Technical paper:

Hot wire narrow groove welding and cladding with nickel-based alloys

The development and application of advanced automatic welding technology will be important in realizing the rebirth of nuclear plant construction in the United States. The use of automated welding, automated hot wire GTAW technology and innovative torch design, such as the rotating tungsten narrow gap torch, will be essential tools in the construction of components for GEN III nuclear power plants.

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It is estimated that by 2030 the global demand for electricity will increase by 50%, necessitating the construction of 1300 to 1900 new power plants over the next two decades. There is a strong case to be made that many of the new power plants required to meet the estimated energy needs should be of the nuclear type. To maintain the current percentage of U.S. generated nuclear electricity would require the building of 50 new 1000 MW nuclear power plants by the year 2030.

There are many advantages to nuclear power over other power sources. For one, to avoid greenhouse gas emissions and the climate change associated with the combustion of fossil fuels. The development of nuclear energy would reduce the U.S. reliance on fossil fuels and foreign fuel suppliers. Furthermore, the nuclear power industry is a mature industry with new, passively safe designs that would eliminate some of the concerns with earlier power plant designs. At this point existing U.S. nuclear power plants are performing well. Nuclear power plants now operate at a 90% capacity factor compared to 56% in 1980 while at the same time, the cost of production has been declining. In contrast to oil and gas, nuclear fuel costs are low and relatively stable, with a present cost of less than 0.5 cent per kilowatt hour. And, as the demand for energy continues to grow, nuclear power is the only available "green" technology that can meet the capacity demand for energy.

The Unit 2 accident at Three Mile Island in 1979 brought about a total collapse of the commercial nuclear market in the United States. The majority of US nuclear manufacturing, forging and construction infrastructure virtually disappeared. At the present time there is more interest in building new nuclear power plants than at any time since the Three Mile Island incident. However, there is real concern that when this happens, manufacturing of major nuclear equipment will be done outside of the United States. Jeff Kikel, Manager, Welding Engineering of the Nuclear Operations Group Barberton Facility, Babcock & Wilcox, quotes from the 2005 DOE Report NP2010 Nuclear Power Plant Construction Infrastructure Assessment: "Major equipment (reactor pressure vessels, steam generators, and moisture separator reheaters) for the near-term deployment of GEN III units would not be manufactured by US facilities. Japanese, Korean, and European manufacturers have the capacity to provide major equipment for US GEN III units."

While construction of nuclear power plants was shut down in the US the rest of the world continued to build plants. The need for energy has continued to grow and interest in nuclear power has been increasing, but in the US cost remains a major hurdle. The high cost of licensing, the initial USD 6-8 billion construction cost and the long term costs of maintaining the plants have inhibited new construction.

Existing US power plants were constructed using 1970s and 1980s technologies. There was little automation and although some orbital GTA welding was done, there was heavy reliance on manual SMAW, and GTAW welding processes. Overseas the technology for building plants and equipment has been advancing. Recent foreign construction time has been reduced to four years or less through the use of advanced technologies and more efficient manufacturing methods.

Advanced technology welding

Jeff Kikel states that in order for the US to remain competitive in the design and building of major nuclear components, they will have to develop and deploy high productivity processes and more efficient joining technologies. Babcock & Wilcox has been using automated welding processes which include the use of hot wire GTAW (TIG) for fabrication of their heavy nuclear components. One of the advanced welding technologies that could be more widely used in the nuclear industry is automated hot wire GTAW. Hot wire GTAW is a variation of the GTAW (TIG) process in which the wire is resistance heated by a separate power supply before it enters the weld pool. Because energy from the GTAW power supply is not used to heat the wire, more energy is available for penetration and faster travel speeds are possible. This results in 3 to 4 times the deposition rate of cold wire GTAW while maintaining a high quality deposit. In some joint configurations cold wire GTAW can be used for controlled penetration root passes while hot wire is used for the fill passes. Hot wire GTAW can be effectively utilized for difficult to weld materials and it can be automated.

Hot wire GTAW has been slow to catch on since its introduction in the 1960s. At that time the application was entirely manual and the results were frequently more theoretical than practical.

Recently equipment suppliers have worked with end users to develop automated hot wire systems that can be operated independently or may be integrated with advanced technology automated GTAW power supplies and controllers into fully automated welding systems. New torch designs have contributed to the versatility and practicality of the process.

Hot wire applications

Babcock & Wilcox designs and manufactures large, heavy components for industry including manufactured components for commercial power reactors. Two important applications of hot wire TIG technology employed by Babcock & Wilcox are the use of hot wire GTAW with a narrow gap torch, and the use of hot wire GTAW for cladding and buttering. The narrow groove configuration provides faster results for welding thick sections. For cladding and buttering applications hot wire GTAW is used when high quality deposits are needed. Essential considerations for nickel-based hot wire welding equipment include the hot wire power supply, torch design, gas cups and automatic voltage (arc gap) control (AVC). Other considerations include joint design, shielding gas selection, parameters, and consumables.

Most automatic GTAW welding systems can be converted to hot wire by adding a hot wire power supply and a conductive wire guide tube. The Model 501 Hot Wire Power Supply from Arc Machines, Inc. can be used as a stand alone power supply operated from a remote operator pendant, or it can be combined with an Arc Machines Model 415 Power Supply/Controller. In the latter case, a command from the Model 415 initiates wire feed as part of the programmed weld schedule.

Hot wire power supplies typically use AC power for resistance (I^2R) heating of the wire. The wave form is important for preventing arc blow. The ability to sense the hot wire voltage at the tip of the wire feed tube in addition to sensing the internal voltage provides an operational advantage since measuring voltage at the work is more accurate and not influenced by cable length that can affect internal readings. Accuracy of measurements help to achieve repeatability from one set up to the next.

Narrow groove welding benefits

The narrow groove joint design is a radical departure from conventional manual welding joint preparations.

In the range of 0.500 inches in width with a depth of up to 12 inches, this configuration results in a significant reduction in consumable costs. There is also a reduction in welding man hours compared to welding a conventional joint. An added benefit is the reduction in residual stress and distortion. Since the subjectivity of bead placement that occurs in manual welding is eliminated, the weld results are more consistent with improved weld quality. In some cases there may also be a reduction in weld prep machining costs.

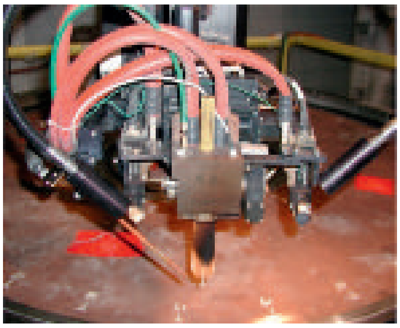

Figure 1. A narrow gap torch mounted on an Arc Machines, Inc. weld head in a Model 2 fixed automation system with remote wire positioning, remote torch tilt and leading and trailing cameras.

Narrow gap torches

The idea of designing a narrow gap torch is not particularly new but use of earlier designs frequently resulted in lack-of-sidewall fusion. Arc Machines, Inc. designed a torch in which both the tungsten and the wire would oscillate from side to side.

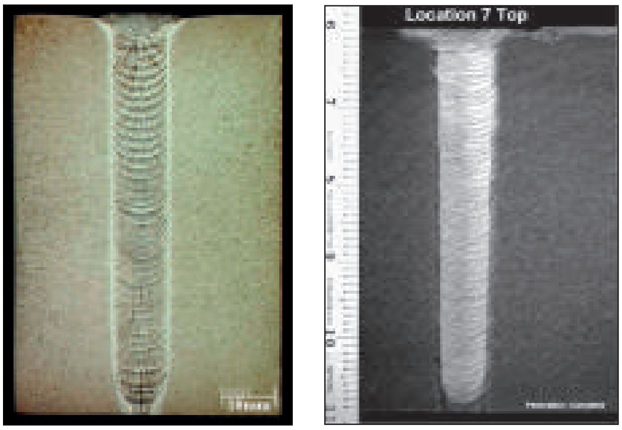

Figure 2. Macrographs of welds performed with a narrow gap torch. Left: Weld bead deposited using a single bead per layer technique in the 5G position Right: Weld beads deposited using a two bead per layer technique in the horizontal position. This technique results in more favorable grain structure.

The "wiggly tungsten" model was able to overcome some of the earlier problems and provide good sidewall fusion. These torches were designed for various depths in the joint and could be changed during the course of welding a heavy walled vessel. Even so, Babcock & Wilcox worked with AMI to develop special narrow gap torches for their applications. Several design features were found to be advantageous to narrow gap welding. These included having a remote controlled wire feed manipulator with motorized tilt and wire positioning. Since it is not possible to have a direct view of the narrow groove during welding, leading and trailing cameras are needed for most applications. Torches should be designed to survive exposure to long term UV and high temperatures. The key parameters to insure sidewall fusion are oscillation of the tungsten to the side wall, wire position, rate of wire feed and hot wire current.

Arc Voltage Control

In its initial trials with the narrow gap torch, Babcock & Wilcox experienced an unacceptable "humping" motion of the torch as the AVC response caused the torch to climb the sidewall.

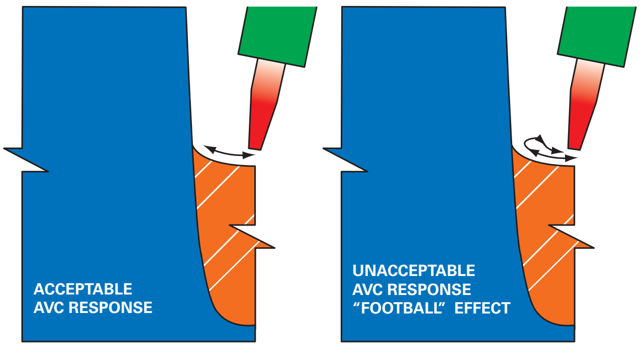

Figure 3. Acceptable and unacceptable AVC response. AVC setting must allow for flat weld bead placement without humping.

Arc Voltage Control is electronic arc gap control. A servo in the power supply electronically adjusts the torch assembly which provides the mechanical means to control arc gap in response to an AVC setting. Correction of the humping AVC response required the development of a better AVC circuit system.

While oscillation allows the weld bead to wet the sidewall and prevent humping, at the same time the tungsten to weld pool distance must be accurately maintained in order to achieve a flat profile while assuring adequate fusion to the side wall. Parameters have been developed to lay down two bead layers across the weld joint. Babcock & Wilcox feels that the weld bead should not be bridged to both walls.

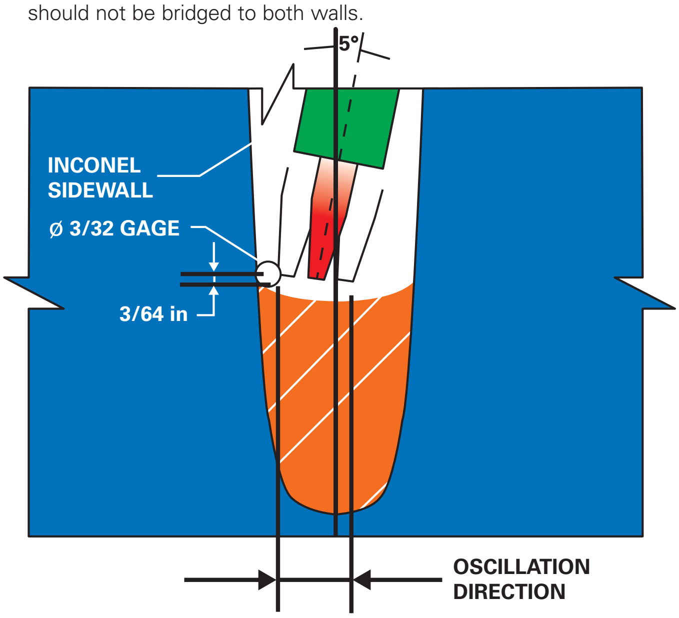

Figure 4. A gauge is used to set the distance between the tungsten electrode and the sidewall.

Important factors

Joint design: With nickel-based materials a groove included angle greater than 8° is typical to insure side wall fusion. The torch design will determine the root width necessary to insure that the bead does not wash both walls. A root width of about 0.500″ is typical. The split bead technique favors competitive grain growth while the single bead technique promotes directional growth which is less favorable from a weldability perspective.

Wire to tungsten distance should be established so as to avoid entry of the wire into the arc plasma column. The wire entry angle should be greater than 40° and to avoid contact with the sidewall, the wire should be positioned to the inside of the tungsten from the wall being welded.

Gas cup design is an essential component of hot wire GTAW technology. Lamellar gas coverage is critical for nickel-based materials. There must be adequate screening in the torch to achieve this. The gas lens must seal adequately around the tungsten. Auxiliary shielding is beneficial near the top of the narrow groove and for cladding operations.

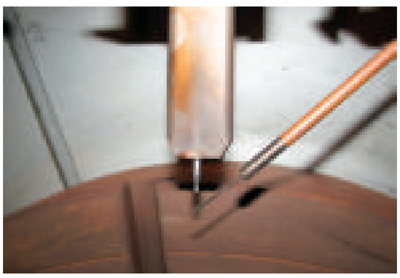

Figure 5. A narrow gap torch with hot wire tube showing the wire angle and position relative to the tungsten.

Wire feed rate and hot wire current: Attempting to push the deposition rate through increased wire feed rate will likely reduce quality. A rate of 150-180 IPM of.045″ wire is typical for nickel based materials. The hot wire current should be maintained to approximately 10-20 Amps below the melting point of the wire. Running the hot wire current too high increases the formation of oxides which decreases weld quality.

Consumable considerations

The quality of consumables such as filler wire, tungsten electrodes and hot wire tip material can make a significant difference in the success of hot wire applications. For filler metal, the processing is important. AOD/VIM melting is preferred for critical applications and the use of ground starting stock that is subsequently rolled should be considered. In high strain applications chemical composition ranges should be specified to reduce the susceptibility to cracking.

Tungsten quality, tungsten type and tip geometry are all important. In a helium rich shielding gas environment Babcock & Wilcox found that lanthanated tungsten electrodes were preferred for longevity. A larger diameter electrode such as 5/32″ with a blunt tip is required for increased penetration and erosion resistance. Fine grain electrodes with a homogenous distribution of oxides are required for erosion resistance and arc length stability. Electrodes from different vendors perform differently, so it is important to confirm performance should the suppliers be changed.

The hot wire tip bore size and finish are critical to consistent current transfer. The bore area changes with time, but the time to tip failure is determined by the tip material. Copper-tungsten alloys were found to give superior tip life to pure copper and other copper alloys.

Cladding

In cladding operations weld beads of nickel-based alloys are deposited on a base plate of carbon or mild steel. Several layers of nickel-based material may be applied in order to achieve a surface consisting of the desired corrosion resistant alloy. With the standard torch, the weld pool extends beyond the area protected by torch shielding gas. Unless additional gas shielding is provided, oxides will develop on the weld bead and porosity may occur. Trailing shields are strongly recommended to provide adequate gas coverage.

Babcock & Wilcox experimented with various gas mixtures to determine the effect on weld bead profile and appearance. At the same current setting, the arc voltage and thus heat input was much greater when helium rather than argon was used as a shielding gas. Babcock & Wilcox found that 100% helium or mixes of helium and argon provide improved wetting which resulted in a desirable wide shallow penetration profile. Pure argon produced a more rounded bead profile with less spreading. Gas mixtures containing hydrogen should not be used in high stress applications due to the increased susceptibility of hydrogen-induced cracking.

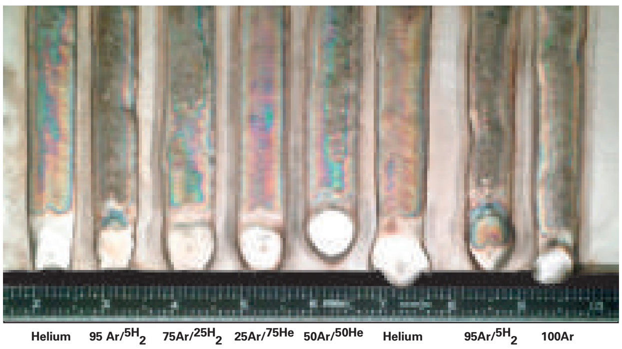

Figure 6. The effect of various shielding gas mixtures on weld bead shape and appearance for cladding applications.

Based on a presentation by Jeff Kikel, Babcock & Wilcox at the Fabtech International & AWS Welding Show Hot Wire Welding and Cladding Conference, November, 2007