Corrosion of Additively Manufactured 316L Stainless Steel Bio-Implants in Simulated Human Body Fluids

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Additive manufacturing (AM) technology is becoming increasingly popular for building complex parts in various industries, including medicine. A surgical procedure for cranial reconstruction with a custom desinged metal implant has been performed using AM technology [1]. Implants such as this are lifelong replacements for body parts, and AM provides an efficient way to create implants and solve other complex medical problems. Medical devices are traditionally made from wrought materials, but because of the increasing popularity and availablity of AM technology, medical professionals are transitioning to AM methods. AM is a popular method in bio-implants because it allows for customization of surgical implants. The material commonly used is 316L stainless steel, a bio-compatible metal. However, the corrosivity of human body fluids can cause breakdown of metal and adverse side effects for the patient.

The objectives of this study are to (1) optimize the laser AM process to fabricate high quality AM 316L SS parts, (2) characterize microstructure of AM 316L SS, (3) understand localized corrosion of AM parts versus wrought parts in simulated body fluids, and (4) understand localized corrosion in as-built AM parts versus heat-treated AM parts in simulated body fluids.

Additive samples were created using a Concept Laser Mlab Direct Metal Laser Melting (DMLM) machine using 316L SS powder. Each sample was etched to reveal microstructures and cellular structures, which were analyzed using a scanning electron microscope (SEM). SEM characterizations were performed on untested AM as-built in both vertical and horizontal orientations, heat-treated AM 316L, and wrought 316L in order to identify important microscructures that may be related to corrosion resistance. The samples were tested using a GAMRY Reference 600+™ Potentiostat. Two cyclic potentiodynamic polarization (CPP) tests were performed for each sample. Figure 1 includes one CPP graph for each material type. The data were analyzed to evaluate the susceptibility of the material to localized corrosion, or pitting. Hank's Balanced Salt Solution (HBSS) with 5.96 g/L of HEPES Buffer Solution with a pH of 7.4 +/-0.2 was used as the electrolyte.

Prior to printing the AM samples, a study was conducted to determine the most efficient printing power, speed, and hatch spacing. A printing power of 90 W, a speed of 600 mm/s, and a hatch spacing of 80 µm were selected. Hatch spacing is the distance between two adjacent scanning paths of the laser used to melt the metal powder. This parameter was found to greatly affect the size, type, and quality of defects present in the specimens.

The microstructural components of each material were drastically different, a result that coincides with the data found from CPP testing. Based on the data, it is clear that both as-built and heat-treated AM 316L SS demonstrated high resistance to localized corrosion in HBSS. In addition, additive 316L SS has superior resistance to localized corrosion when compared to wrought 316L. Lastly, unique microstructures in as-built and heat-treated AM 316L SS parts contribute to their superior corrosion resistance.

Statement of Research Advisor

Catherine contributes to the understanding of the degradation process of additively manufactured stainless steels in the human body environment, which is a critical measure for medical implant devices. She also characterized the defect structures of AM parts as a function of laser processing parameters, which contributed to a collaboration with the other university. She did an excellent job on her research.
-Xiaoyuan Lou, Mechanical Engineering

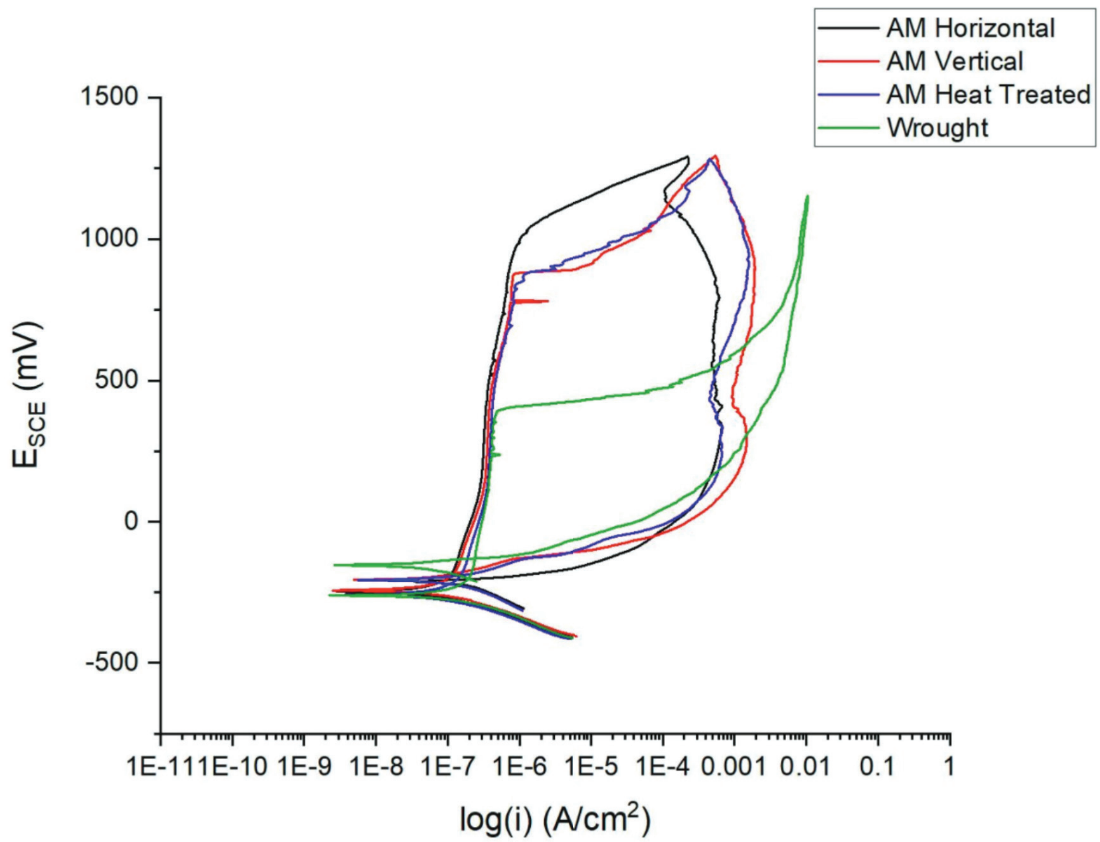

Figure 1. Cyclic potentiodynamic polarization graph for each tested material type.

References

[1] Jardini, A. L., Larosa, M. A., Filho, R. M., Zavaglia, C. A. C., Bernardes, L. F., Lambert, C. S., Calderoni, D. R., and Kharmandayan, P., 2014. Cranial reconstruction: 3D biomodel and custom-built implant created using additive manufacturing, *Journal of Cranio-Maxillofacial Surgery* 42(8), 1877-1884.