SAND2010-5662P

Material Characterization of High Rate Forged 304L Stainless Steel

Lauren Hughes Mills College

Mentors: Nancy Yang 08651 Chris San Marchi 08222

Sandia National Laboratories, CA

Introduction

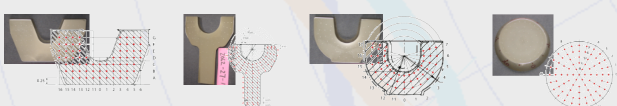
Austenitic stainless steels are commonly used in high-pressure gaseous hydrogen environments due to their resistance to hydrogen embrittlement. As hydrogen fuel cell technologies advance, the use of austenitic stainless steels is expected to grow. While designs of hydrogen systems can be constrained by the low strength of austenitic stainless steels, high-energy rate forging can be used to increase the strength of austenitic stainless steels. The forging process, however, is intrinsically non-uniform and results in large variations of microstructural and mechanical properties in the forgings. The microstructure and hardness were characterized as a function of location in several forgings to determine the distribution of properties in the forgings. The hardness was measured using standard Rockwell Hardness Scale A with spacing measurements approximately 6mm apart. The ASTM grain size was measured with similar spacing using the three-circle method. Grain size was measured with and without consideration of the annealing twins as grain boundaries. Three forging designs were examined over an axial cross section. One forging design was examined over several radial cross sections. Replicate forgings were analyzed for each condition. Mapping of the hardness and grain size show the microstructure and hardness to be non-uniform. The analysis also appears to show a correlation between grain size and hardness: the harder the areas have smaller grains.

Objective

The objective is to determine the distribution of the ASTM grain size through out the forgings using the three-circle intercept method from the optical images of a polished forging cross section and to determine the distribution of the the hardness using the Rockwell Hardness Scale A indentation on the metallographic polished forging cross section.

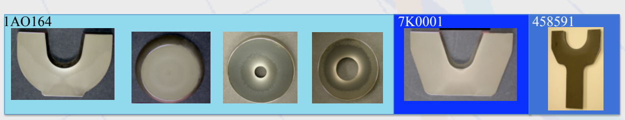
Procedure

The forging cross section was prepared by a conventional metallographic polishing and etching using 75% nitric acid at 1.15 volts. Rockwell hardness indentation was performed on the forging cross sections. Optical images were obtained using Leitz Wetzlar optic microscope adjacent to each indent. (see the figure below). ASTM grain size was measured by the three circle intercept method from optical images. ASTM grain size and Rockwell hardness results were tabulated, plotted and the hardness and grain size contour maps were constructed for each forging.



Materials

Three different types of forging designs made of the alloy 304L with typical composition of .03% carbon, 18-20% chromium, 2% manganese, 8-10% nickel, and balance iron



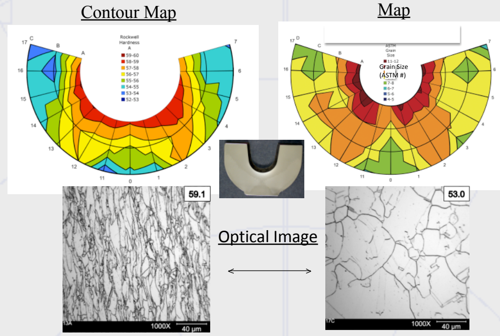
Photos and grids courtesy of Chris San Marchi

Experimental Results

The grain size and hardness on the longitudinal cross section are related:

1AO164 Rockwell Hardness Contour Map

1AO164 ASTM Grain Size Contour Map



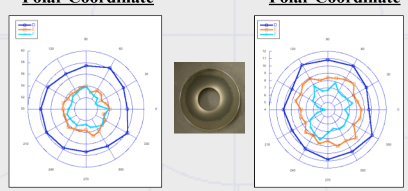
Point 13A is the harder spot with higher ASTM grain size, or small grain.

Point 17C is soft spot with lower ASTM grain size, or large grain.

The grain size and hardness on the transverse cross section are related:

1AO164 Rockwell Hardness Polar Coordinate

1AO164 Grain Size Polar Coordinate

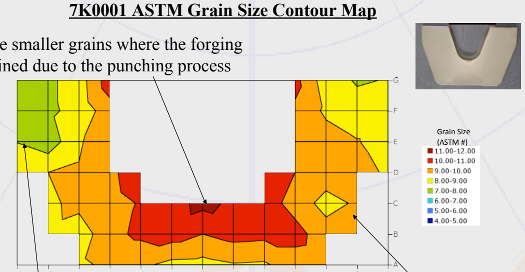


Each color represent a row in the forging. As the hardness increases, the ASTM grain size number also increases.

Grain Size is related to the degree of deformation:

7K0001 ASTM Grain Size Contour Map

There are smaller grains where the forging was strained due to the punching process



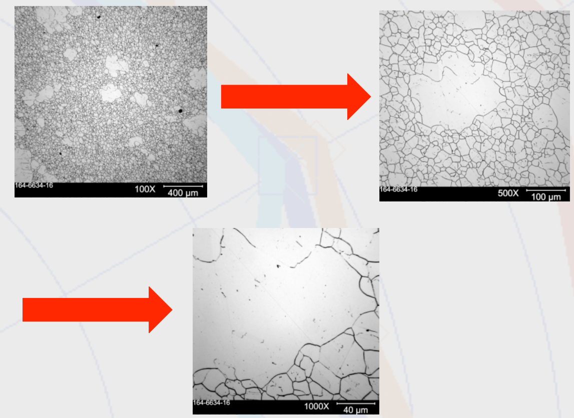
Where very little compression occurred, the grain size is large

There are small grains where the forging was compressed in a dye.

Experimental Results (cont.)

Bimodal distributions of grain size:

Optical Images of 1AO164 14D



Bimodal grain structures were seen in in the forging 1AO164. A statistical representative ASTM grain size and hardness number is hard to reach because these large grains tend to be softer and have inconsistent ASTM grain size numbers in comparison to surrounding area.

Conclusion

The forgings' microstructure, with respect to grain size, and its hardness are found to be non-uniform.

There is a common trend found among the forgings: the hardness is directly related to the ASTM grain size number. The larger the ASTM grain size number (i.e smaller grains) the harder the area.

The inner surfaces of the forgings or the areas, which correspond to high strain and compression locations during the forging process, have a large ASTM grain size number and tend to be harder than the surrounding areas.

There are bimodal distributions of grain size within multiple forgings, which brought a challenge to the ASTM grain size and hardness measurements because these bimodal distributions do not represent the forging as a whole.

Sandia National Laboratories is a multi-program 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