Numerical Study on Strain Behavior during Solidification Evaluation of Solidification Cracking Susceptibility in Low-carbon Austenitic Stainless Steel Laser Weld

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ABSTRACT

In laser processing, the melt zone solidifies rapidly, the solidification mode changes from ferrite-to-austenite (FA) to austenite-to-ferrite (AF), and the content of ferrite decreases in austenitic stainless steel. As a result, susceptibility to solidification cracking increases. Solidification cracking occurs when the strain of the melt zone crosses the solidification brittleness temperature range (BTR). In this study, the strain was studied by numerical analysis, and the occurrence of solidification cracking was predicted by the strain curve intersection or lack of intersection with BTR. The predictions closely correspond to experimental results.

KEYWORDS: stainless steel; laser processing; thermal elastic-plastic analysis; solidification cracking; thermal strain; thermal stress; tensile load

INTRODUCTION

An austenitic stainless steel that excels in corrosion resistance and workability is used in various structures. In nuclear power plants, it is used in the core shrouds and recirculation pipes. Laser processing, which is welding with low heat input, is used for repair and preventive maintenance of stainless steel units. A high-quality weld joint is obtained because laser processing has narrow and deep weld penetration, a smaller heat-affected zone and less distortion. Therefore, laser processing is used for electronic and automobile parts as an alternative to arc welding.

In laser processing, however, the melt zone solidifies rapidly, the solidification mode changes from ferrite-to-austenite (FA) to austenite-to-ferrite (AF), and the ferrite content decreases in stainless steel whose Cr equivalence / Ni equivalence is from 1.45 to 1.67. As a result, susceptibility to solidification cracking of low-carbon stainless steel increases (Kujanpaa 1979). Figure 1 shows a solidification brittleness temperature range (BTR) and ductility-dip temperature range (DTR), where ductility is seriously decreased. Solidification cracking occurs when the strain curve of the melted metal in the solidification process crosses the ductility curve, which signifies a change of the limit of BTR.

If impurities such as phosphorus (P) and sulfur (S) are contained in metal, the BTR becomes large and more susceptible to solidification cracking because the temperature range where solid and liquid exist together is large for solidification segregation (Lippold 1995). This phenomenon which is widening of BTR is a metallurgical factor of solidification cracking. Tensile strain in the direction vertical to the weld line occurs in weld metal during the solidification process. This strain is a mechanical factor. Therefore, for the prediction of solidification cracking, the following are considered: the metallurgical factor, solidification mode and BTR, mechanical factor, tensile strain.

In this study, the focus is the mechanical factor, which is strain. The strain behavior during melting and solidification was examined by a three-dimensional thermal elastic-plastic analysis. The strain behavior is evaluated by the change of bead width formed by laser processing. The conditions leading to cracking were researched, and the influence of load and welding speed on strain was investigated. Additionally, the occurrence of a solidification crack in a laser welded specimen was predicted by comparing the strain behavior achieved by numerical analysis with the BTR obtained by the metallurgical approach. The predicted result by strain behavior and BTR was compared to experimental results in the cantilever cracking test.