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Pulsed Laser Welding of 304 and 316 Stainless Steels

Austenitic stainless steels find extensive use in practically every industry due to their ductility, non-magnetic properties, corrosion resistance, and ability to be used at cryogenic temperatures. The most common austenitic stainless steel is 304 SS and makes up to 50% of all austenitic stainless steels consumption. 316 SS is similar to 304 SS but has 2% Molybdenum (Mo) and provides superior pitting and crevice corrosion resistance; 316 SS is widely used in marine, medical, aerospace, food, pharmaceutical, and architectural applications. Both 304 and 316 are often used in the low-carbon "L" versions which have 0.03 max carbon content and reduce carbide precipitation.

304 and 316 belong to a family of steels aptly named as 18/8; these steels typically have about 18% Chromium (Cr) and about 8% Nickel (Ni). Chromium provides the required corrosion resistance (Rustless Steel – Spring 2013 Weld Nugget) but encourages ferrite formation, while Nickel stabilizes the austenite phase; usually there is enough Ni to overcome the effects of Cr with the resulting steel being almost fully austenitic. In addition to Cr and Ni, there are other alloying elements, some of whom help to stabilize ferrite and act similar to Cr, and others help to stabilize austenite and act similar to Ni. All ferrite stabilizers can be grouped together to give a Cr-equivalent number, and all austenite stabilizers can be grouped together to give a Ni-equivalent number. The ratio of Cr-equivalent to Ni-equivalent drives many of weldability characteristics of these austenitic steels.

When molten austenitic stainless steels cool and start to solidify, the initial phase can be either ferrite or austenite, referred to as primary ferrite or primary austenite, respectively. The cracking tendency is a function of the initial solidification phase which may later transform to another phase. The benefits of primary ferrite solidification are many and include higher solubility of impurity elements in ferrite, poor wetting of ferrite/austenite grain boundaries by any liquid phases, and a tortuous path for crack growth along the grain boundaries; all these factors make it difficult for cracks to form and grow with primary ferrite solidification. However, if initial phase to solidify is austenite, the properties are exactly opposite and makes it easy for crack growth.

The first phase to solidify when molten 304 cools is typically primary ferrite and hence those welds usually do not have any issue with weld cracking. However, when molten 316 cools, the initial phase to solidify is a function composition and cooling rate. At Cr-eq./Ni-eq. ratio of slightly greater than 1.4, the initial solidification phase will be ferrite at low cooling rates such as those encountered during TIG welding (10^2 °C/sec) and CW laser welding (10^3 °C/sec). With pulsed laser welding, the cooling rates are higher (10^6 °C/sec) and initial solidification phase will be austenite, thus making the fusion zone very crack sensitive. To prevent cracking in pulsed laser welding, Lippold et. al. established that the Cr-eq./Ni-eq. ratio in austenitic stainless steels has to be greater than 1.65; the modified Suutala diagram to include effects of rapid cooling (shown below) shows the demarcation line between cracking and non-cracking regions. Data points show that 316L is prone to cracking where as 304L is not.

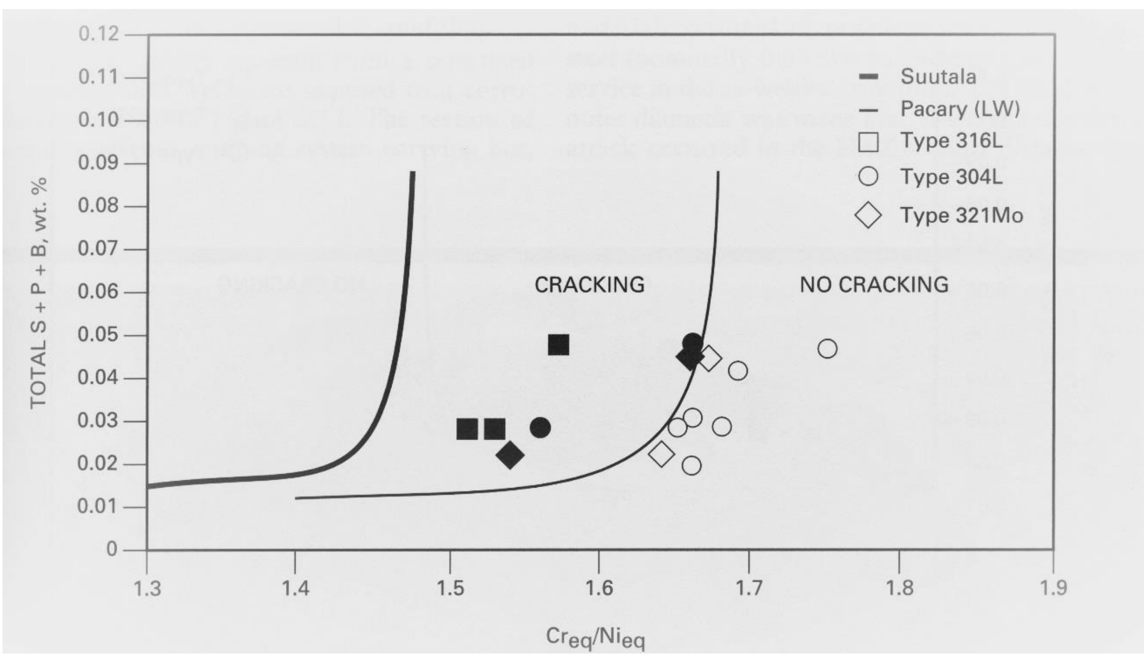

Figure 1. Modified Suutala diagram showing crack sensitivity of 304L, 316L, and 321Mo. Data shows 316L is prone to cracking with pulsed laser welding.

In addition to the primary alloying elements, impurity elements such as Sulfur (S), Phosphorous (P), and Boron (B) also play a role. At very low impurity levels, where S+P+B is less than 0.02 wt.%, the welds are not crack sensitive irrespective of the solidification mode. Another important factor is weld restraint during solidification. If the weld metal has a positive reinforcement, as is typical with filler alloy in TIG welding, or the weld geometry is such that solidification is not pulling the weld nugget apart as is the case with edge welding, then the process will have a larger window to avoid cracking.

So what can you do if you are trying to solve a real-life problem of cracking in 316 pulsed laser welds, and not trying to get a Ph.D. in solidification dynamics? You can try one or more of the following options:

1. Use 316 which is on the high side of Cr-eq./Ni-eq. ratio.
2. Use 316 which has very low impurity content.
3. Mix 304 and 316 by replacing one of the parts with a 304 component or add a pre-placed washer/ring of 304 which acts as a filler and increases the Cr-eq./Ni-eq. ratio.
4. Change from a butt weld to edge or lip weld such that the weld metal is not pulled apart during cooling.
5. Use a long downslope at the end of the welding pulse to reduce cooling rate.

Note that Cr/Ni ratio can be increased by adding other stainless steels such as 308 and 347 which have even greater amount ferrite compared to 304. However, those steels are not easily available in all forms and sizes. Secondly, the welds will have larger fraction of residual ferrite which is not as tough as pure austenite at cryogenic temperatures.

Ref: Welding Metallurgy and Weldability of Stainless Steels, John. C. Lippold and Damian J. Kotecki.

For additional questions or concerns, please contact

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