FEATURE

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FCAW-S is capable of robust mechanical properties at a fraction of the deployment cost of other wire-arc processes.

Renewed Opportunities for GIRTH WELDING in High-Strength Pipelines

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Self-shielded flux cored arc welding has become a viable option for pipeline operators

Self-shielded flux cored arc welding (FCAW-S) was invented in 1959 as an alternative to shielded metal arc welding (SMAW) to improve productivity and reduce cost. It was introduced as a semiautomatic tubular wire process with conventional equipment: a constant-voltage, direct-current power supply; a wire welding gun; and a wire feeder. As shown in Fig. 1, the key difference between FCAW-S and other open-arc welding processes is the absence of shielding gas. FCAW-S employs an arc in air without the intended shielding, so protection comes from a welding wire that is filled with flux and metal powders. These consumables contain aluminum (Al) and magnesium (Mg), which react with the oxygen and nitrogen (N) to remove contamination from the molten weld metal through slag formation. In addition to being a strong oxide and nitride former, Al has high solubility in iron (Fe) and is a strong ferrite former. Other metal powders in the welding wire are alloyed with the weld metal to achieve the desired as-welded properties.

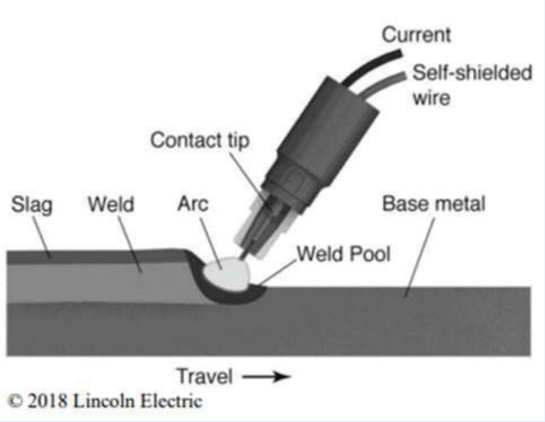

Fig. 1 — Schematic of the FCAW-S process.

Over the years, in North America, the FCAW-S process has gained popularity in shipbuilding and field erection of steel structures, where processes like SMAW, gas metal arc welding (GMAW), and gas shielded FCAW (FCAW-G) experience loss of shielding in high winds and are less productive. With FCAW-S, there is no shielding to disrupt. However, the adoption of semiautomatic FCAW-S for girth welding applications has been slow in North America due to limited operational stability over the wide operating range needed for 5G pipeline applications. Additionally, there are questions about the ability of FCAW-S to consistently deliver the weld performance, particularly Charpy toughness, demanded by the intended service conditions. Despite these concerns, when used appropriately, FCAW-S is a viable option for producing girth welds in high-strength pipelines.

Operational Stability

Operational stability and weld performance are not independent issues with FCAW-S. Although the widest operating range in self-shielded cored welding wires is achieved by increasing the Al to the extent allowed in filler metal specifications, ensuring consistent weld properties requires closer control of the total Al content and maintenance of the stable arc length, as shown in Fig. 2.

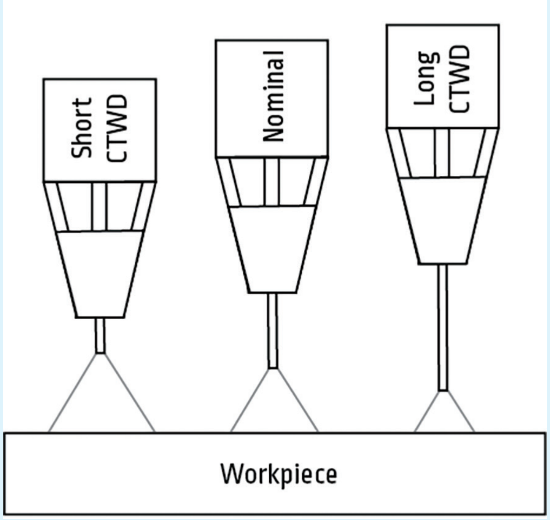

Fig. 2 — Contact-tip-to-work distance (CTWD) and arc voltage.

A consumable delivers enough deoxidizer/denitrider to accommodate the atmospheric contamination that occurs under nominal welding conditions. At a shorter than nominal contact-tip-to-work distance (CTWD), which typically is what a welder controls in semiautomatic welding, the electrical stickout shortens, the arc length increases, and the base of the conical arc increases. There may be insufficient deoxidizer/denitrider to manage the actual level of atmospheric contamination that occurs with a corresponding increase in N porosity and a less-than-ideal weld metal deposit. At a longer than nominal CTWD, the electrical stickout lengthens, the arc length decreases, and the base of the conical arc decreases. In this case, there is a likelihood of more deoxidizer/denitrider being present for the actual level of atmospheric contamination. The Mg will slag off, but the excess Al will remain in the weld, often resulting in a lower toughness and an increase in crack sensitivity. Thus, any difficulty in maintaining a stable arc length with semiautomatic FCAW-S contributes to operational instability and increases spatter, thereby incentivizing contractors to consider new processes and techniques (e.g., mechanization of FCAW-S) for maintaining quality and production rates.

Weld Properties

Al Limits for Pipelines

When it comes to Al limits for pipelines, how much is enough and how much is too much? As discussed previously, Al is a key component in self-shielded flux cored arc welds to achieve operational stability and a favorable microstructure without shielding gas. The best microstructure possible for achieving reasonable notch toughness in the self-shielded flux cored arc weld metal is bainitic ferrite. To achieve this, the final transformation must occur from austenite. In an Fe-Al-Carbon (C) system for FCAW-S, this is highly dependent on the Al level where any possibility of delta ferrite remaining in the as-deposited weld metal must be avoided. The equilibrium phase diagram in Fig. 3 illustrates the influence of Al addition on a simple mild steel (2% manganese [Mn], 0.4% C). There is a targeted range for FCAW-S in pipeline applications. The lower limit is driven by the need to produce a sound weld with an adequate level of operational stability and operating range. The upper limit is controlled by the need to form the most beneficial final weld microstructure. This approach delivers the most desirable and consistent microstructure possible without the shielding gas.

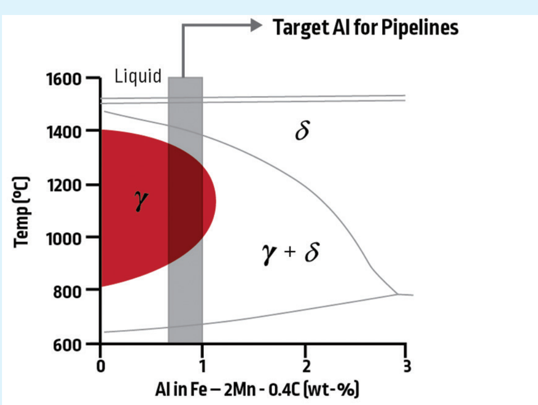

Fig. 3 — Schematic of an equilibrium phase diagram.

How Welding Procedure Impacts Toughness

Simulated pipe joints (SPJ) were welded using E81T8 FCAW-S electrodes to understand the influence of microstructure and welding practice on weld metal impact toughness. Welds were made at relatively high (60 kJ/in.) and low (30 kJ/in.) heat inputs with multiple Charpy V-notch tests conducted for each of the two different E81T8 electrodes. The results for the early-generation pipeline consumable are illustrated in Fig. 4, while Fig. 5 represents a similar study for one of the latest-generation pipeline consumables. Frequency plots were used to illustrate relative consistency or

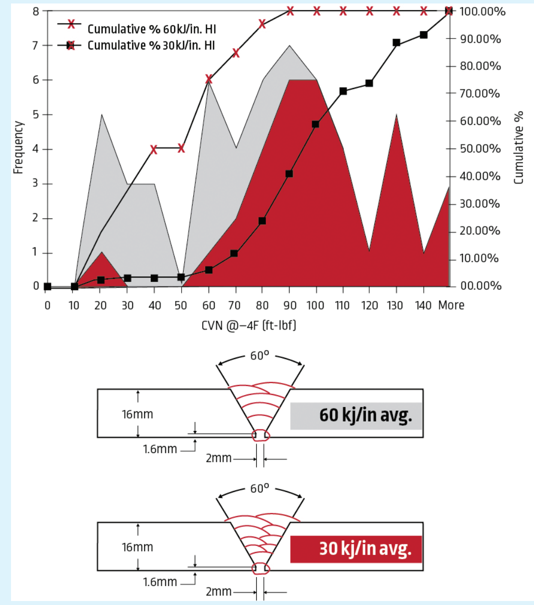

Fig. 4 — Influence of welding procedure on Charpy toughness for an early-generation pipeline E81T8 electrode. (CVN: Charpy V-notch; HI: heat input.)

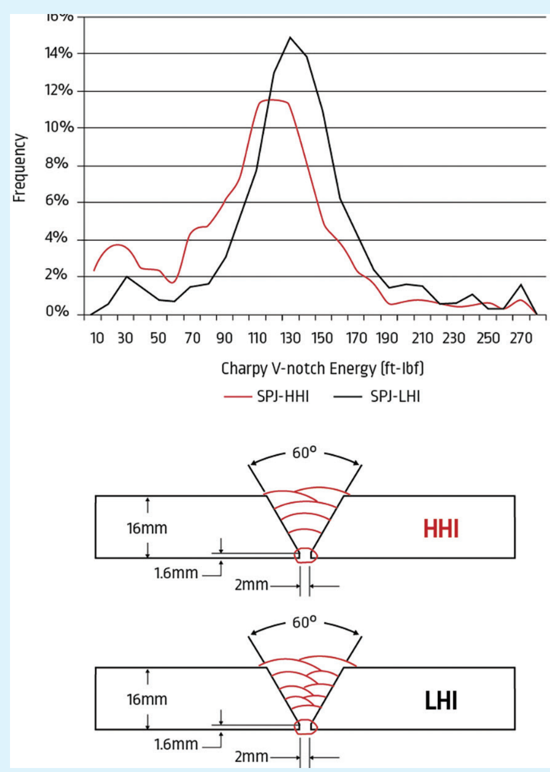

Fig. 5 — Influence of welding procedure on Charpy toughness for a current-generation pipeline E81T8 electrode. (HHI: high-heat input; LHI: low-heat input.)

inconsistency of toughness measurements at a single test temperature.

In Fig. 4, the gray area represents 60-kJ/in. welds completed in five total layers, with single-pass layers up to the final layer. The Charpy behavior was characterized by a bimodal distribution with a relatively high frequency at the low energy levels and a maximum achieved energy of ~ 90 ft-lbf. The red area represents 30-kJ/in. welds completed in six total layers, with split-pass layers above the root/hot passes. The frequency at low energy levels was significantly reduced, and the maximum energy achieved exceeded 140 ft-lbf. Clearly, more weld passes deposited at a lower heat input ensured reduction in the prior austenite grain size in both as-deposited and reheated regions of the weld metal and resulted in a higher Charpy toughness. This type of scatter in FCAW-S Charpy toughness was not uncommon with the early-generation consumables. Subsequent research found this is due to a combination of a coarse microstructure because of welding practice and the relatively large number and size of Al-oxide-based inclusions that remain in the weld metal after solidification.

Figure 5 shows current-generation FCAW-S electrodes, which are designed to minimize the influence of inclusions on Charpy toughness. Again, the same multimodal characteristics are apparent, but the influence of welding conditions was significantly reduced (i.e., frequency at lower energy levels and average/peak performance).

Summary and Concluding Remarks

FCAW-S technology has evolved significantly since its inception in girth welding of pipelines. Welding manufacturers now have a better understanding of the slag system and chemical changes necessary for better inclusion control and microstructure stabilization to achieve improved mechanical properties. They also have a better understanding of the welding practices that influence the key outcomes. When applied appropriately, FCAW-S is capable of robust mechanical properties at a fraction of the deployment cost of other wire-arc processes. Pipeline operators should feel confident that this process is a viable option for high-strength girth welds on their construction projects, and contractors should be excited by the increased deposition without the added cost of protecting the arc. WJ

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