Static Properties of Direct Metal Laser Sintered (DMLS) Titanium Alloy (Ti6Al4V) and the Influence of Machining and Hot Isostatic Pressure (HIP) Treatment

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Statement of Purpose: Additive manufacturing (AM) techniques such as direct metal laser sintering (DMLS) have gained acceptance for many different applications, including the manufacturing of orthopedic implants. Some of these applications require high strengths that rely on the material used and/or processing techniques applied to the material. There are different ways to alter strength properties in AM materials such as heat treatments, surface treatments, and thermal/pressure cycles. This study looked at the influence of machining and hot isostatic pressing (HIP) on DMLS titanium alloy (Ti6Al4V) static mechanical properties

Methods: Tension testing was used to evaluate the impact of a machined surface and post process HIP cycle. Four groups of six (6) samples were designed and built for testing using a DMLS Ti6Al4V process. The four different groups were separated into: (**a**) As DMLS, near-net shape; (**b**) As DMLS, near-net shape w/ HIP treatment; (**c**) machined; (**d**) machined w/ HIP treatment. The sample dimensions were established by ASTM E8[1] guidelines for a round specimen. The machined groups were built as a cylinder and a dog-bone shape was machined out of this cylinder. Testing was performed on an Instron elctromechanical load frame where samples were strain paced at 0.005 mm/mm/min through yield and then displacement controlled to 0.15 mm/min until failure. The ultimate and yield strengths, elongation, and reduction of area were captured at the conclusion of each test. Using a Student's t-test the sample groups were compared to each other. Microstructure analysis was also performed to evaluate the effect of HIP treatment.

Results: Table 1 outlines the average and standard deviations from all groups for tensile strength, yield strength, elongation, and reduction of area. Sample Group d had an outlier sample with yield strength far above the group set and was removed from the study.

Table 1. Table of average (std dev) results from tensile testing. Groups a-d are outlined in **Methods** section

Group	ASTM F2924[2]	a	b	c	d*
Condition	-	DMLS	DMLS HIP	Machined	Machined HIP
Tensile Strength (MPa)	895	962 (4)	964 (2)	1016 (2)	1007 (3)
Yield Strength (MPa)	825	895 (5)	888 (1)	942 (3)	918 (5)
Elongation (%)	10	19 (1)	9 (2)	16 (1)	15 (1)
Reduction (%)	15	50 (2)	19 (4)	54 (1)	42 (2)

**an outlier speciman was removed (n=5)*

Results of the microstructure analysis of the As DMLS samples are shown in Figure 1. The machined samples showed similar morphology. The sample that was not HIP processed shows some evidence of voids within the structure while the HIP processed sample is free from voids. Grain size and morphology appeared to be largely unchanged.

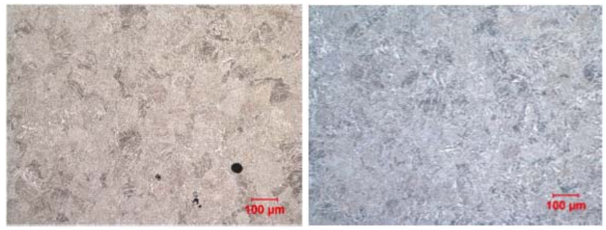

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Figure 1. Microstructure of a (i) DMLS component with no HIP treatment and a (ii) DMLS component with HIP treatment

Conclusions: The only statistical comparison which showed no significant difference was the tensile strength between Groups **a** and **b** (p>0.05). The HIP treatment had a slight impact on the static properties, however, this treatment increases the fatigue limit of a machined sample by 57% (rotating beam fatigue)[3].

The microstructure images show that AM may not completely densify the material. However, the HIP process can be utilized to create a void free part (**Figure 1**). Machining the sample had a far greater impact on static properties than did the HIP process. Due to the notch sensitivity of Ti6Al4V, the characteristics of the DMLS surface reduced the static mechanical performance of the material[4].

The material's strength is impacted by HIP treatment with elongation and reduction of cross-sectional area affected the most. Machining and HIP treating the DMLS Ti6Al4V had the most significant impact on the overall static properties. However, all of the properties fell within ASTM F2924 specifications with the exception of the elongation of Group **b**. This data establishes a starting point to understand the effects of HIP'ing and machining on DMLS Ti6Al4V. The data reflects a small number of samples and may be influenced by compounding factors, such as powder lot and sintering machine parameters. Additional testing will be performed.

References:

[1] ASTM E8 / E8M - 13a Standard Test Methods for Tension Testing of Metallic Materials
[2] ASTM F2924-12a Standard Specification for Additive Manufacturing Titanium-6 Aluminum-4 Vanadium with Powder Bed Fusion
[3] On File - MAKO Surgical Corp.
[4] Long M. Biomaterials. 1998; 19:1621-1639