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Laser-Arc Hybrid Welding of Thick Section Ni-base Alloys – Advanced Modeling and Experiments

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ABSTRACT

Alloy 690 is widely used in pressurized water reactor (PWR) components because of its resistance to stress corrosion cracking. However, it has been suggested that thick section Alloy 690 welds develop micro-cracks between the individual passes of the multi-pass gas-tungsten arc (GTA) and submerged arc (SAW) welding processes. In addition, the repeated exposure of the components to weld thermal cycles during multi-pass welding increases the weld distortion and structural inhomogeneity. During the last wave of nuclear plant construction over three decades ago, the fabrication of structurally sound, reliable, thick-section welds lacked the scientific basis and process technology available today.

Laser-gas metal arc (GMA) hybrid welding, which combines a laser and an arc, represents a potentially attractive technique for the joining of thick section components because of its ability to achieve deep weld penetrations with low distortion in a single pass. Unlike autogeneous laser welding, laser-arc hybrid welding allows for the addition of a filler metal to adjust weld metal chemical composition which, in turn, can have a positive impact on decreasing cracking susceptibility in Alloy 690. However, the applicability of laser-GMA hybrid welding to nickel base alloys, such as Alloy 690, has not been fully explored. In particular, the differences in cracking behavior and how it can be mitigated with the use of single pass welding techniques have not been studied.

Because of the interaction of a large number of processing parameters such as the laser power, focus, arc current and voltage, separation of the heat sources, travel speed, and material properties, there are complex interactions between the plasma, keyhole formation, and mixing of filler metal in the weld pool. A fundamental multi-disciplinary approach is needed in order to develop a comprehensive understanding of the interactions between these various processing parameters. Such an approach is proposed here, and relies on the interaction of several collaborators with expertise in the development of laser and hybrid welding processes, the mathematical modeling of arc and laser based welding processes, and the use of advanced characterization tools for analyzing phase transformations, solidification, and residual stress. A comprehensive experimental and theoretical study is proposed to understand the heat transfer, and liquid metal flow, mixing of filler metal, heating and cooling rates, the evolution of microstructure and residual stress and the resulting mechanical properties of the hybrid welded Alloy 690 welds. This proposed program is unique in its approach to using modeling to determine the solidification conditions and the mechanisms leading to ductility dip and other related cracking mechanisms. This enhanced understanding of the solidification mechanisms will help to lead to improved welding processes and filler metal compositions and to improved performance of these materials in high temperature applications.