SAND2016-12181R

[WPA Name as listed in SSPS]

Welding

J.R. Rodelas and M.C. Maguire*
Sandia National Laboratories
Albuquerque, NM 87185
**Livermore, CA 94551)*

Abstract

Laser welding of 304L stainless steel during component fabrication has been found to alter the chemical composition of the steel due to material evaporation. During repair or rework, or during potential re-use/rewelding of certain components, the potential exists to alter the composition to the extent that the material becomes prone to solidification cracking. This work aims to characterize the extent of this susceptibility in order to make informed decisions regarding rewelding practice and base metal chemistry allowances.

Introduction

Observations of rewelded laser microstructures has shown that the solidification behavior changes from a crack-insensitive microstructure to one which is highly sensitive to solidification cracking. The shift from crack resistant to crack susceptible solidification modes was found to be driven by selective evaporation of alloying species—namely chromium and manganese. The increased solidification velocity of pulse seam welding compared to continuous wave seam welds further increases this risk of cracks during rewelding.

NW production laser weld schedules commonly utilize waveform modulation to vary laser power at high frequency (~10^2 Hz) primarily for reducing keyhole porosity. This high frequency power modulation results in an oscillatory molten weld pool as the beam is traversed along the weld joint. These oscillations can result in instantaneous solidification velocities and peak power densities higher than the average values thereby increasing evaporation rate and sensitivity to solidification mode shift.

Approach

WR VAR 304L with a $(Cr/Ni)_{eq}$ ratio of 1.70 was welded using 300W mean power square wave modulated CW process. Power offset (i.e., the magnitude of laser power varied above and below the mean value) was used at an oscillation frequency of 300 Hz. Autogenous welds were produced with 100% overlap to produce reweld conditions with up to 6 total weld passes. Longitudinal and transverse metallographic sections were produced to examine the weld microstructure and characterize shifts in primary solidification mode resulting from multiple weld passes.

Figure 1 shows etched micrographs for 1, 3, and 6 total weld passes. For up to 3 total passes, the microstructure shows primary ferrite solidification features with expected primary austenite solidification found along instantaneous solid-liquid boundaries associated with the modulation scheme.

Sandia National Laboratories is a multi-mission laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000

The weld with 6 total passes, however, shows mixed mode solidification with the majority of the weld exhibiting cellular substructure characteristic of primary austenite solidification. Additional characterization is required to determine if these primary austenite regions in the weld metal contain terminal eutectic ferrite. No solidification cracks were observed in the 6 total weld pass condition. It should be noted, however, the risk of solidification cracking during welding is comparatively higher than the 1 and 3 total weld conditions.

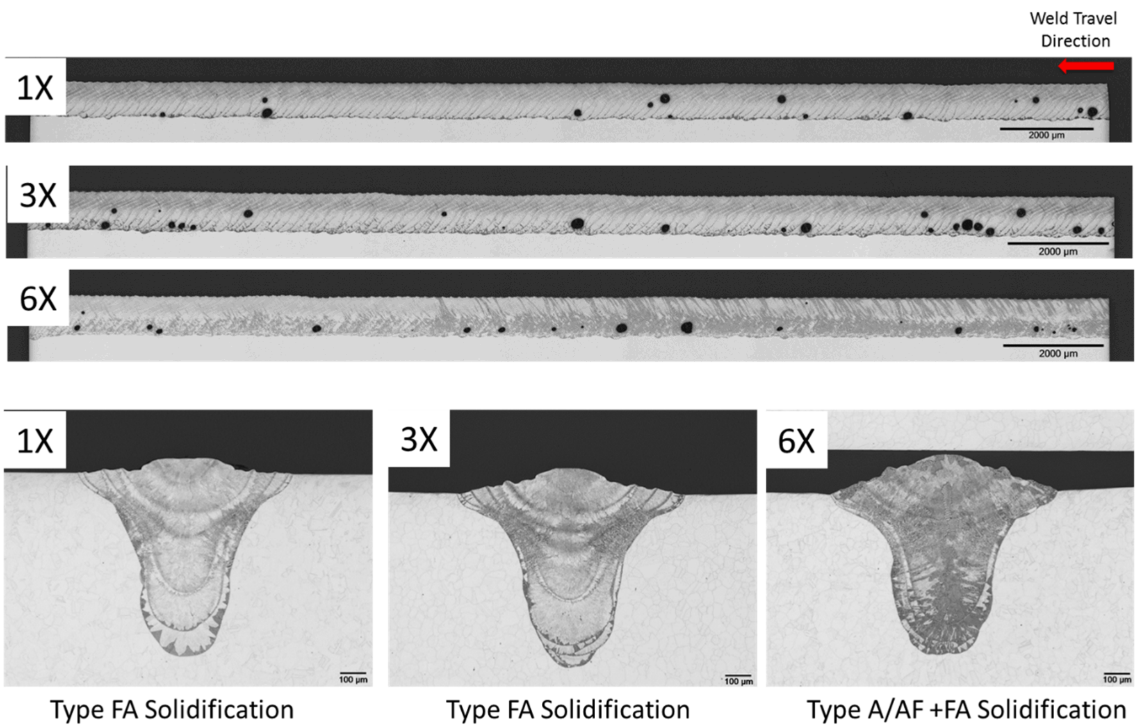

Figure 1 – Effect of rewelding on 304L showing shift in solidification mode from primary ferrite (FA) which is resistant to solidification cracking (left) to one which is crack sensitive with a mixed solidification mode containing primary austenite solidification (A/AF) which is crack-sensitive (right).

While the operative mechanism responsible for the mode shift is increased evaporation of ferrite-promoting elements (relative to austenite-promoting), the mode shift behavior of modulated CW welds is evident at a lower number of total welds compared to non-modulated CW seam autogenous welds performed on comparable $(Cr/Ni)_{eq}$ ratio 304L heats. While additional studies are needed to quantitatively relate evaporation and mode shift behavior to processes parameters, this work qualitatively demonstrates the risk of modulated CW to fall between non-modulated CW and pulsed seam welds.

In collaboration with specialty alloy producer, Metalwerks PMD (Aliquippa, PA), experimental 304L ingots were produced with systematically varying chemistry for the purposes of understanding the role of manganese content on solidification behavior of 304L. Previous FY results showed manganese content may play a role in the evaporation rate of chromium in 304L thereby affecting weld crack susceptibility in reweld scenarios.

[Type here]

Twenty pound vacuum induction melted ingots, shown in Figure 2, approximately 12" long x 3" dia. were produced with manganese varying between 0.70 and 2.40 wt.%. For reference, SNLWR 304L manganese content varies between 1.50 and 2.00 wt.%. In an effort to account to the austenite stabilizing effect of manganese in 304L, the nickel content of these experimental ingots was also varied accordingly in an attempt to keep the $(Cr/Ni)_{eq}$ ratio as constant as practically possible. These ingots will be hot forged into 1" dia. bar to produce laser weld specimens for subsequent laser weldability evaluations.

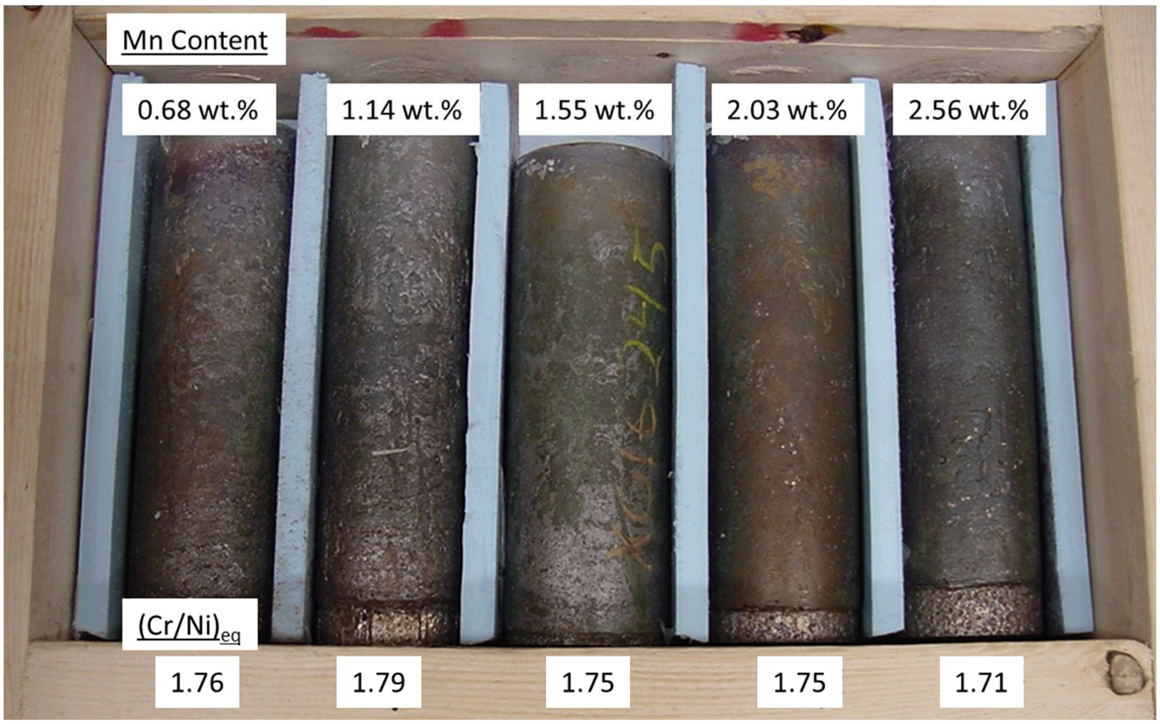

Figure 2 – Bespoke 20 pound heats of 304L with varying manganese contents to be used for laser weldability studies.

Results and Impacts

Rewelding can occur for a few reasons. The first is associated with production processes where rewelding is often allowed to correct a small defect (blowout, lack of fusion, or pinhole). Typically, the entire assembly is rewelded and the type of vaporization induced chemistry changes observed in this work will become more pronounced. The other reason that rewelding might occur is with consideration to re-use certain assemblies in future upgrades to components that would require assemblies to be separated and rewelded to new components. The weld preparation on the reused component, while machined to a new weld preparation, would consist of previously welded material. Allowances for this type of reuse would need to be carefully considered based on this work.

[Type here]

Conclusions and Future Work

The effect of rewelding continues to show the likelihood of increasing the crack susceptibility of 304L stainless steel. In order to understand the role of the most volatile species during welding, manganese, future work will characterize its role and compositional effects on the shift in solidification mode. The bespoke ingots manufactured in FY16 will be characterized with laser welding to determine how manganese levels directly contribute to the shift in welding behavior.

Summary of Findings and Capabilities Related to Aging

Laser welds are not typically prone to aging effects. This work relates more directly to approaches being considered for rewelding and re-use of components (fuzes, firing sets, etc.) in current or future upgrades where welding will occur on material that has already been subject to a laser weld process.

References

N/A

Administrative Addendum

N/A

Related Publications and Presentations:

J.R. Rodelas, C.V. Robino, and M.C. Maguire, “Effect of Multiple Reweld Passes on the Solidification and Cracking Response of 304L Stainless Steel”, MS&T 2016, SAND2016-2922A

Acronym/Abbreviation List

A	Primary austenite solidification
CW	Continuous wave laser welding
AF	Primary austenite solidification terminating with a ferrite+austenite eutectic
FA	Primary ferrite solidification terminating with a ferrite+austenite eutectic or peritectic
VAR	Vacuum arc remelting
$(Cr/Ni)_{eq}$	The ratio of chromium equivalent to nickel equivalent elements. This ratio is specified to be above 1.72 in SNL-controlled specifications for laser welded material