Abstract: Seven samples of 316L stainless steel with various additives were provided by North American Hoganas (NAH) for microstructure evaluation. All samples were provided in the form of TRS (transverse rupture strength) bars. Each bar was sectioned, mounted in an acrylic puck, and subjected to electrolytic etching as well as conventional acid etching to determine the best etching effects for revealing to the microstructure. Following this procedure the samples were evaluated using an optical microscope at various magnification levels. Key structures and features such as grain boundaries, grain types, and porosity were key factors in the evaluation of a material at a microscopic level.

Results and Discussion:

The base material of 316L stainless steel, Fig. 5, was used as a guide in evaluating the other mixes. Several features found in this material were found to be quite useful because it shows a variety of key features. One main evident feature that
can be seen is the areas of oxides that were found along the grain boundaries and along pores but minimal in ferrite grains. These features appear to be an almost leaf structure (A) that is most prevalent in the bottom right of the micrograph. Another feature that was observed was the presence of carbides. Again, much like the oxides found, these carbides reside on the grain boundaries where there is high energy, although not on the ferrite grains. The carbides (B) can be seen as circular inclusions and can be located just above the center of the micrograph. The austenitic annealing twins that formed are very full and very evident when viewing the material. The pore sizes are equiaxed and are evenly spread throughout the material. Having the twinning and pore shapes and sizes as described falls in line with what would be desired as according to Randall M. German [1].
Figure 5: Optical Micrograph of base 316L material at 200X magnification
In mix 1, Fig. 6, there is again multiple features that are present and noticeable. The pore sizes and shapes appear to be equiaxed in shape, although seem to have areas of sharper pointed edges instead of the desired rounded pores. Rounded pores are a good factor in determining proper sintering and also to help determine if the material particles went into solid solution with each other. Having pores that are not perfectly rounded can be contributed to an improper sinter while also can indicate that the material particles did not go into a complete solid solution with each other [7]. Another feature that can be seen in the microstructure of mix 1 are the minimal locations of oxides on the ferrite grains (A) and are not as noticeable on the grain boundaries themselves. They are not as significant as found on the base specimen, but are still visible in these grains. A possible intermetallic phase may also be present as the twinning that occurs is quite different throughout the specimen. Some areas of twinning are close and tightly packed with a different size and color of ferrite grains which could be contributed to a second intermetallic phase.
Figure 6: Optical Micrographs of Mix 1 at 200X magnification
Mix 2, Fig. 7, indicates minimal oxides and does not show the probability of 2 phases within the microstructure. This mix does not seem to show or present any carbide sites like the base material had shown. The possible oxidations sites are found near multiple pore locations and are located within the ferrite grains (A). They seem to agglomerate along the grain boundaries but are not tightly packed along the boundaries as seen in the base material. The twinning that is visible in the mix 2 micrograph is very noticeable and equiaxed in size and distribution throughout the surface. The pores are very rounded and spread evenly throughout the micrograph with the exception of some pores being quite larger than others. Although the pore sizes are not evenly sized, the pores do produce rounding that can be considered ideal as they do not contain sharp or pointed edges. Most pores evaluated are oval to circular in shape. Having pore consistency like in mix 2 points to a good sintering process as well as the material particles solidified properly into a solid solution with each other during sintering. [7]
Figure 7: Optical Micrographs of Mix 2 at 200X magnification
Large pores with no definite size or shape are visibly noticeable in mix 3, Fig. 8. The pores in mix 3 range from very small, <1μm in size, to large sizes, >10μm and are not evenly spread throughout. Pore shapes are not definite by any shape. Circle, oval, and irregular shapes are all found in the microstructure. There are also no evenly spaced locations or gradients of pore shapes or sizes found either. Although there is no even shape and contains a large distribution of pore sizes, they do follow proper rounding in which all pores contain rounded features and do not show any points or sharp edges. The twinning found in mix 3 is very large as compared to the base material. Twinning is spread out evenly and is much larger than what is found in the base material in size. Very closely packed twins also show another trait within the microstructure. Minimal oxides are noticed in the microstructure, and can only be seen in very few areas. One area, (A), that oxides can be vaguely seen is on a ferrite grain, and not along the grain boundaries as found in other mixes. The oxides are shown as small circular black spots on the grains.
Figure 8: Optical Micrographs of Mix 3 at 200X magnification
Martensitic grains can be viewed in the micrograph for mix 4, Fig. 9. This grain structure, although minimal, can be viewed in the upper left section of the micrograph (A). In this section, a very tightly packed grain structure with spider-like effects is evident which is why this structure is believed to be a martensitic grain structure. The pores within the micrograph show large pores that are mildly rounded that have multiple pointed edges. There is a minimal spread of pores that are circular in shape, and are well rounded. There is a possible noticed intermetallic structure within the pores as well. Small island features (B) within the pores point out that an intermetallic phase maybe present in the sample. The twinning that occurs in mix 4 ranges from large to small twins. They are not equiaxed much like the pores. The twinning that does not take place is very tightly packed around the pores. The locations of oxides within the structure are minimal and not visibly noticed by the eye at this magnification.
Figure 9: Optical Micrographs of Mix 4 at 200X magnification
A possible retained austenite feature can be seen visibly in several locations within the micrograph for mix 5, Fig.10. These areas appear as straight line smearing. One thing that distinguishes them from an actual smear is that an artifact, like smearing, will be imbedded in the structure, as what is being viewed seems to be raised slightly from the ferrite grains. [7] Withholding a second phase as retained austenite means that the material causing this structure appears to be nickel. This feature can be noticed in several locations (A). Oxides (B) also reside in the microstructure of mix 5. Oxidation sites can be viewed most dominantly in the lower right hand portion of the micrograph. Twinning in this mix is minimal and spread out. The twins, as noticed in the mix 4 micrograph, are not close and tightly packed. The pore structure in mix 5 is more longitudinal and less circular like that can be viewed in the base material. The pores mostly seem to be spread out unless they are smaller in size (<5um wide). The smaller sized pores seem to agglomerate and produce small clusters unlike the larger pores that maintain distance from other pores. Pores are properly rounded and contain almost no points.
Figure 10: Optical Micrographs of Mix 5 at 200X magnification
The micrograph in mix 6, Fig. 11, is much like that of mix 5, Fig. 10. Retained austenite can be viewed in multiple locations on the microstructure (A), which is created due to the nickel within the material. This mix has a lower number of pores than what is shown in the base material. They are mostly irregular shaped with a minimal mixture of rounded circular pores. Pore location is also very spread out as compared to the base material as well. Pointed edges of the pores are noticeable on the larger pores, although the smaller pores do not appear to contain any pointed edges. Islands within some of the larger pores point towards the sample having a dual phase. [7] The islands that can be seen within the pores (B) could be created due to the nickel austenite phase that can also be seen. The entire structure is, “peppered,” with oxidation sites. These can be viewed as small black circular dots throughout the micrograph (C). Twinning in mix 6 is very spread out. Although the twins are spread out, the locations of the twinning is very tight with what can be seen.
Figure 11: Optical Micrographs of Mix 6 at 200X magnification