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Surface Roughness Characterization of Additive Manufactured Ti6Al4V

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Abstract

Additive manufacturing (AM) allows for the possibility to produce structural elements of any geometry [1]. One of the most popular metals to use in AM and the role of bone implants is Ti6Al4V. Heat treatment and cooling methods were used to alter the surface roughness and hardness of the Ti6Al4V samples. Atomic force microscopy (AFM) and Vickers hardness tests quantified the surface roughness and hardness of the Ti6Al4V samples. AM samples were compared to conventionally manufactured samples (Tables 1 and 2). The conditions that should be further explored are AM Ti6Al4V samples heat treated at 870°C and air cooled. By being able to manipulate the material properties of the Ti6Al4V samples with heat treatments and cooling methods, there is large potential for Ti6Al4V in orthopedic implants.

Introduction

Ti6Al4V has low density, high strength, high corrosion resistance, and is biocompatible [2]. Ti6Al4V can be applied in many areas such as the medical, aerospace, and motorsport industries [1]. Since Ti6Al4V has superior corrosion resistance and excellent biocompatibility, the alloy is primarily used for load bearing biomedical implants [3]. AFM is employed to measures surface topography and produce high resolution images. Heat treatment can optimize the mechanical properties like tensile and fatigue strengths and hardness [4].

Methods

AM (Figure 1) and conventionally manufactured Ti6Al4V samples were heat treated in a furnace at 870°C or 600°C. Ten samples total were used, five being AM and five being conventionally manufactured. Optical microscopy (OM) images were taken at 50x, 100x, 200x, 500x, and 1,000x magnification to qualitatively determine differences in surface roughness. AFM with a Bruker RTESP probe tip was used to take five scans total on each sample with a scan size of 5 x 5μm. Five Rockwell C hardness tests were taken on each sample with a brail penetrator tip and then converted to Vickers hardness scale for analyzing.

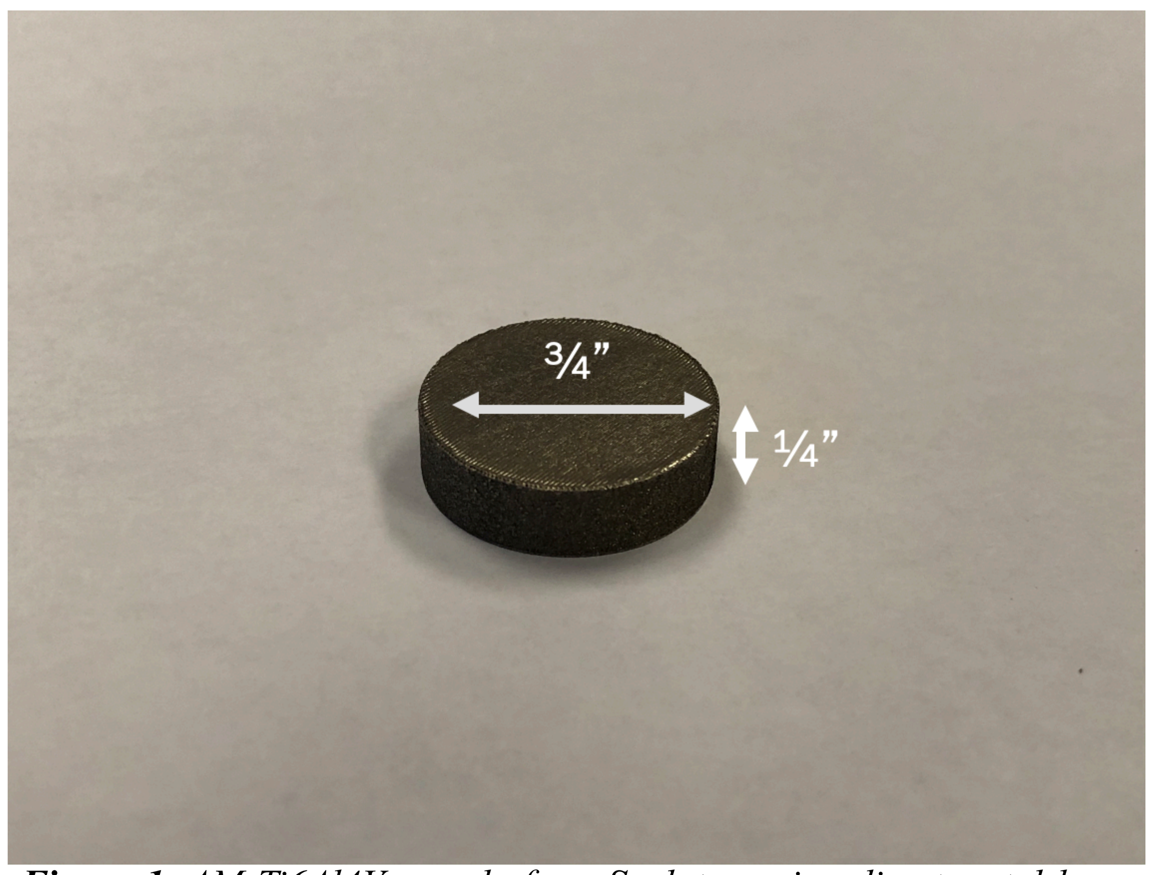

Figure 1. AM Ti6Al4V sample from Sculpteo using direct metal laser sintering process.

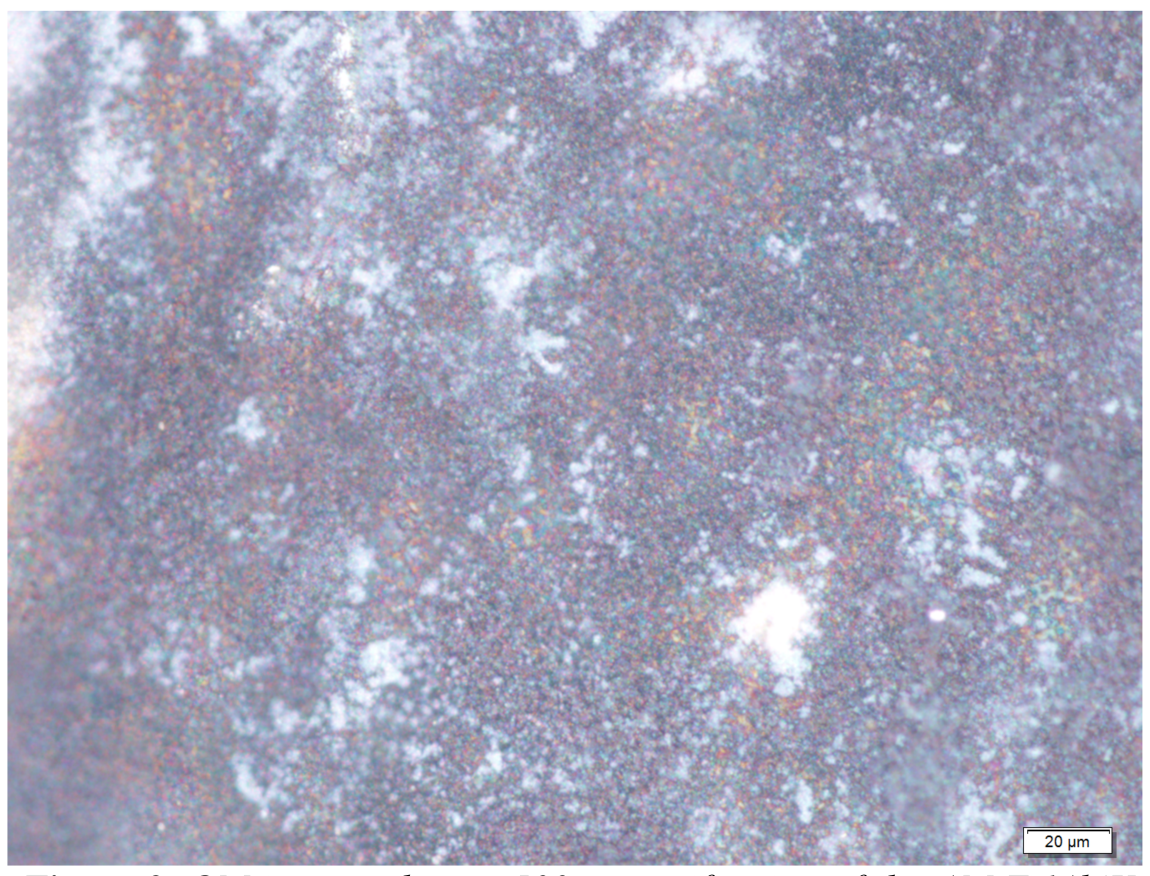

Figure 2. OM image taken at 500x magnification of the AM Ti6Al4V sample heat treated at 870°C and air cooled.

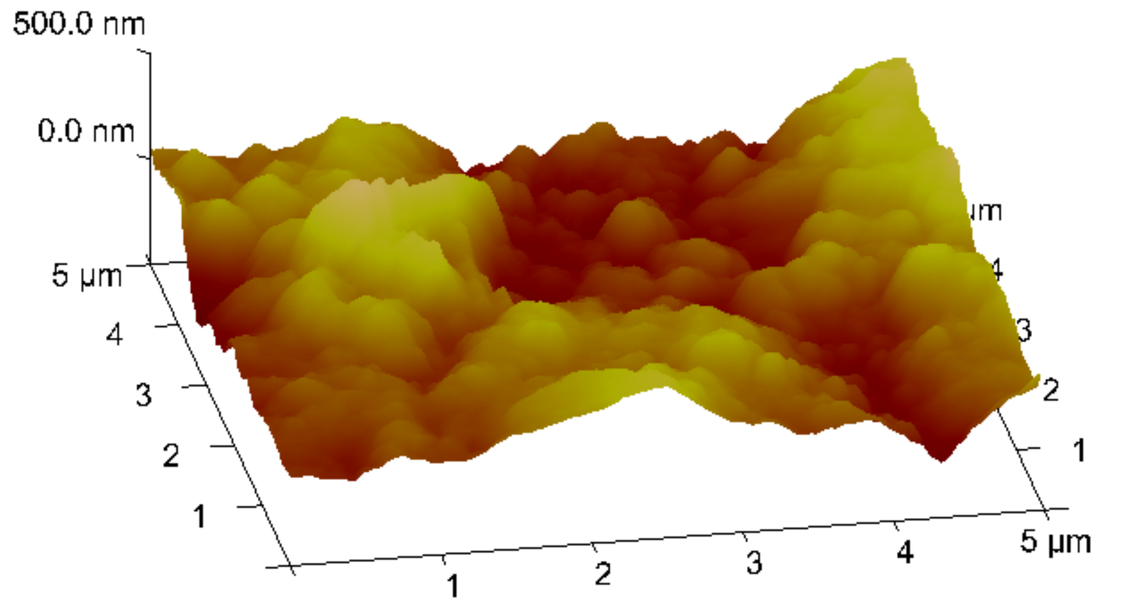

Figure 3. AFM image of a 5 x 5µm scan size of an AM Ti6Al4V sample heat treated at 870°C and water quenched.

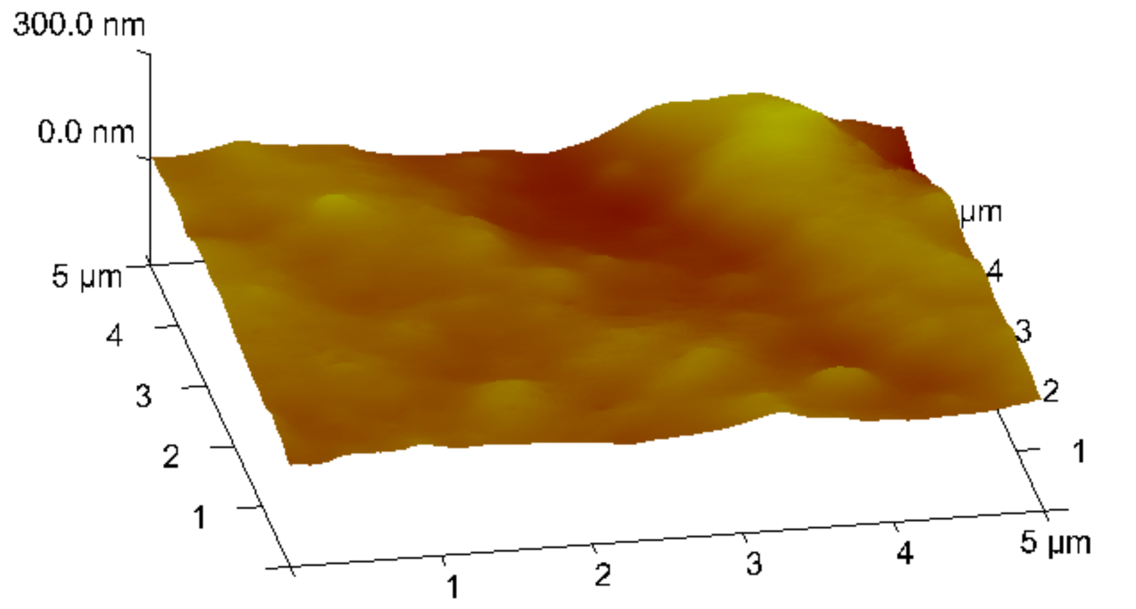

Figure 4. AFM image of a 5 x 5 µm scan size of a control AM Ti6Al4V sample.

Results

***Table 1.** The average arithmetic roughness, R_a and Vickers hardness, HV of the AM Ti6Al4V samples collected by AFM and Vickers hardness test.*

Heat Treatment Temperature (°C)	Cooling Method	R_a (nm)	Hardness (HV)
Control	Control	23 ± 17	385 ± 6
870	Air Cool	100 ± 78	335 ± 5
870	Water Quench	51 ± 11	340 ± 5
600	Air Cool	19 ± 10	393 ± 9
600	Water Quench	28 ± 11	388 ± 7

***Table 2.** The average arithmetic roughness, R_a and Vickers hardness, HV of the conventionally manufactured Ti6Al4V samples collected by AFM and Vickers hardness test.*

Heat Treatment Temperature (°C)	Cooling Method	R_a (nm)	Hardness (HV)
N/A	N/A	15 ± 5	349 ± 9
870	Air Cool	88 ± 23	361 ± 3
870	Water Quench	84 ± 21	325 ± 5
600	Air Cool	24 ± 20	364 ± 6
600	Water Quench	62 ± 11	361 ± 5

Conclusions

The surface roughness and hardness of the samples were altered with respect to the method of processing, the heat treatment temperature, and the cooling method. A reason for increased surface roughness of the heat treated samples could be due to the formation of an oxide layer on the surface of the samples or a microstructure phase transition. Surface roughness and hardness of Ti6Al4V are important properties of a bone implant because an increase in surface roughness leads to an increase in osseointegration at the bone-implant surface interface. Of the conditions that were tested, the condition that should be further explored is AM Ti6Al4V heat treated at 870°C and air cooled to room temperature (Figures 2 and 3). An increase in surface roughness was seen between the AM sample heat treated at 870°C and air cooled (Figure 3) and the control AM sample (Figure 4).

References

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