B. Porosity Formation In Sharp Focus CW Nd:YAG Standing-Edge Welds

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Introduction

A common problem in continuous wave Nd:YAG laser joining, particularly for high power sharp focus welds, is the formation of root porosity. Defocusing the beam, reducing weld speed, or readjusting power are common remedies used to decrease the frequency, size and/or location of porosity. However, all of these detract from the inherent benefits of CW Nd:YAG welding: high speed, deep penetration welds with low heat input. In an ongoing experimental study, porosity is being examined to better understand its cause in high power sharp focus CW welds.

Technical Approach

A Rofin Sinar CW fiber delivered Nd:YAG laser was used to create standing-edge welds on 304L stainless steel. Stainless steel samples were 4 – 4.50 X 1 X 0.050” with weld lengths of approximately 3 – 4”. Laser processing parameters examined including power, spot size, weld speed, focus position, and shielding gas species, which were systematically varied. In addition, the effects of solidification mode were evaluated by examining 304L compositions selected to produce both ferritic and austenitic solidification. Weld porosity was quantified in terms of frequency, pore diameter, and location by using X-ray radiography and metallographic analysis.

Results/Discussion

For the purpose of this study, porosity can be classified into three types: Uniform, Transitional and Root porosity. Uniform porosity is an even distribution of smaller pores through out the fusion zone, and results from high travel speeds. Root porosity is predominately formed at the root of the weld, and occurs at a consistent frequency along the weld length. Transitional porosity demonstrates characteristics of both. At sharp focus and constant beam diameter, porosity formation depends on power and travel speed. By increasing power at a fixed weld speed, the size and occurrence of porosity is increased while the porosity type is unchanged. Conversely, at a fixed power, increasing travel speed drives Root porosity to Uniform porosity, albeit at the expense of penetration. However, by also increasing power, deep penetration welds can be achieved with minimal or no porosity. The penetration depth at which porosity begins to form can be changed by the focal length of the lens. An in focus short lens creates porosity at a shallower penetrations than a longer lens. Shielding gases used in this study included argon, helium, nitrogen, carbon dioxide, and nitrogen-argon mixes with various fractions of nitrogen. Inert gases generally increase pore formation (the degree of which changes depending upon the velocity of the gas) while for reactive gases or welding in air, only small amounts of porosity at high powers (>1000 W) is observed. This change in porosity is thought to be due to changes in the fluid dynamics of the weld pool and how laser energy is absorbed. Computer modeling is being used to better understand this behavior. The solidification mode of 304L is thought to affect the porosity formation through both surface physics and the solubility of pore forming species in the primary solidification constituent.

Conclusion

Porosity in CW Nd:YAG welds is primarily due to weld pool dynamics and can be changed by laser parameters or shielding gas. Longer focal length lenses provide deeper penetration before the onset of pore formation than shorter lenses. By welding at high speeds, porosity is minimized or eliminated and drives Root porosity to Uniform porosity. As power increases (at constant speed and beam diameter), pore diameter and frequency also increase. Surface-reactive gases nearly eliminates porosity in 304L by damping weld pool dynamics. Since compositional changes and poor bead appearance can occur, gas types are being further examined experimentally and computationally.

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