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# HARDNESS AND ELASTIC MODULUS OF TI-6AL-4V AS-CAST AND FABRICATED BY LENS

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***Abstract.*** *This work investigated the elastic modulus and hardness of Ti-6Al-4V as-cast and produced by LENS. The microstructures were characterized by scanning electron microscopy and X-ray diffraction. The density of each alloy was measured by the Archimedes method. The hardness and the elastic modulus were assessed by Vickers hardness test and impulse excitation of vibration technique. Results show α microstructure for samples produced by LENS and α+β microstructure for as-cast alloy. The hardness and elastic modulus results were compared and presented very similar values.*

***Keywords:*** *Ti-6Al-4V, LENS, Microstructure, Hardness, Elastic modulus*

## 1. INTRODUCTION

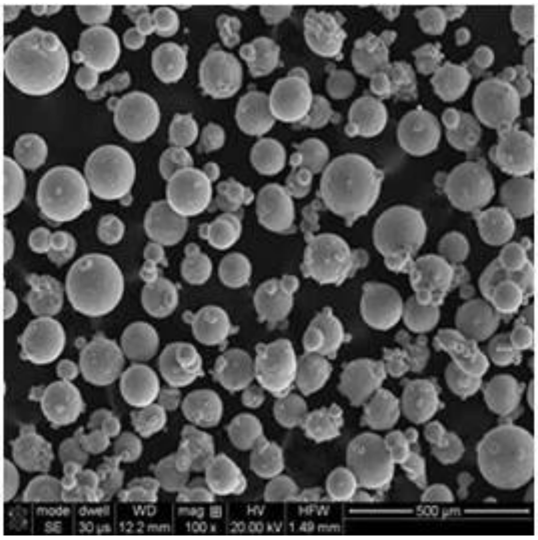
Titanium alloys have emerged as high-performance metal widely used in aerospace, automotive, and medical applications throughout the world, due to the metal´s unique combination of superior mechanical, corrosion resistance and physical properties. However, their use is strongly limited to the higher cost relative to other metallic options. Any method that can produce more effective titanium parts is desirable. Additive Manufacturing (AM) represents a family of advanced near-net-shaping techniques able to build 3D geometries directly from computer models, built up by progressive consolidation of raw material, such as powder, in a layer-by-layer fashion. With this additive approach, parts of greater complexity can be economically produced (Wu, *et al*., 2016; Griffith, *et al.*, 2000).

Laser Engineered Net Shaping (LENS) is a promising technique that produces multifunctional materials or functionally graded materials through layered depositions by altering the materials composition and optimizing the processing parameters. Despite all the advantages that the LENS technique offers over traditional process, the primary requirement for any structural application will be to ensure that mechanical properties are acceptable and reliable (Keicher, *et al.*, 1997). Thus, the aim of this work was to investigate the mechanical properties of a LENS produced hardness and elastic modulus of Ti-6Al-4V and compare to a commercial alloy.

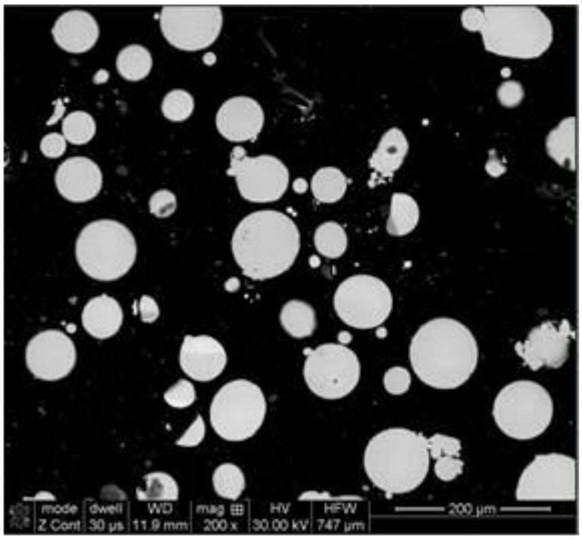
## 2. EXPERIMENTAL PROCEDURE

### 2.1 Materials and manufacturing

Rectangular bar samples were produced by Laser Engineered Net Shaping (LENS) on a MR7 system (Optomec Inc.). The Ti-6Al-4V powder used to produce the samples was obtained from TSL-Technik (Germany). The powder was produced using plasma atomization method and exhibited a spherical particle shape with a size of 45-150 µm and chemical homogeneity and chemical homogeneity (Figure 1).




(a)




(b)

**Figure 1:** Morphology of the initial plasma atomized Ti-6Al-4V (at.%) powder: (a) SEM SE image showing spherical particles; (b) SEM BSE image of the corss-section of the particles that reveals their chemical homogeneity.

The morphology and particle size of the initial powders was analyzed by scanning electron microscopy (SEM) Philips XL 30. The LENS processing parameters were as follows: 250W laser power and 10 mm/s scanning speed. The entire deposition process was performed in a chamber under a continuously purified argon atmosphere. The handling of all of the powders with the powder feeders was conducted in a Labmaster Glovebox Workstation (Mbraun) under a continuously purified argon atmosphere. The amount of oxygen and water was less than 0.1 ppm. The dimensions for rectangular bar samples are presented in table 1.

Table 1. Dimensions for rectangular bar sample.

| Geometry | $m$(g) | $L$(mm) | $t$(mm) | $b$(mm) |
|---|---|---|---|---|
| Rectangular | 12.27 | 55 | 5 | 10 |

### 2.2 Microstructural analysis

Microstructural analyses were investigated by scanning electron microscopy (Tescan Vega 3). Samples were grounded and polished by standard metallographic techniques and etched with Kroll´s reagent. The structural characterization of the alloys was carried out by X-ray diffraction using a Shimadzu XRD-7000 operated at 40kV and 30mA with Ni-filtered $CuK_\alpha$ radiation ($\lambda$ = 1,5418 Å). The phases were identified through the comparison between the obtained data and the JCPD data base.

### 2.3 Microhardness and elastic modulus measurements

The Impulse Excitation test were performed at room temperature and for each test were recorded at least 3 measurements to average out random errors. The measurements were obtained using a computer, signal analyzer, hammer, simple supports (wire suspension), accelerometer for cylindrical bar and a microphone for rectangular bar as well as the samples. In order to obtain the measures for each sample, first the supports were placed at the first mode nodal points of the sample which correspond to 0,224L from each and, then the response was measured by an accelerometer placed close to a nodal point, to generate a clear vibration on signal and minimal interference possible. Ultimately an impact hammer was used to apply a point force excitation at the sample center line. After the mechanical vibration was detected by the signal analyzer and sent to the computer. The following equations were used to calculate Young´s modulus for the flexure frequencies of a rectangular bar sample (ASTM E 1876-01):

$$E = 0.9465\left(\frac{mf_f^{\,2}}{b}\right)\left(\frac{\mathrm{L}^3}{\mathrm{t}^3}\right)\mathrm{T}_1 \tag{1}$$

$$T_1 = 1 + 6.585\left(1 + 0.0752\,\mu + 0.8109\,\mu^2\right)\left(\frac{t}{L}\right)^2 - 0.868\left(\frac{t}{L}\right)^4 - \left[\frac{8.340\left(1 + 0.2023\,\mu + 2.173\,\mu^2\right)\left(\frac{t}{L}\right)^4}{1.000 + 6.338\left(1 + 0.1408\,\mu + 1.536\,\mu^2\right)\left(\frac{t}{L}\right)^2}\right] \tag{2}$$

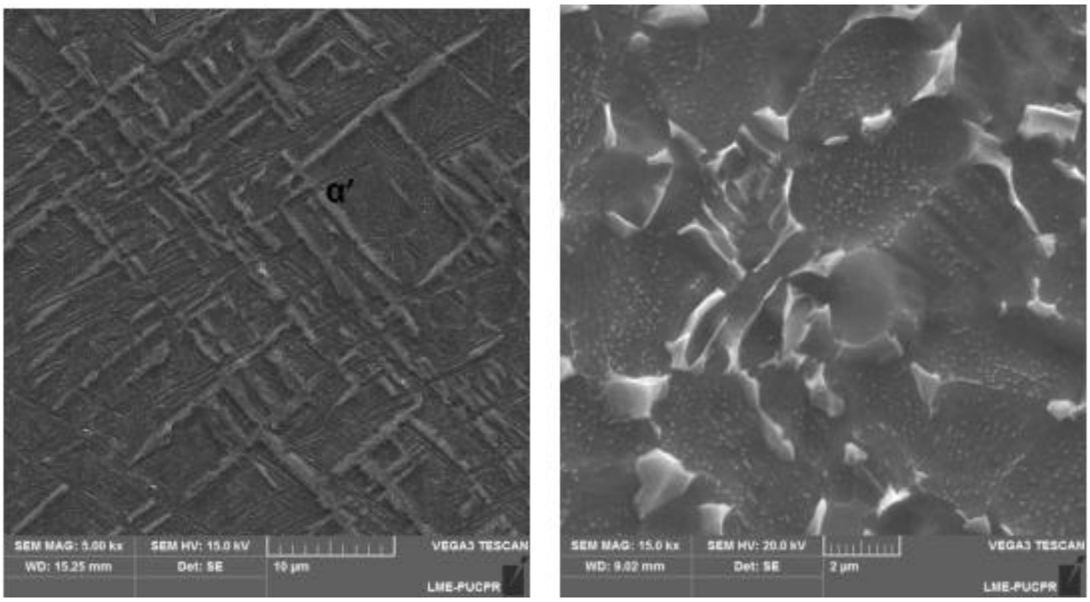
Where:
E = Young's modulus (Pa), m = mass of the bar (g), b = width of the bar, (mm) L = length of the bar, (mm), t= thickness of the bar, (mm), $f_f$ = fundamental resonant frequency of bar in flexure, (Hz), and $T_1$ = correction factor for fundamental flexural mode to account for finite thickness of bar, Poisson's ratio, and so forth.

The density of each alloy was measured by the Archimedes method. The Vickers hardness was measured using the Shimadzu HMV-2T with load of 1.961N for 15 s. The elastic modulus was obtained using impulsive excitation test in accordance with

## 3. RESULTS

### 3.1 Phase analysis

Figure 2 shows the morphology of the samples used in this study. The sample of Ti-6Al-4V produced by LENS (Figure 2a) shows an acicular phase corresponds to the α′phase. In addition, the microstructure of the sample as-cast is characterized by structure of alpha and beta phases with the beta phase dispersed in the matrix of the alpha phase Figure 2b.




(a) (b)

**Figure 2.** The SEM micrograph showing the morphology of Ti-6Al-4V produced by (a) LENS and (b) as-cast.

X-ray diffraction was used to confirm the crystal structure of the samples. Figure 3 shows the XRD diffractograms of the Ti-6Al-4V produced by LENS and as-cast. Notice in Figure 3a the presence of *α/α'* phase (HC), which can be attributed the martensitic phase and Figure 3b the presence of *α* and *β* phase.

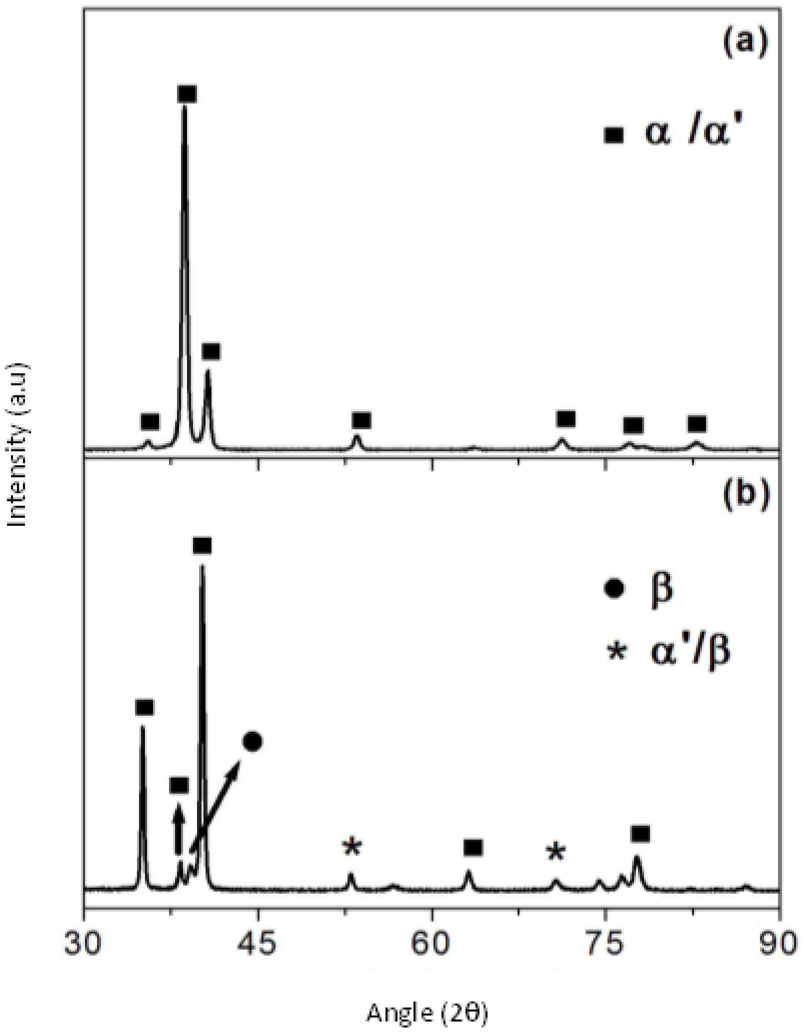



**Figure 3.** Diffraction patterns for alloy Ti-6Al-4V produced by (a) LENS and (b) as-cast.

### 3.2 Mechanical properties

Vickers hardness value obtained from LENS samples (352±24,94 HV) is higher than obtained to as-cast samples (327±17,84 HV), which is associated with the amount of α/α' phase present in the LENS samples.

Young´s modulus values obtained for Ti-6Al-4V are 113,5±2,9 GPa (LENS) and 102,3±5,1 GPa (as-cast). E was calculated using 0.342 as Poisson coefficient ($\mu$) value. These results are in agreement with the standard values obtained for this alloy. The differences between the values are associated with the microstructure differences ($\alpha$ LENS) and ($\alpha+\beta$ as-cast) as well as differences in processing. The densities of Ti-6Al-4V produced by LENS (4,37g/cm$^3$) and as-cast (4,38g/cm$^3$) were in good agreement with published values. In addition, the results also show the good impulsive excitation technique performance. It is already well known that the dynamic modulus is generally more accurate than the corresponded static modulus measured through mechanical testing.

## 4. CONCLUSIONS

The as-cast Ti-6Al-4V alloy presented a ($\alpha+\beta$) microstructure, whereas the Ti-6Al-4V produced by LENS shows a single-phase α microstructure. The density value obtained for Ti-6Al-4V produced by LENS is practically the same obtained for as-cast Ti-6Al-4V alloy which means that the parameters chosen parameters and the LENS process were highly effective. The Young´s modulus results were very satisfatory equivalent to comercially Ti-6Al-4V alloy (116 GPa). Hardness values as-cast (327 HV) and LENS (353 HV) are also associated with the diffences between the microstructures.

## 5. ACKNOWLEDGEMENTS

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## 6. REFERENCES

ASTM E 1876-01 Standard Test Method for Dynamic Young's Modulus, Shear Modulus, and Possion's Ratio by Impulse Excitation of Vibration.ABCM, 2004. "Journal of the Brazilian Society of Engineering and Mechanical Sciences".

Griffith, M. T., 2000. *Understanding the microstructure and properties of components fabricated by laser engineered net shaping (LENS), in: MRS proceedings, Vol. 625, Cambridge Univ Press, 2000, p. 9.*

Keicher, D.M., 1997. Lee, Y.B., 2003. *Using the laser engineered net shaping (lens) process to produce complex components from a cad solid model, in: Photonics West'97, International Society for Optics and Photonics, 1997, pp. 91–97.*

Wu, G., 2016. *Effect of the interaction layer on the mechanical properties of ti–6al–4v alloy castings, Materials Chemistry and Physics 175 (2016) 125–130.*

## 7. RESPONSIBILITY NOTICE

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