Clamp Ring Failure

SAND2019-11065D

The Problem: A custom machined clamp ring (Figure 1) failed unexpectedly during testing (Figure 2). The ring holds together the upper and lower flanges of a system built to contain an explosive process.
The ring was to be made from AISI 4130 per ASTM A322, heat treat per AMS-H-6875: tensile strength 125-150 KSI, Rockwell Hardness C30.

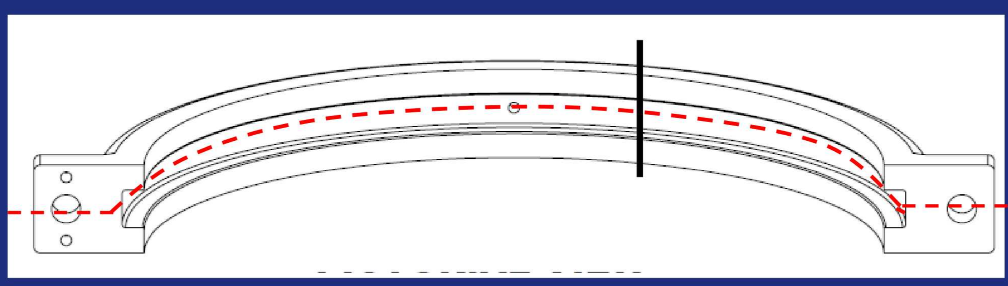

Figure 1. Drawing of containment ring – dotted line is approximate failure location

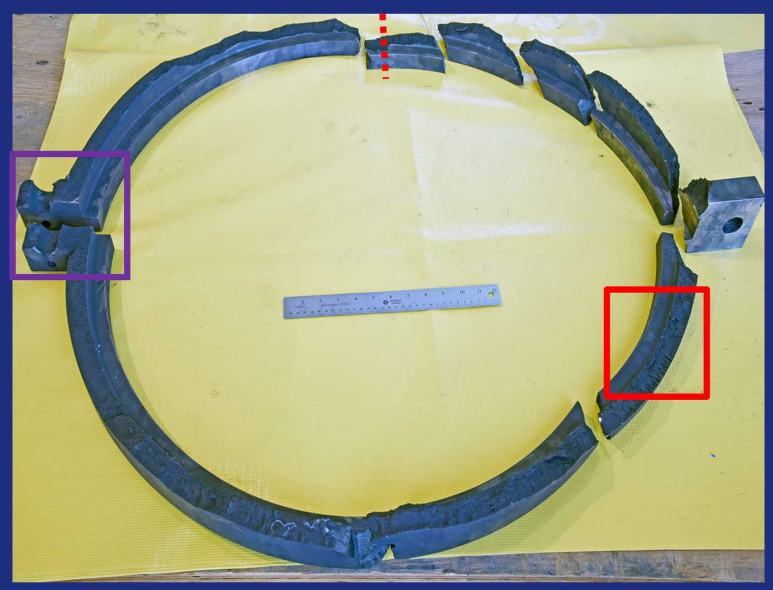

Figure 2. Failed ring, parts are displayed with mirrored mating sections.

Approach and Results: Macro photography was performed using a Cannon D-60 to document the initial failure surface. The marks on the surface (Figure 3) were used to trace back to the expected failure initiation area (Figure 4).

Figure 3. Detail of section showing clear direction of crack propagation (red box in Figure 2.)

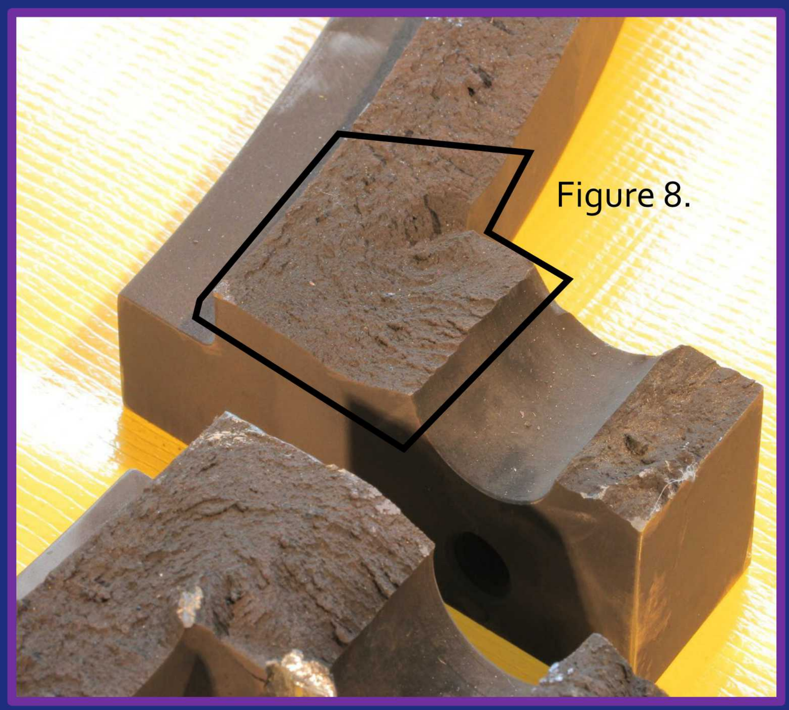

Figure 4. Crack initiation somewhere in these sections (purple box in Figure 2.)

A sample (section indicated by the red dotted line in Figure 1.) was then prepped for optical metallography and microhardness mapping. The sample was mounted in a two part cold mount epoxy then prepped using hand grinding and mechanical polishing to a 3 μm finish. A Vickers microhardness map was performed with a load of 500 g (Figure 5). The sample was then further polished to a 0.3μm finish and etched using Nital to show the microstructure of the material (Figures 6 and 7).

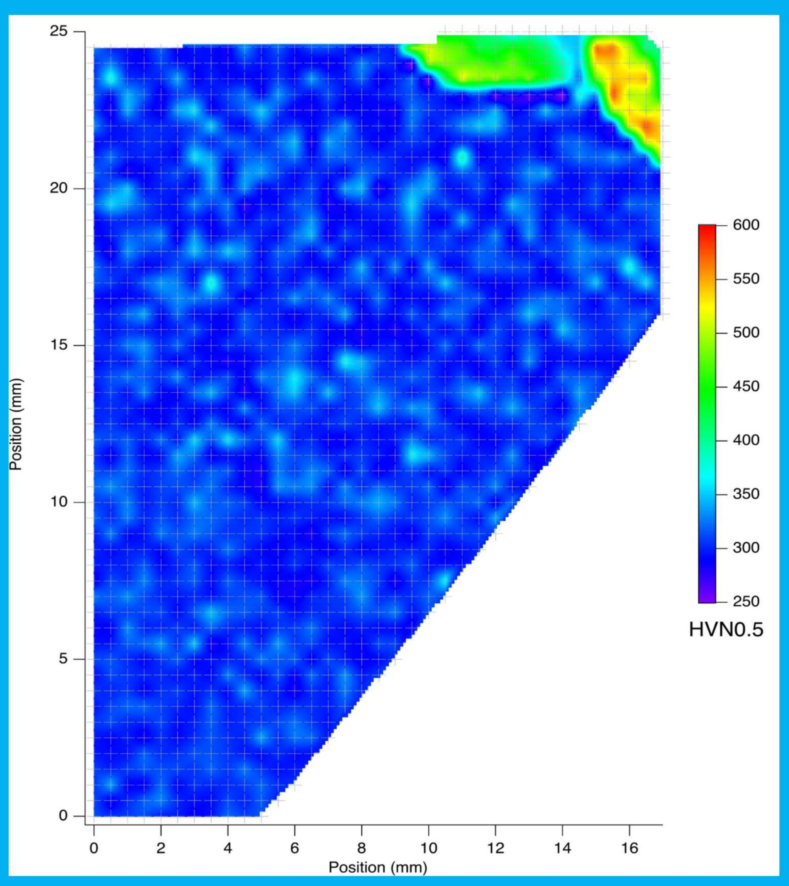

Figure 5. Vickers hardness map showing higher hardness weld (up to 600 VHN) with lower hardness base material (≈300 VHN)

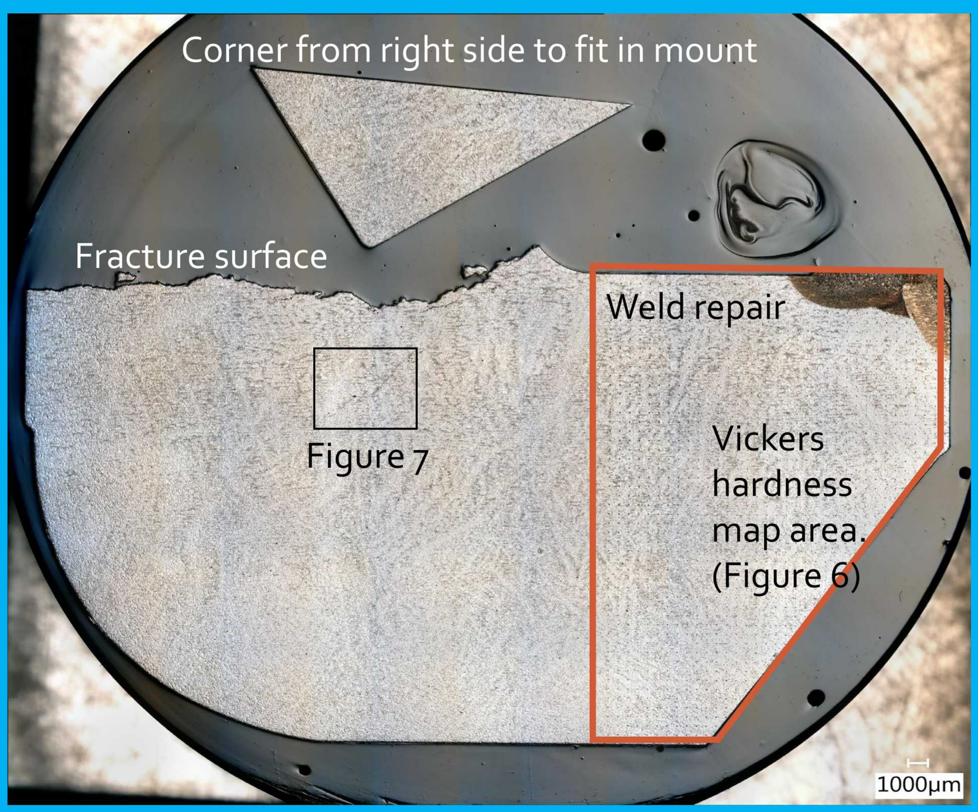

Figure 6. Nital etch reveals microstructure and a weld repair with three passes on the corner.

Figure 7. Microstructure is SOMETHING, secondary transgranular cracks are visible .

Sections for macroetching were taken from the suspected failure region in what would be a planar orientation to the original plate (outlined area in Figure 4) after cutting off the fracture surface to preserve it and from the intact ring from the other side of the assembly in what would be a transverse section on the original plate (Black line in Figure 1). These sections were ground and polished by hand with an 8" grinding wheel. Next a macro etch with Nital was performed to reveal the macro structure. The planar section near the failure initiation (Figure 8) showed a coarse dendritic structure. The transverse section on the intact part (Figure 9) shows the edge-on view of those dendrites only in the center of the plate thickness. This indicates that the plate was not worked enough to break up the dendritic cast structure.

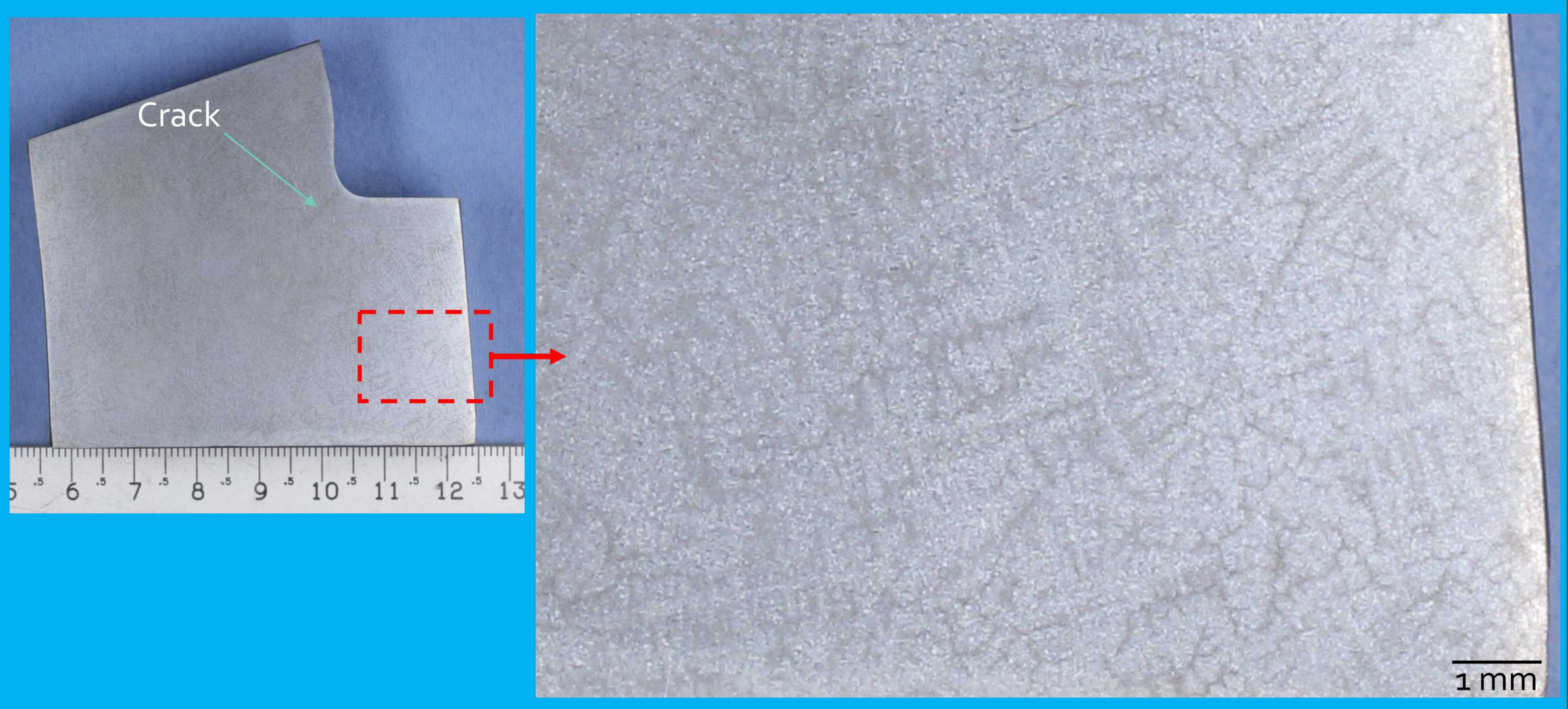

Figure 8. Planar section from the failed portion of the ring which revealed a dendritic as-cast structure.

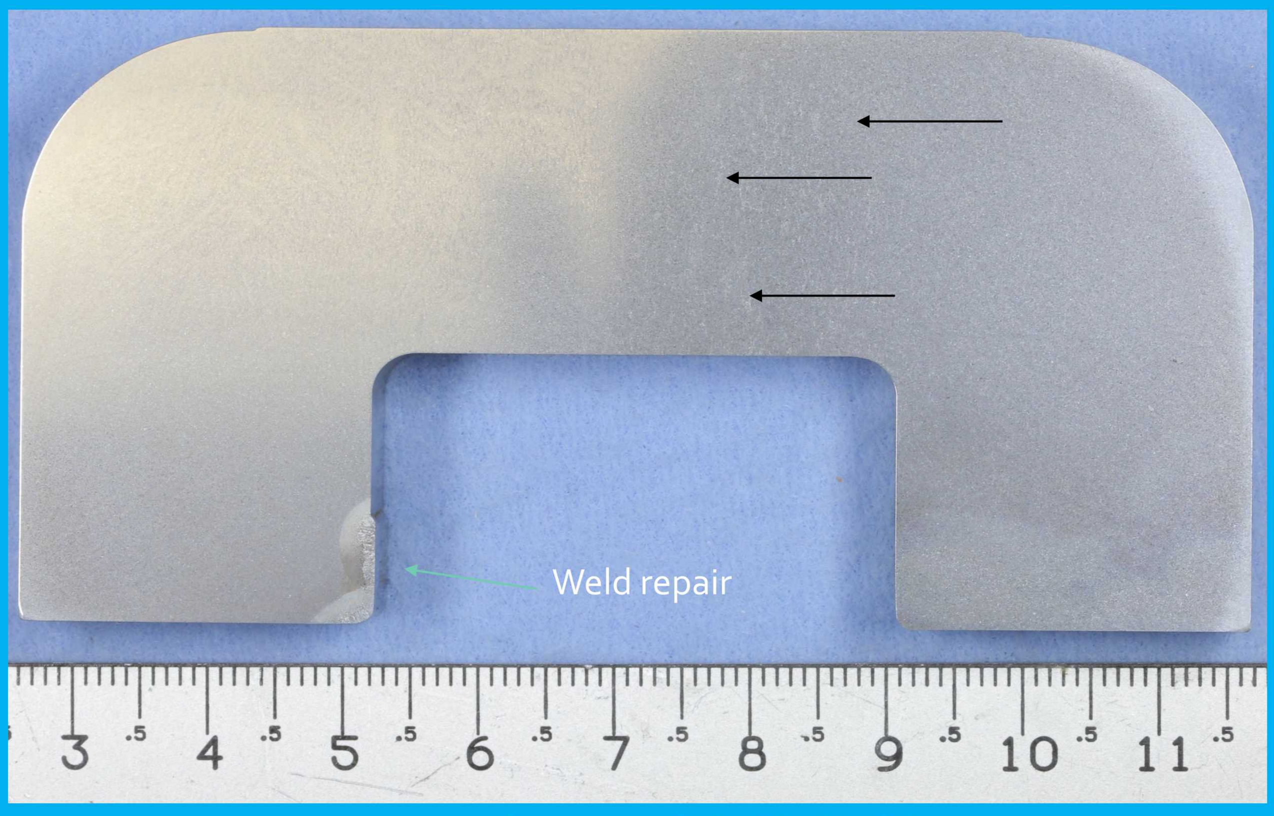

Figure 9. Transverse section from non failed half of the ring. Arrows point out indications of inhomogeneous structure near center of plate thickness.

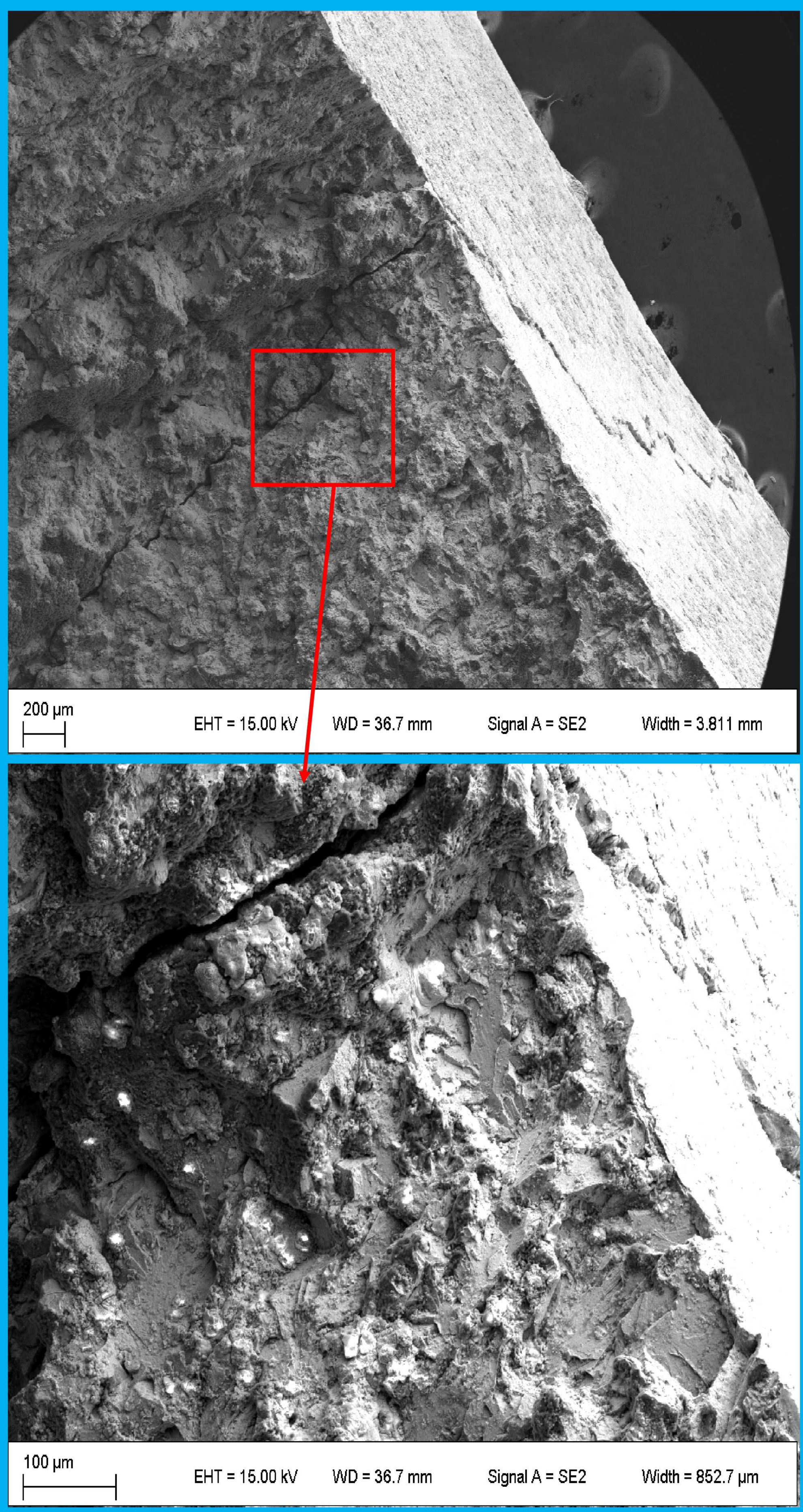

Figure 10 Inter/transgranular cleavage fracture with little ductile tearing and out-of-plane crack

Scanning electron microscopy near the suspected initiation reveals brittle fracture indicative of low toughness alloys. These fracture features would NOT be expected for AISI 4130 tempered per the drawing.

Charpy testing of the failed ring resulted in a average toughness of 5.6 ft-lbs. This is contrasted with the measured toughness of a AISI 4130 ring which was 47.3 ft-lbs.

Chemical analysis showed the failed ring was not 4130, but instead SP300, a injection die steel formulated for air hardenability up to 1 m thickness.

Conclusions:

- Metallography and failure surface analysis determined that material was incorrect.
- SP 300 was sold as "4130 Modified", which was accepted by the mechanical engineer who approved the manufacturing.
- SP 300 has extremely low fracture toughness and is not appropriate for a pressure containing application.

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