>
</tr>
</tbody>
</table>

### Table 3 — Pipe-to-Pipe Mainline Weld Procedure

<table>
<thead>
<tr>
<th>Pass No.</th>
<th>Process</th>
<th>Size (mm)</th>
<th>Amps</th>
<th>Volts</th>
<th>R.O.L (mm)</th>
<th>Time (s)</th>
<th>Speed (mm/s)</th>
<th>Heat Input (kJ/mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GMAW-P</td>
<td>0.9</td>
<td>213-231</td>
<td>21-25</td>
<td>630-670</td>
<td>42-46</td>
<td>14.6/15</td>
<td>0.3</td>
</tr>
<tr>
<td>2</td>
<td>GMAW-P</td>
<td>0.9</td>
<td>208-225</td>
<td>21-25</td>
<td>660-70</td>
<td>96-100</td>
<td>6.6/7</td>
<td>0.7/0.8</td>
</tr>
<tr>
<td>Fill</td>
<td>GMAW-P</td>
<td>0.9</td>
<td>201-228</td>
<td>21-25</td>
<td>660-70</td>
<td>93-98</td>
<td>6.7/7.1</td>
<td>0.7/0.8</td>
</tr>
<tr>
<td>Last 2</td>
<td>GMAW-P</td>
<td>0.9</td>
<td>195-219</td>
<td>21-25</td>
<td>100</td>
<td>12-20</td>
<td>5.0/8.3</td>
<td>0.6/1.0</td>
</tr>
<tr>
<td>Cap</td>
<td>GMAW-P</td>
<td>0.9</td>
<td>159-178</td>
<td>21-15</td>
<td>100</td>
<td>19-26</td>
<td>3.8/5.3</td>
<td>0.8/1.1</td>
</tr>
</tbody>
</table>

**Filler Metal Specification**

- **Classification:** A5.28 ER80S-G
- **Electrical Characteristics:** DC +VF
- **Preheat °C:** 100
- **Interpass Temp °C:** 255
- **Type Classification:** Flow Rate
- **Flow Rate:** 20-27 L/min.
- **Shielding Gas:** Ar/CO₂ 85%/15%
- **Tungsten Electrode:** NA

*Note: GMAW-P (Pulsed gas metal arc welding)*
### Table 4 — Repair to Mainline

Complete Penetration Repair to Mainline Onshore Diameter 406.4 mm Thickness 23.8 mm

<table>
<thead>
<tr>
<th>Pass No</th>
<th>Process</th>
<th>Size (mm)</th>
<th>Amps</th>
<th>Volts</th>
<th>R.O.L. (mm)</th>
<th>Time (s)</th>
<th>Speed (mm/s)</th>
<th>Heat Input (kJ/mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GTAW</td>
<td>2.4</td>
<td>90-160</td>
<td>8-11</td>
<td>65-90</td>
<td>35-88</td>
<td>1.0-2.0</td>
<td>0.6-1.2</td>
</tr>
<tr>
<td>2</td>
<td>GTAW</td>
<td>2.4</td>
<td>160-240</td>
<td>8-11</td>
<td>70-90</td>
<td>27-58</td>
<td>1.6-2.6</td>
<td>0.8-1.1</td>
</tr>
<tr>
<td>Fill</td>
<td>SMAW</td>
<td>3.2</td>
<td>90-140</td>
<td>20-24</td>
<td>80-150</td>
<td>45-60</td>
<td>1.4-2.6</td>
<td>1.0-1.8</td>
</tr>
<tr>
<td>Cap</td>
<td>SMAW</td>
<td>3.2</td>
<td>90-130</td>
<td>20-24</td>
<td>60-110</td>
<td>43-63</td>
<td>1.4</td>
<td>1.2-1.8</td>
</tr>
</tbody>
</table>

**Filler Metal Specification**

- **Classification**: A5.28 ER80S-G
- **Type**: Flux/Shielding Gas
  - **Classification**: High-Purity Argon
  - **99.995% Argon**

**Electrical Characteristics**

- **Preheat °C**: 150
- **Interpass Temp °C**: 300

**Tungsten Electrode**: 2.4 mm, 2% Thoriated

### Table 5 — Pipe-to-Pipe Cut-out/Tie-in Onshore

16-in. Pipe-to-Pipe Mainline Cut-Out/Onshore Tie-in Diameter 406.4 mm Thickness 23.8 mm

<table>
<thead>
<tr>
<th>Pass No</th>
<th>Process</th>
<th>Size (mm)</th>
<th>Amps</th>
<th>Volts</th>
<th>R.O.L. (mm)</th>
<th>Time (s)</th>
<th>Speed (mm/s)</th>
<th>Heat Input (kJ/mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>GTAW</td>
<td>2.4</td>
<td>90-200</td>
<td>8-11</td>
<td>90-235</td>
<td>60-160</td>
<td>1.0-2.1</td>
<td>0.7-1.1</td>
</tr>
<tr>
<td>2</td>
<td>GTAW</td>
<td>2.4</td>
<td>150-280</td>
<td>8-11</td>
<td>100-330</td>
<td>51-120</td>
<td>1.6-2.8</td>
<td>0.8-1.0</td>
</tr>
<tr>
<td>Fill</td>
<td>FCAW-G</td>
<td>1.2</td>
<td>140-220</td>
<td>24-26</td>
<td>90-320</td>
<td>32-141</td>
<td>2.0-4.0</td>
<td>1.1-2.4</td>
</tr>
<tr>
<td>Cap</td>
<td>FCAW-G</td>
<td>1.2</td>
<td>140-215</td>
<td>24-26</td>
<td>100-380</td>
<td>32-86</td>
<td>2.8-4.4</td>
<td>1.0-1.5</td>
</tr>
</tbody>
</table>

**Filler Metal Specification**

- **Classification**: A5.28 ER80S-G
- **Type**: Flux/Shielding Gas
  - **Classification**: High-Purity Argon
  - **99.995% Argon**

**Electrical Characteristics**

- **Preheat °C**: 100
- **Interpass Temp °C**: 300

**Tungsten Electrode**: 2.4 mm, 2% Thoriated
Table 6 — Pipe-to-Pipe Offshore Tie-in

<table>
<thead>
<tr>
<th>Welding Position 6G</th>
<th>Filler Metal Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pass No.</td>
<td>Process</td>
</tr>
<tr>
<td>1</td>
<td>GTAW</td>
</tr>
<tr>
<td>2</td>
<td>GTAW</td>
</tr>
<tr>
<td>Fill</td>
<td>FCAW-G</td>
</tr>
<tr>
<td>Cap</td>
<td>FCAW-G</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Classification</th>
<th>Type</th>
<th>Flux/Shielding Gas</th>
</tr>
</thead>
<tbody>
<tr>
<td>A5.28 ER80S-G</td>
<td>Classification</td>
<td>High-Purity Argon</td>
</tr>
<tr>
<td>A5.28 ER90S-G</td>
<td>Argon 25</td>
<td>99.95% Argon</td>
</tr>
<tr>
<td>A5.29 E80T-K2</td>
<td>75% Argon/25% CO₂</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Electrical Characteristics</th>
<th>Flow Rate</th>
<th>Tungsten Electrode</th>
</tr>
</thead>
<tbody>
<tr>
<td>DC - VE</td>
<td>GTAW 12-20 L/min</td>
<td>2.4 mm, 2% Thoriated</td>
</tr>
<tr>
<td>DC + VE</td>
<td>FCAW-G 15-25 L/min</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Preheat °C</th>
<th>Interverpass Temp °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>300</td>
</tr>
</tbody>
</table>

Table 7 — Weld Metal Chemical Analysis

<table>
<thead>
<tr>
<th>Weld Procedure</th>
<th>C</th>
<th>Si</th>
<th>S</th>
<th>P</th>
<th>Mn</th>
<th>Cr</th>
<th>Mo</th>
<th>Ni</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe-to-Pipe Mainline</td>
<td>0.10</td>
<td>0.52</td>
<td>0.008</td>
<td>0.01</td>
<td>1.24</td>
<td>0.04</td>
<td>0.02</td>
<td>0.03</td>
</tr>
<tr>
<td>Repair to Mainline</td>
<td>0.10</td>
<td>0.52</td>
<td>0.008</td>
<td>0.01</td>
<td>1.17</td>
<td>0.05</td>
<td>0.07</td>
<td>0.62</td>
</tr>
<tr>
<td>Pipe-to-Pipe Cut Out</td>
<td>0.10</td>
<td>0.55</td>
<td>0.007</td>
<td>0.01</td>
<td>1.28</td>
<td>0.04</td>
<td>0.09</td>
<td>0.65</td>
</tr>
<tr>
<td>and Pipe-to-Pipe Onshore Tie-in</td>
<td>0.10</td>
<td>0.44</td>
<td>0.008</td>
<td>0.01</td>
<td>1.17</td>
<td>0.04</td>
<td>0.14</td>
<td>0.68</td>
</tr>
<tr>
<td>Pipe-to-Pipe Offshore Tie-in</td>
<td>0.10</td>
<td>0.44</td>
<td>0.008</td>
<td>0.01</td>
<td>1.17</td>
<td>0.04</td>
<td>0.14</td>
<td>0.68</td>
</tr>
</tbody>
</table>

Table 8 — Cross-Weld Tensile Tests

<table>
<thead>
<tr>
<th>Weld Procedure</th>
<th>Ultimate Tensile Strength (N/mm²)</th>
<th>Fracture Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pipe-to-Pipe (Mainline)</td>
<td>609, 617</td>
<td>Base Break</td>
</tr>
<tr>
<td>Pipe-to-Pipe (Cut Out)</td>
<td>628</td>
<td>Base Break</td>
</tr>
<tr>
<td>Repair to Mainline</td>
<td>588, 550</td>
<td>Base Break</td>
</tr>
<tr>
<td>Pipe-to-Pipe Offshore Tie-in</td>
<td>621, 628</td>
<td>Base Break</td>
</tr>
</tbody>
</table>

Pipe-to-Pipe Mainline Cut Out/Tie-In Onshore. The weld procedure is used for welding butt joints between pipes, which can consist of mainline butt joint weld cutouts and butt joint welding of pipe stalks to pipe stalks, or pipe stalks to reeled pipe. Weld preparation consists of a 50 to 60° bevel where the root run is deposited using gas tungsten arc welding (GTAW) and filled with SMAW. Bridge tacks are used to maintain the root opening, which are removed and repositioned to prevent the opening from shrinking and restricting access. Details of the welding procedure 5G position are illustrated in Table 5. Preheat and interpass temperatures are identical to that applied for the mainline butt joint welds.

Pipe-to-Pipe Tie-In Offshore. The weld procedure used for offshore tie-ins is similar to that used for pipe-to-pipe tie-ins onshore, with the exception that the welding procedure is qualified in the 6G position. Details of the weld procedure are outlined in Table 6.

Weld Metal Properties

Chemical Analyses

Chemical analyses for the above weld procedures are outlined in Table 7. With the exception of the GMAW-P weld procedure, the weld metal compositions for the remaining procedures are similar and contain 1% nickel.

Mechanical and Metallurgical Properties

Weld procedure mechanical testing was carried out in accordance with BS4515-1 (Ref. 1), plus additional requirements specified by the client.
Table 9 — Weld Metal Hardness Survey

<table>
<thead>
<tr>
<th>Location</th>
<th>Pipe-to-Pipe (Mainline)</th>
<th>Pipe-to-Pipe Cut Out</th>
<th>Repair to Mainline</th>
<th>Pipe-to-Pipe Offshore Tie-in</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Top</td>
<td>Middle</td>
<td>Bottom</td>
<td>Top</td>
</tr>
<tr>
<td>Base</td>
<td>188</td>
<td>189</td>
<td>207</td>
<td>188</td>
</tr>
<tr>
<td>Metal</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HAZ</td>
<td>212</td>
<td>194</td>
<td>219</td>
<td>230</td>
</tr>
<tr>
<td>Weld</td>
<td>197</td>
<td>219</td>
<td>247</td>
<td>202</td>
</tr>
<tr>
<td>HAZ</td>
<td>216</td>
<td>192</td>
<td>220</td>
<td>206</td>
</tr>
<tr>
<td>Base</td>
<td>185</td>
<td>183</td>
<td>203</td>
<td>174</td>
</tr>
<tr>
<td>Metal Specification</td>
<td>Weld Metal</td>
<td>Root and Mid-Thickness</td>
<td>Cap</td>
<td>250</td>
</tr>
</tbody>
</table>

Table 10 — Strain-Aged Weld Metal and Heat-Affected Zone Charpy Impact Results at -30°C

<table>
<thead>
<tr>
<th>Location</th>
<th>Pipe-to-Pipe Mainline</th>
<th>Repair to Mainline</th>
<th>Pipe-to-Pipe Cut Out and Pipe-to-Pipe Onshore</th>
<th>Pipe-to-Pipe Offshore</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Position</td>
<td>Joules</td>
<td>Position</td>
<td>Joules</td>
</tr>
<tr>
<td>Weld Cap</td>
<td>0 deg</td>
<td>73, 74, 72, Av 73</td>
<td>Repair</td>
<td>64, 56, 70, Av 63</td>
</tr>
<tr>
<td>Weld Cap</td>
<td>180 deg</td>
<td>83, 77, 75, Av 78</td>
<td>180 deg</td>
<td>119, 85, 98, Av 101</td>
</tr>
<tr>
<td>HAZ Cap</td>
<td>0 deg</td>
<td>94, 172, 184, Av 150</td>
<td>Repair</td>
<td>270, 230, 248, Av 249</td>
</tr>
<tr>
<td>HAZ Cap</td>
<td>180 deg</td>
<td>40, 111, 162, Av 104</td>
<td>180 deg</td>
<td>179, 234, 228, Av 214</td>
</tr>
<tr>
<td>Weld Root</td>
<td>0 deg</td>
<td>81, 80, 80, Av 89</td>
<td>180 deg</td>
<td>83, 39, 82, Av 68</td>
</tr>
<tr>
<td>Weld Root</td>
<td>180 deg</td>
<td>79, 87, 79, Av 82</td>
<td>0 deg</td>
<td>57, 60, 48, Av 55</td>
</tr>
<tr>
<td>HAZ Root</td>
<td>0 deg</td>
<td>88, 129, 168, Av 128</td>
<td>Repair</td>
<td>210, 190, 250, Av 217</td>
</tr>
<tr>
<td>HAZ Root</td>
<td>180 deg</td>
<td>220, 116, 76, Av 137</td>
<td>0 deg</td>
<td>227, 254, 247, Av 243</td>
</tr>
<tr>
<td>Charpy Impact Dimensions</td>
<td>10 x 10 x 2 V</td>
<td>Charpy Impact Test Temperature -30 °C</td>
<td>All Charpy Impacts Heat-Treated at 100 °C for 1 hour after 2.4% Strain</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 3 — Stress/strain curve shows relationship between strain and yield strength.

Tensile Tests

Tensile tests consisting of cross-weld tensile specimens were carried out on all weld procedures. Tensile results varied from 589 to 628 N/mm², depending on the weld procedure, which were well above the minimum pipe tensile result of 567 N/mm². Details of the results obtained are outlined in Table 8. The tensile specimens all fractured in the base metal.

Hardness Survey

Weld joint hardness surveys were carried out at three locations: on the top, middle, and bottom of each macro using a 10-kg load. The results recorded are outlined in Table 9. Hardness results varied from 174 to 222 HV, with the exception of the following isolated values:

- Pipe-to-pipe recorded a weld metal root hardness value of 247 HV.
- Pipe-to-pipe cut-out recorded a heat-affected zone (HAZ) value from the top hardness value of 230 HV, and a weld metal value of 232 from the root.
- Pipe-to-pipe offshore recorded a weld metal value of 247 HV from the root.

The high weld metal root hardness values recorded are difficult to explain, since one would have expected that the root area would have experienced the effect of depositing the hot pass (and subsequent passes) and where the previously deposited microstructure would have been refined. It would appear that the HAZ hardness value recorded from the top survey may be due to a reduction of the preheat temperature.

Strain-Aged Charpy Impacts

Weld metal Charpy impact tests are carried out in the strain-aged condition to simulate the effect that reeling on and off the vessel has on the mechanical properties of the weld metal. Charpy impact specimens were removed from the 0-deg and 180-deg positions and tested at -30°C in the strain-aged condition. To obtain strain-aged Charpy specimens involves removing a section of the pipe weld from the longitudinal direction of the pipe and applying a 2.4% strain and aging at 100°C for one hour. Toughness requirements specified were 40 joules minimum average and 30 joules minimum individual value. Details of the Charpy impact test results in the strain-aged condition are illustrated in Table 10.
The microstructure consists essentially of veins of polygonal ferrite with an acicular ferrite matrix.

Summary

Pipe reeling is considered one of the most reliable methods for laying a pipeline offshore. All welding, with the exception of the offshore tie-ins, is carried out onshore. This practice allows better control over materials, welding, repairs, and weld coatings.

In order to reduce the effect of strain aging on reeled pipe welds, steelmakers are now making additions of niobium, vanadium, molybdenum, or titanium to bind the interstitial carbon and nitrogen atoms to form stable carbides, and aluminium to form nitrides. It has been reported that strain-aged trials carried out on pipeline steels modified with the above elements showed no significant degradation of properties (Ref. 5).

Acknowledgments

The author would like to thank David Baillie for commenting on the preparation of this paper, and Dr. K. Prosser for the useful discussion on strain aging.

Strain Aging

Strain aging is the result of atoms of carbon and nitrogen dissolved in ferrite, which segregate to dislocations and lock their movement (Ref. 3). This increases the strength and hardness of a steel but reduces its ductility. The rate of segregation is controlled by the following essential variables:

- Dislocation density
- Temperature
- Concentration of carbon and nitrogen atoms.

In order to provide a brief description of strain aging, the stress/strain curve illustrated in Fig. 3 (Ref. 4) illustrates the effect that straining has on the yield strength. When the weld specimens are strained, yielding takes place at point "A" upper yield point and drops dramatically to point "B" lower yield point. The horizontal section after point B is known as the "Initial Lower Yield Strength" (Ref. 4). Straining of the weld specimen is allowed to continue to point "C" on the stress/strain curve "x." At this point, the tensile specimen is unloaded and aged at 100°C for 1 hour. When the strain is reapplied to the weld specimen, yielding returns and continues to point "D" on the stress/strain curve "y." The horizontal portion after the yield point is referred to as the "strain-aged lower yield extension." This increase in yield strength \( \Delta \sigma \) is an indication that strain aging has occurred.

However, other factors such as interstitial atoms of carbon and nitrogen play significant roles in the strain aging process. Weld metal dislocation is effectively immobilized during cold working by interstitial atoms of carbon and nitrogen along the cores of the dislocation (Point B-C). Further cold work results in the unlocking of new dislocation, resulting in blocking at point "D." Yielding continues until no further dislocation movement is available. However, if the strain is continued fracture would result.

Strain-aged tests are carried out on all weld procedures where the strain rate and aging temperature can vary depending on the diameter and thickness.

In addition to the above, the steel supplier carries out strain-aged tests on pipe material where test specimens are strained at 5% and aged at 250°C.

Weld Metal Microstructures

Figures 4 and 5 illustrate the pipe material and weld metal microstructures respectively. The pipe material was processed through a quenched and tempered route, producing a microstructure consisting of tempered martensite. Although weld metals were deposited by different consumables and processes, their the weld metal compositions were similar, with the exception of the GMAW-P.

References

Welding repair procedures were updated to adjust for reduced oil flow rates

BY WILLIAM A. BRUCE AND ALAN S. BECKETT

The existing welding practices and procedures used in conjunction with maintenance and tie-in welding on the Trans-Alaska Pipeline System (TAPS) have not been significantly revised since they were prepared shortly after original construction in the mid-1970s. The originally qualified procedures have served the operator, Alyeska Pipeline Service Co., well to date, and there is no evidence that the procedures are unsound. However, operating conditions on the pipeline have changed over time, while some new developments have occurred in in-service welding technology that may be appropriate for Alyeska to consider adopting. The objective of a recently completed project at Edison Welding Institute (EWI) was to review early work for Alyeska and existing Alyeska procedures and practices. The purpose of this project was to examine alternative procedure options for avoiding hydrogen cracking during in-service welding on TAPS, and to recommend and assist in the requalification of new procedures, if required.

Background

TAPS transports crude oil from the North Slope of Alaska to the marine terminal in the ice-free port of Valdez, Alaska. The pipeline is 48 in. (1219 mm) diameter and 800 miles (1287 km) in length. Construction began on March 27, 1975, and was completed on May 31, 1977. The United States depends on TAPS to deliver 17% of its domestic oil production.

When welding onto an in-service pipeline, to facilitate a repair or to install a branch connection using the “hot tapping” technique, there is a risk of hydrogen cracking from the fast cooling rates that tend to be produced by the flowing contents removing heat from the pipe wall. To prevent hydrogen cracking, at least one of the three conditions necessary for its occurrence must be eliminated. Beyond the use of low-hydrogen electrodes to minimize hydrogen levels, many companies...
have developed procedures that minimize the formation of crack-susceptible microstructures. Procedure options for minimizing the formation of crack-susceptible microstructures for welds made onto an in-service pipeline include the use of a sufficiently high heat input level, the use of preheating, the use of a temper bead deposition sequence, or some combination of these.

The existing procedures used by Alyeska for in-service welding use low-hydrogen electrodes and rely on achieving a preheat temperature of at least 125°F (52°C). Preheating has the dual benefit of reducing weld cooling rates somewhat, which can reduce hardness levels, and allow time for hydrogen diffusion. The operating temperature of TAPS has decreased over the years as the volume of crude oil flowing through the system has decreased. The average operating temperature at the present flow rate of approximately 1.0 million barrels per day is approximately 68°F (20°C) compared to 116°F (47°C) at 1.85 million barrels peak production. This lower operating temperature results in difficulty achieving the 125°F minimum-required preheat temperature. It was therefore desirable to examine alternative procedure options for avoiding hydrogen cracking during in-service welding on TAPS.

Extensive testing was carried out at Cranfield Institute of Technology (now Cranfield University) for Alyeska in 1977 and 1979 (Refs. 1, 2). The purpose of this work was to investigate variables affecting weld quality and to develop a welding procedure for attaching repair fittings to TAPS with regard to both hydrogen cracking risk and the risk of lamellar tearing (decohesion of sulfide inclusions). This work resulted in the establishment of a minimum-required preheat temperature and recommendations for fillet weld size.

### Review of Alyeska Maintenance Welding Procedures

The existing welding procedure specifications (WPSs) and supporting procedure qualification records (PQRs) were reviewed with regard to good welding practice in general, and for compliance to API RP 1107 and API Specification 1104, Appendix B requirements. The adequacy of the existing procedure was also evaluated using the results of a recently completed group-sponsored project (GSP) at EWI (Ref. 3), where procedures for in-service welding that are resistant to hydrogen cracking over a wide range of conditions were developed and qualified to the requirements of a variety of industry codes.

With very few exceptions, the Alyeska procedures were found to be in compliance with ASME Section IX and API 1107. API 1107 has been superseded by Appendix B of API 1104 (19th Edition), however. Comparison of the Alyeska procedures with the results of the recently completed GSP at EWI indicates that several procedure options exist for current operating conditions of TAPS.

### Laboratory Trials to Determine Adequacy of Existing Procedures

Small-scale welding trials were carried out to demonstrate that a range of parameters could be used to produce sound crack-free welds without the use of preheat. Two pipe materials, a 0.462-in. (11.7-mm) -thick X65 and a 0.562-in. (14.3-mm) -thick X70 (Table 1), were supplied by Alyeska.

Trial welds approximately 12 in. (300 mm) in length were made using hydrogen-controlled electrodes and candidate parameters under simulated in-service conditions. These conditions included simulating the ability of the flowing contents to remove heat from the pipe wall by circulating water across the inside surface of the pipe material while the welds were made. Restraining welds were also used to produce realistic levels of residual stress — Fig. 1. Multipass fillet welds were made over a wide range of heat inputs (25 and 40 kJ/in. [1.0 and 1.6 kJ/mm]) and using a temper bead deposition sequence — Fig. 2. Metallographic specimens were extracted for examination and the resulting HAZ hardness was measured and compared with previously established limits for in-service welds (Ref. 4). In addition, mechanical test specimens were extracted and tested so that any hydrogen cracks would be revealed.

The results of these trials indicate that all of the candidate parameters (25 and 40 kJ/in. minimum-required heat input, and temper bead deposition sequence) produced sound crack-free welds without

### Table 1 — Chemical Analysis Results for Laboratory Trial Materials

<table>
<thead>
<tr>
<th>Element</th>
<th>0.462 in.</th>
<th>0.562 in.</th>
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<tbody>
<tr>
<td>C</td>
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<tr>
<td>Mn</td>
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<td>1.37</td>
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<tr>
<td>P</td>
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<td>S</td>
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<td>Ni</td>
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<td>B</td>
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<tr>
<td>Ca</td>
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<td>—</td>
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<tr>
<td>Cu</td>
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Table 2 — Chemical Analysis Results for Procedure Qualification Trial Materials

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<th>Element</th>
<th>Chemical Composition (wt-%)</th>
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<td>CE&lt;sub&gt;NW&lt;/sub&gt;</td>
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</tr>
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</table>

Monitoring of Maintenance Procedure Requalification Activities

Procedure requalification trials were carried out in Fairbanks at an Alyeska facility using contract welders selected by Alyeska. The setup for these trials involved lengths of 48-in.-diameter pipe material to which end plates and legs were welded. The ability of the flowing contents to remove heat from the pipe wall was simulated using ambient-temperature tap water as before — Fig. 3. Segments of procedure qualification welds were made between the pipe material and sections of fitting material on the top, side, and bottom of the pipe. Two rounds of procedure qualification trials were carried out.

In the first round, four different welding consumables were evaluated using target welding parameters that would result in a heat input level of at least 40 kJ/in. without the use of preheating. The pipe surface temperature was 58°F (14°C). During the first round, some difficulty was experienced maintaining a heat input level of at least 40 kJ/in. The GSP results also indicate that a procedure that relies on 25 kJ/in. minimum-required heat input with preheating (200°F [93°C]) is adequate for materials with carbon content greater than 0.10% and CE<sub>NW</sub> up to 0.42%. In the second round, target parameters that would result in a heat input level of less than 40 kJ/in. with a reduced level of preheating (86°F [30°C]) were investigated as an alternative to a heat input level of at least 40 kJ/in. Two consumables used in the first round were selected for use in the second round. Preheating was achieved using Alyeska's Miller Electric induction heating system — Fig. 4.

An example of a completed weld is shown in Fig. 5. Following each round, metallographic and mechanical testing specimens were extracted and tested in accordance with the requirements of API 1104 Appendix B.

Materials

It was not possible to locate pipe material with a CE<sub>NW</sub> of 0.39 (i.e., the highest of the pipe material delivered for TAPS), so for the first round, a length of pipe 0.562-in. (14.3-mm) thick X70 with a CE<sub>NW</sub> of 0.34 was made to suffice. For the second round, a length of pipe was fab-
Fabricated from 0.625-in. (15.9-mm)-thick ASTM A516 Grade 70 plate material with a CEIw of 0.39. The fitting material consisted of sections of A537 Class 1 plate, taken from the center of an actual T.D. Williamson Stopple® fitting, which had a CEIw of 0.41. The edges of the fitting material were beveled to resemble the edge of a Stopple fitting. Chemical analysis results for the pipe and fitting material are shown in Table 2.

Four different consumables were used during the procedure qualification trials. The first was an E8018-C1, which has been the standard consumable used by Alyeska for maintenance welding. Since over-matching strength is not necessarily desirable for in-service sleeve fillet welds (higher residual stresses tend to develop), two lower-strength consumables were also evaluated. These were E7018-1 and E6018. The latter electrode was developed specifically for applications where hydrogen cracking is a concern, as the low-strength weld metal allows shrinkage strains to accumulate in the weld metal as opposed to the crack-susceptible HAZ. The fourth electrode was an E7016, which is similar to an E7018-1 except that the iron powder content in the coating is lower. These electrodes produce relatively small weld beads and are useful for applications where a high level of heat input is required and/or tempering from subsequent passes is desired.

Round 1 Results (40 kJ/in, without Preheat)

Two sections for metallographic examination and hardness testing were removed from each weld. The 12 hardness measurements, six in the pipe material HAZ and six in the fitting material HAZ, were made using a Vickers indenter with a 10-kg load. A summary of the HAZ hardness testing results for the first round of procedure qualification trials is shown in Fig. 6. The results indicate that no one electrode type produced HAZ hardness levels that are substantially lower than another. The E7016 seemed to be the most variable; while it produced some of the lowest maximum hardness values, it also produced some of the highest.

In terms of absolute numbers, the results were encouraging. The maximum measured HAZ hardness in the pipe material is 337 HV, which is well below the maximum allowable value. For the chemical composition of the fitting material, the previously developed acceptance criterion allows HAZ hardness of up to 400 HV for welds made using good low-hydrogen practice. Several of the HAZ hardness measurements in the fitting material approach 400 HV, but none are above.

As before, two sections for metallographic examination and hardness testing were removed from each weld. A summary of the HAZ hardness testing results for the second round of procedure qualification trials is shown in Fig. 7. The results were again encouraging. All of the measured HAZ hardness values in the pipe material were less than 350 HV. The maximum measured value in the pipe material is 346 HV. Some of the measured HAZ hardness values in the fitting material exceeded 350 HV, but as indicated above, the acceptance criterion allows HAZ hardness of up to 400 HV for welds made using good low-hydrogen practice for the chemical composition of the fitting material (up to 0.42 CEIw).

In general, the E7016 seems to have produced lower HAZ hardness values than the E8018-C1, although the E7016 produced the highest measured value (381 HV measured on the fitting-side HAZ of one section).

Resulting Welding Procedure Specification

The data from both rounds of the procedure qualification exercise were incorporated into a single WPS by Alyeska. This WPS specifies preheating the pipe material to 86°F (30°C), with a higher preheat temperature required for the fitting material, but allows reduced preheat provided that the heat input is 40 kJ/in. or greater.

Verification of Procedure Suitability

During the course of this project, an
opportunity arose to verify the suitability of the resulting WPS during a previously scheduled remote gate valve (RGV) replacement operation. This was accomplished using the confirmation weld scheme. The confirmation weld scheme involves making a weld using the qualified procedure onto the portion of the pipeline that will be removed; in this case, the pipe material adjacent to the RGV. A section of T.D. Williamson Stopple fitting material approximately 6 in. (150 mm) wide and 18 in. (450 mm) in length, with the edges beveled to resemble the edge of a Stopple fitting, was welded to the TAPS main line under actual in-service conditions — Fig. 8.

The TAPS main line in this area consists of 0.562-in. (14.3-mm) thick X70 material. One side was welded without preheat while maintaining a heat input of at least 40 kJ/in. and the other side was welded with preheat without heat input control. An example of a completed weld is shown in Fig. 9. Following replacement of the RGV, the pipe material adjacent to the RGV containing the confirmation weld was sent to EWI for analysis.

Upon arrival at EWI, two metallographic sections were removed from each weld. Analysis consisted of metallographic examination, hardness testing, and chemical analysis. A micrograph of a typical weld is shown in Fig. 10. Chemical analysis results for the pipe and fitting material are shown in Table 3.

A summary of the HAZ hardness testing results for the procedure confirmation exercise is shown in Fig. 11. The results of the analysis indicate that both procedure variations produced sound crack-free welds with acceptable hardness levels. This is the case in spite of pipe material having a rather rich chemical composition (0.15% C and a CEII_W of 0.43). The robustness of the two procedure variations is demonstrated by their ability to produce acceptably low hardness levels in spite of the pipe material being relatively rich.

**Summary**

The procedure requalification exercise that was carried out allowed the suitability of procedures to be demonstrated for the current and projected future operating conditions for TAPS using current industry-based guidance. The initial procedure that was qualified involves no preheating and a minimum required heat input of 40 kJ/in. The acceptability of these parameters under these conditions for material with a CEII_W up to 0.42 is based on OSP results. Because of anticipated difficulty to reliably achieve a heat input of 40 kJ/in. in the field, a second procedure was qualified that involves a reduced level of preheating (from the level in the existing procedure) and a reduced level of heat input. The acceptability of these parameters under these conditions for material with a CEII_W up to 0.39 is based on the results of the procedure qualification testing that was performed. The data from the procedure qualification exercise were incorporated into a single WPS by Alyeska. Analysis of confirmation welds taken in conjunction with an RGV replacement operation indicates that both procedure variations are suitable under actual in-service conditions for material with a CEII_W up to 0.43.

**Acknowledgments**

The authors would like to thank Alyeska Pipeline Service Co. for sponsoring this project and for allowing the results to be published, and Frank Caito for his helpful assistance. The contribution of Mike Rosenfeld from Kiefner & Associates is also gratefully acknowledged.

**References**


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Circle No. 5 on Reader Info Card
Since its beginning in 1922, the Hollywood Bowl has had four shells. The original 1922 shell was constructed out of wood and canvas. The Bowl was rebuilt three times over the next seven years, the last time taking place in 1929. That shell, which became one of the world’s most recognized outdoor music venues, was constructed out of a steel frame overlaid with wood. The Bowl remained a Los Angeles landmark for more than 74 years, and served as the summer home of the Los Angeles Philharmonic. Hundreds of thousands of visitors have enjoyed performances and admired the beauty of this outdoor marvel over the years.

As impressive as it was, the Bowl was plagued with acoustic problems. Several attempts were made throughout the years to solve those problems, but they met with little success. A second problem with the bowl was its size; the amphitheater could not accommodate the entire Los Angeles Philharmonic. One-third of the orchestra’s members had to perform outside of the shell. In 2000 it was recognized that there was only one thing that would solve these problems: tear down the aging landmark and reconstruct a
new state-of-the-art amphitheater (see lead photo). The Los Angeles-based architectural firm of Hodgetts + Fung Design Associates undertook the challenge of designing a bigger structure with better acoustics, while still retaining the charm and trademark look of the 1929 Hollywood Bowl. After three years of design and preparation work, the ground was broken and construction of the new Hollywood Bowl was under way in 2003.

The Hollywood Bowl shell project, according to the Los Angeles Philharmonic Association, "creates a new shell that preserves the iconic Moderne curve of the previous shell, while improving acoustics for performers on stage and enhancing the musical experience for concertgoers with new lighting, sound, and theatrical elements."

**Building the New Bowl**

The general contractor, Matt Construction of Santa Fe Springs, Calif., was responsible for coordinating all of the contractors taking part in the project and to make sure the Hollywood Bowl was ready for its summer concert schedule.

![Fabrication of the trusses](image1)

**Fig. 1** — Fabrication of the trusses was on a fast track in order to meet the philharmonic’s summer concert schedule.

![Much of the field welding](image2)

**Fig. 2** — Much of the field welding took place at heights 42 ft or more from the ground.
Fig. 3 — A member of Ironworkers Local 433 works on a truss prior to its being lifted into place.

A Brief History of the Hollywood Bowl

The following facts about the Hollywood Bowl were provided by the Los Angeles Philharmonic Association.

- The Hollywood Bowl is the largest natural amphitheater in the United States and is a Los Angeles County Park (see photo).
- It can seat nearly 18,000 concertgoers.
- The Bowl’s first stage, built in 1922, consisted of a simple wooden platform with a canvas top. Patrons sat on movable benches.
- A cooperative society of 33 Los Angeles architects built the Bowl’s first arched proscenium in 1926. The curved wooden frame consisted of a low elliptical arch in the background with a circular arch inside, framing the musicians. It was torn down at the end of that season because of acoustical problems.
- Lloyd Wright, eldest son of Frank Lloyd Wright, designed two shells for the Hollywood Bowl. The first shell was intended only as a temporary structure and was used for one season. Wright used wood from the dismantled set of Robin Hood to build a pyramid-shaped structure intended to enhance the Bowl’s acoustics and complement the rustic setting.
- Wright’s second commission included the specific instruction to design a circular music shell. The 1928 shell consisted of nine concentric, segmental arches that could be “tuned” panel by panel. For reasons that remain unclear, it was left standing through the winter of 1928 and began to deteriorate. It was declared unsafe and was demolished in 1929.
- The shell constructed in 1929 preserved the visual essence of Lloyd Wright’s 1928 design, but substituted a semicircle for Wright’s elliptical form. Made of transite panels covering a steel frame, the 55-ton shell was designed on a track system. The shell could be moved off the stage area to allow for theatrical staging to be built for a specific purpose. From the beginning, the curved shape caused serious acoustic problems, including focused sound randomly returning to the stage.
- Numerous attempts were made to improve the 1929 shell’s acoustics. In 1970, architect Frank Gehry and acoustician Christopher Jaffe devised an inexpensive, temporary solution by creating “sonotubes,” manufactured cardboard forms that looked like concrete columns. Their arrangement inside the shell and extending along the outer wings enhanced the sound but disguised the Bowl’s famous curved shape. The sonotubes remained in place until 1980.
- Development in the area also disturbed the natural amphitheater’s acoustics. The addition of the Hollywood Freeway in 1952, the grading of hillsides, home building, and other factors began to surround the once tranquil grounds with ambient noise.
- In 1980, Gehry-designed hollow fiberglass spheres were hung inside the shell in a carefully calculated arrangement. While helpful, the spheres did not solve the Bowl’s acoustical problems.
- The new shell project was funded by voters through the passage of Proposition A. The project also includes new backstage areas. Specifically, the shell project preserves the recognizable, 1920s Modernconcentric ring look of the 1929 shell, dramatically improves the shell’s acoustics, creates 30% more stage space to accommodate a full orchestra inside the shell, and allows lighting and sound technology to be integrated into the design, restoring the shell’s clean, uncluttered look.
Fig. 3 — A full view of the acoustical canopy. (Rendering by Hodgetts + Fung, courtesy of the Los Angeles Philharmonic Association.)

The project was constructed with A36 steel. The lower sections of the trusses are 10 × 10 × 1/16-in. tube steel. The upper sections were either back-to-back 6 × 4 × 1/8-in. angle iron or 6 × 6 × 1/8-in. tube steel. Field welding utilized both shielded metal arc welding with 7018 electrodes and flux cored arc welding with self-shielded E71T-8 wire. The truss field splices were complete joint penetration welds, with fillet welds making up the rest of the welds. The deputy inspector of the city of Los Angeles performed visual inspections on all the fillet welds; the tube steel complete penetration welds underwent ultrasonic testing.

The primary difficulty in constructing the Bowl was that each truss was a different height and radius. The front truss was 62 ft high with a 54-ft, 3-in. radius and the back truss was 42 ft high with a 35-ft, 11-in. radius. Each piece of steel fit at a compound angle. Workers had to spend a lot of time and pay close attention to detail in the fabrication of the trusses because x, y, and z coordinates all had to be taken into consideration. The angles had to be right the first time, because once welded together the trusses could not be refitted and rechecked due to their size. One of the main challenges for the welders was that nearly all field welding took place above ground using a Zoom Boom telescoping handler — Fig. 2.

Final positioning of the preassembled trusses required a 360-ton crawler crane. Positioning required a 160-ft lift radius, because of an underground parking structure that was in the way. When the trusses were ready to erect, the 360-ton crawler lifted the pieces into position and the ironworkers set them in place — Figs. 3, 4. Because of the quality of fabrication, there were almost no alignment problems.

Improving the Sound

The shell is designed to be load-bearing so in addition to the trusses, bracing has been added to help support the weight of all the high-tech sound and lighting equipment. The Bowl's design features an acoustical ring that will allow sound engineers to fine-tune the quality of the sound — Fig. 5. This should eliminate the acoustical problems of the past. The acoustical ring is mounted on a pulley system and can be raised and lowered as needed.

The stage area of the new Hollywood Bowl is 30% larger than the 1929 structure. Not only is the stage floor larger, but the entire structure is significantly bigger to the point that the old shell could have easily fit inside the new one. The new Hollywood Bowl incorporates modern technology while retaining the beauty and tranquility of its surroundings. Now that it is complete, the Hollywood Bowl should continue as a Los Angeles landmark for at least another 70 years. •
Welding the World’s Strongest Linepipe in Arctic Conditions

X120 pipe is 50% stronger than standard gas transmission pipe, but needs special welding procedures

BY ROSS HANCOCK

To field test its experimental X120 steel linepipe, ExxonMobil wanted to prove the pipe’s compatibility with standard construction practices for natural gas transmission.

“They wanted to use a normal contractor using normal welders,” said Brian Laing, president of CRC-Evans, Houston, Tex., the company that helped develop welding procedures for the new pipe.

But its hard to believe there’s anything
normal about the welders from Louisbourg Contractors of Mississauga, Ontario, who spent late January and early February near the top of the world, in northern Alberta, joining a mile of the new pipe. These extraordinary workers successfully established that a new generation of ultra-strong pipe can be put into use in the most challenging of environments.

The X120 steel, with a yield strength of 120 ksi, making it the world's strongest commercialized pipeline material by a margin of 50%, was jointly developed by ExxonMobil, Nippon Steel Corp., and Mitsui & Co. Current gas transmission pipelines are made from X60, X70, or X80 steel, with yield strengths of 60, 70, or 80, respectively.

Stronger pipe steel means more gas can be delivered through a pipeline at higher pressure. Reduced pipe wall thickness adds to the increased throughput.

Prior to last winter's field test, the X120 steel was subjected to extensive testing at CRC-Evans to prove its mettle and to develop girth welding procedures that could match the base metal's strength. Welds were burst-tested at -40°C. Welds were made in pipes that were intentionally misaligned. Surface-breaking, fatigue pre-cracked defects were introduced into the root sides of the welds, and the joined pipes were loaded to the point of failure.

In all the tests, the welds had enough fracture toughness and defect tolerance to hold up to stresses approaching the tensile strength of the pipe material.

The team developed and tested new welding consumables for the high-strength pipe. Laing recalls that it was the 29th candidate welding wire that finally delivered the required performance. The special composition of the weld metal creates a unique "dual phase" microstructure that ExxonMobil engineers call "AFIM" (acicular ferrite interspersed in martensite), which provides a uniform dispersion of a soft phase (acicular ferrite) in a matrix of harder constituents (mostly lath martensite and degenerate upper bainite).

Laing said the welding procedures utilize the "next level of technology in welding equipment." In the Canadian wilderness, this high-tech equipment was placed on sleds and pulled by tractors alongside the mile of preplaced pipes. Mobile welding sheds were lowered over the joints by cranes. After pipe-facing, a root pass would be made with an internal welding machine (which incorporates alignment machinery) using a short circuiting transfer gas metal arc welding process. The hot pass, fill passes, and cap pass were made using CRC-Evans' microprocessor-controlled automatic welding machines, which can be operated by a remote pendant. The machines can be equipped with a joint-tracking technology that sees through the arc to follow the bevel.

Pipeline owner TransCanada Pipelines Ltd., Calgary, Alberta, reports that the mile of X120 pipeline, the strongest gas transmission line in the world, was installed with lower-than-normal weld defect rates, and is operating successfully as part of a longer pipeline-looping operation, delivering natural gas from northwestern Canada to markets all over North America.
When discussing Ni-based alloy filler metals frequently used for piping and pressure vessels by refineries, chemical plants, and power plants, one must start with dissimilar joints such as welding 300 Series austenitic stainless steels to carbon and low-alloy steels and also consider weld cladding operations.

For Dissimilar Welds, E310 Is a Poor Choice and E309 Has Limited Applications

Initially, Type E310 (~25%Cr-20%Ni) electrodes were used for such applications. They were easy to use, had welder appeal, and the amount of dilution was not very critical. However, many such welds failed in service because the inherent microfissuring of these fully austenitic deposits propagated into cracks when subjected to thermal stresses caused by the large differences in coefficients of thermal expansion (CTE). By replacing the E310 with E309 (~23%Cr-13%Ni), a stainless steel with some ferrite, the micro-fissuring problem was reduced or even eliminated, but these joints are more dilution sensitive. However, since they retain the large differences in CTE, users were concerned with high stresses and possible thermal fatigue along the ferritic-to-austenitic steel weld interface when the weld was subjected to a heat treating operation and/or to high temperature (>320°C/600°F) service.

The 600 Series Comes on the Scene

The 600 Series Ni-alloy filler metals (~72%Ni, 15%Cr, 8%Fe), which are also known as INCONEL®, have a CTE about halfway between ferritic and austenitic steels. This reduces the thermal stresses by dividing them between two weld interfaces. They are also less sensitive to dilution problems and microfissuring. In the discussion of these Ni-alloys, trade name designations and AWS/ASME classifications are used. When the latter start with an “E” they refer to coated electrodes for the SMAW process; when they start with “ER”, they refer to rods and bare wire used for gas metal arc, gas tungsten arc, and submerged arc welding processes.

The use of NiCrFe filler metals started with INCO-WELD-A® (ENiCrFe-2) and INCO-ROD-A® now called Filler Metal 92 or INCONEL® 92 (ERNiCrFe-6). While both of these materials fulfilled their intended objective, both presented some new problems. The coated electrode had little welder appeal since its weld pool was not very easy to control; this has since been improved by a modification of the secondary chemicals and by the introduction of Filler Metal (INCONEL®) 182 (ENiCrFe-3). The composition of the Filler Metal (INCONEL®) 92 bare wire made the deposit subject to age hardening when exposed to heat treatment or service temperatures >700°C/1300°F, which increased strength but decreased ductility. For most applications, this wire has been replaced by Filler Metal (INCONEL®) 82 (ERNiCr-3), which does not age harden.

Corrosion and Temperature Sensitivity

Weld deposits containing high Ni-to-Cr ratios are more susceptible to sulfur corrosion when subjected to temperatures >370°C/700°F. This ratio and the risk of sulfur corrosion have been lowered by selecting alloys that contain more Cr and/or some Mo, such as Alloy 671 with ~44% Cr (ERNiCr-4) and Alloy 625 with ~22%Cr and 9%Mo (ENiCrMo-3 and ERNiCrMo-3). However, currently, Alloy 671 has only been AWS/ASME classified as a bare wire filler metal and Alloy 625 filler metals should not be used for service at temperatures >540°C/1000°F, since the deposits tend to embrittle with time. For applications up to 1000°C/1830°F, Type 617 alloy coated and bare wire filler metals with Co additions (ENiCrCoMo-1 and ERNiCr-CoMo-1) have been developed.

Two Other Nickel Alloys

In addition to some of the 600 Series al-
Table 1 — Typical or Nominal Chemical Compositions of Filler Metals

<table>
<thead>
<tr>
<th>AWS Class Filler Metals</th>
<th>Common Name</th>
<th>Ni%</th>
<th>Cr%</th>
<th>Mo%</th>
<th>Other %</th>
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<tr>
<td>E and ER309</td>
<td>309</td>
<td>13</td>
<td>23</td>
<td>-</td>
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<tr>
<td>E and ER310</td>
<td>310</td>
<td>20</td>
<td>25</td>
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<td>-</td>
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<tr>
<td>ENiCrFe-2</td>
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<td>65</td>
<td>15</td>
<td>-</td>
<td>Mn 2</td>
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<td>ERNiCrFe-6</td>
<td>92</td>
<td>65</td>
<td>15</td>
<td>-</td>
<td>Ti 3</td>
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<tr>
<td>ENiCrFe-3</td>
<td>182</td>
<td>65</td>
<td>15</td>
<td>-</td>
<td>Mn 7</td>
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<tr>
<td>ERNiCr-3</td>
<td>58</td>
<td>65</td>
<td>20</td>
<td>-</td>
<td>-</td>
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<td>ERNiCr-4</td>
<td>671</td>
<td>55</td>
<td>44</td>
<td>-</td>
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<td>E and ERNiCrMo-3</td>
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<td>65</td>
<td>22</td>
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<td>-</td>
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<td>Cu 70</td>
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<tr>
<td>E and ERCuNi</td>
<td>187</td>
<td>30</td>
<td>-</td>
<td>-</td>
<td>-</td>
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</tbody>
</table>

lohs, two other groups of Ni-alloy filler metals are of primary interest when dealing with refineries, chemical plants, and utilities. The 800 Series Ni-alloys, also known as INCONEL® (-33%Ni, 21%Cr, and Fe) have a number of base metal applications. Since AWS/ASME has not classified a matching filler metal, these alloys are usually welded with some of the 600 Series NiCrFe filler metals (INCONEL®), which are quite compatible. However, in Europe a number of near matching Alloy 800 type filler metals have been developed and are accredited by some regulatory agencies.

The 400 Series Ni-alloys, also known as MONEL® (-65%Ni and 30%Cu), are provided with matching filler metals. After years of development, we are now using the 7th composition (ENiCu-7 and ERNiCu-7) to weld Alloy 400 to itself, to different steels, and to other nickel alloys. However, here we must provide a word of caution. One supplier uses the term MONEL® for two quite different alloys.

In addition to the Ni-Cu alloy mentioned above, one supplier also uses this term for a copper-nickel alloy (~70%Cu and 30%Ni), which AWS/ASME classifies as ECuNi and ERCuNi. To prevent mix-ups, it is suggested that people use the applicable AWS/ASME classification or that suppliers rename the filler metals “NiCu-Monel” and “CuNi-Monel.”

Versatility of Ni-alloy Filler Metals

More than 60 Ni-alloy filler metals have been classified by AWS/ASME, and more are pending. Many are designed to meet specific or special requirements that do not usually apply to piping and pressure vessels. However, the versatility of Ni-alloy filler metals continues to make them valuable for a variety of industrial applications.

Acknowledgments

The author wishes to thank Ni-alloy filler metal experts Mr. R. Fuchs, Mr. S. Kiser, and Dr. F. Winsor for their constructive review of this paper.
Backup Purging of Root Welds

For certain alloys or for high-purity applications, exposure to air at the back side of the weldment can contaminate the weld when making the root pass. To avoid this problem, the air must be purged from this region. Argon, helium, and nitrogen are commonly used gases for backup purging. Gas flow requirements for the purge may range from 0.5 to 42 L/min (1 to 90 ft³/h) based on the volume of air to be purged. As a general rule, a relatively inert atmosphere can be obtained by flushing the area with four times the volume to be purged. After purging is completed, the flow of backup gas during welding should be reduced until only a slight positive pressure exists in the purged area. After the root and first filler passes are completed, the backup purge may be discontinued, depending on quality requirements.

Several devices are available to contain shielding gas on the back side of plate and piping weldments. One of those devices is shown in Fig. 1. When purging piping systems, provisions for an adequate vent or exhaust with baffles to contain the purge gas are important to prevent excessive pressure buildup during welding. The dimensions of the vents through which the backup gas is exhausted to the atmosphere should be at least equal to the dimensions of the opening through which the gas is admitted to the system. Care must be taken to ensure the backup purge pressure is not excessive when welding the last inch or two of the root pass to prevent weld pool concavity or blowout.

When using argon or nitrogen the backup gas should enter the system at a low point to displace the atmosphere upward and should be vented at points beyond the joint to be welded. In piping systems with several joints, all joints except the one being welded should be taped to prevent gas loss.

Manual welding of reactive metals can be facilitated if the entire weldment is placed in a controlled-atmosphere chamber. Purging is started after the assembly is placed in the chamber. Readings are taken from instruments that analyze oxygen, nitrogen, and water vapor to ensure contaminants are at a low level before welding is started.

For some metals a trailing shield is necessary if chambers or other shielding techniques are not available or practical. A trailing shield (Fig. 2) is a device that directs the flow of shielding gas so that it provides inert gas coverage over the weld area until the molten weld metal has cooled to the point that it will not react with the atmosphere. Fixed barriers (Fig. 3) also aid in containing shielding gas within the area immediately surrounding the electrode.

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The Navy Joining Center (NJC) completed a Navy MANTECH project with the Air Force and Composite Affordability Initiative (CAI) to characterize manufacturing variables that affect adhesive bonding for composite joints used in the fabrication of primary aircraft structures. The project developed adhesive joint mechanical property data that quantify the effects of manufacturing variability in adhesive bonded systems to meet Navy aircraft service requirements for bonding composite structures. This project was accomplished by several airframe manufacturers and Edison Welding Institute (EWI).

The use of adhesive bonding for primary aircraft structures has the potential to save significant weight and cost over conventionally riveted or bolted joint designs. New bonded joint designs have been developed that minimize peel stresses and provide a more robust joint as part of the Core Technology Plan for the CAI program. The joint, commonly referred to as a Pi (π) or tongue-and-groove joint, includes male and female sections bonded with an adhesive. This type of joint is more tolerant to damage and flaws than other composite joint designs. The joints are lighter and less expensive to fabricate than conventional mechanically fastened joints.

The target applications for this joint include skin-to-ribbed box composite subassemblies requiring both structural and closeout connections. Even though the Pi-joint configuration has the potential to improve the performance of adhesively bonded joints, fabrication issues were addressed in the project to ensure that the bonded joints can be reliably manufactured for primary structures. This project complemented earlier CAI activity by addressing manufacture "scale-up" and testing of adhesive-bonded joints under operational conditions. Large Pi-joint fabrication test elements were manufactured using a range of process variables. Test specimens were produced from the large Pi-joint test elements in sufficient numbers to provide data on shear loading, combined-angle loading, and fatigue performance.

A number of manufacturing variables were identified by the airframe manufacturers and tests were performed quantifying their effects on adhesive-bonded joints. The manufacturing variables investigated for adhesive bonding included surface preparation, bond line thickness, offset web, porosity, and impact damage. These results have been released to the Navy, Air Force, and the CAI community. Some data developed early in the project were used by designers for bonding of composite structures in the Joint Strike Fighter (JSF) program. Figure 1 shows the application of bonding technology on the JSF inlet duct assembly. Flight testing continues for other applications for advanced aircraft structures.

The results of this project support the Navy and Air Force requirements for future adhesive-bonded aircraft structures for enhanced performance and reduced operation costs. Cost savings of 60-70% are being realized in assembly operations in bonded structures. In addition, the CAI has been provided with data to support certification efforts, design specifications, and manufacturing processes to aid in maturing the technology.

The CAI analysis tools have benefited from new bonding data that enable improved accuracy with reductions in testing and analysis time. As the reliability of adhesive bonding is confirmed, both the Navy and the airframe manufacturers will encourage the use of this joining technology for primary structures.

For more information, contact George Ritter at (614) 688-5199, george.ritter@ewi.org, or Larry Brown at (614) 688-5080, larry_brown@ewi.org.

Fig. 1 — Cost savings of 60% are being realized in the adhesive assembly of these JSF F-35 composite inlet duct structures.


American Ceramics Society Meetings, Aug. 23-27, Conference on Ferrites, San Francisco, Calif.; Sept. 12-16, Pacific Coast Regional and Basic Science Division meeting, Seattle, Wash.; Sept. 12-16, International Conference on High-Temperature Ceramic Matrix Composites, Seattle Wash.; Nov. 7-11, Glass and Optical Materials Division full meeting, Cocoa Beach, Fla. Contact: customersrv@acers.org; or www.ceramics.org.


6th Pacific/Asia Offshore Mechanics Symposium, Sept. 12-16, Vladivostok, Russia. Sponsored by the International Society of Offshore and Polar Engineers. For more information, contact www.isope.org; or meetings@isope.org.

Overcoming the Problems of Dissimilar Metal Joining Conference, September 14-15, New Orleans, La. Considered will be laser beam, friction stir, magnetic pulse, and inertia welding, as well as transition joints to join aluminum to steel, and diffusion and adhesive bonding as alternatives. Contact: AWS Conference Department, (305) 443-9353, ext. 449 or e-mail conf@aws.org.


26th Annual Industrial Ventilation Conferences, Oct. 20-23, Birmingham, Ala. Sponsored by the University of Alabama at Birmingham, and University of Nevada at Las Vegas. For complete information contact (205) 934-8994; www.eng.uab.edu/epd.

Tube China 2004, Oct. 25-28, Shanghai New International Expo Center, Shanghai, China. Contact: Messe Düsseldorf North

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9th Beijing Essen Welding & Cutting Fair. Nov. 10–13, China International Exhibition Centre, Beijing, China. Cosponsored by the German Welding Society (DVS) and the Chinese Mechanical Engineering Society (CMES). Contact: suzy@cmes.org, or www.cmes.org/gshendon/aisen/index/aisen1.htm.


JOM-12, Twelfth International Conference on the Joining of Materials, and Fourth International Conference on Education in Welding. March 20–23, 2005, Helsingør, Denmark. Contact Institute for the Joining of Metals, telephone: +45 46355458; e-mail: jom_aws@post10.tele.dk.


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Welding Technology Workshop. July 1, Ball State University, Muncie, Ind. For everyone interested in welding. Fee $25. Contact Ed Wyatt at wyatt.w@worldnet.att.net, (317) 576-6420, ext. 303.

Fundamentals of Visual Inspection. July 7, Sept. 8. Classes held at Hobart Institute of Welding Technology, Troy, Ohio. For further information and 2004 schedules, call (800) 332-9448 or e-mail hiwt@welding.org; www.welding.org.


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Blacksmithing Indiana State Fair. Aug. 11-22, Indianapolis, Ind., McKenzie Career Center, Robert Dalrymple Blacksmithing Shop. Contact Ed Wyatt at wyatt.w@worldnet.att.net; (317) 576-6420, ext. 303.

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Women's Welding Workshop and Retreat. September 5-11, Spitfire Forge, Taos, N.Mex. This hands-on welding and blacksmithing workshop includes all materials, field trips, lodging, and meals. Contact: Christina Sporrong at spitfire4rg@yahoo.com or visit the Web site www.spitfireforge.com for complete information.

Cold Spray 2004 Technology Workshop. Sept. 27-28, Hilton Hotel, Akron (Fairlawn), Ohio. Emphasis on aerospace, defense, gas turbines, and automotive. Sponsored by ASM International. For reservations or more information, contact Joanne Miller (800) 336-5152, ext. 6; jimiller@asminternational.org; or visit www.asminternational.org/events.

ASME International — Section IX Seminars. Oct. 4-6, Pittsburgh, Pa. A three-day seminar covers writing, qualifying welding procedures, and qualifying welders. Emphasis is on meeting Code requirements economically while providing useful direction to welders. Impact tested qualification and brazing are also covered. For information, visit www.asme.org/pro_dev.

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<td>Anchorage, Alaska</td>
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<td>Sept. 18</td>
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<td>Oct. 31–Nov. 5</td>
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<tr>
<td>(API 1104 Clinic also offered)</td>
<td></td>
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<tr>
<td>Milwaukee, Wis.</td>
<td>Sept. 26–Oct. 1</td>
<td>Oct. 2</td>
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<tr>
<td>(API 1104 Clinic also offered)</td>
<td></td>
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<tr>
<td>Minneapolis, Minn.</td>
<td>Sept. 19–24</td>
<td>Sept. 25</td>
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<tr>
<td>(API 1104 Clinic also offered)</td>
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<tr>
<td>New Orleans, La.</td>
<td>Sept. 12–17</td>
<td>Sept. 18</td>
</tr>
<tr>
<td>(API 1104 Clinic also offered)</td>
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<tr>
<td>New Orleans, La.</td>
<td>Sept. 13–18</td>
<td>9-Year Recert Course</td>
</tr>
<tr>
<td>Orlando, Fla.</td>
<td>July 11–16</td>
<td>July 17</td>
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<tr>
<td>(API 1104 Clinic also offered)</td>
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<tr>
<td>Orlando, Fla.</td>
<td>Nov. 15–20</td>
<td>No Test</td>
</tr>
<tr>
<td>9-Year Recert Course</td>
<td></td>
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<tr>
<td>(API 1104 Clinic also offered)</td>
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<tr>
<td>Phoenix, Ariz.</td>
<td>Oct. 3–8</td>
<td>Oct. 9</td>
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<td>(API 1104 Clinic also offered)</td>
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<tr>
<td>(API 1104 Clinic also offered)</td>
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<tr>
<td>Portland, Mainc</td>
<td>July 25–30</td>
<td>July 31</td>
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<tr>
<td>(API 1104 Clinic also offered)</td>
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<tr>
<td>Portland, Ornc.</td>
<td>Nov. 7–12</td>
<td>Nov. 13</td>
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<tr>
<td>(API 1104 Clinic also offered)</td>
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<tr>
<td>Reno, Nev.</td>
<td>Oct. 31–Nov. 5</td>
<td>Nov. 6</td>
</tr>
<tr>
<td>(API 1104 Clinic also offered)</td>
<td></td>
<td></td>
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<tr>
<td>Rochester, N.Y.</td>
<td>EXAM ONLY</td>
<td>Aug. 21</td>
</tr>
<tr>
<td>Sacramento, Calif.</td>
<td>Aug. 8–13</td>
<td>Aug. 14</td>
</tr>
<tr>
<td>(API 1104 Clinic also offered)</td>
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<tr>
<td>Sacramento, Calif.</td>
<td>Oct. 4–9</td>
<td>No Test</td>
</tr>
<tr>
<td>9-Year Recert Course</td>
<td></td>
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<tr>
<td>St. Louis, Mo.</td>
<td>EXAM ONLY</td>
<td>Dec. 4</td>
</tr>
<tr>
<td>Salt Lake City, Utah</td>
<td>July 18–23</td>
<td>July 24</td>
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<tr>
<td>(API 1104 Clinic also offered)</td>
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<tr>
<td>(API 1104 Clinic also offered)</td>
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<td></td>
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<tr>
<td>San Diego, Calif.</td>
<td>Sept. 19–24</td>
<td>Sept. 25</td>
</tr>
<tr>
<td>(API 1104 Clinic also offered)</td>
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<tr>
<td>San Juan, P.R.</td>
<td>Dec. 5–10</td>
<td>Dec. 11</td>
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<tr>
<td>(API 1104 Clinic also offered)</td>
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<tr>
<td>Seattle, Wash.</td>
<td>Sept. 19–24</td>
<td>Sept. 25</td>
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<tr>
<td>(API 1104 Clinic also offered)</td>
<td></td>
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<tr>
<td>Sioux Falls, S.Dak.</td>
<td>Nov. 14–19</td>
<td>Nov. 20</td>
</tr>
<tr>
<td>(API 1104 Clinic also offered)</td>
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<tr>
<td>(API 1104 Clinic also offered)</td>
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</tbody>
</table>

An Important Event on Its Way?

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

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

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

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

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

For specifics on the nomination requirements, please contact Wendy Sue Reeve at AWS headquarters in Miami, or simply follow the instructions on the Counselor nomination form in this issue of the Welding Journal. The deadline for submission is February 1, 2005. The committee looks forward to receiving these nominations for 2006 consideration.

Sincerely,

H. E. Cable
Chairman, Counselor Selection Committee
CLASS OF 2006
COUNSELOR NOMINATION FORM

DATE ________________________ NAME OF CANDIDATE ____________________________

AWS MEMBER NO. __________________________ YEARS OF AWS MEMBERSHIP __________

HOME ADDRESS __________________________

CITY __________________________ STATE ______ ZIP CODE ______ PHONE ______

PRESENT COMPANY/INSTITUTION AFFILIATION __________________________

TITLE/POSITION __________________________

BUSINESS ADDRESS __________________________

CITY __________________________ STATE ______ ZIP CODE ______ PHONE ______

ACADEMIC BACKGROUND, AS APPLICABLE:

INSTITUTION __________________________

MAJOR & MINOR __________________________

DEGREES OR CERTIFICATES/YEAR __________________________

LICENSED PROFESSIONAL ENGINEER: YES ______ NO ______ STATE ______

SIGNIFICANT WORK EXPERIENCE:

COMPANY/CITY/STATE __________________________

POSITION __________________________ YEARS __________________________

COMPANY/CITY/STATE __________________________

POSITION __________________________ YEARS __________________________

SUMMARIZE MAJOR CONTRIBUTIONS IN THESE POSITIONS:

________________________________________________________________________

SUGGESTED CITATION (50 TO 100 WORDS, USE SEPARATE SHEET) INDICATING WHY THE NOMINEE SHOULD BE SELECTED AS AN AWS COUNSELOR. IF NOMINEE IS SELECTED, THIS STATEMENT MAY BE INCORPORATED WITHIN THE CITATION CERTIFICATE.

**MOST IMPORTANT**

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

SUBMITTED BY:

PROPOSER __________________________ Print Name __________________________

AWS Member No. __________________________

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

NOMINATING MEMBER: __________________________ Print Name __________________________

AWS Member No. __________________________

NOMINATING MEMBER: __________________________ Print Name __________________________

AWS Member No. __________________________

NOMINATING MEMBER: __________________________ Print Name __________________________

AWS Member No. __________________________

NOMINATING MEMBER: __________________________ Print Name __________________________

AWS Member No. __________________________

SUBMISSION DEADLINE FEBRUARY 1, 2005
Nomination of AWS Counselor

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

To be eligible for appointment, an individual shall have demonstrated his or her leadership in the welding industry by one or more of the following:
- Leadership of or within an organization that has made a substantial contribution to the welding industry. (The individual’s organization shall have shown an ongoing commitment to the industry, as evidenced by support of participation of its employees in industry activities such as AWS, IIW, WRC, VICA, NEMA, NSRP SP7 or other similar groups.)
- Leadership of or within an organization that has made substantial contribution to training and vocational education in the welding industry. (The individual’s organization shall have shown an ongoing commitment to the industry, as evidenced by support of participation of its employees in industry activities such as AWS, IIW, WRC, VICA, NEMA, NSRP SP7 or other similar groups.)

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

III. NUMBER OF COUNSELORS TO BE SELECTED
Maximum of 10 Counselors selected each year.

Return completed Counselor nomination package to:
Wendy S. Reeve
American Welding Society
550 N.W. LeJeune Road
Miami, FL 33126
Telephone: 800-443-9353, extension 293

SUBMISSION DEADLINE: February 1, 2005
Welding students at Triangle Technical School, Pittsburgh, Pa., are using their welding skills to help restore the USS Requin, a 59-year-old submarine active for 30 years during the Cold War. Now dry docked, she serves as a major attraction for the hundreds of visitors to the Carnegie Science Center in Pittsburgh.

The Requin was unsafe for visitors when she arrived at the Center in 1990. Before being opened to the public, she had to be fitted with a new deck using many of the original supports. But down below, the ravages of time, rust, and corrosion had taken their toll, and major structural supports were failing.

Triangle Tech Student Chapter Advisor Donald A. Kowalski said, "Therefore, to eliminate the risk of injury to visitors, the Carnegie Science Center and Triangle Technical School decided to add new supports to the existing framework beneath the deck. But before the students are allowed to work on this project, they are required to take extensive detailed measurements, prepare design plans and templates, and devise a detailed course of action." This is not a simple undertaking. Welding instructors, engineers, and other professionals are consulted to verify the planned work complies with the applicable construction standards and codes.

American Bridge Co. and Vince's Gas and Welding are generously donating the materials and equipment required by the Chapter members to do the job. The restoration begun last summer will go on for many years.

The students have found the project to be a positive and enjoyable experience for many reasons. Bill Caronni said, "It is an excellent opportunity for us to use our skills in design and fabrication on a project that not only benefits us, but also the community."

Taylor Knepper noted, "It gives me a chance to leave my work on a site that will be seen by thousands of people."

Welding student Chris Ruffner added, "Because of the top-notch training I have received from my instructors at Triangle Tech, I am very confident to go into the workforce to be a knowledgeable and productive employee. This project provides a hands-on experience in a real working environment."

Proud to be associated with the newly chartered AWS Student Chapter and its important project are Jeff Mask, president; Lisa Groves, vice president; Bill Kraft, secretary; Al Moen, treasurer; and advisor, Donald A. Kowalski, who keeps the project moving along.

Commissioned April 28, 1945, at Portsmouth Naval Shipyard, N.H., the USS Requin was built to be a formidable fighting machine — but she never fired a shot in anger. Requin left Portsmouth with ten torpedo tubes and 24 torpedoes. She boasted a range of 11,000 miles, and could go up to 90 days without refueling and could run 48 hours submerged. On the surface, its diesel engines moved her at 21 knots; underwater she cruised at 8 knots using battery power to drive the two screws. The Requin served most of her active life as a radar "picket" submarine, guarding the sea lanes. When she finally was called to active duty at Pearl Harbor, Hawaii, she arrived just in time for her crew to learn that WW II was over.

Now the Requin, a shadow of her former self, gives students a chance to learn, and they in turn are welding new life into her aging frame.
The American Welding Society has honored 12 of its members by conferring on them the titles of Fellow and Counselor to recognize their outstanding accomplishments. The new Fellows and Counselors were officially inducted at the AWS Annual Meeting held April 5 during the AWS Expo in Chicago, Ill.

In 1990, AWS established the Fellow of the Society designation to recognize AWS members for distinguished contributions to the field of welding science and technology, and for promoting the professional stature of welding. The 2004 Class of Fellows are as follows:

- **F. Michael Hosking** for his sustained research and achievements leading to improvements in the understanding of soldering technology.

- **Samuel D. Kiser** for his teaching skills and expertise in the field of welding nickel alloys.

- **Radovan Kovacevic** for his outstanding achievements in developing high-speed machine vision and arc sensing in welding technology.

Dr. **Peter W. Marshall** for his work in welded connections in the area of complex large tubular structures.

Dr. **Charles V. Robino** for his significant contributions to the field of welding metallurgy in a wide range of engineering alloys.

The Counselors Selection Committee elected the following members to the 2004 Class of Counselors. Each is recognized for his distinguished organizational and leadership skills, which has enhanced the image and impact of the welding industry. The 2004 Class of Counselors follows:

- **Jack R. Barckhoff** for his career of more than 50 years promoting welding as an engineering science, helping individuals, companies, and the welding community to improve welding quality and productivity.

- **Richard W. Couch, Jr.** for his dedication to progress in welding technology, especially in plasma arc cutting and welding, and for his leadership in the development of many products that have benefited the welding industry.

- **Jack Dammann** for his contributions and long history as an employer and a community leader, noted for his personal involvement promoting quality education and its positive effects on the general public and welding community.

- **Alfred F. Fleury** for his enthusiasm and leadership as a lively and incisive communicator, highly regarded for his welding-related expertise.

- **Rudolph Murray** who has enhanced the image of welding as a mentor dedicated to the welding community.

- **Ronald C. Pierce** for his tireless promotion of the welding industry with his positive attitude and persistence in getting every job done.

- **F. R. Bob Schneider, Jr.** for his management skills, and highly regarded opinions and recommendations.

For more information on the AWS Awards program, contact Wendy Sue Reeve at (800) 443-9353, ext. 293; wreeve@aws.org.
**Call for Papers**

The AWS Technical Papers Committee seeks papers on topics related to welding and joining of products and components for pipeline and energy applications for presentation next year.

Authors are invited to submit a 500 to 1000-word abstract by July 30, 2004, to be considered for presentation at the 2005 Symposium on Welding for Pipeline and Energy Applications.

This two-day symposium will take place during the 53rd Annual AWS Welding Show, April 26-28, 2005, at the Dallas Convention Center, Dallas, Tex.

Papers are sought on original experimental investigations, theoretical and statistical modeling, and applications in welding and joining for pipeline and energy applications.

Typical topics will include properties and structural integrity of weldments, design and manufacture of welded structures, corrosion of weldments, NDE of weldments, weldability of high-strength steel and aluminum alloy pipelines, weld phase transformations and microstructures, welding of dissimilar materials and joining of graded materials, welding processes and procedures, innovative welding consumables, sensing, control and automation, computer modeling and simulation, advanced and alternative joining technologies, robotics and automation, and application studies.

Visit [www.aws.org/conferences](http://www.aws.org/conferences), click the Call for Papers icon, then download the Technical Program Abstract Submission Form.

For more information, contact Dorcas Troche, manager, conferences and seminars, at dorcas@aws.org, or (800) 443-9353, ext. 313.

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**District 21 Conference Meets in Palm Springs**

Shown at the District 21 Conference held May 15 in Palm Springs, Calif., are (back row, from left) W. Sarin (Long Beach/Orange County), J. Fitzpatrick (Arizona), R. Schneider (San Diego), J. Hollenberg (Hawaii), Mrs. E. Schneider (San Diego), Mrs. N. Samanich (Nevada), R. Jablonski (Hawaii), G. Lawson (AWS Vice President), R. Gibson (Los Angeles/Inland Empire), T. Mustaleski (AWS President 2003-04), G. Niday (Kern), R. Samanich (Nevada), A. Davis (AWS Managing Director Technical Services), H. Jackson (Los Angeles/Inland Empire), S. Luiz (California Central Coast); (front row, from left) G. Watkins (San Fernando Valley), L. Gustafson (Long Beach/Orange County), J. Compton (San Fernando Valley), M. Welsh (Kern), B. Callender (San Fernando Valley), and M. Jaquez (Los Angeles/Inland Empire).

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**AWS Expands Its Mission Statement**

Eighty-five years after its founding, the American Welding Society expanded its mission statement to reflect more accurately its wide variety of member interests. The new statement follows:

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

The six months of strategic planning that resulted in the mission statement change also created 13 new Society initiatives affecting welding education and training programs, and the development of international standards.

**Livellink® Puts Technical Committees Online**

Livellink® software from Open Text Corp. has been implemented by the AWS Technical Department to dramatically streamline the technical standards development process. The new program not only serves as a repository for committee documents, but permits documents and ballots to be circulated quickly. Another major advantage is it permits Technical Committees to meet online using the companion software Livellink MeetingZone®.

Now, data can be disseminated both in real time and as-needed by committee members. It offers a long-awaited alternative to circulating lengthy e-mail attachments, which have caused delivery problems from firewall settings and e-mail account sizes.

Technical documents in-process are now stored on the AWS e-committees secure server. The volunteers are directed to the server to download relevant information at their convenience.

Livellink® is well suited for standards development and other teamwork-related activities that require individuals from various parts of the world to exchange ideas and develop consensus.

Andrew Davis, managing director, AWS Technical Services Division, said, "We have received positive feedback from a number of committee members who are impressed with its features."

For more information on the AWS Technical Committees activities, contact Andrew Davis at adavis@aws.org; (800) 443-9353, ext. 466. For more information on the new software, visit [www.opentext.com/livelink](http://www.opentext.com/livelink).
Listed below are participants in the 2003-2004 Member-Get-A-Member Campaign. For campaign rules and a prize list, see page 87. For more information, call the Membership Department at (800) 443-9353, ext. 480.

**Winner’s Circle**

AWS Members who have sponsored 20 or more new Individual Members per year, since June 1, 1999. ( ) Denotes the number of times the member has earned Winner’s Circle status.

J. Compton, San Fernando Valley (4)
E. H. Ezell, Mobile (2)
J. Merzthal, Peru (2)
B. A. Mikeska, Houston (1)
R. L. Peaslee, Detroit (1)
W. L. Shreve, Fox Valley (1)
G. Taylor, Pascagoula (2)
S. McGill, Northeast Tennessee (1)
T. Weaver, Johnstown/Altoona (1)
G. Woomer, Johnstown/Altoona (1)
R. Wray, Nebraska (1)

**President’s Guild**

AWS Members sponsoring 20 or more new Individual Members between June 1, 2003, and May 31, 2004.

**President’s Roundtable**


R. Purvis, Sacramento — 14
G. Taylor, Pascagoula — 13
P. Evans, Chicago — 12
T. Hart, Mobile — 12

**President’s Club**


K. Baucher, Fresno — 10
C. Daily, Puget Sound — 9
J. Powell, Triangle — 9
W. Drake, Jr., Osark — 8
J. Compton, San Fernando Valley — 7
P. Walker, Ozark — 7

**President’s Honor Roll**

AWS Members sponsoring 1-5 new Individual Members between June 1, 2003, and May 31, 2004. Only those sponsoring 2 or more AWS Individual Members are listed.

R. Fontenot, Oklahoma City — 5
D. St.-Laurent, Northern Alberta — 5
B. Suckow, Northern Plains — 5
C. Wesley, Northwestern Pa. — 5
D. Wright, Kansas City — 5
S. Ahurca, Illinois Valley — 4
B. Diephuis, Detroit — 4
C. Dynes, Kern — 4
J. Smith, Columbus — 4
C. Boulden, North Texas — 3
K. Campbell, L.A./Inland Empire — 3
J. Cantlin, Southern Colorado — 3
C. Chilton, Osark — 3
R. Culbert, L.A./Inland Empire — 3
B. Franklin, Mobile — 3
J. Greer, Chicago — 3
S. Jamaluddin, Long Island — 3
T. Nichols, West Tennessee — 3
R. Norris, Maine — 3
H. Shore, Tulsa — 3
G. Ullman, Lakeshore — 3
C. Casey, Arizona — 2
S. Colton, Arizona — 2
A. DeMarco, New Orleans — 2
E. Duplantis, San Antonio — 2
S. Henson, Spokane — 2
R. Holman, Florida Space Coast — 2
R. Johnson, Detroit — 2
P. Krishnasamy, India — 2
T. Lettich, Sacramento — 2
S. Luis, Jr., Calif. Central Coast — 2
C. Morehouse, L.A./Inland Empire — 2
G. Mulee, Rochester — 2
J. O’Neal, Osark — 2
R. Painter, Holston Valley — 2
S. Schreckengost, Pittsburgh — 2
T. Shirks, Tidewater — 2
R. Stobahn, Jr., Carolina — 2
W. Strother, Lake Charles — 2
R. Warner, Utah — 2
M. Wilkes, Mahoning Valley — 2
R. Wright, Southern Colorado — 2
F. Wernet, Lehigh Valley — 19
J. Carey, Boston — 18
B. Chesney, Green & White Mts. — 17
T. Baldwin, Arrowhead — 16
J. Daughtery, Louisville — 16
R. Durham, Cincinnati — 16
A. Reis, Pittsburgh — 16
J. Hepburn, Johnstown-Altoona — 15
D. Roskiewich, Philadelphia — 15
M. Anderson, Indiana — 14
D. Vranich, North Florida — 14
W. Harris, Pascagoula — 13
T. Strickland, Arizona — 13
K. Ellis, Central Pennsylvania — 12
A. Badeaux, Washington D.C. — 12
W. Galvery, Long Beach/Orange Cty — 12
J. Miller, San Diego — 12
J. Smith, Jr., Mobile — 12
P. Walker, Osark — 12
D. Weeks, Southwest Virginia — 12
J. Boyer, Lancaster — 11
G. Putnam, Green & White Mts. — 11
R. Tupta, Jr., Milwaukee — 11
R. Williams, Osark — 11
M. Kochler, Milwaukee — 10
W. Komios, Utah — 10
J. Pelster, Southeast Nebraska — 10
A. Vidick, Wyoming — 10
D. Zabel, Southeast Nebraska — 10
J. Albert, Johnstown-Altoona — 9
H. Browne, New Jersey — 9
G. Gannull, Northeast Mississippi — 9
W. Johnson, Portland — 9
S. Colton, Arizona — 8
W. Howell, Sabine — 8
J. Mendoza, San Antonio — 8
J. Morash, Boston — 8
R. Rux, Wyoming — 8
J. Swoyer, Lehigh Valley — 8
J. Compton, San Fernando Valley — 7
A. Dommer, Kern — 7
R. Gallagher, Jr., Lehigh Valley — 7
C. Kipp, Lehigh Valley — 7
A. Oehou, San Francisco — 6
R. Richwine, Indiana — 6
M. Tryon, Utah — 6
J. Carney, Western Michigan — 5
J. Crosby, Atlanta — 5
T. Kienbaum, Colorado — 5
J. Livesay, Nashville — 5
A. Mattox, Lexington — 5
S. MacKenzie, Northern Michigan — 5
W. Miller, New Jersey — 5
H. Riviere, South Florida — 5
S. Williams, Central Arkansas — 5
J. Ciaramitaro, North Central Fla. — 4
R. Douglas-Wells, Atlanta — 4
E. Henry, L.A./Inland Empire — 4
S. Luis, Jr., Calif. Central Coast — 4
W. Menegus, Lehigh Valley — 4
J. Olivarez, Jr., Puget Sound — 4
D. Smith, Niagara Frontier — 4
W. Wilson, New Orleans — 4
Standards Notices

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

August 12. Technical Activities Committee. Columbus, Ohio. General meeting. Staff contact: Peter Howe, ext. 309.

Standards for PINS

Development work has begun on the following new or revised standards. Directly and materially affected individuals are invited to contribute to the development of such standards. Those wanting to participate may contact the Staff Engineer listed with the document.

Participation on AWS Technical Committees and Subcommittees is open to all persons.

B5.9:200X, Specification for the Qualification of Welding Supervisors. This standard establishes requirements for the qualification of welding supervisors. It describes how personnel are qualified, the principles of conduct, and the practice by which qualification may be maintained. Stakeholders: Employers and supervisors of welders. Revised standard. Engineer: Steve Hedrick, ext. 305.

D14.3/D14.3M:200X, Specification for Welding Earthmoving, Construction, and Agricultural Equipment. This specification applies to all structural welds used in the manufacture of earthmoving, construction, and agricultural equipment. It reflects the welding practices employed by manufacturers within the industry and incorporates various methods that have been proven successful by individual manufacturers. No restrictions are placed on the use of any welding process or procedure, provided the weld produced meets the qualification requirements of this specification. No attempt is made to limit or restrict technological progress in the welding of earthmoving, construction, and agricultural equipment, nor should any such limitation be inferred. Stakeholders: Manufacturers of earthmoving, construction, and agricultural equipment. Revised standard. Engineer: Peter Howe, ext. 309.

Standards for Public Review

The American Welding Society (AWS) was approved as an accredited standards-preparing organization by the American National Standards Institute (ANSI) in 1979. AWS rules, as approved by ANSI, require that all standards be open to public review for comment during the approval process. This column also advises of ANSI approval of documents. The following standards are submitted for public review. 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 (800/305) 443-9353, ext. 451, e-mail: roneill@aws.org.


ISO Draft Standards for Public Review

Copies of the following draft International Standard are available for review and comment through your national standards body, which in the United States is ANSI, 25 W. 43rd St., Fourth Floor, New York, NY, 10036; 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.


AWS Foundation Scholarship Update

The American Welding Society Foundation’s Harley Davidson Raffle raised more than $5500 to be used to fund welding scholarships to high school and college students. Robert Flores of La Porte, Ind., won the 1200 Custom Sportster Harley-Davidson motorcycle.

The drawing took place April 8 during the 2004 AWS Welding Show in Chicago, Ill.

AWS Foundation scholarships support the growth and development of the welding industry. In 2003, it awarded more than $400,000 in scholarships to 275 students. Financial support from companies and individuals in industry is crucial to the success of the programs.

Visit www.aws.org/foundation; or e-mail vpinsky@aws.org; or call (800) 443-9353, ext. 212, for information on AWS Foundation scholarships and programs.

Let AWS Help You Find a Job or an Employee

Jobfind, an AWS free service for job seekers, is the right place to start looking for a job, a better position, or hiring that needed employee. Here is the meeting place for welders, CWIs, engineers, technicians, welding managers, supervisors, and consultants.

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All job seekers enjoy free access to job listings specific to the materials joining industry. They can post a public or confidential résumé in a searchable database, and apply directly online for positions with prospective employers. They also can edit a résumé at any time and upload additional résumés without cost. Check out Jobfind first, it’s online at www.aws.org/jobfind.
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6162C 15th St. E
Bradenton, FL 34203

DDS, Inc.
4121 Wagon Trail Ave.
Las Vegas, NV 89118

ICON Shelter Systems, Inc.
7900 Logistic Dr., Ste. C
Zeeland, MI 49464

Educational Institutions
Blackstone Valley Regional Vocational Technical High School
65 Pleasant St.
Upton, MA 01568

Garden City High School C.C.
1412 N Main
Garden City, KS 67846

Middle East Industrial Training Centre
P.O. Box 32329
Mafrag, Abu Dhabi, U.A.E.

Senai Centro de Tecnologia de Solda Rua Sáo Francisco Xavier #601
Rio de Janeiro, RJ 20.550-011, Brazil

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As an AWS Sustaining Company Member you are entitled to have up to ten Individual Members on your company’s roster at no extra charge.
You can even add your customers to your roster as a special “thank you” to them.

AWS Welding Distributor Members enjoy five Individual Memberships (a $375 value), a listing on the Distributor Locator Map on the AWS Web site with a hyperlink to take visitors directly to their Web page.

Educational Institution Members receive three Individual Memberships. Each Member receives the Welding Journal and The American Welder publications, discounts on AWS publications and American Welder™ products.
To obtain member application forms or more information, contact AWS Membership Dept., (800) 443-9353, ext. 259; or e-mail: marthac@aws.org.

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1099 Highland Dr.
Ann Arbor, MI 48108

Affiliate Companies
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Fort Walton Beach, FL 32548

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1235 Washington Blvd.
Pittsburgh, PA 15206

PPB Fabrication, Inc.
1117 S Tripp Ave.
Odessa, TX 79763

R. J. Ilten
10170 Beech Ave.
Fontana, CA 92335

Robert Mitchell, Inc.
350 Decarie
St. Laurent, QC, Canada H4L 3K5

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Cincinnati, OH 45230

Sanweld Industries
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Worcester, MA 01610

Cryostar provides equipment solutions to the cryogenic industry, including centrifugal single- and multistage, reciprocating, turbo-expanders, boil-off gas compressors for industrial gas, LNG, and hydrogen applications. Its equipment features increased reliability, safety of operation, ease of installation, and reduced maintenance costs.

Metka S.A. has been a leading contractor in the energy and defense sectors in Greece for 35 years. With headquarters in Athens, it maintains two industrial facilities in Volos (in central Greece near the Volos port).

Metka employs more than 500 experienced and skilled personnel, including 120 highly qualified engineers with expertise in the fields of energy projects, sophisticated metal constructions, and defense projects.

ARC Specialties, founded in 1983, designs and builds automated manufacturing systems, robots, and custom equipment with emphasis on weld joining, overlay, cladding, cutting, and forming. ARC is a major supplier for engineering services, process development, systems integration, service, parts, and training. ARC Specialties has installed and supported systems worldwide. Its success in the marketplace is due to a combination of experience, reputation, equipment functionality, and cutting-edge technology.
Jim Cambell (right) and Tom Ferri, Boston Section chair, discuss the major welding projects needed to complete the restoration of the steamship SS Nobska.

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

BOSTON
May 3
Activity: The Section toured the SS Nobska in dry dock at the old Boston Navy Yard in Charlestown, Mass. Jim Cambell, restoration coordinator for the New England Steamship Foundation, made a presentation then led a tour of the ship and the dry dock. More than $3 million in federal money has already been spent on the Nobska. New ribs have been installed, and all of its hull plates have been replaced. But before she can float, more than 5000 feet of seam welding will be required to join those new plates.

GREEN & WHITE MOUNTAINS
March 20
Activity: The Section hosted the Vermont SkillsUSA Welding Contest for ten secondary and two postsecondary students. The event was held at Advanced Welding Institute in South Burlington, Vt.

April 8
Activity: The Green & White Mountains Section members toured Lyndon Institute in Lyndon, Vt., then critiqued the welding contest they hosted March 20. Welding instructor Jim Blanchard, judge Joe Tokarski, and organizer Geoff Putnam presented gold awards to Chad Franklin and Jason Koch; silver awards to Damon Carr and Mike Greenwood; and a bronze award to Leif Trott.

May 13
Activity: The Green & White Mountains Section held its executive committee meeting in West Lebanon, N.H. Russ Norris presented the chairman's pin to Ray Henderson. Members discussed SkillsUSA, the District conference, scholarships, and fundraisers.

MAINE
March 11
Speaker: Jeff Fields
Affiliation: Bath Iron Works
Topic: Preparing for the Maine SkillsUSA Contest
Activity: The program included hands-on training for everyone on FCA, GTA, SMA, and PAC welding using machines provided by Hypertherm, Miller, Lincoln Electric, and Hobart. The event was held at United Technology Center in Bangor, Maine.

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

NEW JERSEY
April 26-29
Activity: The Section hosted a four-day hands-on seminar featuring orbital welding. The sessions were held at GMP Systems in Pine Brook, N.J.

Shown at the Green & White Mountains Section awards-presentation program April 8 are (from left) Joe Tokarski, Geoff Putnam, Chad Franklin, Leif Trott, Damon Carr, Jim Blanchard, Mike Greenwood, and Jason Koch.

Historian Gus Manz spoke at the New Jersey Section meeting in May.
MAY 18
Speaker: Gus Manz, engineer
Topic: A history of welding
Activity: The New Jersey Section presented awards to participants in its student welding contest. Those honored included students Donald Gibson, Charles Dominguez, Jason Kubilus, Mike Smiegelinski, Jeff Yannetta, Joe Sciarangello, and instructor Bill Miller.

NEW YORK
MARCH 29
Speaker: Bojidar Yanev, director of bridge inspections
Affiliation: NYC Bureau of Bridges
Topic: Restoration of the Manhattan Bridge and other major bridge projects worldwide

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

LANCASTER
APRIL 22
Speaker: Robert Blauser, senior welding engineer
Affiliation: Harley-Davidson
Topic: Welding motorcycles
Activity: The program was held at Apple Tree Restaurant in Lancaster, Pa.

MAY 13
Activity: The Lancaster Section toured Direct Wire & Cable, Inc., in Denver, Pa. The presenters were Eric Laubach, vice president of sales; and Mike Diem, sales department.

DISTRICT 4
Director: Ted Alberts
Phone: (540) 674-3600, ext. 4314

NORTHEAST CAROLINA
APRIL 22
Speaker: David Schaefer, technical representative
Affiliation: The Lincoln Electric Co.
Topic: Visual inspection techniques
Activity: Joe Lyon, an instructor at Wayne Community College, was elected both education and membership committee chair. A new Section banner was presented by Chairman Roy Lanier to replace the banner lost during Hurricane Floyd.

SOUTHWEST VIRGINIA
APRIL 19
Speaker: Clay Dillard
Ed Wyatt (left) presents the Chairman’s Appreciation Certificate to Bill Rhodes at the Southwest Virginia program in April.

Affiliation: United Abrasives
Topic: Grinding safety
Activity: Bill Rhodes, Section chairman, presented the Industry Support Certificate of Appreciation to Airgas. Accepting the award were Richard Watson and Barry Cumbie, Airgas southwest region vice president and branch manager, respectively. Rhodes accepted the Chairman’s Appreciation Citation from Awards Chair Ed Wyatt.

DISTRICT 5
Director: Leonard P. Connor
Phone: (954) 981-3977

PUERTO RICO
MARCH 4
Speaker: Harry Rosario, operations manager
Affiliation: Technical Welding Services
Topic: The value of becoming an AWS Student Member
Activity: The program was held at Tomás Honig Vocational School for 47 attendees.

MARCH 17
Speaker: Harry Rosario, operations manager
Affiliation: Technical Welding Services
Topic: The AWS CWI program
Activity: This Puerto Rico Section program was held for 30 attendees at Salón América in San Juan.

MARCH 18
Speaker: Harry Rosario, operations manager
Affiliation: Technical Welding Services
Topic: Building Student Chapter membership
Activity: The Puerto Rico Section held two programs this day. The morning program attracted 73 students and adults, and the afternoon session drew 84. The programs were held at Antonio Lucchette Vo-Tech School. Arecibo Job Corps representatives attended.

Harry Rosario, an energetic promoter of the Puerto Rico Section, makes a presentation for welding students in March.

The Antonio Lucchette Vo-Tech students proudly pose at the Puerto Rico Section’s introduction to welding program led by Harry Rosario, held March 18 at Antonio Lucchette Vo-Tech School.
Speaker Dave Lackey (right) is shown with Gale Mole, chairman of the South Carolina Section, at the April meeting.

Chris Anderson described the benefits of the new digital welding machines for Dayton Section members in April.

Sparks flew when Dayton Section members tried the new inverter technology at its April meeting held at Motoman.

These welding students appear eager to get started on the welding contest sponsored by the Greater Huntsville Section.

**DISTRICT 6**
Director: Neal A. Chapman
Phone: (315) 349-6960

**DISTRICT 7**
Director: Donald C. Howard
Phone: (814) 269-2895

**COLUMBUS**
May 13
Activity: The Section hosted its election of officers event at Hooters Restaurant in Columbus, Ohio. Jerry Van Meter presented the chairman's pin to outgoing chair John Lawmon.

**DAYTON**
April 13
Speaker: Chris Anderson, marketing director
Affiliation: Motoman, Inc.
Topic: Digital GMAW machines
Activity: Anderson demonstrated high-frequency inverter power sources and offered hands-on "test drives" for the 30 members in attendance. The program was held at Motoman, Inc., in Troy, Ohio.

May 11
Activity: The Dayton Section members toured KTH Parts Industries, St. Paris, Ohio, a Tier One just-in-time supplier to Honda.

**SOUTH CAROLINA**
April 20
Speaker: Dave Lackey, district manager
Affiliation: The Lincoln Electric Co.
Topic: GMA welding of aluminum
Activity: The Section held its nominations for officers for 2004-2005.

**Triangle Tech Pittsburgh Campus Student Chapter**
April 13
Speaker: David Bloom
Affiliation: Vince's Gas and Welding Supply Co.
Topic: Safety rules for the oxyfuel processes
Activity: Chartered in April 2004, the Chapter's first meeting accentuated the importance of safety. This hands-on program prepared the students to work on their long-term project to restore the USS Requin SS481, a 59-year-old submarine dry docked at the Carnegie Science Center in Pittsburgh, Pa. Read the illustrated story of their project featured on page 71 of this issue of Society News.

**DISTRICT 8**
Director: Wallace E. Honey
Phone: (256) 332-3366

**GREATER HUNTSVILLE**
April 16
Activity: Joe Smith, a welding instructor at Marshall Technical School, conducted a welding contest for students from Blount, Morgan, Etowah, Dekalb, Marshall, and Jackson counties. More than 100 attended the event. First-year student winners were Kyle Ayers, Zack Nall, and Randy Moore. Advanced-level winners included Henry Carden, Deric Freeman, and Joey Turner. The college student-level top awards went to Mark Parker, Sharron Chelsey, and Keith Coledt. The event was held at Marshall Technical School.

**DISTRICT 9**
Director: John Bruskotter
Phone: (504) 363-5900

**MOBILE**
April 15
Activity: Several members made presentations about their personal experiences in the welding industry to inspire the many students in attendance. Jim Sullivan, a welding instructor at Locklin Technical Center, accepted funds from the Section to support his team's expenses to participate in the Florida State SkillsUSA-VICA competition held April 26-28. Honored were Matthew Myers and Kevin Green, from
Greg Pierce (left) accepts the past chairman's pin from his dad, Ron Pierce, at the May meeting of the Mobile Section.

Locklin Tech, who won the first and second place trophies in the local welding competition.

MAY 13
Activity: The Mobile Section hosted its annual Past Chairmen's Night program, highlighted by honoring Greg Pierce for serving as chair for the past year. His father, Ron Pierce, a past AWS president and two-time Mobile Section chair, presented his son with the past chairman's pin. Leo Veal, the first Mobile Section chair, attended.

NEW ORLEANS
APRIL 20
Speaker: Kyle Cortello, sales representative
Affiliation: McDonough Marine Service
Topic: Economic impact of the barge and tugboat industry
Activity: The program was held at C&C Marine and Repair, Belle Chasse, La., owned by Anthony Cibilich.

MAY 1
Activity: The New Orleans Section hosted its Sixth Fishing Rodeo at C-Way Marina at Lafitte, La., for 100 attendees including 50 contestants. Ron Crotwell and Norman Gauthreaux took top honors in the redfish category. Ron Perez landed a 39-lb calcutta, while Randy Stevenson and Butsie Duhun snagged the speckled trout category prizes. Lloyd Lemle won the auction for an original oil painting. Mike Skiles served as rodeo master, and Ivy Bernard officiated as weighmaster for the event.

DISTRICT 10
Director: Victor Y. Matthews
Phone: (216) 383-2638
Shown at the March Milwaukee Section program are (from left) Scott McCallister, Dick Tupta, Daniel Hunt, Larry Gross, David Maloney, Michael Brown, and Christopher Nielsen.

Indiana Section Chair Mike Anderson (left) presents the speaker plaque to Dick Alley at the April meeting.

DISTRICT 11
Director: Eftihios Siradakis
Phone: (989) 894-4101

DETROIT
MAY 1
Activity: The Section hosted its 31st annual high school welding contest at Schoolcraft College. Students from seven schools participated in the written exam and practical exercises. Taking the top eight spots were Shawn Jedinak, Kyle McNew, Shaun Thorsrud, Lance Kujawski, Richard Neifert, Justin Ferguson, Jesse Holbrook and David Dowd.

MAY 7
Activity: The Detroit Section held its annual Ladies’ Night event at the Cobo Center in downtown Detroit. Attended by 430 members and their families, the event’s guest of honor was AWS President Tom Mustaleski.

DISTRICT 13
Director: Jesse L. Hunter
Phone: (309) 359-8358

CHICAGO
MAY 11
Speakers: Randy Counselman, and Craig Brown
Affiliation: Stork Technimet
Topic: Failure analysis of weldments
Activity: This was a joint meeting with members of the local chapter of ASM International.

DISTRICT 14
Director: Tully C. Parker
Phone: (618) 667-7744

INDIANA
APRIL 19
Speaker: Richard L. Alley, AWS past president (1989-90)
Topic: The image of welding
Activity: The Section held its election of officers. The program was held at MCL Cafeteria in Indianapolis, Ind.
LEXINGTON
APRIL 29
Activity: The Section met at Central Kentucky Vo-Tech School for a program presented by Victor Torches. Products shown included oxygen and acetylene welding equipment. District 14 Director Tully Parker and about 90 members and guests attended the program. Student Carl Watson received the VICA award for earning first place in the welding competition.

DISTRICT 15
Director: J. D. Heikkinen
Phone: (800) 249-2774

ARROWHEAD
APRIL 15
Activity: The Section toured the L&M Radiator, Inc., designing, manufacturing, fabricating, and welding facilities located in Hibbing, Minn. Douglas Pioske, general manager, discussed the manufacturing processes used to make radiators and heat exchangers for industrial applications.

DISTRICT 16
Director: Charles F. Burg
Phone: (515) 233-1333

KANSAS
APRIL 28
Activity: The Section met at Barton County Community College's welding shop where Mark Ward, owner of Ward Welding, gave a demonstration on carbon arc gouging and the proper use of the torch. Following the demonstrations, the attendees took turns testing their welding and gouging skills.

KANSAS CITY
APRIL 15
Activity: The Section toured the Shawnee Steel & Welding Co. plant to study the robotics and fixturing used in its operations. Host for the tour was Scott Gronberg, project manager. The Section held its nominations of officers. Nominated were Barry Hamilton, chairman; Jim Benny and Scott Gronberg, vice chairs; and Dennis Wright, secretary.

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

EAST TEXAS
MAY 5
Activity: Mike Player accepted the Section Educator of the Year Award from Robert Warke, chairman, and Bill Kielhorn, secretary-treasurer. Player, an AWS Certified Welding Inspector, was cited for his outstanding improvements to the welding lab and training at Kilgore College, Kilgore, Tex.

NORTH TEXAS
APRIL 20
Speaker: Tom Mustaleski, AWS president, BWXT Y-12 LLC, Oak Ridge, Tenn.
Topic: AWS educational opportunities
Activity: District 17 Director Oren Reich presented Kirk Jordan the CWI of the Year Award and Paul Stanglin the Distinguished Service Award.

TULSA
APRIL 27
Activity: The Section toured the John Zink Co., in Tulsa, Okla., to study the building of industrial heaters and drilling rig flares. Todd Fradd, project coordinator, made a presentation on the company's operations. Dennis Armiger, machine shop supervisor, and Finis Richardson, supervisor of aftermarket products, conducted the tour.
Shown April 27 during the Tulsa Section's Zink Company tour are (from left) Dennis Arriger, Paul Morgan, and Finis Richardson.

Sabine Vice Chair Tom Holt (left) presents James Amy with the chairman's pin and an appreciation certificate at the April program.

Grady Hatton (right) accepts the CWI of the Year Award from John Mendoza, District 18 Director, at the Sabine Section awards program.

Dennis Eck, Houston Section vice chair (left), presents a speaker gift to Art Fabra at the Houston Section program in May.

Larry Smith, outgoing Houston Section chair, displays his certificate of appreciation for his great service to the Section.

Tom Holt (right) accepts the Meritorious Award from John Mendoza, District 18 Director, at the April Sabine Section meeting.

**HOUSTON**

**MAY 19**

Speaker: Art Fabra

Topic: Lean manufacturing, the use of strategic management, quality systems, and safety

Activity: Dennis Eck presented the Dr. Daryle Morgan Scholarship to welding student Phillip Thornton. John Husfeld introduced Barbara Cupial, the winner of the AWS 2004 Poster Exhibition. Chair Larry Smith accepted a certificate of appreciation for his services during the past year.

**SABINE**

**APRIL 20**

Activity: The Section members toured American Valve & Hydrant in Beaumont, Tex., conducted by Philip Bean, Tim Sudela, and Pat Lowry. District 18 Director John Mendoza presented District Director Awards to Morris Weeks and Mark Clark, the Section Educator Award to Randy Howell, CWI of the Year Award to Grady Hatton, Private Instructor Award to Darrell Pnsey, and the Meritorious Award to Tom Holt. The Section announced the establishment of its fifth annual $850 scholarship. This one was named in honor of longtime member Alton Wolf. Mendoza presented Ed with a proclamation formally dedicating the scholarship in his name.

**DISTRICT 18**

Director: John L. Mendoza
Phone: (210) 860-2592

**DISTRICT 19**

Director: Phil Zammit
Phone: (509) 468-2310 ext. 120
John Mendoza, District 18 Director (left), presents Randy Howell the Sabine Section Educator Award.

**DISTRICT 20**
Director: Nancy M. Carlson
Phone: (208) 526-6302

**EASTERN IDAHO/MONTANA**

**JANUARY 23**
Activity: The Section toured the Montana Resources Co. welding and mining operations in Butte, Mont. The tour included a trip through the mine. Employees discussed the employment opportunities for welders in its extensive operations. Dinner was held at the Red Lion Hotel.

**APRIL 29**
Activity: The Eastern Idaho/Montana Section members toured the Idaho Falls City Power division hydroelectric plant located on the Snake River.

**DISTRICT 21**
Director: Jack D. Compton
Phone: (661) 362-3218

**SACRAMENTO VALLEY**

**APRIL 21**
Speakers: Milt Heft, owner
Affiliation: Petrogen, Inc.
Topic: Oxy-gasoline cutting
Activity: Milt Heft demonstrated his patented oxy-gasoline cutting system designed to cut through steel up to 14 in. thick steel with no slag. The event was held at Elmer's Portable Welding facility, hosted by Elmer Crain, owner, and Milt Heft.

**INDIA**

**APRIL 17**
Activity: The Section joined the Indian Institute of Welding to sponsor a full-day workshop for 52 attendees titled Trends in Weld Quality Assurance. Prominent speakers from industry addressed welding processes, weld discontinuities, NDE, weld codes, and a system approach for QA of welds. The seminar was held at I QC Training and Services Pvt. Ltd., in Chennai, India.

**New Student Chapters**

American River College, Sacramento Section, Dist. 22; Bellingham Technical College, Puget Sound Section, Dist. 19; Columbiana County Career & Technical Center, Mahoning Valley Section, Dist. 10; Columbus Technical College, Atlanta Section, Dist. 5; Seacoast School of Technology, Maine Section, Dist. 1; John Handley High School, Cumberland Valley Section, Dist. 3; Lake Washington Technical College, Puget Sound Section, Dist. 19; Triangle Technical School, Pittsburgh Campus, Pittsburgh Section, Dist. 3; WITC -- Rice Lake, Northwest Section, Dist. 15.

**And the Winners Are . . .**

The Board of Directors established the Student Chapter Member Award to recognize Student Chapter members who have produced outstanding school, community, or industry achievements.

This award is presented to Matthew R. Bonidie, and Will H. Bouzel by the Tri-State Business Institute AWS Student Chapter in Erie, Pa., District 10.

To qualify for this award, candidates must be an AWS Student Member affiliated with an AWS Student Chapter. Visit [www.aws.org/sections/awards/student_chapter.pdf](http://www.aws.org/sections/awards/student_chapter.pdf) to download form.

The District Director Award provides a means for District Directors to recognize individuals who have contributed their time and efforts to the affairs of their local Section or District.

District 1 Director Russ Norris has nominated the following members for this award for 2003–2004:

- Al Moore — Connecticut Section
- John Gullotti — Connecticut Section
- John Jones — Connecticut Section
- Walter Chojnacki — Connecticut Section
- Glenn Myrick — Boston Section
- James Shore — Boston Section
Guide to AWS Services
550 NW LeJeune Rd., Miami, FL 33126
Phone (800) 443-9553; (888) WELDING; FAX (305) 443-7559
Internet: www.aws.org
Phone extensions appear in parentheses.

AWS PRESIDENT
James E. Greer ..............................................
Moraine Valley Community College
248 Circlegate Rd., New Lenox, IL 60451

ADMINISTRATION
Executive Director
Ray W. Shook .............................................
Deputy Executive Directors
Jeffrey R. Hufsey ..........................................
John J. McLaughlin ........................................
CFO/Deputy Executive Director
Frank R. Tafara ...........................................

Corporate Director of Quality Management Systems
Linda K. Henderson ........................................
Executive Assistant for Board Services and HY
Gricelda Manallch ........................................

human resources
Director
Luisa Hernandez ...........................................

database administration
Corporate Director
Jim Lankford .............................................

INTERNATIONAL INSTITUTE OF WELDING
Information: info@aws.org ................................
Provides liaison activities involving other professional societies and standards organizations, nationally and internationally.

GOVERNMENT LIAISON SERVICES
Hugh K. Webster .......................................... Washington, D.C.
(202) 466-2976; FAX (202) 835-0243

identifies funding sources for welding education, research, and development. Monitors legislative and regulatory issues of importance to the industry.

BRAZING AND SOLDERING MANUFACTURERS' COMMITTEE
Jeff Weber ..................................................

WELDING EQUIPMENT MANUFACTURERS' COMMITTEE
Mary Ellen Milia ...........................................

WELDING INDUSTRY NETWORK (WIN)
Mary Ellen Milia ...........................................

CONVENTION & EXPOSITIONS
Exhibiting Information: ................................
Associate Executive Director/Sales Director
Jeff Weber ..................................................

WELDING INDUSTRY NETWORK (WIN)
Director of Convention & Expositions
John Ospina ..............................................

PUBLICATION SERVICES
Department Information ..........................
Managing Director
Andrew Cullison .........................................
Welding Journal
Publisher/Editor
Andrew Cullison .........................................
National Sales Director
Rob Saltstein ...............................................
Welding Handbook
Welding Handbook Editor
Annette O’Brien .........................................

MARKETING
Corporate Director
Bob Bishoff ..............................................
Plans and coordinates marketing of AWS products and services.

Marketing Communications
Senior Manager
George Leposky ...........................................
Manager
Amy Nathan .............................................

MEMBER SERVICES
Department Information ..........................
Associate Executive Director
Casie R. Burrell .........................................
Director
Rhonda A. Mayo ........................................
Serves as a liaison between Section members and AWS headquarters. Informs members about AWS benefits and activities.

PROFESSIONAL INSTRUCTION SERVICES
Managing Director
Debrah C. Weir ........................................
Proposes new products and services. Researches effectiveness of existing programs.

Educational Product Development
Director
Christopher Pollock ....................................
Responsible for tracking the effectiveness of existing programs and for the orchestration of new product and service development. Coordinates in-plant seminars and workshops. Administers the S.E.N.S.E. program. Assists Government Liaison Committee with advocacy efforts. Works with Education Committees to disseminate information on careers, national education and training trends, and schools that offer welding training, certificates or degrees.

Conferences and Seminars
Director
Giselle Perez ...........................................
Responsible for conferences, exhibitions, and seminars on topics ranging from the basics up to the leading edge of technology. Organizes CWI, SCWI, and 9-Year Renewal certification-driven seminars.

CERTIFICATION OPERATIONS
Director
Terry Perez .............................................
Information and application materials on certifying welders, inspectors, and educators.

INTERNATIONAL BUSINESS DEVELOPMENT
Director
Walter Herrera .......................................... (470)

AWS AWARDS, FELLOWS, and COUNSELORS
Managing Director
Wendy S. Reece ........................................
Coordinates AWS awards and AWS Fellow and Counselor nominees.

TECHNICAL SERVICES
Department Information ..........................
Managing Director
Andrew R. Davis ........................................

International Standards Activities
American Council of the International Institute of Welding (IIW)

Manager, Safety and Health
Stephen P. Hedrick ........................................

Machinery & Equipment Welding, Robotic & Automatic Welding
Manager, Technical Publications
Stephen P. Hedrick ........................................

Technical Publications
Senior Manager
Rosannda O'Neill ........................................

AWS publishes more than 200 technical standards and publications widely used in the welding industry.

Engineers
Harold P. Ellison ........................................


John L. Gayler ..........................................

Structural Welding, Welding Iron Castings
Rakesh Gupta ............................................


Cynthia Jenney ...........................................

Transactions of the International Institute of Welding
Richard McGinnis ........................................

Procedure & Performance Qualification, Railroading, Mechanical Testing of Welds, Methods of Inspection.

Brian McGrath ...........................................


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

WEB SITE ADMINISTRATION
Director
Keith Thompson ........................................

86 JULY 2004
RECRUIT NEW MEMBERS... WIN GREAT PRIZES

A simple way to give back to your profession, strengthen AWS and win great prizes is by participating in the 2004-2005 Member-Get-A-Member Campaign. By recruiting new members to AWS, you're adding to the resources necessary to expand your benefits as an AWS Member. Plus, you become part of an exclusive group of AWS Members who get involved. Year round, you'll have the opportunity to recruit new members and be eligible to win special contests and prizes. Referrals are our most successful member recruitment tool. Our Members know first-hand how useful AWS Membership is. Who better than you to encourage someone to join AWS?

AWS MEMBER BENEFITS CHECKLIST:

- Annual subscription to the Welding Journal.
- A 25% discount on hundreds of first-rate AWS technical publications and 140+ industry codes.
- Deep discounts on 120+ technical training events every year.
- Access to widely recognized AWS Certification programs.
- New Members can save nearly 90% off an AWS publication. Choose from four of our most popular titles (see reverse).
- AWS Membership Certificate and Card.
- Networking opportunities through local Section meetings, the AWS Welding Show and an online bulletin board on the AWS website at <www.aws.org>.
- Members'-only discounts on auto insurance, car rentals, credit cards and more.
- Connection to career opportunities through AWS JobFind – at www.awsjobfind.com
- The American Welder section of the WJ geared toward front-line welders.
- And much more!

GET INVOLVED TODAY, AND WIN!

PRIZE CATEGORIES

President's Honor Roll:
Recruit 1-5 new Individual Members and receive a welding ball cap.

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™ polo shirt, American Welder™ T-shirt and a welding ball cap.

President's Guild:
Recruit 20 or more new Individual Members and receive an American Welder™ watch, a one-year free AWS Membership, the 'Sheldon 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 2005).

Sponsor of the Year:
The individual who sponsors the greatest number of new Individual Members during the campaign will receive a plaque, a trip to the 2006 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 a welding ball cap.

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 2004, as well as in February and June 2005.

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SUPER SECTION CHALLENGE
The AWS Section in each District that achieves the highest net percentage increase in new Individual Members before the June 2005 deadline will receive special recognition in the Welding Journal.

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

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*The 2004-2005 MCM Campaign runs from June 1, 2004 to May 31, 2005. Prizes are awarded at the close of the campaign.
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 Ernest D. Levert, 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 2005. The term of office for candidates nominated at this meeting will commence June 1, 2006.

Honorary-Meritorious Awards

The Honorary-Meritorious Awards Committee makes recommendations for the nominees presented for Honorary Membership, National Meritorious Certificate, William Irgang Memorial, and the George E. Willis Awards. These awards are presented during the AWS Exposition and Convention held each spring. The deadline for submissions is July 1 prior to the year of awards presentations. Send candidate materials to John J. McAulughlin, Secretary, Honorary-Meritorious Awards Committee, 550 NW LeJeune Rd., Miami, FL 33126.

A description of the awards follow.

National Meritorious Certificate Awards: 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 advance the American Welding Society's goal of advancing the science and technology of welding over the past five-year period.

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

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

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

Jeff Schnabel was appointed to the new position of sales manager, hardfacing and stainless alloys, at Select-Arc, Inc., Fort Loramie, Ohio. Schnabel, with 15 years of experience in the industry, will oversee the company's new line of welding electrodes.

Hulvy Joins Alloy Engineering

The Alloy Engineering Co., Berea, Ohio, has appointed Steve Hulvey as sales engineer for its Ohio, Michigan, western West Virginia, and the Ohio-river area of Kentucky. Hulvey has 25 years of experience with the company in various positions, including specialty products sales manager, quality assurance manager, and product manager.

VP Named at Rolled Alloys

Rolled Alloys Canada, Inc., Mississauga, Ontario, has named Hugh Khan vice president and director of Canadian operations. With the company since 1996, Kahn previously served as sales manager.

EWI Fills Nine Key Positions

Edison Welding Institute, Columbus, Ohio, has appointed three senior engineers: Brian Lu, for microjoining, previously worked for Stellite Coatings; Evgeni Todorov, for nondestructive evaluation, formerly was employed at Bombardier Aerospace, Toronto, Canada; and Yu-Ping Yang, for computational modeling of welding, cutting, and forming, came from Battelle Memorial Institute.

Five applications engineers were appointed: Vikram Thyagarajan, Brian Girvin, Brandon Shinn, Brian Baughman, and Joe Dirksheide. Thyagarajan specializes in nondestructive evaluation; Girvin will pursue resistance and solid-state welding projects; Shinn is experienced in laser beam welding; Baughman works with pulsed gas metal arc welding; and Dirksheide's line is advanced gas metal arc welding processes.

Leah Kohr joins the company as a proposal coordinator in the Technical Division. Previously, Kohr was a project manager and quality engineer with Bell Laboratories/Lucent Technologies.

President Named at Cellar Services

Sue Vivian was named president of Cellular Services, Inc., Sterling Heights, Mich. Jack Goodrich, CSI founder, is director of research and development for the resistance welding equipment company. Vivian, a CPA, has ten years of experience in the resistance welding industry.

L.A. NTMA Taps Its Trustee

Mike Kartsonis, president and founder of Dynamic Fabrication, Inc., Santa Ana, Calif., was appointed trustee for the Los Angeles chapter of the National Tool and Machining Assn. (NTMA). Kartsonis will act as a liaison between the chapter and the NTMA's governing body based in Washington, D.C.

Four Posts Filled at Tregaskiss

Tregaskiss Ltd., Windsor, Ont., Canada, named Brian Krieger as a regional business manager; Dongmei Sun as a design engineer; and customer service representatives Stanley Cox and Richard Hinds. Krieger, with 25 years of experience in the industry, will be responsible for the company's northeast region of Ontario. Sun has worked as a research welding engineer for five years in robotic
welding and quality control systems. Cox previously worked as an engineer in the aerospace industry for several years. Hinds brings considerable experience in international sales management.

**Coxreels Announces Top-Level Changes**

Coxreels, Tempe, Ariz., a manufacturer of hose, cord, and cable reels, has appointed Brad Cox as president and COO, and his brother Jeff Cox as executive vice president. Former president, Don Cox, will manage as chairman of the board and CEO for the company. Previously, Brad was executive vice president, and Jeff served as vice president of manufacturing.

**Real Time Solutions Names Sales Manager**

Jeff Runnion was named Midwest regional sales manager for Real Time Solutions, Emeryville, Calif., an FKI Logistics company. The company is a provider of hardware and software order-filling solutions for warehouses and distribution centers. Runnion has 22 years of experience in the materials handling industry.

**Matheson Tri-Gas President to Sit on Nippon Sanso Board**

William J. Kroll, president and CEO of Matheson Tri-Gas, Inc., Parsippany, N.J., was appointed to the board of directors of Tri-Gas's parent company Nippon Sanso Corp. Kroll has held senior-level positions at Matheson Tri-Gas since 1994.

**Techalloy Designates Product Manager**

Gary Powell was appointed product manager at Techalloy's Baltimore Welding Division where he manages the Customer Service and Shipping Departments with sales responsibilities in North America and the United Kingdom. Prior to joining the company, Powell was a welding specialist for several metal supply companies.

**TRUMPF Appoints Three Managers**

TRUMPF Inc., Farmington, Conn., has named Donald Forrest as national service manager; James Rogowski as product manager for the automation and bending groups; and Tony Mirisola as product manager for the portable power tools unit. Forrest formerly served the company as manager of VectorMark (laser marking) service. Rogowski previously was a product engineer in the automated systems group. Mirisola previously served as a sales engineer in the portable power tools group.

**Lincoln Appoints Manager**

Leo Landers was named distributor account manager for The Lincoln Electric Co., Cleveland, Ohio. An employee since 1984, Landers has served as a country manager for South Korea and Taiwan, and regional sales manager for South America. He most recently was district manager in Lincoln’s Milwaukee office.

**Minser Joins ESAB**

Jack Minser has joined ESAB Welding & Cutting Products, Florence, S.C., as business product manager for gas apparatus. Previously, Minser worked for Victor Equipment Co. for 25 years in various marketing positions.

**Koike Aronson Names Manager**

Eric Christofferson was appointed to the new position of field sales manager at Koike Aronson, Inc., Arcade, N.Y. With many years of sales experience with Miller Electric Co. and Airgas Intermountain, Christofferson most recently was owner and president of Integrated Technologies & Services, Inc., Colorado Springs, Colo.

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ABSTRACT. This paper summarizes work on finite element modeling of nugget growth for resistance spot welding of aluminum alloy to steel. It is a sequel to a previous paper on experimental studies of resistance spot welding of aluminum to steel using a transition material. Since aluminum alloys and steel cannot be readily fusion welded together due to their drastically different thermal physical properties, a cold-rolled clad material was introduced as a transition to aid the resistance welding process. Coupled electrical-thermal-mechanical finite element analyses were performed to simulate the nugget growth and heat generation patterns during the welding process. The predicted nugget growth results were compared to the experimental weld cross sections. Reasonable comparisons of nugget size were achieved. The finite element simulation procedures were also used in the electrode selection stage to help reduce weld expulsion and improve weld quality.

Introduction

Steel and aluminum are the most important construction materials for the mass production of today's automotive structures. It is well known that metallurgical bonds between aluminum and steel are difficult to achieve with fusion welding because of the inherent discrepancies in electrical, thermal, and mechanical properties between the two materials. For fusion welding processes such as direct resistance spot welding (RSW), little or no mutual solubility of aluminum and steel exists. The intermetallic compound that is formed between the two metals often results in cracking, brittleness, and susceptibility to corrosion. The use of a transition material to facilitate the spot welding process of aluminum to steel is a concept that has shown promise in the past (Refs. 1, 2). Use of this transition insert allows for two separate weld nuggets to be formed in their respective aluminum/aluminum and steel/steel interfaces. Bonding at the aluminum/steel interface is achieved by the cold-clad process (Ref. 1).

Very few previous studies exist on this subject matter, and almost all of these studies focus on experimental nugget growth studies using consecutive metallurgical cross-sectioning. There is a lack of fundamental understanding on the heat generation and nugget growth kinetics as well as the effects of different electrode combinations on nugget growth kinetics. The purpose of this study was to use the incrementally coupled finite element modeling procedure to simulate the heat generation and nugget formation sequence in resistance welding of aluminum to steel with a transition layer. As discussed in Part I of this study, the transition layer used was a cold-rolled clad material of aluminum to steel with 20% cladding ratio. The process development and joint performance issues were addressed in Part I of this study using experimental approaches. The following welding parameters were used for spot welding of 2-mm 5182-O to 1.4-mm SAE1008 with 1.5-mm-thick transition material:

- Electrode on Al side: 30-deg truncated cone Class 2 electrode with 8-mm face diameter and 3-in. face radius
- Electrode on steel side: 30-deg truncated cone Class 2 electrode with 8-mm diameter, flat-faced
- Electrode force: 1050 lb-ft
- Welding current: 13.6 kA with 97% heat
- Welding schedule: 3 pulses of [12 cycles welding + 3 cycles holding]
- Cooling water flow rate: 1.75 gallons per min

With the rapid advancements in software and hardware for scientific computing, finite element weld process simulation has been a powerful tool in understanding the fundamental physics associated with the resistance spot welding process. Several authors have developed different finite element models to address various aspects associated with the resistance spot welding process. Among them are Nied (Ref. 3), Tsai et al. (Ref. 4), Sheppard (Ref. 5), Murakawa (Ref. 6), and Dong et al. (Ref. 7). Most of the above-mentioned studies use sequentially coupled finite element modeling in which a one-step electrical-thermal analysis is performed after the initial mechanical analysis of the holding cycle. No changes in contact areas between the electrode and worksheet are monitored and updated during the modeling process.

During actual welding, however, the contact area changes on the faying interface and the two electrode/workpiece interfaces can significantly influence the heat...
generation and nugget formation processes (Ref. 8). This is particularly true for aluminum spot welding with radius-tip electrodes. In this study, we used the incrementally coupled finite element procedure developed by Sun and Dong (Ref. 9) to simulate the nugget growth and heat generation process for resistance spot welding of aluminum to steel. The theoretical framework regarding the coupled electrical-thermal-mechanical phenomena associated with spot welding was presented in Ref. 9 and its implementation procedure with commercial code (e.g., ABAQUS) is illustrated in Fig. 1. This incrementally coupled modeling procedure has been proven successful in modeling aluminum spot welding and steel projection welding processes (Refs. 9-11).

**Finite Element Modeling Procedure**

Figure 2 shows the typical finite element mesh for half of the electrode-sheet assembly with axisymmetric condition being assumed. The 2-mm AA5182-O is in contact with the top electrode and the aluminum side of the transition clad layer. The 1.4-mm SAE1008 sheet is in contact with the bottom electrode and the steel side of the transition layer. The total thickness of the transition material is 1.5 mm. The model consists of four-node linear elements.

The initial squeeze cycle is modeled by a mechanical analysis. Uniformly distributed pressure calculated according to the specified electrode force is applied on the top surface of the upper electrode, and the bottom of the lower electrode is restrained from motion in the vertical direction. Contact pairs are set up for the electrode/sheet interfaces and the two facing interfaces to model surface interactions (Refs. 9, 12). Results generated from the squeezing cycle mechanical analysis, including deformed shape and coordinates, contact pressure, contact radius, element groups in and not in contact, etc., are extracted and passed to the subsequent electrical-thermal analysis in which the welding current is applied. Temperature-dependent mechanical properties are used for AA5182-O and SAE1008, as well as the copper electrodes. These data are collected from various references (Refs. 13-16). For example, Figs. 3 and 4 show the temperature-dependent Young's modulus, Poisson's ratio, and thermal expansion coefficient for the different materials used in the analyses. Note that the material properties for the aluminum and steel layers in the transition material are assumed to be the same as AA5182-O and SAE1008, respectively.

In the electrical-thermal analysis, the deformed shape of the electrode-sheet assembly calculated from the previous mechanical analysis is used. Zero electrical potential is imposed on the bottom of the lower electrode tip, and distributed current density input calculated from the current input value is applied on the top of the upper electrode. All the free surfaces of the electrode and sheet assembly that are not in contact at this time increment are assumed to have free convection with the surrounding air, and the two electrodes are assumed to be water cooled with a forced-convection coefficient spec-
The contact electrical conductance for the faying interfaces and the electrode/sheet interfaces is determined using the formulation developed by Li et al. (Ref. 8):

\[ \sigma = \frac{1}{\rho \lambda} = \frac{1}{k} \frac{L}{2\pi T_1 - T_0}, \]

in which \( \lambda \) is the Lorentz constant; \( T_1 \) is the solidus temperature of the interface; and \( T_0 \) is the interface temperature (both in Kelvin). For most metals, \( \lambda \) is found to be around 2.4 x 10^7 (V/K)². The contact radius \( r_c \) for the electrode-sheet interfaces and the faying interface is extracted from the previous increment mechanical analysis results. The solidus temperatures \( T_s \) for different interfaces used in the analyses are

- Steel/Electrode: \( T_s = 1200°C \)
- Electrode/Al: \( T_s = 550°C \)
- Al/Al: \( T_s = 200°C \)
- SAE 1006
- AA 5182-O
- Copper

The temperature distribution computed from the above electrical-thermal analysis for a certain time increment is then imposed as thermal loading conditions for the subsequent thermal-mechanical analysis module. This updating procedure repeats itself for a specific time increment, i.e., the updating frequency, until the entire welding cycle is totally completed. The flowchart of the analysis procedure is shown in Fig. 1. The entire analysis procedures are fully automated with a suite of user-interface routines.

**Results and Discussions**

**Nugget Development Study**

The modeling procedure described above was used to simulate the RSW process of aluminum to steel with transition clad material. In the coupled finite element analyses, the updating frequency for the first welding pulse (12 cycles of welding current) was set to be \( \frac{1}{3} \) cycle to capture the rapid changes of the contact radii on different interfaces as depicted in Fig. 8. Toward the end of the first welding pulse, the contact radii on different interfaces reached their respective plateaus, then single-step thermal-electrical analyses were performed for the subsequent second and third welding pulses.

The predicted nugget shape and size compared with the weld cross sections from the actual weld samples are shown in Figs. 9-13. It should be mentioned that since aluminum and steel have different melting temperatures, different contour scales had to be used in plotting the temperature contours of the model prediction in order to show molten zones in both aluminum and steel in one picture. In Figs. 9-13, the red areas in the predicted results represent molten metal, and the gray areas in the predicted results represent base material: light gray for aluminum and dark gray for steel. The sharp transition
regions between the base material and the molten zone are the predicted heat-affected zone (HAZ). Furthermore, in order to show the model predicted fusion zone size and shape, Figs. 9-13 were plotted at the end of the welding cycles, not at the end of the holding and cooling cycles as those in the experimental cross sections. Since the materials are still hot at the end of the welding cycle and are still undergoing thermal expansions, these temperature contour plots can only be used to determine the fusion zone width and its depth relative to the original sheet thickness. They do not represent the final weld indentation and sheet separation. This is particularly true for the softer aluminum side, where large deformation will occur during the cooling and holding cycle. And it explains why the contour plots in Figs. 9-13 do not show significant weld deformations as shown in the experimental cross sections.

Figures 9-11 show the molten zone formation sequence for the first welding pulse (12 welding cycles). At the end of the first four welding cycles, no melting is predicted, neither on the aluminum side nor on the steel side. This is consistent with the experimental observations in Fig. 9. At the end of the eighth welding cycle, some amount of melting is predicted on the aluminum side of the transition material in Fig. 10. This melting is caused primarily by the heat conducted from the steel/steel interface. Since the melting temperature for steel is much higher than aluminum, melting is not yet observed for the steel side at the end of the eighth cycle. Some discoloration is observed on the steel/steel interface in the metallurgical cross section in Fig. 10 with no clear columnar weld structure present. This discoloration could be the result of recrystallization, grain growth, and reaustenization of the material. The maximum temperature predicted for the steel/steel faying interface at the end of the eighth welding cycle is 1437°C, very close to the melting temperature of steel. The metallurgical cross section in Fig. 10 shows that some amount of melting occurred in the aluminum base material in addition to the aluminum layer in the transition material. Since the steel side of the entire cross section was much hotter than the aluminum side at the end of the eighth cycle, heat from the steel side continued to be conducted to the much cooler aluminum side when the weld current was turned off. This "postweld" heat conduction may cause additional melting on the aluminum side after the current was turned off. Again, since our prediction results are only depicted at the end of the eighth welding cycle, it does not include any additional melting caused by the heat transfer after the current was turned off. This effect should be particularly strong for the first welding pulse when thermal gradients between the two sides were very high.

At the end of the first welding pulse (12 cycles), both metallurgical cross section and prediction indicated clear molten zones on the steel side as well as the aluminum side — Fig. 11. The molten zone on the steel side has a regular, elliptical shape, with major axis along the interface of the SAE1008 and the steel side of the transition material. Clear dendrite solidification structures surrounded by the heat-affected zone can be observed in the steel nugget. These structures start at the outer edge of the molten nugget and grow like fingers stretching toward the center of the nugget. The molten zone on the aluminum side is only the top half of a regular elliptically shaped spot weld with a slightly larger molten zone diameter in the transition material. This again suggests that the heat for nugget formation on the aluminum side is conducted from the steel side. In addition, pores and gaps were also seen on the aluminum/steel interface. The possible reasons for the pores and gaps to
form were discussed in Part I of our study, and their influence on the weld performance was also discussed. It should be mentioned that the finite element analyses procedure used here cannot be used to predict the formation and location of such pores and gaps.

The predicted weld cross sections at the end of the second and the third welding pulses are shown in Figs. 12 and 13 together with experimental cross sections. Figure 14 compares the predicted and measured fusion zone diameters along the aluminum/aluminum interface and steel/steel interface. Overall, the predicted fusion zone diameters and depths (relative to sheet thickness) are in good comparison with the experimental cross sections on both steel and aluminum sides.

It should be noted that the experimental cross sections shown in Figs. 12 and 13 indicate a large amount of one-sided weld indentation and interface metal squeeze-out. These could be the results of electrode misalignment during the actual welding process. Since the analysis procedures used in this study were based on axisymmetric assumption, the effects of electrode misalignment and one-sided expulsion were not predicted using the current modeling procedure.

**Electrode Selections**

As discussed in Part I of this study, during the initial electrode selection stage, the electrode pair first used was based on a Ford specification (Ref. 17) in which 30-deg truncated Class 2 electrodes with 8-mm face diameter and 3-in. face radius were used on both sides. Initial experimental welding trials with this electrode pair resulted in frequent weld expulsion and large sheet separation.

In parallel with the experimental efforts, the coupled finite element modeling procedures described above were also used to study the effects of electrode combinations on the fusion zone size and sheet separation. Figure 15 shows the predicted nugget size and sheet separation with the original electrode pair in which radius-faced weld tips were used on both sides. The welding parameters used in the analyses are also indicated in Fig. 15. It is worth mentioning again that different contour scales were used for the steel and the aluminum sides in generating the contour plots to illustrate two fusion zones in one picture. In Figs. 15 and 16, the red areas represent the molten metal and the blue areas represent the base metal. The sharp transitions between these two colors are the heat-affected zone.

The predicted temperature contour and weld deformation show that this electrode combination generates a rather large sheet separation and a much larger fusion zone on the aluminum/aluminum faying interface. As a result of the large fusion zone and sheet separation, there is a lack of contact pressure confinement at the fusion zone periphery, which suggests a strong tendency for expulsion and metal squeeze-out at those locations. This prediction is consistent with the experimental observations from our initial welding trials using this pair of electrodes, where expulsion frequently occurred. In addition, a ring of softened aluminum was observed being squeezed out from the nugget periphery, and it formed a collar of aluminum outside the nugget area on the aluminum/aluminum faying interface, which further aggravated the final sheet separation.

In order to better contain the molten metal on the aluminum side, a larger con-
Conclusions

The objective of this research was to investigate whether spot welding between aluminum and steel can be achieved using a transition material. Both experimental welding trials and finite element simulations were used in determining the optimal electrode combinations and welding parameters. The nugget formation process was then examined using consecutive metallurgical cross-sectioning and finite element analyses. It was found that two distinct fusion zones formed during the spot welding process of aluminum to steel using a transition aluminum-clad steel strip. The nugget on the steel side is a regular, elliptical weld with dendritic grain structure inside the nugget region. The nugget on the aluminum side is the top half of the elliptical shape. It demonstrated that the incrementally coupled finite element simulation procedure can be used to study the nugget growth kinetics during the welding process. The analysis procedure was also used in rationalizing the welding test results and in selecting the final electrode combinations for weld coupon fabrication.

Together with the results of Part I of our study, this study suggests that the aluminum-clad steel transition layer can be used in forming a structural weld between aluminum and steel. Moreover, it can be used as a material transition between the aluminum parts and the steel parts of a vehicle to optimize safety and weight reduction of a particular vehicle design.

Acknowledgments

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References


Welding Research

IIW Annual Assembly Convenes in Japan

The 57th Annual Assembly of the International Institute of Welding (IIW) will be hosted by the Japan Institute of Welding (JIW), at the Osaka International Convention Center, Osaka, Japan, July 11-16, 2004

The IIW is the global body in the science and application of joining technology providing networking and knowledge exchange. Its technical field encompasses the joining, cutting, and surface treatment of metallic and nonmetallic materials by such processes as welding, brazing, soldering, thermal cutting, thermal spraying, adhesive bonding, and microjoining and embraces allied fields including quality assurance, nondestructive testing, standardization, inspection, health and safety, education, training, qualification, design, and fabrication.

The United States will be represented by members of The American Council of the IIW, which is the United States' national committee for the IIW. As a comprehensive forum for professional cooperation through interaction with representatives of the other 41 member countries, the IIW provides a unique opportunity for sharing technological innovations and can be an important avenue for international trade.

For further information on the IIW and membership on The American Council, please contact Andrew Davis, Managing Director, Technical Services Division, at adavis@aws.org, (305) 443-9353, ext. 466; or Gricia Manalich, IIW Coordinator, at gmanalich@aws.org, (305) 443-9353, ext. 294. Further information, including registration forms, can also be obtained from the IIW Secretariat in Paris, France, at www.iiw-us.org.
An Investigation on the Effects of Gases in GTA Welding of a Wrought AZ80 Magnesium Alloy

BY M. MARYA, G. R. EDWARDS, AND S. LIU

ABSTRACT. Magnesium alloy components are frequently used in the aerospace industry due to their high specific strength and low density. However, welding of magnesium alloys presents challenges due to their high reactivity with hydrogen and the formation of porosity. In this study, the effects of gases such as argon, helium, and nitrogen on welding of magnesium alloy AZ80 were investigated.

Introduction

The demand for vehicles with improved fuel efficiency has created greater incentives for the engineering of components of magnesium and aluminum. Among other attractive properties, magnesium alloys have two-thirds the density of aluminum alloys, and their strength-to-weight ratios are greater. However, industrial exploitation of magnesium alloys is still restricted, partly due to magnesium's low formability. To date, magnesium components are mainly cast, but routes are being developed to produce formable magnesium alloy sheets. In the absence of sheet products, welding has been confined to isolated applications (Ref. 1). However, realizing that welding, like forming, would open a whole new range of applications, weldability of magnesium alloys has recently been investigated with a variety of processes, particularly gas tungsten arc welding (GTAW), laser beam welding, and friction stir welding (Refs. 1-5). Of all commercial magnesium alloys, those with aluminum as the primary alloying element are most weldable using any of these three processes (Refs. 2-6). With arc welding processes, lack of weld penetration is generally a limitation of the magnesium alloys. In arc welding with a nonconsumable tungsten electrode (i.e., GTAW), the electrode arc is struck by applying a direct current, an alternating current, or a current with other waveforms. For magnesium alloys, alternating current offers a major advantage over the direct current to initiate a weld pool, and this advantage is the cathodic cleaning of the magnesium covering the surfaces (Ref. 6). However, compared to direct current where the electrode is negative and operates as a cathode, alternating current lowers the heat input to the base material and produces shallower welds, especially when argon is selected over helium (Refs. 6-8). Here, the addition of a diatomic gas, like hydrogen (H₂) or nitrogen (N₂), to a monatomic gas, like argon (Ar) or helium (He), is proposed to increase the melting of magnesium alloys during GTA welding.

While hydrogen and nitrogen have been safely introduced to argon or helium for increasing weld penetration in transition-metal alloys, their use has not been reported for joining magnesium. The magnesium-hydrogen phase diagram (Ref. 9) shows that hydrogen solubility in magnesium decreases by about 25 wt.% when magnesium solidifies at 650°C. This characteristic alone indicates that hydrogen accumulates rapidly at the solid-liquid interface, and if hydrogen partial pressure is sufficient, gaseous bubbles will form. In general, pores appear in welds when the ratio of solubility at the average pool temperature and at the melting temperature (either in the liquid phase or solid phase) is high (Refs. 8-10). The concentration of a gas absorbed by the weld pool depends upon its partial pressure in the arc atmosphere and the temperatures at the weld pool surface. Knowing that surface temperatures of GTA weld pools must approach the material's boiling temperature (for magnesium) and that pure magnesium solidifies at 650°C, Sievert's law can be applied to estimate the propensity of hydrogen to generate porosity. For liquid magnesium (Ref. 10), Sievert's law can be represented as:

\[ [H] = 608 \cdot p^{1/2} e^{-\frac{24,400}{RT}} \]  

(1)

where \([H]\) is the total volume of hydrogen in the liquid metal in mL/100 g, \(p\) is the partial pressure of hydrogen in the arc expressed in atmospheres, \(R\) is the universal gas constant (8.31 J mol⁻¹ K⁻¹), and \(T\) is the molten metal temperature in kelvin. Equation 1 predicts that the equilibrium solubilities at 1 atm hydrogen pressure for 1090°F and 650°C are 70.6 and 25.5 mL/100 g, respectively, as validated by independent measurements by Fromageau et al.
It follows that hydrogen solubility in solid magnesium at the melting temperature, being about 25% less, is in the vicinity of 19 mL/100 g. Although all these values of solubility will be affected by welding, the proposed estimates using equilibrium conditions are valuable to assess hydrogen potency in porosity formation. Equation 1 shows that the pressure required to keep all the hydrogen gas in solution is (70.6/25.3)² = 7.8 atm when the pool cools from 1090 °C to 650°C. For gas bubbles to form, which requires that the amount of dissolved hydrogen exceeds the equilibrium solubility at 1-atm hydrogen pressure, the hydrogen partial pressure at 1090°C must be greater than 7/7.8 = 0.13 atm (i.e., hydrogen concentration must exceed 13% of the arc atmosphere). This calculation shows that the minimum concentration of hydrogen to induce porosity is significant in magnesium. A comparable calculation for aluminum would show that hydrogen partial pressure is smaller by about two orders of magnitude (Ref. 8). However, no research has been reported. Further, since the magnesium-nitrogen phase diagram has not been entirely established (Ref. 14), it is even difficult to predict the potential effects of nitrogen on the weld fusion zone. Based upon work of Aizawa et al. on plasma sprays (Ref. 15), an alloying with nitrogen may be expected for the weld region, and this alloying could in fact result in an improved corrosion resistance. However, the literature does not tell how nitrogen will influence the arc and especially how nitrogen compares to the other gases under comparable welding conditions.

This research pursues complementary objectives: 1) determine if diatomic gas additions can increase GTA weld penetration in magnesium alloys, 2) determine if hydrogen can be introduced to argon or helium, and 3) investigate the role of nitrogen during arc welding of magnesium. In this paper, the physical properties of gases are first discussed, followed by a description of the experimental procedure and results. The discussion of the results first addresses the effects of gases on the arc, and then their effects on melting, defect formation, and fusion zone microstructure.

**Physical Properties of Gases**

In GTA welding, the voltage established between the nonconsumable tungsten electrode and the base material is normally self-regulated to deliver a constant current. With the current being approximately invariant, Ohm's law indicates that voltage and electrical conductance of the arc are inversely proportional. The conductance of the arc is a function of its dimensions, particularly the distance between the electrode and the base material (i.e., the arc length), as well as the local values of its electrical conductivity. As a simple definition, the electric arc is a sustained discharged plasma with physical properties that relate mainly to the ionization of its gaseous species. In the arc, electrical conductivity is greater where electrons are generated at low temperatures. A monatomic gas, thus a gas composed of unbound atoms (Refs. 7, 18-20). Figure 2 (Refs. 7, 20) compares physical properties of argon, helium, and several diatomic gases. The graph at the top-left corner is a semilog representation of the electrical conductivity as a function of temperature. It is seen that electrical conductivity of argon is greatest (9.8 eV), followed by that of diatomic oxygen (5.1 eV) and diatomic hydrogen (4.5 eV) (Refs. 7, 19).
argon is considerably greater than that of helium at temperatures less than about 3000 K. This is a direct consequence of argon's smaller first ionization potential. However, at higher temperatures, the population of charged particles (i.e., positive ions and electrons) rapidly levels off in both gases (Ref. 7, 16) and the electrical conductivities become comparable, at least until secondary ionization takes place. Compared to argon, diatomic nitrogen and diatomic hydrogen exhibit smaller electrical conductivities. Beyond 2000 K, their conductivities are also less than that of helium. Of the properties seen in Fig. 2, enthalpy and thermal conductivity of diatomic gases differ most significantly from those of argon and helium. The top-right corner graph reveals that enthalpies of the gases also extract thermal energy more efficiently, as well-depicted by the lower graph. The fact that thermal conductivity of hydrogen and oxygen rapidly decrease after 4000 K indicates that a large fraction of the diatomic molecules have already split into single atoms. Due to a substantially greater dissociation energy (9.8 eV), electrical conductivity of nitrogen does not drop before 7000 K. All the property differences depicted in Fig. 2 between argon, helium, nitrogen, and hydrogen will influence GTA welding, particularly the voltage necessary to stabilize the arc, the heat that this arc generates, and thus the heat input to the base material.

**Experimental Procedure**

To study the effects of monatomic and diatomic gases using a limited number of experiments, only five gases were selected. They were commercially pure argon, argon with 1% and 6% hydrogen, helium with 1% hydrogen, and nitrogen with 1% hydrogen. With the first three gases, the influence of hydrogen additions could be investigated. Further, considering 1% hydrogen, the effects of argon, helium, and nitrogen could be compared. However, a direct comparison of the two diatomic gases, hydrogen and nitrogen, could not be made. In addition to five gases, three currents (30, 40, and 50 A) and four arc lengths (0.5, 1.0, 2.0, and 4.0 mm) were used, leaving a total of 60 bead-on-plate welding experiments and, with two cross sections per weld bead, 120 cross sections to examine.

Bead-on-plate gas tungsten arc (GTA) welding was completed using constant current conditions, a travel speed of 100 mm/min, and a gas flow rate of 40 L/min. A set of 2-mm-diameter tungsten electrodes was prepared with a typical tip angle of 60 deg. When tip wear was observed, the tungsten cathodes were replaced to guarantee consistent and comparable experimental results. A digital multimeter with a precision of 0.01 V and a digital camera with a dark filter were utilized to investigate contributions of the various gases on the arcs. Visual characteristics of the arc as well as voltages, measured at the welding power supply, were captured. This voltage, although not measured directly across the arc, is closely related to the arc voltage, and was therefore sufficient to compare the various gases quantitatively.

All the welding specimens were fabricated from a single 180-mm-diameter extruded AZ80 magnesium alloy plain cylinder. The selection of a wrought alloy as opposed to a cast alloy guaranteed that the initial material did not contain any pores, in particular hydrogen pores. The AZ80 alloy of this study had approximately 8.50 wt-% aluminum and 0.60 wt-% zinc, as estimated using glow discharge spectroscopy. In this investigation, the extruded cylinder was sliced into 3.8-mm-thick circular plates, which were then ground to exhibit smooth and shiny surfaces. Depending upon welding parameters and gases, partial and fully penetrating welds were obtained. On each plate, six bead-on-plate welds were deposited parallel to each other. No fixtures were applied during welding, as the plates were simply positioned on top of a flat and bulky aluminum support, which also eliminated the need for a secondary root shielding.

After bead-on-plate welding, the specimens were cross-sectioned, ground, and polished with silicon-carbide papers and diamond pastes (6 and 1/xm), etched with 2% nital, and examined with a stereomicroscope at magnifications from 10 to 40 x. Dimensions of fusion zones (penetration and width) were measured and porosity (if encountered) was quantified using conventional image analyses based on area measurements. Optical microscopy, scanning electron microscopy, electron dispersive spectroscopy (EDS), X-ray diffraction (XRD), and thermodynamic calculations were also used to complement the analyses of the weld fusion zones.

**Results and Discussion**

**Arc Morphology**

Figure 3 displays digital images of the arc produced using various combinations of gases and arc lengths, as the arcs were viewed from the side. For the purpose of photographing the arc, the welding current of 30 A was preferred. Of the three selected currents, this current generated
the least heat, and therefore minimized the brightness of the arc on the captured images. With a few exceptions, the images exhibited good contrast and they were clean enough for analyses.

By first examining the images of Fig. 3 from top to bottom, the influence of each gas can be examined. The color of the arc was found to vary with the composition of the gases. Since temperatures, radiation wavelength, and color are related, as previously explained, the colors captured on the images were important features to examine. Behind the dark filter, the arcs with pure argon were yellow. The additions of hydrogen caused the yellow arcs of argon to become increasingly green. The substitution of argon by helium and nitrogen produced entirely green arcs. The arcs were also considerably larger. A comparison of the various argon arcs reveals that hydrogen did not broaden the arc, as could have been expected from the arc colors observed with helium and nitrogen. On the contrary, the argon-hydrogen arcs appeared as if they were constricted, which was particularly apparent by examining the brightest region of the 2.0- and 4.0-mm arcs. Based upon this observation, the possibility was raised that fusion zone penetration might be improved by the use of hydrogen additions, likely through an increase in current density and thus Lorentz electromagnetic force.

The observation that arcs were narrower in the presence of hydrogen is consistent with Fig. 2, where both thermal conductivity and specific heat are significantly increased by hydrogen, especially at low temperatures where hydrogen is still in its diatomic form. In the arc periphery, where temperatures are lower than in the arc central region, hydrogen is therefore most effective in restraining the arc from expanding. In the case of the helium enriched with 1% hydrogen, the arcs did not appear to be as bright as the argon arcs. These arcs were also distinctively deflected in the direction opposite to the displacement of the tungsten electrode. This arc deflection was most evident when the arcs were longer, as seen by comparing the pictures of Fig. 3 from left to right.

Compared to the other gases, the arcs produced with the nitrogen-rich gas were noticeably different. Figure 3 does not indicate that these arcs were deflected. On the contrary, they were quite symmetrical, and therefore the direction of electrode displacement, thus arc deflection, could not be determined, as was found with the other gases. As shown in Fig. 3, the digital images of the arcs with the nitrogen-rich gas were also blurry irrespective of the welding parameters. These hazy images were attributed to the heavy fumes encountered when welding was conducted with this diatomic gas. Figure 3 shows that the images corresponding to arc lengths of 0.5 and 1.0 mm exhibited the brightest features. This observation could be indicative of exceptionally high arc temperatures, and most probably high welding voltages, since these two characteristics are largely related, as explained previously.

**Voltage**

Figure 4 shows five voltage-current lines, all constructed from average voltage readings with the different gases and all accompanied with a least-square root equation. The error bars indicate that voltage readings were dispersed within a range that represented about 10% of their values. Due to scatter, the voltage measurements made with the different gases occasionally overlapped. However, the data points could still be properly fit using five distinct straight lines. These five separate lines are proof that electrical conductivity (defined as the ratio of current over voltage) for the various arcs differed noticeably. Also, the fact that the five lines were parallel (with a constant slope of 0.04 V/A) indicates that voltage and current varied at a constant rate, and this rate did not depend on the gas.

Regardless of the current, the arcs with pure argon exhibited the smallest voltages, followed by the arcs with argon containing 1% and 6% hydrogen, respectively. On average, the addition of 1% hydrogen increased voltage by about 15% over that of argon, and the addition of 6% hydrogen doubled this voltage increase. The helium enriched with 1% hydrogen increased the voltage even further, leading to an average 25% increase in voltage over the 1% hydrogen-enriched argon gas, and about 40% over the pure argon gas. With nitrogen as a substitute to argon and hydrogen concentration still at 1%, the voltage was increased by 45% beyond that of...
With nitrogen compared to argon was well substantiated by Fig. 2, where enthalpy and thermal conductivity of the nitrogen are considerably greater than those of argon and helium. These characteristics suggest that the elevated temperatures needed to ionize and thus create an electrically conductive arc gap require more heat generation with nitrogen. Such a heat generation, and thus heat input to the material, was confirmed by the voltage readings, the fumes observed during welding (which explained the hazy images seen in Fig. 3 with nitrogen), and the bright spots revealed in the same images.

Figure 5 directly complements the set of photographs of Fig. 3 by also describing the effects of both arc length and gas. In agreement with Fig. 3, the voltage (thus the heat generated by the arc) increased with the arc length. As in Fig. 4, the voltage was minimum with argon and increased with the other gases, as given by the sequence shown from top to bottom in Fig. 3. Figure 5 also demonstrates that voltage reached about 21 V when electrode and base material were 4 mm apart, and when 1% hydrogen was added to nitrogen. When examining the effects of arc length, note that voltage appeared to increase at a greater rate in the presence of short arcs.

With both Figs. 4 and 5, the effects of hydrogen could be further analyzed. In both figures, the argon gas containing 1% hydrogen is located about halfway between the pure argon and the argon with 6% hydrogen. This result indicates that the first 1% hydrogen was about as effective in increasing the voltage as the 5% hydrogen that was subsequently added. Consequently, the arcs produced with hydrogen were conceivably sustained with both a limited dissociation of the diatomic molecules and a slight ionization of the hydrogen atoms. If that is the case, the major contribution of hydrogen would be to cool the arc central region, which would be made possible by increasing thermal conductivity and specific heat of the arc atmosphere.

Weld Fusion Zone Morphology

Figure 6 reproduces optical micrographs of five bead-on-plate welds for which the arcs were presented in the last column of Fig. 3. The welds gathered in Fig. 6 have striking differences. First, starting with the weld made with argon, the presence of transverse striations at its surface as well as frequent lateral deviations suggest that the heat input to the base material was unsteady and insufficient to form a stable and penetrating weld pool. In contrast, the introduction of 1% hydrogen to argon clearly improved arc stability, as the welds were straight and rather indistinguishable from beginning to end. Since the striations at the weld surface were still present, melting also probably occurred within a shallow depth under the surface. However, with an addition of 6% hydrogen, the welds were distinctly wider, as expected from the voltage measurements presented previously. With 6% hydrogen, spherical-like protrusions, perhaps representing subsurface pores caused by the rejection of hydrogen during solidification, also became visible. When helium was replaced by argon, the widths of the welds were further increased. The surface of the weld was also smooth, a condition that signaled the presence of lesser defects. If that was indeed the case, the 1% hydrogen added to helium could be advantageous. When nitrogen was selected as replacement to argon or helium, weld surface looked noticeably different. As seen in Fig. 6, the coloration of the nitrogen-rich welds was darker. Closer examination by scanning electron microscopy revealed that an agglomerate of fine particles, as shown by the inset image, covered the entire weld surface. Such proof of chemical interactions between the weld fusion zone and nitrogen will be further developed later where the bulk of the fusion zone will be examined in great detail.

Relationships between penetration and width of fusion zones were searched to further characterize the morphology of the produced bead-on-plate welds. As shown in Fig. 7, widths, as seen in Fig. 6, and penetration of the fusion zones were mathematically related irrespective of the gases. Since dimensions of fusion zones were at first, in the results of Figs. 6 and 7 infer that fusion zone penetration with the hydrogen additions was greater than those made with pure argon, and the same ranking of gases seen for the.
voltage probably applied to the fusion zone penetration.

Figures 8 and 9 specifically show how fusion zone penetration with the different gases varied as a function of arc length and current. Despite scatter caused by measurements on different cross sections, the scatter was small enough to guarantee excellent comparisons. Both Figs. 8 and 9 appear to substantiate the ranking earlier established with the voltage readings, except that the helium with 1% hydrogen gas produced slightly greater voltages than the 1% enriched nitrogen gas. As found for the voltage, fusion zone penetration increased with both arc length and current. In contrast with voltage readings, however, the slopes for each line seen in Figs. 8 and 9 varied differently from one gas to the other. The argon line exhibited the smallest slope, followed by that of the argon with 1% hydrogen and that of the argon with 6% hydrogen. The lines for the helium and nitrogen gases were noticeably steeper, although precise values for their slopes could not be determined from the two data points only available. Figures 4, 7, and 8, among others, clearly reveal that enlargements of the fusion zones are to some extents related to the voltage readings. Despite significant scatter, Fig. 10 confirms that such a correlation between fusion zone penetration and voltage existed.

Figures 8–10 also reveal that the fusion zones left by the nitrogen enriched with 1% hydrogen were slightly smaller than those anticipated from the voltage readings — Figs. 4, 5. An explanation can perhaps be found by considering the distinct arc profiles seen in Fig. 3 for the nitrogen-rich gas. With nitrogen as a substitute for argon or helium, both the arcs and the fusion zone penetrations indicate that more heat must have been dissipated into the surrounding of the arc. In other words, nitrogen likely created less energy density than the other gases, although overall heat generated within the arc was greater, as indicated by voltage. This possibility is also strongly suggested by Fig. 2, which indicates that nitrogen had the greatest electrical conductivity of all the gases, in addition to a particularly high enthalpy.

Similar to the effects of nitrogen, the effects of the hydrogen concentration added to argon could also be further examined. As mentioned earlier for the voltage, the line for the 1% hydrogen argon gas was located approximately halfway between the lines of the pure argon and the argon with 6% hydrogen. Figures 8 and 9 indicate that the contribution of 1% hydrogen on the fusion zone dimensions was closer to that of pure argon than to that of the argon with 6% hydrogen. This result, which might appear counterintuitive at first, could also simply suggest that the heat flow had changed, as voltage started to exceed some critical values from which heat flow quickly changed from three-dimensional to two-dimensional (Refs. 6, 22, 23).

Figure 10 confirms that fusion zone penetration and voltage were not proportional to each other, but that fusion zone penetration appeared to increase at a greater rate with the voltage.

Weld-Gas Interactions

The cross-sectional views of Fig. 11 demonstrate that hydrogen is a source of porosity, as theorized previously, whereas nitrogen created weld fusion zones with two distinct regions, which for convenience were designated as FZ1 and FZ2. The first region, FZ1, possessed the normal composition and microstructure of welds made with the monatomic gases, and therefore will not be described in this article. However, the second region found in the upper part of the weld fusion zone, FZ2, revealed an unusual microstructure, as already detected in Fig. 6. In this section, interactions between the AZ80 magnesium alloy and gases like hydrogen and nitrogen are discussed.

Effects of Hydrogen

As suggested in Fig. 6 with the weld produced with 6% hydrogen, Fig. 11 confirms that large spherical pores were encountered when hydrogen was present in the arc atmosphere. However, based upon Figs. 6 and 11, the size and perhaps amount and concentration of pores appeared to be influenced by the concentration of hydrogen, the gas that is mixed with hydrogen, as well as the current that is selected. In this section, the influence of welding parameters is therefore pri-
welds where fusion zone penetration was with a current measuring at least 40 A — wider and deeper weld fusion zones — viewed. First, recall that voltage stepped zone area) at currents of 30 and 40 A is over two-thirds of the workpiece thick-

Fig. 10 — Fusion zone penetration vs. welding voltage at two current levels (40 and 50 A), as measured using arc lengths from 0.5 to 4.0 mm

mary to discuss. Since porosity is the re-

Fig. 11 — Optical micrographs of bead-on-plate welds produced with various combinations of current and gas (arc length: 0.5 mm).

result of a nucleation and growth process depending upon mass transport and solubi-

lity of hydrogen (Ref. 21), the effects of process parameters that affect hydrogen transport, particularly the arc length and the current, were studied. Further, relations with weld fusion zone morphology, already discussed, were searched.

In Fig. 12, the concentration of hy-

drogen pores (defined in percent of fusion zone area) at currents of 30 and 40 A is graphically represented as a function of the arc length for each of the hydrogen-enriched gases. Due to variations between weld cross sections, the data were considerably dispersed. While the contribution of current to porosity could not be established using the two currents shown in Fig. 12, a clear correlation between pore concentration, arc length, and hydrogen concentration was found. Figure 12 shows that porosity decreased when the arc length was increased and when hydrogen concentration was reduced.

To understand this last result, some of the results already presented must be re-

Fig. 14A–D depicts optical and sec-

ondary electron images with EDS and XRD results for the region in Fig. 11 that has been designated as FZ2. This new region demonstrates that a measurable amount of nitrogen had permanently entered the weld, most particularly its upper part, FZ2. In one of two reasonable explanations, nitrogen interacted with the weld pool well before its dimensions reached that of the fusion zone. The presence of nitrogen at the weld pool surface, either in solution or as a nitride layer covering the pool, could explain why hydrogen did not induce porosity. In this situation, the contribution of nitrogen would have been to prevent hydrogen to enter the weld pool. Alternatively, nitrogen could have been dissolved in the entire fusion zone, implying that during solidification, hydrogen would have been gradually rejected by the fast-growing magnesium solid phase. In this second explanation, FZ2 would have formed the last, after the material in FZ1 would have solidified without being effectively influenced by hydrogen or nitrogen. To valid
date this second explanation, hydrogen would have been dissolved in restricted amounts in the magnesium liquid phase. Reduced hydrogen solubility, thus low hydrogen partial pressure for pore nucleation, could well explain the absence of pores in all the fusion zones made with nitrogen. Although a complete understanding of the interaction between the magnesium weld pool, nitrogen, and hydrogen might be out of reach given the initial purposes of this study, the data of Fig. 14 are worth examining to better understand weld formation with the nitrogen-rich gas.

Figure 14A and B clearly shows that FZ2 exhibited an uncharacteristic banded microstructure. Such microstructure is as intriguing and puzzling as the presence of the two regions, FZ1 and FZ2. The banded microstructure of FZ2 indicates that nitrogen had entered the weld pool, and had possibly partitioned from a magnesium-rich phase to periodically reach concentrations large enough to stabilize at least one new nitrogen-rich phase. If that is the case, the rejection of nitrogen from a magnesium-rich phase would demonstrate that this magnesium alloy has no solubility for nitrogen. Thermodynamically, this would mean that enthalpy of mixing for a solution comprising magnesium, its alloying elements, and nitrogen is strongly positive, at least when the solution composition is far from that of the new nitrogen-rich phase. If the microstructures of Fig. 14A and B are the result of normal partitioning, the new nitrogen-rich phase must have formed after the magnesium-rich phase, as would be seen in a eutectic transformation. In the presence of a eutectic transformation, the temperatures where the alloyed region, FZ2, would be liquid would be lower than that of the AZ80 alloy (i.e., the material of FZ1). The presence of a lower melting point eutectic mixture (although not validated by other measurements or a complete binary phase diagram (unavailable), is in agreement with the observation that FZ2 is located near the weld upper surface, where it would be expected if it had solidified at last.

However, the fact that nitrogen accumulated along concentric bands, well following the solid/liquid interface, also appears to be unusual for eutectic decompositions, and this last explanation may therefore be invalid. Although no data are provided to support this discussion, the unusual phase morphology seen in Fig. 14A and B may be better explained if capillarity is considered. Rejection of nitrogen from magnesium-rich growing dendrites and transport of nitrogen along the dendrite boundary toward the dendrite tips (driven by capillarity) would be a satisfactory explanation for the banded microstructures of Fig. 14A and B, if supporting data were available. In that particular situation, nitrogen would constantly advance at the same time as the solid/liquid interface until the nitrogen buildup would become enough for a new phase to form and magnesium to continue solidifying beyond the magnesium nitride phase.

Figure 13 — Pore size distribution as a function of arc length and current for the welds produced with the 6% hydrogen-enriched argon gas.
cally represented as a function of temperature in Fig. 15. In this figure, it is confirmed that the magnesium nitride phase, \( \text{Mg}_2\text{N}_2 \), was the most stable equilibrium product. However, it is also shown that the \( \text{Mg}_3\text{N}_2 \) phase formed at much higher temperatures than anticipated (about 1500 K), and certainly at temperatures where magnesium was still in a gaseous state. This new result therefore strongly indicates that some unknown fraction of the magnesium nitride seen in Fig. 14 had formed in the arc atmosphere before condensing on top of the weld. Consequently, the first analysis, suggesting that hydrogen was prevented from entering the weld pool because of nitrogen at the weld surface, is validated. This new result still does not mean that the second explanation, invoking the nitrogen partitioning, is invalid. It simply means that understanding weld pool formation in the presence of nitrogen is more complicated than initially thought and requires further research.

Conclusions

The effects of gases, in particular hydrogen and nitrogen, have been investigated with the general objective of increasing melting during GTA welding of magnesium alloys. The following conclusions were reached:

- The weld fusion zone dimensions, particularly the penetration (Fig. 7), were increased with gases having a high first ionization potential, because voltage and thus heat input (under a constant current condition) were increased — Figs. 4, 5.

Helium, due to its high first ionization potential (24.5 eV), produced deeper fusion zones than argon (15.9 eV).

- When 1% hydrogen was added to either argon or helium, the fusion zones were more penetrating than with only the monatomic gases. Also, nitrogen substituted for either argon or helium, generated even more melting, although its first ionization potential is less than that of either argon or helium. The properties of diatomic gases (Fig. 2), particularly enthalpy and thermal conductivity, could well explain the increased voltage and penetration observed with these gases — Figs. 4, 5.

- Despite desirable increase in melting, hydrogen was also a powerful source of porosity — Fig. 13. However, porosity could be prevented by establishing fully penetrating welds, where heat flow is two-dimensional. Due to a slower cooling than in partial-penetration welds, pores could nucleate, grow, and leave the weld pool.

- Regardless of the welding parameters, nitrogen stabilized a second phase near the weld surface — Fig. 14. Although examined in this paper, the interaction between magnesium and nitrogen is not yet well understood.

- Minor additions of hydrogen to argon or helium could be recommended to increase melting. With nitrogen, the properties of the nitride layer must be further investigated.

Acknowledgments

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Call for Papers

The American Welding Society announces a Call for Papers for the 2005 Professional Program to be held as part of Welding Show 2005 on April 26–28, 2005, in Dallas, Texas.

Submissions should fall in one of the following three categories and will be accepted only in a specific format. Individuals interested in participating should contact Dorcas Troche, Manager, Conferences & Seminars via email at dorcas@aws.org for specific details. Deadline for submission of paper is Friday, July 30, 2004.

Technical/Research Oriented
- New science or research
- Selection based on technical merit
- Emphasis is on previously unpublished work in science or engineering relevant to welding, joining and allied processes.
- Preference will be given to submittals with clearly communicated benefit to the welding industry.

Applied Technology
- New or unique applications
- Selection based on technical merit
- Emphasis is on previously unpublished work that applies known principles of joining science or engineering in unique ways
- Preference will be given to submittals with clearly communicated benefit to the welding industry.

Education
- Welding education at all levels
- Emphasis is on education/training methods and their successes
- Papers should address overall relevance to the welding industry.

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ABSTRACT. The effect of external restraints and thermal management techniques (heat sinking and gas tungsten arc [GTA] preheating) on the relationship between cumulative plastic strains and angular distortion in fillet welded T-joints was investigated using plasticity-based distortion analysis (PDA). External restraints reduced the bend-up angular distortion by increasing the bend-down angular distortion induced by the transverse cumulative plastic strain. The higher restraint produces the less angular distortion. Heat sinking increases the bend-up angular distortion. This technique mainly controls the nominal cumulative plastic strains. The bend-down angular distortions induced by the transverse and vertical components are decreased. These changes resulted in an increase of the total bend-up angular distortion.

Gas tungsten arc preheating reduced the angular distortion by decreasing the bend-up angular distortion induced by the xy-plane shear cumulative plastic strain. The characteristic relationship between cumulative plastic strains and angular distortion in fillet welded T-joints was not affected by the external restraints and thermal management techniques.

Introduction

Distortions induced by welding have been regarded as a critical issue in terms of performance, quality, and productivity. Many techniques have been developed to minimize the distortions induced by welding, such as external restraining, preheating, auxiliary side heating, heat sinking, and others. In general, most of the distortion mitigation techniques have been developed according to conventional understanding to explain their effectiveness in distortion controls, and then evaluated by comparing with test results. These conventional understandings may include not only theoretical and mathematical knowledge, but also generally accepted knowledge from experience or analogy. For example, the concept of predeformation is based on direct intuition after observing the distortion patterns; welding-induced deformation is compensated for by the counterdeformation formed in joints prior to welding. The other example can be heat control techniques applying preheating or side heating in order to reduce the temperature gradient. Once the basic idea is tested and evaluated, a number of parametric studies may follow to find the optimum condition and explain the effect of mitigation parameters.

Masubuchi (Ref. 1) summarized methods for reducing distortions in welded joints based on the research. He reviewed the general distortion-reduction methods in terms of weld dimensions, joint designs, welding processes, multipass welding, constraints, welding sequences, intermittent welding, and peening. More detailed discussions on the effects of external restraints and thermal-pattern alterations were presented. Pavlovsky and Masubuchi (Ref. 2) reviewed the various distortion control methods studied by U.S.S.R. researchers. Conrardy and Dull (Ref. 3) reviewed the distortion control techniques applicable in thin ship panel structures. To reduce buckling, modifying panel design, applying intermittent welding, reducing heat input, and applying thermal tensioning were recommended. Restraining, back-bending and backside line heating were recommended as techniques for reducing angular distortion.

Recently, the finite element method has been used to investigate the performance of various distortion control techniques, and has provided the fundamental understanding of the distortion mechanism and the effects of distortion control techniques on distortion patterns. Park (Ref. 4) developed a model to predict the thin plate panel distortion, and simulated the effect of welding sequences on the reduction of the distortions. Ohata et al. (Ref. 5) introduced the GTA preheating method to reduce the angular distortion in fillet welded aluminum thin plates, and performed weld tests and finite element analyses to evaluate its effectiveness. Michaliris and his coworkers (Refs. 6, 7) studied the effect of thermal tensioning buckling in panel structures using tests and finite element analysis. Ma et al. (Ref. 8) simulated the effects of weld sequences, a working table, and external restraints on the angular distortion of fillet welded T-joints, using 2-D finite element analysis. Han (Ref. 9) simulated the effects of side heating, heat sinking, and their combination on the distribution pattern of the longitudinal plastic strain associated with the longitudinal compressive stress causing buckling, using 2-D finite element analysis.

However, no rigorous studies have been carried out to investigate how these techniques affect the relationship between cumulative plastic strains and distortion. Recently, Han (Ref. 9) investigated how heat sinking and side heating affect the longitudinal cumulative plastic strain, and explained the effectiveness of the methods based on the relationship between the longitudinal cumulative plastic strain and the longitudinal residual stress associated with buckling in butt joint welded plates.

Jung (Ref. 10) developed the procedure, the so-called plasticity-based distortion analysis (PDA), which enables the investigation of the relationship between
cumulative plastic strains and angular distortion in fillet welded T-joints. The PDA successfully explained each cumulative plastic strain's contribution to angular distortion in fillet welded T-joints.

This study investigated the effect of external restraints and two specific thermal management techniques (heat sinking and GTA preheating) on the relationship between cumulative plastic strains and angular distortion for fillet welded thin plate T-joints using PDA.

Plasticity-based Distortion Analysis (PDA) for Fillet Welded T-Joints

During welding, materials experience plastic deformation due to the thermal stresses induced by the temperature gradient, the external restraints, and the material softening. Plastic strains are cumulated during the plastic deformation, and then remained permanently after temperature reaches room temperature and some temporary restraints are removed. These cumulative plastic strains result in residual stresses and distortions in the welded joints. The inherent shrinkage model is one of the methods to incorporate these cumulative plastic strains in the welded joints using the equivalent forces and moments, and to predict the welding-induced distortions without performing the thermal-elastic-plastic analysis (Refs. 11, 12). However, when the joint configuration is complex, such as T-joints, it is difficult to calculate the equivalent forces and moments because of the lack of knowledge about the relationship between cumulative plastic strains and distortions.

On the other hand, PDA enables us to predict distortions by mapping all cumulative plastic strains into elastic models using the equivalent thermal strains instead of the equivalent forces and moments, and provides the quantitative relationship between cumulative plastic strains and distortions.

The PDA includes the following three parts:
- Part 1: Thermal-elastic-plastic analyses (EPA) to obtain cumulative plastic components and distortions
- Part 2: Elastic analyses with thermal strains, which are equivalent to the cumulative plastic strains obtained from the EPA to predict the individual distortions that are associated with only one cumulative plastic strain component
- Part 3: Postprocessing to check the accuracy of the predicted distortion. If the accuracy does not satisfy the required accuracy, update a finite element model and repeat Parts 1, 2, and 3.

Thermal-Elastic-Plastic Analysis

The 3-D uncoupled thermal-elastic-
plastic analysis for fillet welded T-joints without any external restraints and thermal management techniques was performed to obtain the baseline information, such as the characteristic distribution patterns of cumulative plastic strains and the corresponding angular distortion, using ABAQUS.  

The material is magnesium Alloy AZ91 C, which application has been expanded because of its relatively lower density. In this study, weld tests were not performed; only numerical simulations were performed. It is assumed that the present analysis procedure provides the reasonable distribution patterns of the cumulative plastic strains and the corresponding angular distortion in fillet welded T-joints. The validity of the present EPA procedure was evaluated by comparing the angular distortions obtained from the EPA and experiments for aluminum fillet welded T-joints (Ref. 10).

Two fillet welds running simultaneously at two sides constructed the T-joint. The given gas metal arc welding parameters were voltage = 13 V, current = 110 A, weld speed = 10 mm/s for 3.2-mm-thick plates (Ref. 13).

Figure 1 shows a symmetric half finite element model used in the EPA for a fillet welded T-joint, with a flange, 100 x 200 x 3.2 mm, and a web erected on the flange plate, 100 x 100 x 3.2 mm. Quadratic brick elements with 20 nodes, DC3D20 (thermal analysis), and C3D20R (elastic-plastic analysis) in ABAQUS (Ref. 14) were used. The total number of elements and nodes used were 6100 and 30,068, respectively.

Figure 2 shows the temperature-dependent thermal properties (Ref. 15). The latent heat, solidus, and liquidus temperature are 3,73EF5 J/(kg°C), 470°C, and 595°C, respectively. Natural convection boundaries shown in Fig. 3 were described on the entire free surfaces of the joint except for a symmetric plane. Figures 4–6 show mechanical properties depending on temperature. Nonlinear kinematic strain hardening proposed by Chaboche (Ref. 14, 17) was used.

The effect of a moving heat source was incorporated by the user-subroutine in ABAQUS, DFLUX (Ref. 14). Body flux had a double ellipsoidal distribution proposed by Goldak (Ref. 16). Heat input calibration was carried out by matching the boundary of the molten pool with the pre-designed fillet size. UVARM (Ref. 14) was developed to calculate the maximum peak temperature overall nodes. Figure 7 shows a map of the maximum peak temperature with a calibration factor of 0.6 including the arc efficiency. During the elastic-plastic analysis, symmetric boundary conditions were described on the YZ plane in Fig. 1, and the top free edge of the web plate was fixed. The effects of the filler metal deposition, the stress and strain relaxation at melting temperature, and metallurgical transformation were not considered in the present EPA.

The characteristic cumulative plastic strain distribution patterns and the associated angular distortion for fillet welded thin plate T-joints were obtained from the EPA. The angular distortion was defined by the displacement in the Y-direction (Fig. 1) at the free edge of the flange plate (at X = 100 mm). The obtained averaged angular distortion from the EPA was 1.04 mm.

**Elastic Analysis**

The finite element model and mechanical boundary conditions used in the elastic analysis are the same as those of the EPA. The cumulative plastic strains obtained from the EPA were mapped into elastic models with the same nodes and elements, elastic modulus (4.3E4 [MPa]) and Poisson's ratio (0.35) at room temperature using the equivalent thermal strains.

Each cumulative plastic strain component can be mapped independently into six elastic models. Anisotropic thermal expansion coefficients and corresponding temperature fields replace the cumulative plastic strains. For example, the transverse cumulative plastic strain, \( \sum \varepsilon_{i j} (x,y,z) \), can be mapped by using the temperature field calculated by Equation 1 (Ref. 14):
3. 

Fig. 7: Maximum peak temperature map in the T-joint

White Colour: over 505 °C

Fig. 8: Averaged angular distortions calculated by EPA and PDA.

Apply restraint during welding and cooling, and then remove it

Case A: x = 100 mm
Case B: x = 50 mm
Case C: x = 24.7 mm

Fig. 9: Characteristics of thermal strain in second-order elements

Fig. 10: Locations of applied external restraints

\[ \varepsilon_{ij}^p = \alpha_{ij} F(x, y, z) \]

where \( F(x, y, z) \)

\[ \Delta_{\alpha} = \text{constant}, \alpha_{yy} = \alpha_{zz} = \alpha_{xy} = \alpha_{xz} = \alpha_{yz} = \]

where \( E^p \) = averaged cumulative plastic strain at nodes, \( \theta = \) temperature, \( \alpha = \) anisotropic thermal expansion coefficients. Other temperature fields associated with other cumulative plastic strain components can be obtained using Equation 1 as well.

Six cumulative plastic strains can also be simultaneously mapped into an elastic model using the equivalent thermal strains depending upon six field variables defined by Equation 2 (Ref.14):

\[ \varepsilon_{ij}^p = \alpha_{ij} F(x, y, z) \]

where \( F(x, y, z) \)

\[ \Delta_{\alpha} = \text{constant}, \alpha_{yy} = \alpha_{zz} = \alpha_{xy} = \alpha_{xz} = \alpha_{yz} = \]

This simultaneous mapping method was used to demonstrate the validity of the addition procedure to obtain the total distortion and the unique relationship between cumulative plastic strains and distortions.

Figure 8 also clearly shows the quantitative relationship between cumulative plastic strains and angular distortion. The transverse, \( E^p_{xx} \), and the vertical, \( E^p_{yy} \), cumulative plastic strain components result in the bend-down angular distortion, and the longitudinal, \( E^p_{zz} \), and the x-plane shear, \( E^p_{xy} \), cumulative plastic strain components generate the bend-up angular distortion. Most bend-up angular distortion is induced by the xy-plane shear cumulative plastic strain, and the angular distortion induced by other shear, \( E^p_{xy} \), and \( E^p_{yz} \), cumulative plastic strains is small enough to be negligible.

Postprocessing

The total distortion induced by all cumulative plastic strains is obtained by adding the individual distortions calculated from six independent elastic analyses:

\[ \delta^{\text{total}}_{\text{PDA}} = \sum_{i=1}^{6} \delta_i \]
The accuracy of the PDA procedure can be determined by comparing the distortions from the EPA with the total distortions obtained from the PDA using Equation 3.

\[
\text{Error} = \left| \frac{\delta_{\text{EPA}} - \delta_{\text{PDA}}}{\delta_{\text{EPA}}} \right| \times 100 \% \quad (4)
\]

This accuracy of the PDA procedure may be affected by some factors such as the nonlinearity of material and the mapping accuracy.

One factor is material nonlinearity, which does not allow the linear suppositions if the effect of nonlinearity is dominant. Material nonlinearity comes from the plastic deformation and the temperature dependency of material properties in the welding situation. In the PDA, material nonlinearity due to temperature dependency does not exist anymore because temperature is constant (room temperature) after completing welding. Nonlinearity due to the plastic deformation can also be negligible because the PDA is somewhat elastic, reloading analysis up to the final plastic deformation after welding.

The mapping accuracy may also affect the accuracy of the PDA procedure. The mapping accuracy is strongly dependent upon the number of elements/nodes and the order of shape function of element. Figure 9 shows the applied cumulative plastic strain using temperature and the calculated thermal strain within two second-order elements in which the thermal strain is linear. Unless the individual distortions are distributed uniformly or linearly within an element, the mapping error is unavoidable even though second-order elements are used. The averaged cumulative plastic strains at nodes may also result in the error when significant discontinuity of the cumulative plastic strains at the integration points between the adjacent elements is present. In order to reduce the error induced by mapping, a finer-meshed model with second-order elements is recommended.

In this study, it was assumed that the acceptable error range of the PDA procedure was 0 to 10% in view of the engineering application. Since most errors come from the mapping, the finite element model should be updated until the required accuracy is achieved. The averaged total angular distortion obtained from the PDA was 1.01 mm, which had 3% error compared with 1.04 mm obtained from the EPA. This accuracy is acceptable.

In order to evaluate the PDA application to fillet welded T-joints and demonstrate the unique relationship between cumulative plastics and distortion, the simultaneous mapping analysis was performed under the combined cumulative plastic strains. Table 1 shows that the displacements obtained from the simultaneous mapping analysis are equal to those calculated by the PDA, which satisfies the linear superposition requirement described in Equation 5. Therefore, the PDA procedure is valid and each individual distortion can be uniquely determined by the associated cumulative plastic strain.

\[
\begin{align*}
&L_1 \left( \Sigma e_{x}^P, \Sigma e_{y}^P, \Sigma e_{z}^P, \Sigma e_{x y}^P, \Sigma e_{x z}^P, \Sigma e_{y z}^P \right) \\
&= L_2 \left( \Sigma e_{x}^P \right) + L_3 \left( \Sigma e_{y}^P \right) + L_4 \left( \Sigma e_{z}^P \right) \\
&+ L_5 \left( \Sigma e_{x y}^P \right) + L_6 \left( \Sigma e_{x z}^P \right) + L_0 \left( \Sigma e_{y z}^P \right) \\
\end{align*}
\]

Effect of External Restraints on Angular Distortion in T-Joints

The external restraining techniques have been widely known as useful techniques for reducing the angular distortion in welded structures. For pressure vessels or large-scale pipes, pre-expanding has been adopted to reduce the radial shrinkage. In the case of T-joints, it has been reported that restraining and back-bending of the flange plates are effective means for reducing angular distortion (Ref. 3).

In this study, the PDA investigates the effect of external restraints on the characteristic relationship between cumulative
plastic strains and angular distortion in fillet welded T-joints.

Thermal Analysis (Part 1)

Some amount of heat loss through the contact surfaces between the fixtures and the flange may occur, but it was assumed that heat loss through the contact surfaces would be negligible. Therefore, the same temperature evolution obtained from the previous thermal analysis was used in the following elastic-plastic analyses for the three cases with differing degrees of external restraining.

Elastic-Plastic Analysis (Part 1)

It has been reported that the angular distortion is affected by the degree of external restraining (Refs. 1, 18); the higher degree of restraining, the less angular distortion. In this study, external restraints were applied along the flange plate with fixed boundary conditions. The degree of restraining is inversely proportional to the distance between the weld interface and the line of the fixed boundaries.

Figure 10 shows the locations of external restraints. Three cases designated as Case A, Case B, and Case C have differing degrees of external restraining. The locations applying the fixed boundary conditions for Case A, Case B, and Case C were x = 100 mm, 50 mm, and 24.7 mm, respectively. Case C has the highest restraining of the three cases. These fixed boundary conditions were applied during heating and cooling, and then removed after cooling was completed. The final angular distortion was obtained after removing external restraints. From these simulations, we can obtain the characteristic cumulative plastic strain distribution patterns and the angular distortion associated with differing degrees of external restraining, both of which can be used in the PDA to investigate the effect of the external restraints on the angular distortion in T-joints.

Figure 11 shows the deformed shapes after removing the external restraints with the same scaling factor. The averaged angular distortions for Cases A, B, and C are 0.65, 0.30, and 0.05 mm, respectively. They are plotted in Fig. 12 with dimensionless parameters. Figures 11 and 12 show that
less angular distortion is expected at a higher degree of restraining. A minute angular distortion is produced in Case C with external restraints at $x = 24.7$ mm where it is close to the boundary of the plastic zone ($x = 21.58$ mm) produced in the case without external restraints.

These differences among the three cases may result from the change in the cumulative plastic strain distributions due to the external restraints. The effects of the external restraints on the distribution patterns of the cumulative plastic strains can be observed by plotting the cumulative plastic strains. However, this observation may not give the right and quantitative interpretation of the relationship because the cumulative plastic strains have complicated distribution on the welded region. Therefore, the PDA was carried out to study the effect of the external restraints on the characteristic relationship between cumulative plastic strains and angular distortion.

**Elastic Analysis and Postprocessing (Parts 2, 3)**

The cumulative plastic strains obtained from the three cases with differing degrees of external restraining were mapped into elastic models using the equivalent thermal strains.

In order to investigate the effect of external restraints on the relationship between cumulative plastic strain and angular distortion, the individual and the total angular distortions for the three cases and a case without external restraints are plotted together in Fig. 13. Reasonable accuracy of the PDA is shown for all cases.

No change of the basic relationship between cumulative plastic strains and angular distortion is observed: bend-down angular distortion is due to transverse/vertical cumulative plastic strains, bend-up angular distortion is due to longitudinal/shear cumulative plastic strains, and no angular distortion is caused by other shear cumulative plastic strains.

The major change due to the external restraints is observed in the individual angular distortion induced by the transverse cumulative plastic strain, $\Sigma P_{y\gamma}$. A higher degree of restraining produces a more bend-down angular distortion induced by the transverse cumulative plastic strain. Figure 14 shows the change in the transverse cumulative plastic strain distributed on the flange plate. There is no change in the distribution on the web plate, but the area with the positive plastic strain on the top surface of the flange plate occurs because the role of the positive transverse cumulative plastic strain on the top surface of the flange plate.

For the vertical cumulative plastic strain, $\Sigma P_{x\gamma}$, only a slight change in the angular distortion is shown. In general, less bend-down angular distortion is induced by higher external restraining. No change in the angular distortion induced by the longitudinal cumulative plastic strain occurs. This may imply that the external restraints applied on the flange would not affect the distribution patterns of the longitudinal cumulative plastic strain.

For the angular distortion induced by the shear cumulative plastic strain, $\Sigma P_{y\gamma}$, no change in the individual angular distortion is shown except Case C with the external restraint close to the boundary of the plastic zone. Figure 15 clearly shows how the external restraints affect the distribution of the xy-plane shear cumulative plastic strain. There is no change in the distribution pattern for Case A, Case B, and the case without external restraints. For Case C, the external restraint close to the boundary of the plastic zone disturbs the distribution of the xy-plane shear cumulative plastic strain. The change in the individual angular distortions induced by other shear components is negligible.

Based on results of the PDA, it can be concluded that the reduction of the angular distortion by the external restraints applied on the flange results from an increase of the bend-down angular distortion induced by the transverse cumulative plastic strain. The region where the positive transverse cumulative plastic strain exists is expanded by increasing the degree of external restraining.
Effect of Thermal Management Techniques on Angular Distortion in T-Joints

Two thermal management techniques were selected: heat sinking and GTA preheating. They are inherently different in terms of heat control. Heat sinking reduces the heat-affected zone by applying a cooling chamber beneath the bottom of the flange. On the other hand, GTA preheating increases the heat-affected zone by preheating, which is carried out by running a gas tungsten arc ahead of gas metal arc welding (GMAW) on the bottom surface of the flange.

It has been reported that heat sinking is an effective way to reduce buckling (Ref. 7), and GTA preheating reduces the angular distortion in T-joints (Ref. 5). Most research has been focused on showing their effectiveness using weld tests and numerical simulations. Recently, Han (Ref. 9) investigated the relationship between cumulative plastic strains and buckling for butt joints. However, it is still unknown how thermal management techniques affect the relationship between cumulative plastic strains and angular distortion in T-joints. Therefore, the effect of thermal management techniques on the relationship between cumulative plastic strains and angular distortion was investigated using the PDA.

Thermal Analysis (Part 1)

The effect of heat sinking was simulated by applying the relatively low film coefficient, 1.0E-2 W/(mm² °C) with temperature 21°C, on the bottom surface of the flange within x = 0~24.8 mm as shown in Fig. 16. Gas tungsten arc preheating was modeled by running a gas tungsten arc 50 mm ahead of GMAW at the same speed as GMAW on the bottom surface of the flange as shown in Fig. 17. The GTA heat was one-third of that of GMAW, 477 W (= 110 V × 13 A × 0.6) with a heat input calibration factor of 0.6.

A nugget with heat sinking will be smaller than that with GTA preheating because preheating raises the temperature in and around the weld region. Figure 18 shows the maximum peak temperature maps calculated by the user-subroutine, UVARM. Compared to the nugget without thermal management, heat sinking generates a smaller nugget and GTA preheating gives a larger nugget.

Heat management techniques affect not only the size of the heat-affected zone, but also the rate of heating and cooling, which can be related to the instantaneous gradient of temperature in the plates. In general, heat sinking results in a higher temperature gradient due to a higher cooling rate, and facilitates achieving a uniform temperature in the plates compared to the case without thermal management. Contrarily, GTA preheating increases the maximum peak temperature and reduces the temperature gradient.

Figure 19 compares temperature evolutions on three points located on the top surface of the flange, x = 4.8, 9.8, and 24.8 mm. The distance between the curves represents the temperature gradient and their slopes show the heating and cooling rate. For heat sinking, a significant change of the magnitude of the maximum peak temperature, the temperature gradient, and the rate of cooling are observed. Gas tungsten arc preheating does not give significant changes in the temperature gradient and the cooling rate compared with the case without thermal management. During heating, two spikes on each curve show the effect of GTA preheating. Preheating also increases the maximum peak temperatures of each curve, which results in a wider nugget and heat-affected zone.

Based on the results of the thermal analysis, the two thermal management techniques, heat sinking and GTA preheating, may give the opposite impact on not only the temperature evolution and profile, but also the angular distortion.

Elastic-Plastic Analysis (Part 1)

All boundary conditions for the two cases were the same as those of the case without the external restraints described in the previous section. The temperature evolutions for the two cases calculated by the thermal analyses were retrieved and applied to the elastic-plastic analysis.

Figure 20 shows the deformed shapes for the three cases with the same magnification scale factor: Case 1 = without ther-
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Fig. 20 — Comparison of deformed shapes for the cases with different thermal management techniques.

Fig. 21 — Comparison of averaged angular distortions for the cases with different distortion control plans.

mal management, Case 2 = heat sinking, Case 3 = GTA preheating. The average angular distortions calculated for Cases 1, 2, and 3 are 1.04, 2.75, and 0.5 mm, respectively, and are plotted with dimensionless parameters in Fig. 21. It shows that heat sinking increases angular distortion, but GTA preheating reduces angular distortion. This opposite effect between the two thermal management techniques on the angular distortion was expected after observing the results of the thermal analysis. Figure 21 shows that external restraining and GTA preheating effectively reduces the angular distortion. The effect of the combination of GTA preheating and external restraining (Case A, restrained at X = 100 mm) was also tested, but a slight increase in the angular distortion was obtained compared to the case with only GTA preheating.

To investigate the causes of these differences, cumulative plastic strain maps for the three cases are plotted in Fig. 22. For Cases 1 and 3, a similar distribution pattern of the cumulative plastic strains is shown. On the other hand, a significant reduction of the size of the plastic zone is obtained by heat sinking. The distribution pattern of the transverse cumulative plastic strain for Case 2 is different from those of Cases 1 and 3. For Case 2, the transverse cumulative plastic strain on the top surface of the flange is wider than on the bottom of the flange, which may cause the bend-up angular distortion and eventually reduce the amount of the bend-down angular distortion. For the vertical cumulative plastic strain, the reduced size of the plastic strain zone in the flange may affect the angular distortion as well. Even though there is significant change in the distribution pattern of the longitudinal cumulative plastic strain, the resultant effect may be small because the longitudinal component is not as sensitive as other components on the angular distortion. For the xy-plane shear cumulative plastic strain, no significant change is shown. For Case 3, it is not clear what causes the reduction of the angular distortion because there is no significant difference of cumulative plastic strain distributions between Cases 1 and 3. Compared to other components, it is observed that the distribution of the xy-plane shear cumulative plastic strain is slightly affected by GTA preheating. Gas tungsten arc preheating increases the area of the positive shear strain region on the bottom (or corner) of the flange and the area of the negative shear strain region on the top of the flange. However, it is not clear if this observation and interpretation is right at this point.

Elastic Analysis and Postprocessing (Parts 2 and 3)

As discussed previously, it is not easy to figure out the relationship between cumu-
The PDA was performed to investigate the effect of the thermal management techniques on the relationship between cumulative plastic strains and angular distortion.

The individual and the total angular distortions are plotted and compared for Cases 1, 2, and 3 in Fig. 23. No matter what types of thermal management techniques are applied, the basic characteristic relationship between cumulative plastic strains and angular distortion is not changed: transverse and vertical cumulative plastic strains result in bend-down angular distortion, and longitudinal and xy-plane shear cumulative plastic strains generate bend-up angular distortion.

Figure 23 shows that heat sinking increases the bend-up individual angular distortion, reducing the bend-down angular distortion, and ultimately causing an increase in the total angular distortion. The main cause of the increase of the total angular distortion comes from the reduction of the bend-down angular distortion induced by the transverse and the vertical components. A relatively small increase of the angular distortion due to the longitudinal and the xy-plane shear components is shown. These results obtained from the PDA are similar to the ones discussed in the EPA based on the maps of the cumulative plastic strains, but provide more quantitative information.

On the other hand, GTA preheating does not significantly change the individual angular distortions except the one induced by the xy-plane shear cumulative plastic strain. The reduction of the total angular distortion by GTA preheating is mainly related to the reduced bend-up angular distortion induced by the xy-plane shear cumulative plastic strain only. In order to reduce the bend-up angular distortion, the negative xy-plane shear strain resulting in the bend-down angular distortion must act more dominantly to reduce the bend-up angular distortion than the positive one. Therefore, the wider region of the negative xy-plane shear cumulative plastic strain on the top surface of the flange as shown in Fig. 22, the smaller bend-up angular distortion.

Based on results from the PDA, it can be concluded that heat sinking increases the total bend-up angular distortion by reducing the bend-down angular distortions induced by the transverse and the vertical cumulative plastic strains, and GTA preheating reduces the total bend-up angular distortion by reducing the bend-up angular distortion induced by the xy-plane shear cumulative plastic strain.

In addition, in terms of optimizing the welding-induced distortion, the selection of thermal management techniques should be carefully performed. Based on this study, heat sinking can help to reduce buckling, but may result in more angular distortion. On the other hand, GTA preheating can reduce the angular distortion, but it may possibly result in buckling or a more transverse shrinkage because GTA preheating generates a wider plastic zone (Ref. 9).

**Conclusions**

The effect of external restraints and thermal management techniques on the relationship between cumulative plastic strains and angular distortion in fillet welded thin plate T-joints was discussed using results from the PDA. The major findings are summarized as follows.

1) The PDA successfully investigated the effect of the external restraints and the thermal management techniques on the relationship between cumulative plastic strains and angular distortion.

2) Angular distortion was reduced by increasing the degree of external restraining applied on the flange of T-joints. The PDA showed that the reduction of the angular distortion by external restraints resulted from the increase of the bend-down angular distortion induced by the transverse cumulative plastic strain. The effect of the external restraints on other cumulative plastic strains was small enough to
be negligible.

3) Heat sinking increased the angular distortion. The PDA showed that heat sinking mainly controlled nominal cumulative plastic strains, such as transverse, vertical, and longitudinal components. The bend-down angular distortion induced by the transverse and the vertical components was reduced by heat sinking, which resulted in the increase in angular distortion. For other components, the change in angular distortion was relatively small, thus negligible.

4) Preheating with a gas tungsten arc reduced the angular distortion. The PDA showed that GTA preheating mainly controlled the contribution of the x-y-plane shear cumulative plastic strain existing in and around the welded region. The reduction in angular distortion resulted from the reduction of the bend-up angular distortion induced by the x-y-plane shear cumulative plastic strain.

References


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Papers are sought on the welding and joining of products and components related to pipeline and energy applications. Authors are encouraged to submit a 500 to 1,000 word abstract by July 30th, 2004, to be considered for presentation at the 2005 Symposium on Welding for Pipeline and Energy Applications. The two-day Symposium is taking place in conjunction with the 53rd annual AWS Welding Show, April 26 through April 28 at the Dallas Convention Center in Dallas, Texas.

Papers representing original experimental investigations, theoretical and statistical modeling, and applications in welding and joining for pipeline and energy applications are sought in the following areas:

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