A super duplex success story:
from CalEnergy and Carolina Energy Solutions

Super duplex field welding technology - first employed in the cold North Sea – is now hard at work in the arid California desert, thanks to a teamwork effort led by CalEnergy and WEC Carolina Energy Solutions. This challenging application involves geothermal power generation at CalEnergy's Salton Sea complex. A leader in the renewable energy field, CalEnergy is a US – based independent power producer, providing over 340 megawatts to the California power grid. Similarly well known is Carolina Energy Solutions of Rock Hill, SC – a renowned innovator of highly specialized field welding and machining technology. Stainless Steel World first reported on this effort in the October, 2006 issue. We revisited senior project engineer George Furmanski at CalEnergy Imperial Valley engineering headquarters for an update on this intriguing application of super duplex stainless steel in a uniquely corrosive environment.

By John M. Griffin

The blistering California desert has become a testing ground for advanced stainless steel alloys. It is here that superheated geothermal fluid reservoirs are tapped to drive steam turbine generators, producing clean, reliable energy for power hungry Southern California.

Externally, the ten Imperial Valley CalEnergy generation plants appear quiet and efficient, collectively producing 340 MW of net baseload power with an impressive 93% capacity factor. Only upon closer inspection does the internal picture come into focus: an ongoing battle to harness one of the world's most aggressive naturally occurring geothermal fluids.

About WEC Carolina Energy Solutions

Carolina Energy Solutions is home to some of the world's most advanced welding technology. The real essence of the company, however, is a unique ability to harness this technology in truly demanding applications. CES routinely performs technically exacting welds under tight turnaround schedules and extremely tough field conditions. A division of the Westinghouse Electric Company Welding and Machining business, Carolina Energy field crews can be found at nuclear, fossil, and renewable jobsites throughout the world. CES trains highly certified welders at "hands on" instruction centers, graduating over 100 craftsmen each year. WEC field machining, welding, and inspection equipment is designed and built in house, then stocked at strategic centers around the country for quick deployment.

Headquartered in Rock Hill, SC, the WEC Carolina Energy manufacturing facility produces highly engineered weldments and fabrications in support of field operations. Sister Westinghouse companies, PCI in LakeBluff, IL and WesDyne in Madison, PA provide custom welding equipment, robotic inspection, and advanced NDE technologies. www.wecwam.com; tel: +1 803 980 3070.

About CalEnergy

CalEnergy's domestic geothermal operations are a part of CE Generation, LLC, a limited liability company owned by MidAmerican Energy Holdings Company and TransAlta (CE Gen) Investments USA Inc. MidAmerican Energy Holdings Company specializes in the production of energy from diversified fuel sources including geothermal, natural gas, hydroelectric, wind, and coal. TransAlta is a power generation and wholesale marketing company that operates a highly contracted portfolio of similarly diversified assets in Canada, United States, Mexico, and Australia. CalEnergy's geothermal operations in California produce 340 megawatts of electricity – enough power to meet the energy needs of 340,000 homes. www.calenergy.com

The concentration of chlorides, hydrogen sulfide, and carbon dioxide make this one of the most abrasive, corrosive potpourris imaginable

Rising thousands of feet as caustic superheated brine, this fluid is flashed to steam, which drives turbine generators year 'round. Released of energy, the brine is then reinjected back into the underground geothermal reservoir.

A witch's cauldron

Entering the borehole at roughly 300°C and 40 bar, the superheated brine is a witch's brew of two phase liquid/vapor and dispersed solids. The chemical combination of chlorides, hydrogen sulfide, and carbon dioxide make this one of the most abrasive, corrosive potpourris imaginable. Typical samples test at pH 4.5 – 5.7, with chloride concentrations of 106,000 – 167,000 ppm, H_2S of 10 – 50 ppm, and CO_2 of 800 – 4800 ppm. Dissolved solids constitute 25% of the saturated brine solution. Liquid phase silica precipitation occurs readily at temperatures below 205°C – making deposition and scaling a constant concern.

Battling corrosion

When George Furmanski arrived at CalEnergy in 2001, the battle against corrosion was well underway. At that point, ongoing experiments with cement lined carbon steel pipe were producing mixed results. While an excellent solution in steady state thermal conditions, the widely differing expansion coefficients of steel and cement inevitably produced cracks and voids – particularly in the critical high temperature/high pressure turbine feed network. Even with summer ambient temperatures routinely reaching 50°C, the thermal shock associated with duty cycling 245°C feed lines was simply too great. And once a cement liner is breached, the SA 106 carbon steel 32mm wall x 76cm diameter pipe material erodes at a rate of up to 1.3 mm per month, reducing effective service life to two years or less.


Corrosion test pipe specimens

A promising experiment

Though technical solutions existed – the overriding issue was cost. For example, experiments had shown pricey Inconel 625 pipe and fittings to be an excellent choice in well head applications. Similarly, expensive titanium grade 29 bore casing was well proven over a number of years, whereas carbon steel counterparts typically failed within 18 months.

Calling upon extensive experience with duplex and lean duplex alloys in high temperature caustic environments, Mr. Furmanski moved quickly to install turbine feed test loops, in one case specifying super duplex 2507 (ASTM A928 UNS 32750). The long term results of this choice were gratifying. Over a 50 month test period, corrosion of less than 0.1mm per year was measured, indicating a greatly extended service life. And super duplex 2507 – though expensive – promised to be far more cost effective than the Inconel 625 piping alternative also under consideration.

When Stainless Steel World spoke with George Furmanski in 2006, it seemed that a solution for the problem of frequent and pricey pipeline replacement was close at hand.

About geothermal power

Geothermal power is a renewable source of energy that uses the natural heat of the earth to generate electricity. The US Department of Energy is now funding demonstration projects to showcase enhanced geothermal technologies. www.geothermal.id.doe.gov

Daunting obstacles

A number of obstacles still remained, however. The most daunting was a very practical one: how could over nine kilometers of 2507 pipeline be economically assembled on site without degrading corrosion resistance of the base metal?

There's a good reason for this dilemma. While SDSS 2507 may be readily welded using similar 2507 filler, maintaining correct metallurgy within the heat affected zone requires strict adherence to highly exacting weld procedures, including precise mechanical and chemical preparation, restrictive interpass temperature limits, and – most importantly - demanding post weld heat treatment. In a factory setting, these requirements can be met as a matter of course. However, accomplishing them in the middle of the California desert is another matter altogether.

Balancing act

Duplex stainless steels are defined by a microstructure containing both ferrite and austenite - hence the term "duplex". Maintaining the delicate balance of this ferrite/austenite microstructure in the weld heat affected zone (HAZ) is critical to ensuring long service life in highly corrosive environments.

Why specify super duplex? In a nutshell, duplex stainless steels provide superior resistance to stress corrosion cracking, together with higher overall strength than standard and super austenitic stainless steel. Super duplex stainless steels are characterized as alloys containing higher levels of Ni, Cr, Mo and N than standard duplex stainless steels. Some super duplex stainless steels are additionally alloyed with tungsten.

Welding wizardry

The relative proportions of ferrite and austenite in the weld deposit and heat affected zone closely depend upon filler composition and cooling rates. Rapid cooling rates result in higher levels of ferrite, particularly when welding is undertaken using duplex stainless steel filler metals. Practically, heat inputs in the range of 0.5-1.5kJ/mm for super duplex, and 0.5–2.0kJ/mm for standard duplex stainless steels are employed; this in conjunction with maximum interpass temperatures of 100°C and 150°C, respectively. Interpass temperature is often further restricted on thin wall super duplex materials to prevent the precipitation of third phase intermetallics.

In the quest for optimum corrosion resistance, a number of HAZ countermeasures are possible. One is close specification of the inert shield gas recipe. For example, a nitrogen rich shielding gas acts to aid the high temperature reformation of austenite in the weld region. Nitrogen also tends to improve erosion toughness, especially of the austenite phase.

Over alloying

Selection of filler metals is similarly crucial. For field welding, typical consumables for duplex are similar in composition to that of the base material, but may exhibit higher levels of nickel to ensure an appropriate phase balance (30-60% ferrite) in the deposited weld metal.

As an example, super duplex filler metal is often used for welding standard duplex stainless steels. Using such an "over alloyed" filler metal in these circumstances produces weld deposits with enhanced pitting corrosion resistance relative to standard weld deposits.

North Sea treasure

Further researching super duplex field welding, George found that others had faced similar job site welding issues in the North Sea. There, 2507 alloy bore casing – selected for both high strength and resistance to chloride stress corrosion cracking – must be welded under very tough offshore oil rig conditions. Furmanski discovered that a metallurgical solution had been developed which employed highly overalloyed fully austenitic nickel alloy filler materials. The use of a fully austenitic nickel alloy weld deposit removes the requirement which exists with duplex stainless steel filler metals to produce welds with balanced quantities of austenite and ferrite.

The treasure chest? This discovery opened a door to the possibility of performing optimum super duplex pipeline field welding without the need for post weld heat treatment.Time has proven the durability of North Sea field welds. Properly executed, they exhibit excellent corrosion resistance and superior mechanical properties. The question: Would this magic work half a world away?

One step forward

After further research and experimentation, Furmanski settled upon a Special Metals Inco-Weld™ 686 CPT filler material (AWS A5.14 ERNiCrMo-14) as a possible technical solution. Nominal composition is 57% nickel, 21% chrome, 16% moly, and 4% tungsten. Very carefully employed, this filler will preserve 2507 corrosion resistance without requiring post weld annealing.

As ever, cost control was paramount. With many kilometers of pipeline, the next step was to find mass produced SDSS 2507 pipe and fittings of the correct mechanical tolerances, together with a method of cost effectively field welding them using Inco-Weld™ 686 CPT.

The first issue took a good deal of travel and effort to resolve. A solution was eventually found in Knesebeck, Germany at H. Butting GmbH. Once involved, Butting engineers worked quickly to address production and fit up issues – an important consideration

Heavy duty rim line-up clamps

WEC Aggressive Equipment™ split frame portable lathe

with tough, high tensile SDSS 2507 piping.

A major stumbling block

Field welding 2507 turned out to be an even thornier problem, however. At first, George Furmanski searched for a qualified welding service with little success. Test samples and RFQ's were sent out with poor response. Proposals fell short as either too expensive, or technically unacceptable – or both. Test sample welds routinely failed inspection. Enter Carolina Energy Solutions of Rock Hill, SC. Well known for precision technical welding in nuclear and similar applications, CES relished the CalEnergy challenge. First, Carolina Energy worked to develop a 2507 base/686 CPT filler parameter set. Innovations included a 686 shield gas recipe appropriate to field applications, together with a "quick purge" internal backing gas fixture. Next came close engineering of computerized power supply and arc control characteristics, followed by in house weld specimen inspection and testing. The initial result: CES weld samples passed all CalEnergy tests with flying colors.

The Desert Rats

The next hurdle proved a daunting one: How could these exacting welds be performed – economically and precisely – while burdened with some of the toughest field conditions under the sun? CES site management worked side-by-side with CalEnergy "Desert Rats" rolled up their sleeves and got to work. CES project management worked side by side with CalEnergy, whilst simultaneously co-ordinating technical matters with the CES jobsite team of welding, machining, quality, and safety specialists. Along the way, field fixturing and tooling approaches had to be developed for groove prep and fit up – an undertaking that called upon the full scope of CES design and machining experience.

Field machining

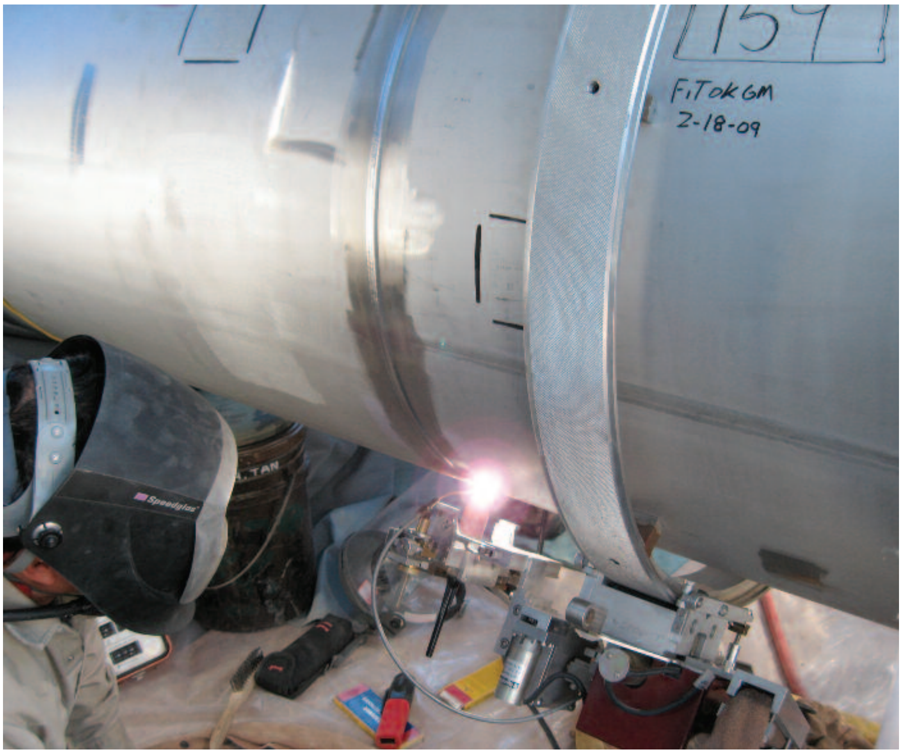
SDSS 2507 is famously tough to machine, and may be subject to work hardening and embrittlement if tool zone stresses and temperatures are not carefully controlled. Additionally, fixturing must be simple and rugged, allowing rapid, precise set up under harsh field conditions. With hundreds of pipe and fitting junctions, machining productivity is equally important to work efficiency – the trick is a combination of high cutting speeds and low feed rates. With groove faces machined, fit up concentricity is equally demanding. The solution was a split frame WEC Aggressive Equipment™ portable lathe, combined with heavy duty rim line-up clamps.

Orbital machine welding

After lab tests were successfully completed, Carolina Energy established a gas tungsten arc welding procedure employing manual root passes and orbital machine fill welding. With productivity and quality control as the principal drivers, this procedure was refined through extensive on site field testing.

Manual GTAW root passes allowed highly skilled CES welders to accommodate the gap and offset variables inevitable with cross country pipeline installations. Clean up and inspection completed this step, enabling the Carolina Energy orbital machine crews to quickly set up for fill passes.

During procedure development, numerous obstacles confronted the



Carolina Energy Solutions orbital machine welding

Desert Rats. With perseverance and teamwork, practical solutions were eventually found. Desert night/day temperatures routinely swing through 16ºC, making moisture condensation an issue - even in ultra low humidity conditions. The solution: thermal blanketing of pipeline junctions. Grit laden dust storms whip daily over the Salton Sea. The solution: portable sheltering for operators, shield gas, and arc control. Critical interpass temperatures can vary widely as the desert sun rapidly heats exposed pipe sections. The solution? Interactive weld control parameters tied to base metal temperature rise.

About George Furmanski

George Furmanski received a master's degree in metallurgy at the Academy of Mining and Metallurgy in Cracow, Poland in 1970. After a brief spell at Skawina Aluminium Smelter as a plant engineer, he joined Chemadex as a design engineer working on projects related to environmental engineering and pyrometallurgical plants.
In 1981, Mr. Furmanski went to Australia to work on uranium projects for Wright Engineers in Sydney. In 1983 he joined BHP Engineering Australia, where he was involved in numerous hydrometallurgical projects that in 1997 brought him the Rio Tinto Award of Excellence in Chemical Engineering for outstanding achievement. This award was give for his participation in the design of the Electrolytic Manganese Dioxide Plant where lean duplex 2304 and duplex 2205 were used for the first time in hot sulphuric leaching. His long-term involvement in chloride metallurgy was finally tested at CalEnergy, where he has been working since 2001 on demonstration projects related to the selection of materials for construction for high chloride, high-temperature geothermal brine applications.

Super duplex 2507 turbine feed pipeline.

Radiographic NDE

To meet ASME B31.1, all project field welds must be 100% inspected. To economically accomplish this under harsh field conditions, CES relied upon long experience with non destructive examination (NDE). In this case, a radiographic telemetry (RT) approach was employed. After development and refinement, the final inspection procedure was easily accomplished in cadence with machining, fit up, root pass, and fill operations.

Success at last!

Working closely together, Carolina Energy Solutions and CalEnergy have successfully tackled a really tough application. The results are impressive: over nine kilometers of SDSS 2507 production feed pipeline now glitter in the desert sun, silently powering more than a quarter million California homes and businesses with clean, renewable geothermal energy.
Thanks to innovation, perseverance, and teamwork, CalEnergy has accomplished a major goal: 15 years plus of trouble free production turbine feed pipeline service life. Importantly, the practical application of this unique stainless alloy now encompasses one of the most strategically important fields imaginable: expanding the use of our precious geothermal energy resources.

Looking forward...

With this breakthrough in hand, CalEnergy now envisions a major capacity expansion at Salton Sea – nine new geothermal wells generating a combined 495 MW. Current plans call for construction to begin in 2011, with new capacity coming on line through 2020. And - as you might imagine - super duplex 2507 is specified throughout.

About the author

John Griffin received a bachelors degree in industrial engineering at Cal Poly San Luis Obispo in 1981, followed by a masters at Duke University in 1993. His background includes the development and application of industrial control and servo systems. At GE and Fanuc, John was instrumental to the introduction of modern microprocessors to computer numerical control and programmable logic systems. Working with machine designers and builders, John further developed digital servo system applications in concert with these technologies. After executive management stints with Square D Schneider, Kollmorgen Motion Technologies, and Interroll Corporation, Mr Griffin cofounded EnergyPath Corporation in 2001. EnergyPath provides technical and financial decision support services to energy industry OEM's and power producers worldwide. www.nrgpath.com; tel: +1 252 675 1936.