HIP Conditions: Key Operation for Controlling Mechanical Properties of 3D Printed Ti6Al4V

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Selective Laser Melting (SLM) is a process used for near-net shape fabrication of complex parts. The process consists of metal powder melting and rapid solidification resulting in complex microstructure and formation of defects such as micropores. Ductility and especially fatigue resistance are sensitive to presence of defects such as micropores. Hot Isostatic Pressing (HIP) is a well-known process that permits to compact the material and in the case of SLM manufactured parts eliminate the micropores. A common project with ProtoShape GmbH and Bern University of Applied Sciences has been launched to develop full-chain SLM process fabrication for Ti6Al4V alloy for aerospace applications. Present investigation focused on improving the mechanical properties of SLM manufactured parts by HIP post treatment.

Ti6Al4V alloy is a well-known alloy for aerospace application as it offers low density and high mechanical properties. SLM process enables nearly unlimited freedom in design, which permits to fabricate parts with improved performance or design novel unique components. Preliminary investigations focused on topology optimization and microstructure were reported earlier [1].

Table 1: Mechanical properties of samples in as printed and after post treatment compared to commercial alloy.

	Commercial alloy (aged)	As manufactured	HIP (a)	HIP (b)
$\sigma_{0.2}$ (MPa)	1020-1080	833	1273	1000
σ_{max} (MPa)	1100-1270	1310	1290	1080
ε (%)	8-13	5.3	2.0	18.4

The present study focused on establishing full-chain process development for SLM manufacturing of Ti6Al4V alloy to obtain homogenous material with mechanical properties be as good as the commercial alloy. Table 1 summarizes mechanical properties measured for as-build samples as well as after HIP treatment. For comparison the properties of the commercial alloy in aged condition are also presented [2]. The process optimization permitted to obtain samples with the density of 99.9 % and well-controlled microstructure. In as-built SLM samples, the yield stress is about 20% lower than for the commercial aged alloy (833 MPa instead of 1050 MPa) and the ductility is about half of the commercial alloy (5.3% instead of about 10%). The maximum tensile strength is comparable to the commercial alloy (1310 MPa). The variation of mechanical properties according to build direction (X, Y and Z) were below 15%. The microstructure of as-built samples investigated by SEM and TEM (Figure 1) showed that the sample is nearly fully martensitic α' phase.

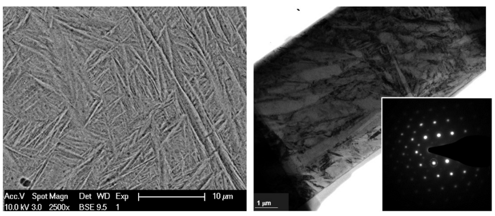

Figure 1: SEM and TEM micrographs of as-built SLM sample. The microstructure is fully martensitic α' phase.

Samples prepared using optimized SLM parameters were HIP treated (900°C and 2000 bar). The main objective of HIP treatment was to remove microporosity and enhance properties. HIP process (Table 1) improved $\sigma_{0.2}$, however, the ductility varied between 2 to 18% according to HIP cycle. Detailed analysis showed that in the case of low ductility HIP(a), the microhardness of samples was higher near sample surface compared to the bulk (Figure 2). Ductility of Ti6Al4V alloy is very sensitive to oxygen content as presence of oxygen during heat treatment forms a brittle alpha case layer at the surface [3]. Increase of the near-surface microhardness is consistent with the presence of a brittle alpha case that causes the significant drop in ductility for HIP(a) cycle. Thus, obtained results lead to the conclusion that the atmosphere in the chamber during HIP(a) cycle contained oxygen enough to influence the sample properties.

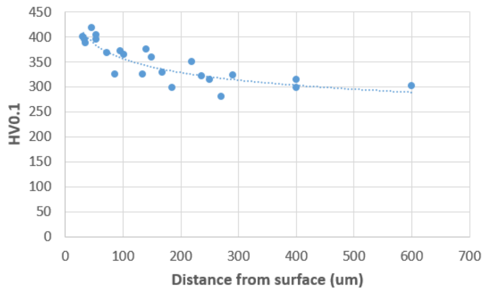

Figure 2: Microhardness variation in the HIP(a) treated sample along the cross-section. The variation is consistent with the presence of brittle alpha case layer rich in oxygen.

The microstrucure and XRD analysis showed that after HIP post-treatment two-phase α + β microstructure was achieved (Figure 3).

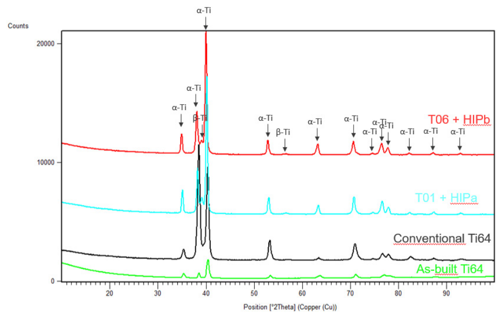

Figure 3: Microstructure and XRD diffractograms after HIP treatment. The main phases detected are α- and β-Ti.

The study established the full-chain process to achieve the mechanical properties of SLM Ti6Al4V manufactured samples comparable to the commercial material. To prevent poor ductility it is important to control oxygen content during HIP treatment. The current project gives full manufacture process for reliable SLM implementation into mass production for aerospace application.

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[1] S. Zabihzadeh, V. Pejchal, S. Biselli, *et al.*, CSEM Scientific and technical Report (2017) 42.

[2] Metals Handbook, Vol.2, ASM International 10th Ed. 1990.

[3] S. Birhan, Licential Thesis, Lulea University of technology, 2014.