

## Investigation of Grain Flow Microstructure in Forged Nitronic 50 Stainless Steel

R. E. Goddard, R. P. Walsh, and K. Han

National High Magnetic Field Laboratory, Florida State University, 1800 East Paul Dirac Drive, Tallahassee 32310

Nitronic 50 is an engineered high nitrogen austenitic stainless steel that has excellent anti-corrosive and strength properties [1]. In addition Nitronic 50 has low magnetic permeability when cold rolled. After forging grain morphology is expected to follow the die impression of the sample.

Samples were sectioned with observation surface parallel to the normal of the short transverse direction (ST) that were removed from Block B as shown in Figures 1 and 2. A sample was polished and then etched with Agua Regia. The sample was then analyzed in a Leica MEF4M metallograph to observe microstructure and then analyzed in a Zeiss 1540 XB Field Emission Gun Scanning Electron Microscope (FEGSEM).

Etching revealed both the austenite grain and twin boundaries and an alternating pattern in the light microscope (Fig. 3). In SEM images the discontinuous alternating morphological bands were observed trending parallel to the indent corner created by the die (Fig 4). The bands were analyzed by use of Energy Dispersive X-ray Spectroscopy (EDS) inside the FEGSEM and found to be of two distinct chemistries (Fig. 5). The iron-depleted bands (zone 1) contain tabular and spherical inclusions, precipitates [2], that are rich in niobium, chromium, molybdenum, and probably carbon and nitrogen. The tabular nature of some inclusions was confirmed by Focused Ion Beam (FIB) dissection that showed a continuous feature extending into the subsurface. Niobium content is close to 50 wt% in some of the tabular particles. It is likely that niobium, combining with nitrogen and carbon, forms niobium carbon nitrides. The tabular particles of zone 1 are arranged parallel with the long axis plane of zone 1 and normal to the forged indent corner. Spherical particles have relatively large densities and are rich in niobium and molybdenum. However, inclusions are not distributed homogeneously.

Zone 2 is more susceptible to chemical attack as noted by the presence of an abundance of etch pits (Fig. 3). In zone 1 the grain boundaries were more difficult to etch as indicated by white arrows (Fig. 3). In zone 1 the austenite grain boundaries can be revealed with high contrast. The zone features crossed grain boundaries and followed more the forged surface.

Although the austenite grains appear equiaxial, the inhomogeneous distribution of the particles and chemistry may result in anisotropy of the material properties, particularly the ductility, fracture toughness, and the crack growth rate. Detailed microstructure and mechanical property measurements are required in order to better characterize this material.

### References

- [1] Guo, W., Nemat-Nasser, S., Flow stress of Nitronic-50 stainless steel over a wide range of strain rates and temperatures, *Mechanics and Materials* 38 (2006) 1090-1103
- [2] KIND Forge Report, EMR-12012 (2012)
- [3] This work has been supported by the National Science Foundation award number DMR-9527035

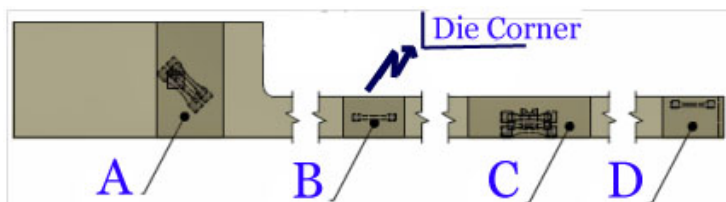


Figure 1. Sectioned Forged Nitronic 50

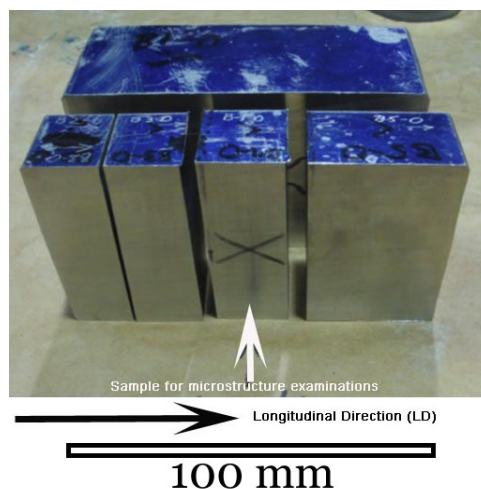


Figure 2. Division of Section B

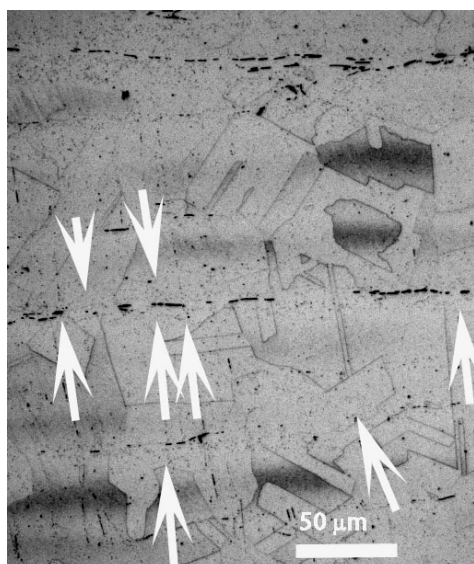


Figure 3. Optical Micrograph of Grain Boundaries

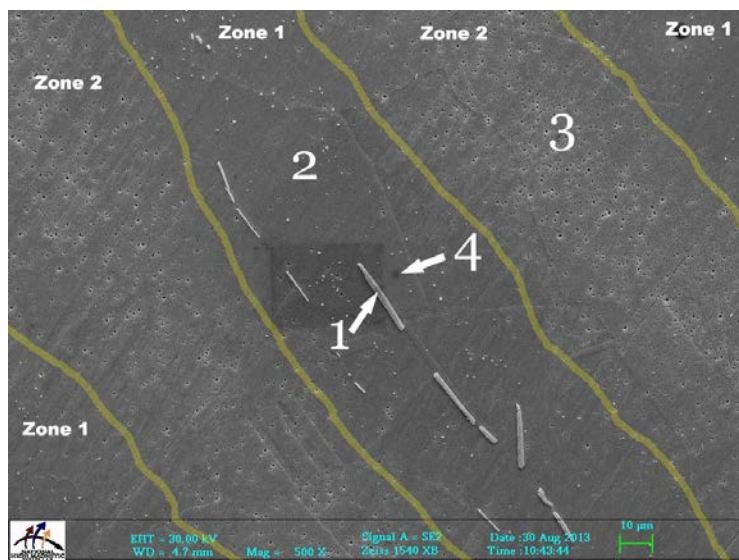


Figure 4. SEM Micrograph of Discontinuous Bands

| Location                                    | Si  | Mo  | Cr   | Mn  | Fe   | Ni   | Nb   |
|---|-----|-----|------|-----|------|------|------|
| 1-Tabular inclusion                         |     | 5.5 | 33.2 | 2.8 | 19.5 | 3.0  | 36.0 |
| 2-Matrix-Zone 1                             |     | 2.7 | 23.2 | 5.7 | 55.5 | 12.1 | 0.8  |
| 3-Matrix-Zone 2                             | 1.0 | 2.0 | 21.6 | 5.0 | 59.6 | 10.5 | 0.4  |
| 4-Spherical inclusion with surrounding area | 2.0 | 3.9 | 26.2 | 4.1 | 38.1 | 7.4  | 18.4 |

Figure 5. Chemical Analysis of Zones 1 and 2