When Using SAW to Weld Creep-Resistant Steels: Less Is More

Controlling bead size, shape, and placement is important when using submerged arc welding to join creep strength-enhanced ferritic steels such as P91

Submerged arc welding (SAW) has long been used in the fabrication of high-energy and heavy wall piping. This process is utilized for several reasons including high deposition rates, relatively low operator skill requirements, no visible arc flash, and the ability to deposit welds that generally possess very good mechanical and metallurgical properties. Alloying of the fluxes also allows further refinement of weld properties depending on the demands of the application.

Of these advantages, the most appealing one is arguably the high deposition rate. Schedules, available man power, end user demand, and global competition have forced manufacturers and fabricators to rely heavily on SAW to deposit a relatively large amount of weld metal when compared to other common arc processes. The ability to deposit 10 lb an hour or more can speed the fabrication process considerably. This is normally accomplished by depositing weld beads that are considerable in size and penetration, in addition to high heat input.

Creep Strength-Enhanced Applications

A high deposition, high heat input practice is more common than not for most carbon- and low-alloy steels depending on the application. Lower alloyed materials generally do not encounter complex metallurgical transformations during the heating and cooling cycles of welding. However, in the never ending quest to develop alloys with higher performance, new materials have been developed that are unlike anything that has come before. This is especially true in high-temperature, high-pressure applications (such as in power generation) where creep resistance is a primary design consideration. The development of creep strength-enhanced ferritic steels (CSEF) such as Grade 91 have become a mainstay in designs and applications due to their high creep strength and significant weight savings offered.

Because SAW is such a simple and easy to use process, many times engineers and operators will overlook the considerations that need to be made when welding CSEF steel with SAW. It is easy to put the correct spool of wire on the feeder, load the correct flux in the hopper, push the start button and be on your way. However, using traditional “hot and heavy” SAW practices, the engineer may find the weld possesses poor mechanical properties when tested. Materials with low ductility in the weld metal and heat-affected zone (HAZ) will likely fail to meet many equipment owners’ specifications. Scattered hardness readings may also fall out of specification.

Considerations When Using SAW

For the reasons discussed above, careful consideration must be taken when developing welding procedures for SAW CSEF applications. These advanced materials require special welding and heat treating practices in order to remain safe and reliable during their operating life. One of the most effective and practical ways to achieve the desired metallurgical structures is through regulated deposition rates, heat input and, most importantly, control of regulated bead size, shape, and placement.

Depositing a high amount of filler metal takes a considerable amount of heat input. In most cases this will also lead to a very large and deep penetrating bead that also contributes to a high amount of dilution — Fig. 1. When welding similar metals with a matching filler metal, a high dilution isn’t necessarily a problem; however, when welding dissimilar metals, high dilution rates can be a potential hazard. A region of uncertainty will be present along the weld interface adjacent to the HAZ. This hybrid alloy may or may not have the properties one desired. Regardless of dilution rates, a very large bead with high heat input has the potential to degrade the mechanical properties of any metal (Refs. 1, 2). While a slow cooling rate is generally desirable with many metals, the cooling rate of a very heavy bead on a material that already has a 400°F preheat will be far too slow. It can be expected the yield strength, hardness, and impact properties will all be reduced significantly.

Follow a Different Formula

In many cases, a welding engineer would turn to the traditional heat input formula to monitor and predict heat input as well as bead shape. This method should be used with caution, as the heat input formula simply...
measures the electrical energy spent, and does not take into account the effectiveness of that energy or how efficiently it was used. There are several studies that show SAW cross-sectional bead size and penetration can vary a great deal with the same or similar heat input using the traditional formula as illustrated in Figs. 2 and 3.

Research performed by Linde and many others in the past 60 years has shown this to be true in many cases for a variety of processes, not just SAW (Refs. 1–4). The reason for this is there are too many other variables that affect the weld, including the use of constant voltage vs. constant current, preheat, material thickness, electrode extension (this significantly affects I²R heating), and current density when using different-diameter electrodes and characteristics of different batches of flux.

The Way to Go

An effective way to obtain desirable mechanical properties from welds in CSEF steels is deposit beads of a more conservative size that can be placed accurately and evenly as the joint is filled — Fig. 4. The smaller cross section of these beads also lend themselves to further tempering and promote grain refinement by the heat from subsequent beads. This tempering technique helps the weld metal obtain the desired mechanical properties, especially ductility and toughness. Using such a technique, it is not uncommon to see impact properties at room temperature ranging 40–50 ft-lb or more throughout the weld metal and HAZ. These values are only a fraction of what can be obtained with other steels, but they are considered very good for CSEF materials.

Conclusion

Submerged arc welding is an excellent process for joining CSEF materials, but careful consideration needs to be taken into account when developing procedures and executing production. Submerged arc welding has always lured fabricators with promises of high deposition rates and relatively moderate operator skill. While this is true in many cases, a CSEF application requires diligence by the engineers and production personnel to develop procedures and techniques that obtain welds with controlled bead size, profiles, and the desired properties.

Acknowledgment

The authors would like to acknowledge James Hales, president of Special Welding and Machining, LLC, for his contributions.

References


Fig. 4 — 2.0-in.- (50-mm)-thick Grade 91 SAW weldment using consistent and evenly placed beads.