Fatigue Analysis of Additively Manufactured Ti-6Al-4V for Biomedical Applications: Permanent Bone Screws

Luke Toshiharu Dommerich Hase, Mechanical Engineering

Mentor: Dr. Yongming Liu

School for Engineering of Matter, Transport and Energy

Introduction

In the health sector, the use and study of additively manufactured (AM) materials has been on the rise. Applications of titanium AM parts in the health sector include dental implants, exact fit surgical implants, and much more- all of which require high cyclic fatigue life. Titanium is used because it doesn't corrode in the body.

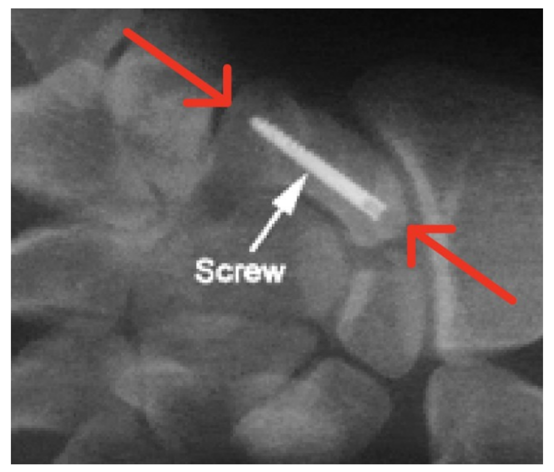


Figure 1. Bone screw holding carpals together.

Figure 2. Typical example of a surgical screw.

Abstract

AM materials are highly advantageous as they can be quickly produced and are custom-created to exactly fit the application. In this research, the fatigue life of AM Ti-6Al-4V is studied and compared to the fatigue life of standard produced Ti-6Al-4V. The comparison will determine whether or not AM Ti-6Al-4V is suitable for the specific application of human bone screws. If AM screws are determined suitable for the application based on fatigue life, more research should be conducted on the osseointegration of AM Ti-6Al-4V in the human body.

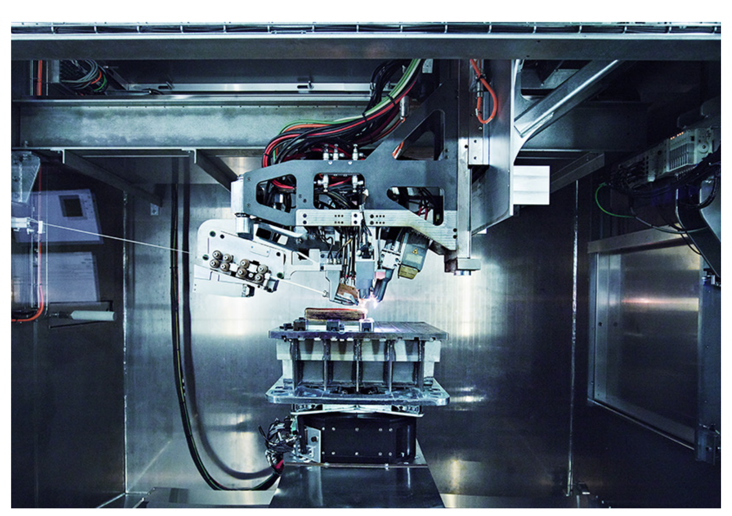


Figure 3. Example of an AM machine.

Figure 4. Examples of other AM biomedical products.

Method

First, fatigue tests were completed on a dozen AM Ti-6Al-4V specimens. Using the force data, strain data, time data and physical measurements of the specimens, the Young's Modulus and Poisson's ratio were calculated. A model of the specimens was then created in Soldworks. These were then used in a finite element analysis software to model the fatigue of Ti-6Al-4V. Finally, the results are compared to a model with the Young's Modulus of Elasticity and Poisson's ratio of a traditionally manufactured Ti-6Al-4V alloy.

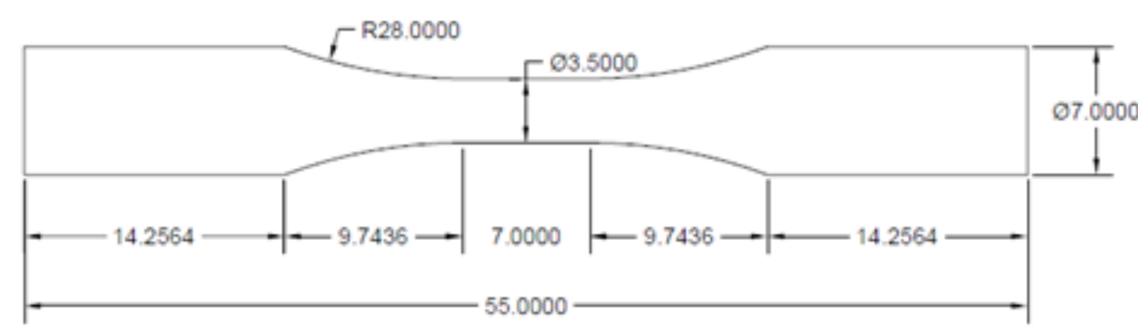


Figure 3. Specifications for the specimens tested.

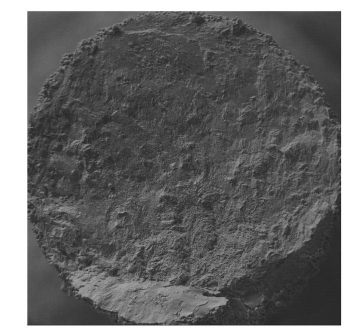
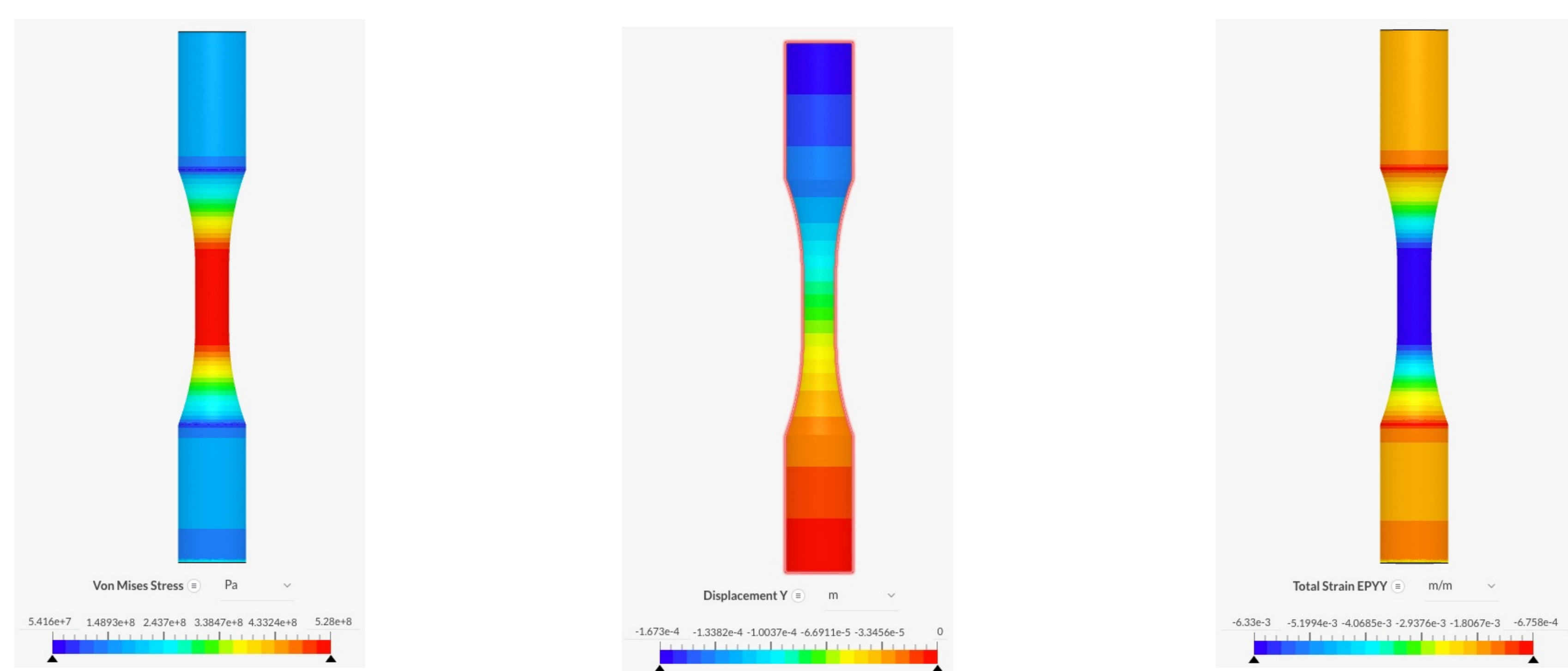


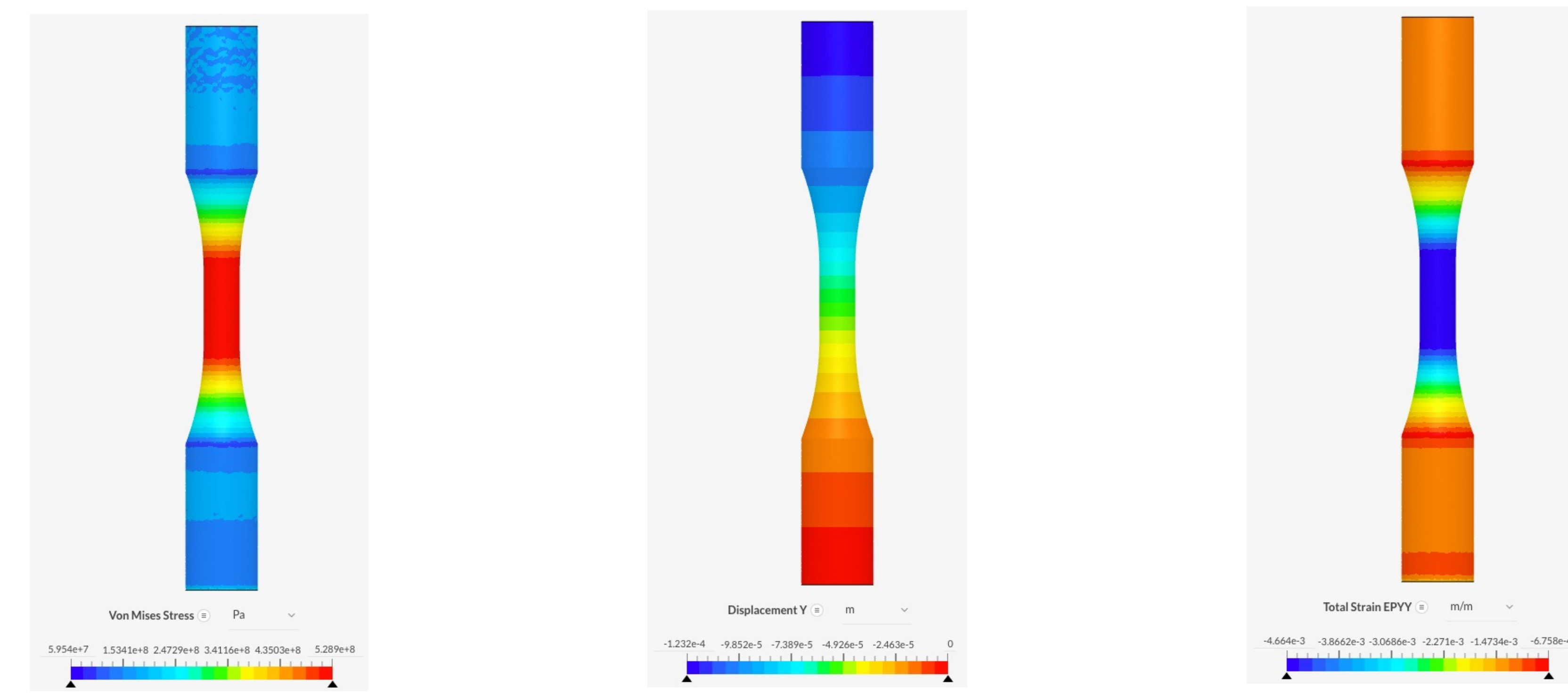
Figure 4. Scanning electron microscope image of the cross section of a fractured specimen.

Results

The Young's Modulus of Elasticity obtained was 83.6GPa, significantly lower than the 113.8GPa of traditionally manufactured Ti-6Al-4V. This is a 26.5% deficit. The AM specimen was displaced 0.167mm compared to 0.123mm, a 26.3% difference. Because the AM specimen has a lower Young's Modulus, Poisson Ratio, ultimate yield strength and so on, the fatigue life will be lower.



Figures 5,6,7. Stress, displacement, and strain contour plots for the AM alloy- produced by Simscale model.



Figures 8,9,10. Stress, displacement, and strain contour plots for the traditionally produced titanium alloy data- produced by Simscale model.

Conclusion

In terms of fatigue life, additively manufactured Ti-6Al-4V can be used in the application of medical bone screws. Although AM Ti-6Al-4V is xx-yy% weaker than traditionally manufactured Ti-6Al-4V, the difference isn't severe enough considering the base strength is extremely good. When estimating the fatigue life with the standard equation Sigma= AN^B, the smaller the stress, the greater fatigue life will be. As AM Ti-6Al-4V posses less dense layers and weaker properties, the internal stresses will be greater and cause fatigue life to decrease. If this experiment were to be conducted again, special attention should be paid to the fatigue testing procedure to ensure there were no errors when loading the specimen into the machine. Errors in loading the specimen may include the specimen being off axis and fracturing earlier than it should.

Sources and Acknowledgments

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