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Laser weld hot cracking behavior of austenitic stainless steel with boron microalloying additions

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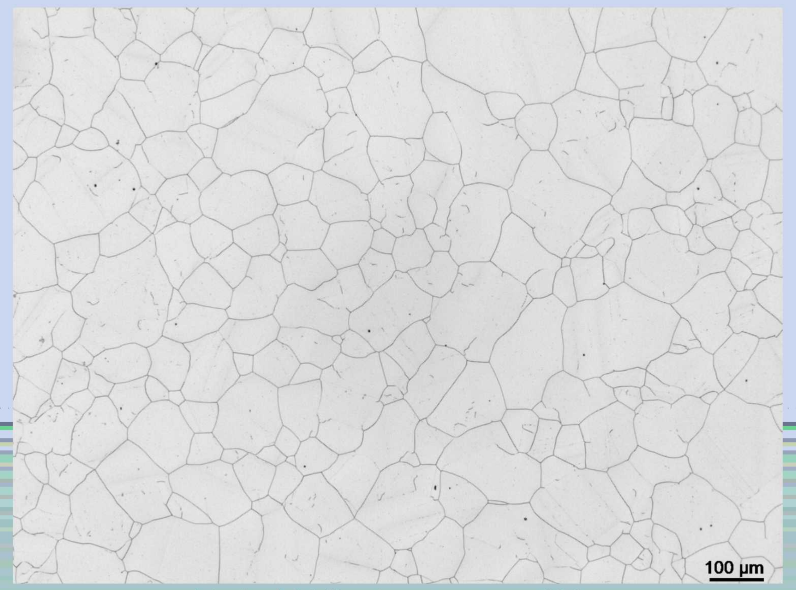
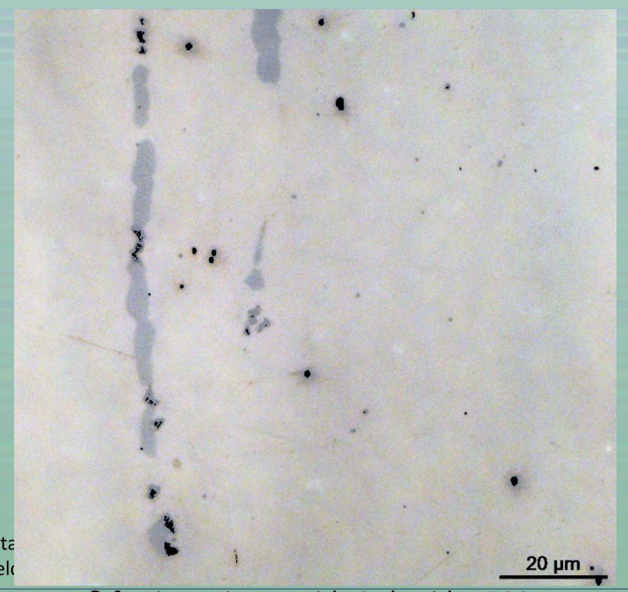
Background

Alloy chemistry is the most effective variable influencing hot cracking of austenitic stainless steels (i.e., cracking during welding in the presence of a liquid film). Because laser welding does not rely on added filler metal during the process (also termed 'autogenous' weld), the part to be joined, in effect, is the filler metal. As a result, crack-free welds made with laser welding requires strict control of alloy chemistry and impurity elements.

Impurity elements in stainless steels typically considered include phosphorus and sulfur; however, there are other elements that can cause cracking in the weld metal and/or heat affected zone (HAZ). These elements include tin, bismuth, lead, antimony, and boron. In particular, boron can affect the likelihood of HAZ cracking due to the formation of boride phases and/or incipient grain boundary melting due to elemental partitioning of boron to grain boundaries. While boron has been shown to cause HAZ cracking in sufficiently high concentrations[1,2], it can be present in small concentrations (~ppm) originating from the steelmaking process.



Typical 304L microstructure 100x



δ-ferrite stringer with Cr-borides 500x

1. Karlsson, L., et al. Acta
2. Kleuth, R.L., et a., Wel

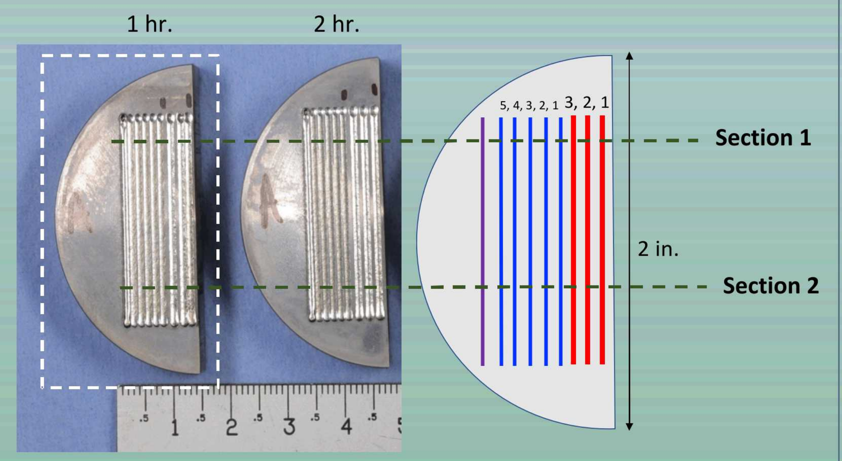
Motivation

Previous work at SNL has related the concentration of boron to HAZ cracking risk in arc and laser welds showing that crack free laser welds can be obtained despite boron concentrations as high as 20 wt.ppm[3]. However, recent observations have revealed instances of laser weld HAZ cracks in parts thermally processed (ex., heat treated as part of brazing or glass sealing) despite the material containing less than 20 wt.ppm. During these thermal processing steps, micro-structural changes can occur such as grain coarsening and second phase dissolution. These observations suggest that weld HAZ cracking susceptibility may depend not only on boron concentration but also thermal history and associated microstructural changes. This work aims to characterize laser weld HAZ cracking behavior for 304L stainless steel subjected to various time-temperature combinations.

3. Rodelas et al., FABTECH 2017, November 7th, 2017, Chicago, IL. (SAND2017-12591C)

Experimental

Autogenous laser welds were made on 304L stainless steel subjected to various heat treatments. Multiple welds were examined metallographically by sectioning transverse to the welding direction. The sections were cold-mounted, ground, polished, and etched using ASTM E407-07 #219 (60/40 HNO_3 and H_2O by volume, 2V, 10 sec., stainless steel cathode)

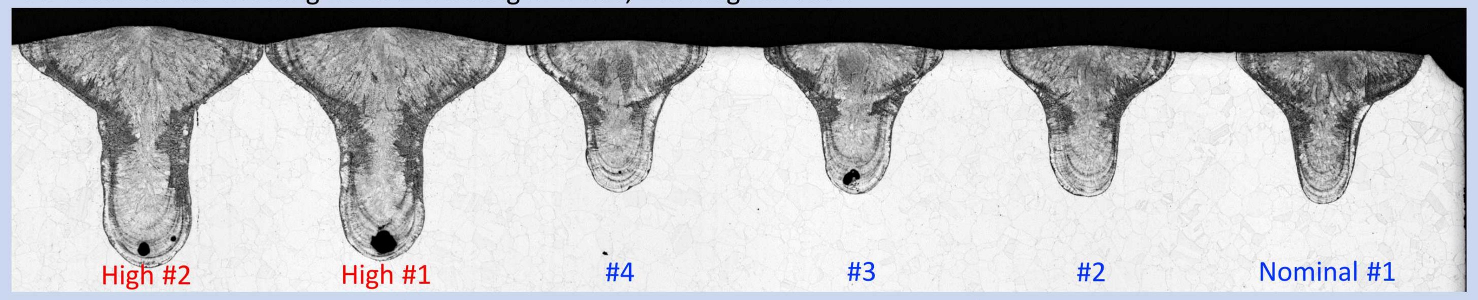


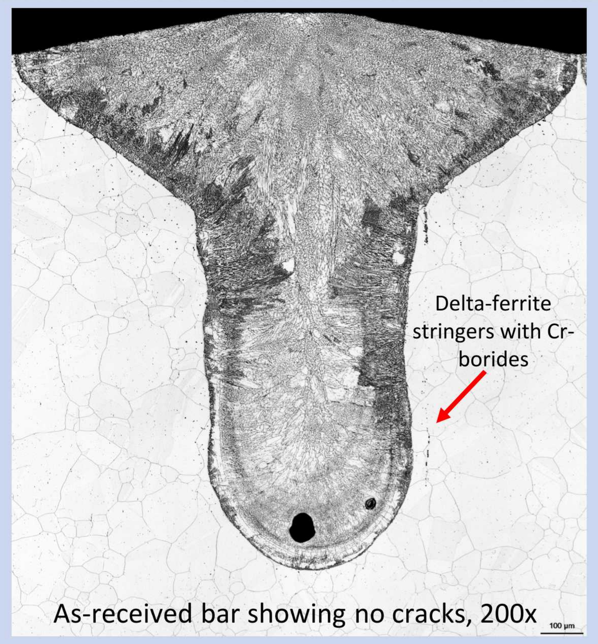
Results & Discussion

Heat treatments performed on 304L at 1100°C resulted in an increase in grain size and a decrease in the amount of ferrite stringer phase present in the microstructure, via dissolution of ferrite at 1100°C. In the as-received material, chromium-rich borides present in the ferrite stringers dissipate with heat treatment and form along grain boundaries as a dark-etching phase.

Weld cross sections show HAZ cracks only in heat treated material, with more cracks observed at longer heat treat conditions. These HAZ cracks follow austenite grain boundaries that are decorated with the Cr-rich boride phase.

As-received bar showing no HAZ cracking in welds, 25x magnification

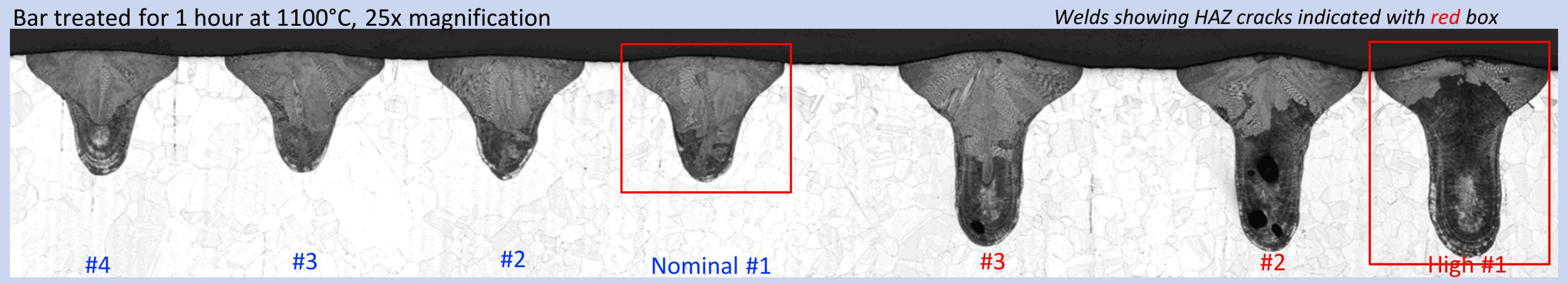


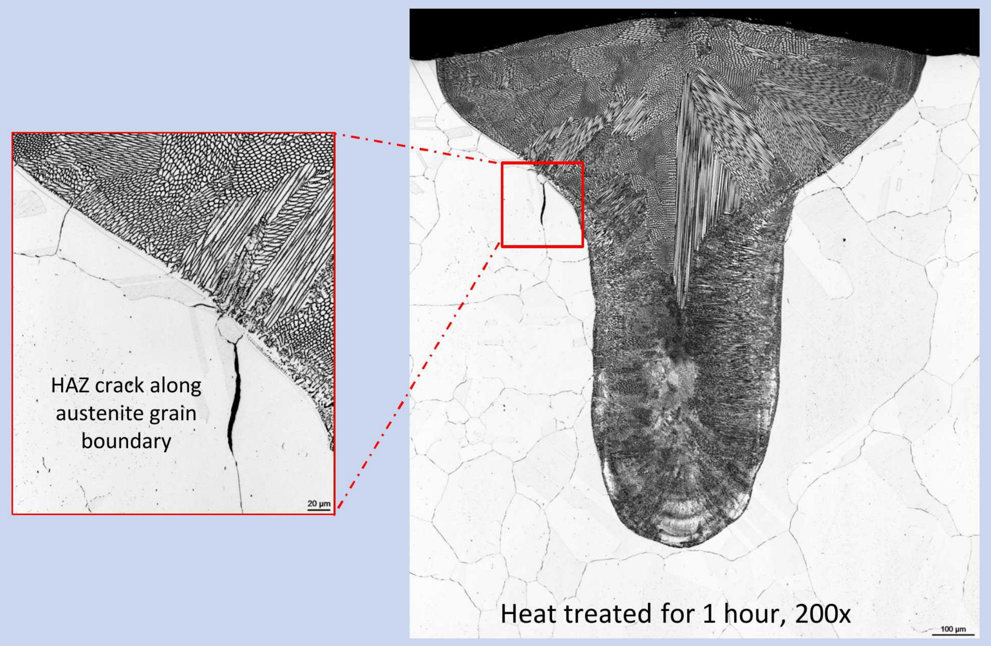


As-received bar showing no cracks, 200x

Bar treated for 1 hour at 1100°C, 25x magnification

Welds showing HAZ cracks indicated with red box

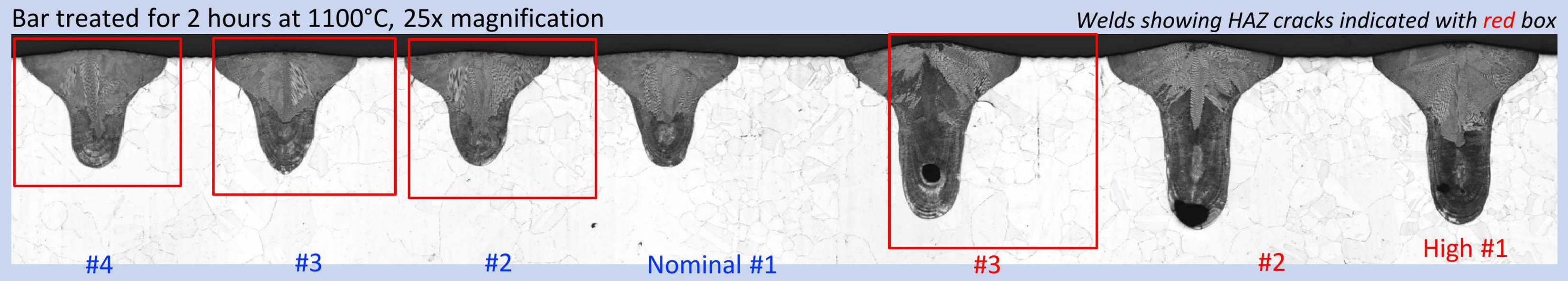


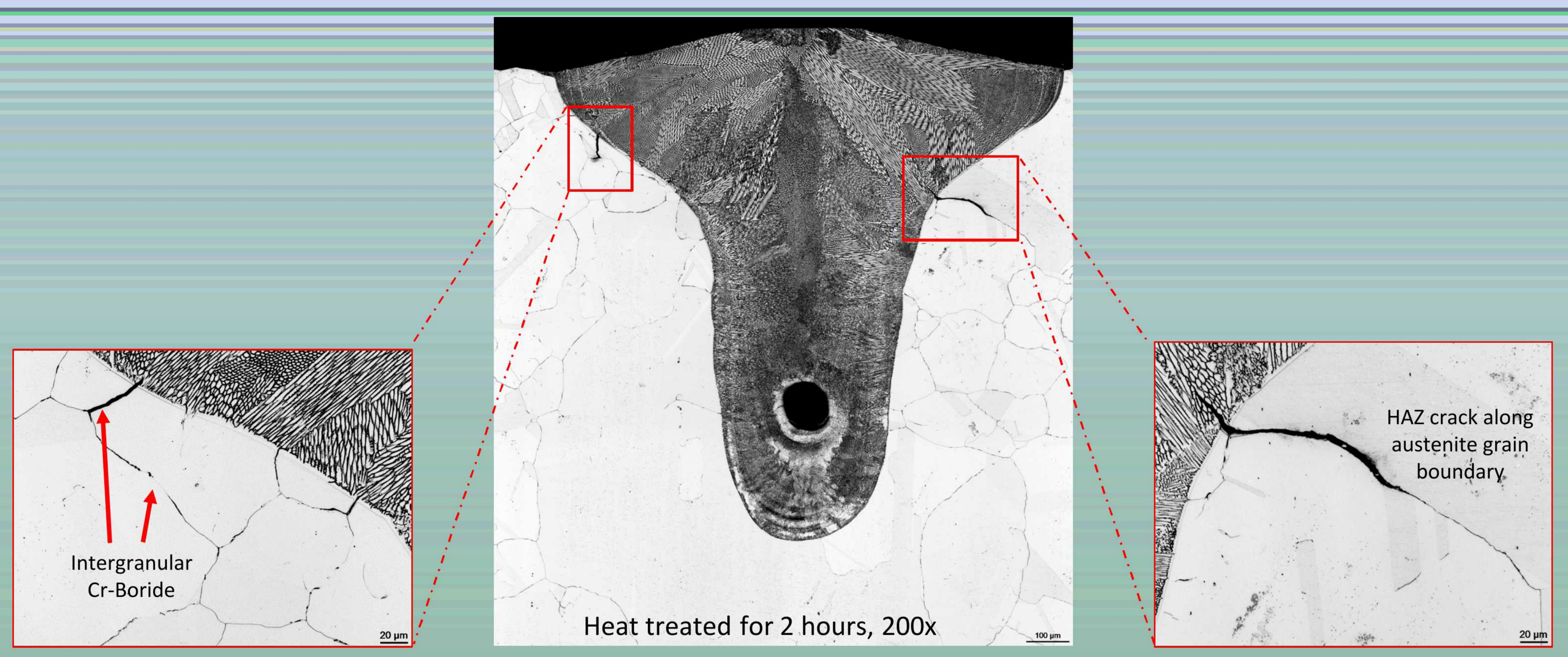


Heat treated for 1 hour, 200x

Bar treated for 2 hours at 1100°C, 25x magnification

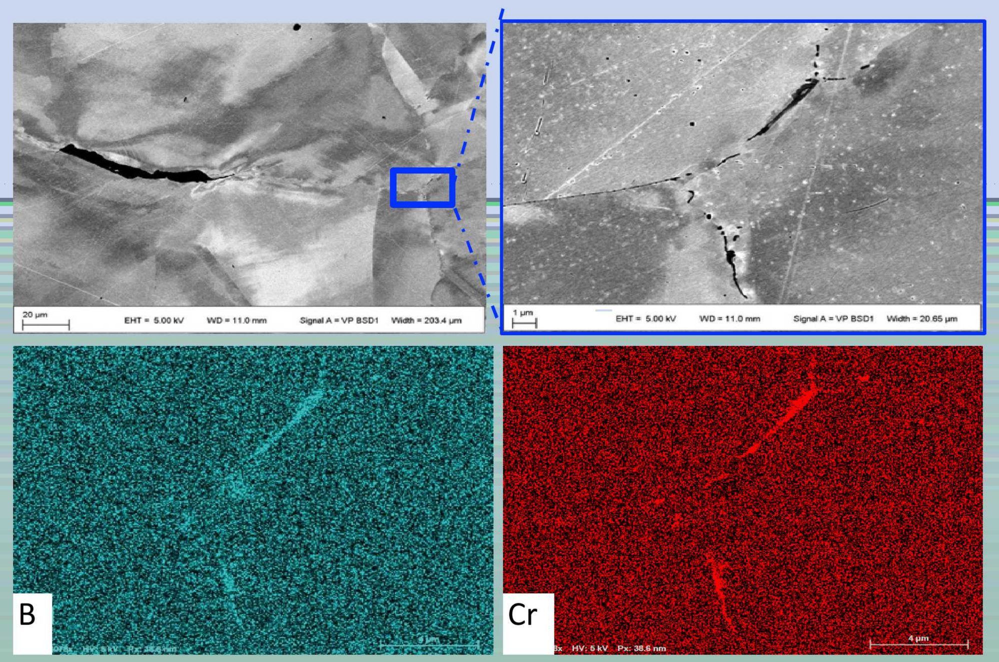
Welds showing HAZ cracks indicated with red box





Heat treated for 2 hours, 200x

Closer examination of the HAZ cracks using scanning electron microscopy shows low atomic number (dark contrast) phase present at grain boundaries. Energy dispersive x-ray spectroscopy mapping indicates this phase is rich in Cr and B, consistent with a chromium boride. These chromium borides that form as a result of the heat treatment process are likely responsible for the HAZ cracking when laser welded.



EDS map showing concentration of Cr borides at grain boundaries

Conclusions

- When exposed to high temperatures (~1100°C), 304L was shown to demonstrate HAZ cracking susceptibility for a concentration of boron that would otherwise be crack free without thermal processing.
- The HAZ cracking appears to be associated with grain coarsening (grain growth) and redistribution of boron to grain boundaries. Electron micro-scopy indicates HAZ cracking may be associated with a boron rich grain boundary phase.
- Caution should be exercised for 304L subjected to thermal processing if boron is present in material

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