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ASSESSMENT OF MECHANICAL PROPERTIES OF TITANIUM SAMPLES, MANUFACTURED WITH THE USE OF ADDITIVE TECHNOLOGIES

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Abstract: *This work determines the endurance of titanium alloy samples Ti-6Al-4V, made by the incremental technique using LENS technology, and evaluated how the direction of specimen placement on the 3D printer work platform affects these properties. A static tensile test was carried out with simultaneous application of a digital image correlation system. The tests performer showed the effect of the direction of specimens alignment during printing process on the maximum stress at break. Printing direction had no significant effect on parameters such as maximum force at break, Young's module, strain and Poisson's ratios.*

Keywords: Titanium, 3D printing, Young's modulus, LENS.

1. Introduction

With the use of various chemical compositions, metal alloys are characterized by a wide range of properties and have found wide application. Titanium alloys are characterized by low density, good corrosion resistance and biocompatibility. It is due to these features that interest among producers from various industries is growing, resulting in a constant desire to improve this material and adapt it to the needs of the consumer. The dynamically developing medical industry has also drawn attention to the advantages of titanium, in particular its biocompatibility, good corrosion resistance in the tissue environment and much lower density compared to iron. To influence the properties of titanium alloy, attempts are made to modify its chemical composition and processing parameters. In the era of technological development, incremental techniques involving the layered creation of a three-dimensional object based on its geometric notation in CAD software are becoming increasingly important. One of the 3D printing methods is the LENS method (laser engineered net shaping), which involves local application of material in the form of spherical metal, ceramic or metal-ceramic powders and sintering it with a high-power laser (Oosthuizen, 2011; Arthur, 2018). The input in the form of spherical powders with a gradation of 44 to 150 μm should be characterized by high purity, chemical uniformity, and no defects. This met can be used both to produce new models and to supplement existing ones (Mellor, 2015; Razavi, 2018). The work, which aims to assess the mechanical properties of titanium samples made of the Ti-6Al-4V alloy by using LENS technology, will present

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the results obtained during a static tensile test with the simultaneous use of a digital image correlation system.

2. Methods

The assessment of mechanical properties was carried out using the MTS Insight 2 static testing machine and micro-correlation by Dantec Dynamic. The MTS Insight 2 static testing machine used enables static tensile, compressive and bending tests to be performed with computer registration of force and elongation measurements. The DIC digital micro-correlation system used by Dantec Dynamic is a technique for measuring displacements and strains in real time, based on the analysis of high-resolution images performed while loading the test element. Images with an appropriate speckle structure (the technique requires imposing a structure on the tested surface) are archived during loads and then analyzed by specialized Istra 4D software. The results are presented in the form of colorful maps of displacements and deformations, which makes it possible to verify the formulated numerical models. The measurement system is fully compatible with MTS testing machines by synchronizing measurement points between the machine and the correlation system. This connection ensures full control over research, acquisition and processing of the obtained measurement data. During measurements, not only static images are obtained, but it is also possible to visualize the deformation process in the form of animations. In addition to measuring the values of the tested parameters, this gives the opportunity to analyze the deformation process itself, including observing the processes of cracking, crack propagation and destruction on a micro scale. The research material consisted of 12 paddle-shaped samples with dimensions of 65×10×2 mm, made using the LENS method from powdered titanium alloy Ti-6Al-4V. The samples were printed in two different orientations on the build plate: horizontally (X samples) and vertically (Y samples). All samples were annealed in an oven at 920 °C for 4 hours to eliminate internal stresses. Then they were rinsed twice in an ultrasonic bath for 60 minutes using waves with a frequency of 37 kHz and dried for 60 minutes. Finally, each surface was mechanically ground and polished. Then, a special speckled structure was applied to each sample using aerosol paints (white, black) in order to identify deformations by the digital image correlation system (Fig. 1).

a)

b)

Fig. 1: Example of a test sample: a) before painting, b) after painting.

Before starting the research, the digital image correlation system was calibrated using a specialized calibration plate provided by the system manufacturer. Each sample was subjected to a static tensile test at a speed of 5 [mm/min] at room temperature (Fig. 2, Fig. 3). In order to calculate the Poisson number, the value of longitudinal and transverse strains in the range of elastic strains was recorded for the tested samples.

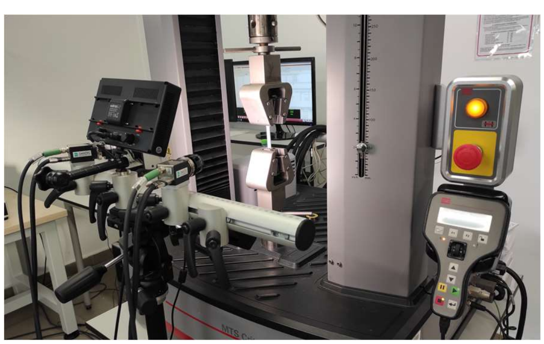

Fig. 2: Test stand.

Fig. 3: Sample after the test.

3. Results

The values obtained during the tests, such as the maximum force and stress at break, were read from the testing machine, and the strain and Young's modulus were read from the digital image correlation system (Fig. 4). The results are presented in Tabs. 1 and 2. Fig. 5 shows the stress-strain curves for the tested samples.

Sample number	**Peak Load [kN]**	**Ultimate tensile stress [MPa]**	**Young's modulus [GPa]**	**Strain at Break [%]**
x1	18.9	946.9	-	15.8
x2	19	950.4	116.6	15.6
x3	18.9	945.3	114.3	14.6
x4	18,9	943.5	114	16.6
x5	19	948.6	113.9	17.6
x6	18.1	903.5	117.3	15.5
Average	18.8 ± 0.3	939.7 ± 17.9	115.2 ± 1.6	16 ± 1

Tab. 1: Test results for samples X.

Sample number	**Peak Load [kN]**	**Ultimate tensile stress [MPa]**	**Young's modulus [GPa]**	**Strain at Break [%]**
y1	18.5	925.7	113.8	14.1
y2	18.6	928.8	113.2	15.8
y3	18.6	931.3	114.3	17.5
y4	18.6	928.1	113.8	18.1
y5	18.6	932.1	117.6	15,8
y6	18.4	919.2	119.9	17.1
Average	18.6 ± 0.1	927.5 ± 4.7	115.4 ± 2.7	16.4 ± 1.5

Tab. 2: Test results for samples Y.

a)

b)

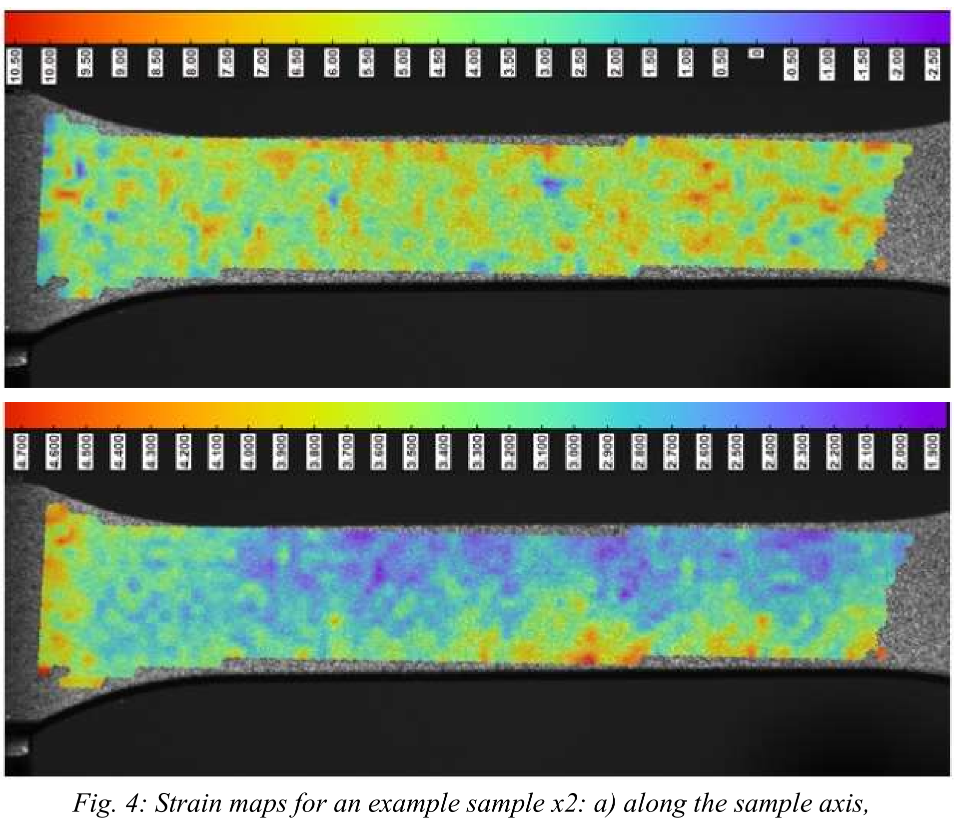

Fig. 4: Strain maps for an example sample x2: a) along the sample axis, b) perpendicular to the sample axis.

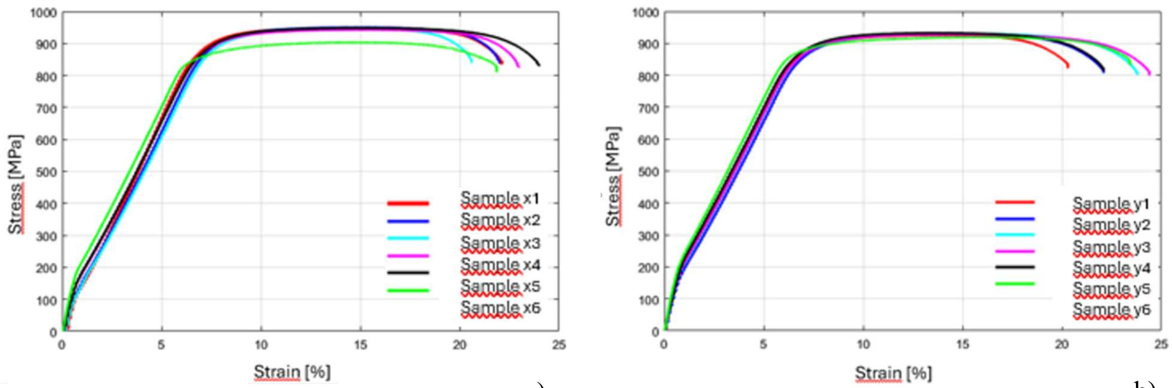

Fig. 5: Stress-strain curve of samples: a) samples X, b) samples Y.

Analyzing the influence of printing direction on the average values of maximum ultimate tensile stress, higher values were observed in the case of horizontal orientation of the print - 939.7 [MPa] compared to vertical arrangement - 927.5 [MPa]. The average maximum peak load was higher for horizontal samples compared to vertical ones and amounted to 18.8 and 18.6 [kN], respectively. However, the average values of Young's moduli and strain at break were higher for the vertical direction than for the horizontal direction and were 115.4 and 115.2 [MPa] and 16.4 [%] and 16 [%], respectively. Fig. 4 shows example strain maps obtained from the digital image correlation system for a plane parallel to the direction of sample stretching and for a perpendicular plane. The strain values read for two mutually perpendicular directions were then used to calculate the Poisson number. The average value of Poisson's number for samples X was 0.3 and for samples Y it was 0.4.

4. Conclusions

The tests carried out showed the influence of the printing direction on the maximum value of stress at break. A greater result was observed in the horizontal than in the vertical position. However, the printing direction did not have a significant impact on parameters such as maximum force at break, Young's modulus, strain and Poisson's ratios.

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