Advancing and Commercializing Hybrid Laser Arc Welding (HLAW) for Nuclear Vessel Fabrication, Including Small Modular Reactors

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Program: Advanced Reactor Development

Collaborators: Sandia National Laboratories (National Technology & Engineering Solutions of Sandia, LLC), Lincoln Electric, Edison Welding Institute

Abstract:
Holtec International's (Holtec) objective for this proposal is to advance the innovatory technology of Hybrid Laser Welding and Laser Assisted Welding for use in fabrication of Small Modular Reactors (SMRs) and dry storage canisters for spent nuclear fuel. Holtec will develop, qualify, demonstrate and commercialize this revolutionary metal joining process to solve major manufacturing challenges associated with the fabrication of nuclear components, including: narrow gap welding (of Small Modular Reactor forgings), minimization of Stress Corrosion Cracking (SCC) in austenitic steels, and improvements in the reliability, quality, and cost associated with traditional multi-pass manual welding.

Background:
Hybrid Laser Arc Welding (HLAW) combines traditional Gas Metal Arc Welding with high-powered laser welding. The HLAW process has existed since the 1970s. However, HLAW has experienced limited commercial adoption because of the cost and technical limitations of laser technologies. Recent advances in laser technologies (such as Fiber lasers and YAG lasers) have only now brought HLAW technology within reach of commercialization.

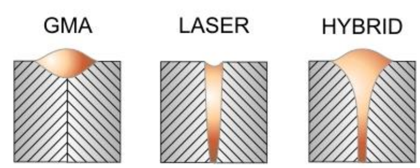

Figure 1: GMA, Laser, and Hybrid Welding Processes

Phase 1- HLAW - Single Pass, Full Penetration, Deep Welds: In HLAW, two metal pieces are butted together, and the arc and laser welding processes are used simultaneously to join the pieces. The laser cuts a deep narrow slot in to the material, while the electrode provides filler material into this slot. Current commercialized HLAW processes are able to produce full penetration welds in plates up to 3/8" in thickness. Experimentation with high-powered lasers (up to 20 kW), has demonstrated the potential to join 1" thick plates with a single pass, full penetration weld. The cross-sections below demonstrate how HLAW welds differ from multi-pass welds.

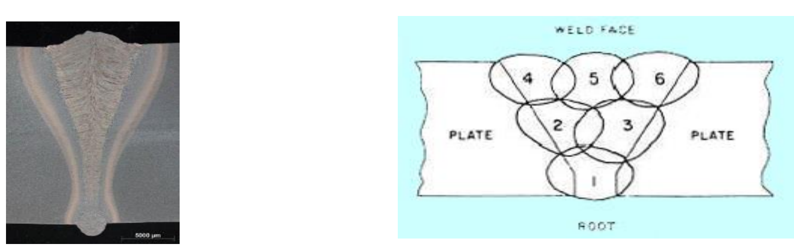

Figure 2: HLAW Single Pass (Left) vs. Traditional Multi-Pass (Right)

Advantages: The HLAW technique has many potential advantages over standard arc welding. It is up to ten (10) times faster than conventional welding and produces a deep, narrow weld that requires fewer passes than arc welding, in which a large "V" at the joint is filled with multiple weld passes. The HLAW weld uses less filler metal, shielding gas and energy. The substantially reduced Heat Affected Zone (HAZ) provides the benefit of less residual weld stress. Reduced residual weld stress reduces susceptibility to SCC, which is a major concern in the nuclear industry.

Figure 3: Typical Thick-Walled Pressure Vessel

Phase 2 - Laser-Assisted Narrow Gap Welding: This process has the potential to significantly enhance the manufacturing process to join large nuclear pressure boundaries. The development of this process will be highly advantageous to the production of SMRs and similar nuclear components, given improvements in quality, reliability, cost and efficiency required to be competitive in the US energy markets.

Figure 4:
"V" Groove Welding (Top)
Narrow Gap Welding (Bottom)

Currently, joining of thick walled vessels requires "V" Groove welding that requires up to 100 passes of manual or semi-manual welds stacked in non-uniform layers. This process is variable and time-consuming, due to the manual nature of making numerous passes, the need for frequent non-destructive testing and high risk of in-process rework. X-ray examination of the welds and repair of any defects found in this configuration is challenging.

Narrow Gap welding is different from "V" Groove in that a single layer is added in a continuous spiral. This Additive Manufacturing technique deposits layer-on-layer to create a repeatable and consistent metal joining process. Narrow Gap welding has existed for decades but has been plagued by difficulty in obtaining adequate sidewall fusion. This defect occurs when the molten weld pool fails to melt into the sides of the gap, creating potential failure points. The lack of side wall fusion becomes more pronounced on thick walled vessels since the vessel acts as a large heat sink, cooling the weld pool before it has time to fuse with the base material.

Laser Assisted Narrow Gap welding has the potential to solve poor side wall fusion by adding more energy into the molten weld pool. This feature is accomplished by using a laser in the weld process that can produce more heat and energy than an electrode alone. Developing and commercializing this process will raise the standard on how SMR components are fabricated.

Advantages: The Laser Assisted Narrow Gap technique has many advantages over standard V-Groove welding. It is swift, repeatable and 10x - 20x more efficient than manual welding. This manufacturing technology is an enabler to scale production of SMRs in a factory setting.

Partners: Holtec plans to work with Sandia National Laboratories, Lincoln Electric, Edison Welding Institute, and several other specialized testing companies to develop and characterize Hybrid Laser Welding manufacturing processes and the physical properties of the resulting welds respectively.