Direct metal laser deposition of titanium powder Ti-6Al-4V

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Abstract. The paper presents the results of mechanical properties study of the material produced by direct metal laser deposition of VT6 titanium powder. The properties were determined by the results of stretching at tensile testing machine, as well as compared with the properties of the same rolled material. These results show that obtained samples have properties on the level or even higher than that ones of the samples obtained from the rolled material in a certain range of technological regimes.

1. Introduction
Titanium alloys have already well approved themselves in chemical, marine, aerospace industries. They are very strong, able to withstand heavy loads and have reduced mass. In addition, titanium alloys are used for manufacturing implants and prostheses. Tissues around such implants are not subjects to change. They are resistant to corrosion in aggressive environment of the human body, and oxide coating on their surface prevents the escape of the implant ions into the body. However, the manufacture of titanium parts and implants is strictly individual task, as it is a material, which is difficult to process. This fact significantly increases the cost of a product. There is a significant interest in using different additive technology for manufacturing titanium parts in recent times. It is necessary to provide wide complex of researches and tests. Titanium alloys are used in the following additive technology: melting layer by layer powder by electron beam (EBM) [1, 2] or laser (SLM, SLS methods) [3, 4], feeding melted powder or wire by plasma arc [5, 6] or laser (DMLD) [7, 8]. We suggest using laser metal deposition technology for manufacturing of titanium parts. This technology involves melting of metallic powder feeding through the nozzle coaxially with the radiation. When the nozzle moves along the surface, new metal layer will be formed after solidification. Thus, it is possible to produce parts of the desired shape. The research presents the results of the mechanical properties study of the samples obtained by laser metal deposition technology by different technological modes.

2. Materials and equipment
Experimental equipment is shown in figure 1. Cladding processing cell (1) is equipped with a control unit (2). Cell (1) consisting of 5-axis positioning system, optical head with water cooling and supply of protective gas and powder from the feeder (3) Sulzer Metco Twin 10 - C, as also industrial digital camera for positioning parts and monitoring the process. We use fiber laser (4) LS-3.5 power up to 3.5 kW.

The metal powder is fed into the treatment zone via a coaxial nozzle, under the impact of laser radiation it is heating and melting. Simultaneously, the previous layer is melting. The track is
produced during the motion of the nozzle relative to the substrate after cooling. New layers are formed by sequential application of tracks with some overlapping.

![Experimental equipment.](image)

**Figure 1.** Experimental equipment.

Tensile tests were performed on the machine INSTRON 5966, which has the following operational characteristics: allowable load is 10 kN, maximum speed is 1500 mm/min, minimum speed is 0.001 mm/min.

We used a titanium powder VT6, produced by "Normin". VT6 alloy powder consists of spherical particles with size distribution 40-110 microns, the chemical composition of which is shown in the table 1.

|          | Fe  | Al  | V   | O   | N   | C   | Ti       | Balance |
|----------|-----|-----|-----|-----|-----|-----|----------|---------|
| Content  | 0.11| 6.1 | 3.9 | 0.08| 0.01| 0.03| Balance  |         |

**Table 1.** The chemical composition of VT6 powder.

![VT6 powder.](image)

**Figure 2.** VT6 powder.

3. **Results of experiments**

Samples in the form of two-side blades of 316L stainless steel powder have been received and investigated in our previous works [9, 10]. Then the optimal strategy for the creation of such samples was selected. It has been shown that repeated melting of layers does not improve the mechanical properties. The optimal strategy for the creation of samples was the following. Two directions were chosen for double-sided cladding blades: parallel to the direction of tension (figure 3) and perpendicular (figure 4). If cladding direction is parallel, then contour of the blade 1 would be deposited first, and then it would be inner part, consisting of several regions, numbered 2-5.
Perpendicular application consists in drawing the contour, and then filling it with consistent cladding tracks. Also, alternating start peaks cladding were performed to improve thickness uniformity of the sample. After the deposition of two layers with different application areas rolls starting at point A, the nozzle moves to point B, where the cladding is also made of two layers. The operation was repeated further starting at point C and D.

![Figure 3. Scheme of cladding of rollers in a longitudinal direction.](image)

The following process parameters were varied during operation in this process: laser power, scanning speed, powder feed rate. A scope of mechanical tensile tests were carried out for each technological regime at room temperature in accordance with GOST 1497-84. This standard specifies methods of static tensile tests of ferrous and non-ferrous metals and their products (samples) to determine at 20 °C the limit of strength $\sigma_{ts}$, yield strength $\sigma_{0.2}$ and others. Also, the samples of titanium rolled material were tested. The stress-strain diagrams were obtained during the test (figure 5) for each samples.

Yield strength $\sigma_{0.2}$ and tensile strength $\sigma_{ts}$ were determined according to the obtained stress-strain diagrams (figure 5) for the produced and rolled samples, and their dependences (figure 6-11) were built on the technological parameters of process: laser power, surface scanning speed, powder feed rate.

![Figure 5. Summarized stress-strain diagram for the produced and rolled samples.](image)
Figure 6. Dependence of yield strength \( \sigma_{0.2} \) on the laser power.

Figure 7. Dependence of tensile strength \( \sigma_{ts} \) on the laser power.

Figure 8. Dependence of yield strength \( \sigma_{0.2} \) on scanning speed.

Figure 9. Dependence of tensile strength \( \sigma_{ts} \) on scanning speed.

Figure 10. Dependence of yield strength \( \sigma_{0.2} \) on powder feed rate.

Figure 11. Dependence of tensile strength \( \sigma_{ts} \) on powder feed rate.

The curve slope of the stress-strain is almost identical in the elastic region, it means equality of Young's modulus of created and cast materials. Yield strength \( \sigma_{0.2} \) of created by laser metal deposition materials exceeds a similar value for the cast material by 10-25%. It leads to the fact that under equal stresses in structures made from cast material and the created by laser metal deposition material yield point (the occurrence of irreversible plastic deformation) occurs in the created material much later. The tensile strength \( \sigma_{ts} \) of created by laser metal deposition materials exceeds the similar value of cast material by 20-30%. Therefore, the construction made from created by laser metal deposition materials is capable to withstand large external load with the same size of construction of the cast material, or it will allow making a smaller construction of the created material than from the cast.
material under equal external loads. The average value of the maximum relative deformation of the created by laser metal deposition material is ~ 7%, a similar value for the cast material is about 10%. In this regard, the plastic deformation of the structure, made of created by laser metal deposition materials is less than the cast material. Thus created by laser metal deposition materials are most suitable for manufacturing of structures working in cramped conditions displacements. Change in the laser power has a greater influence on the mechanical properties of created by laser metal deposition materials than the change in the scanning speed of the surface or the powder feed rate. Increase in power led to a significant growth of yield strength $\sigma_{0.2}$ and tensile strength $\sigma_{ts}$, which allowed to make properties of the created materials better than of cast ones.

4. Conclusion
The samples in paper were created by direct metal laser deposition under various technological regimes and the study of their mechanical properties was performed. The results showed that the greatest influence on the mechanical properties of the samples, produced by direct metal laser deposition, has a change of laser power. It also shows that the produced samples were not inferior to the characteristics of the rolled samples. Thus, the Young's modulus of the rolled material and produced ones coincide, yield strength and tensile strength materials have grown up and produced materials deform less under tension than the samples of the rolling material.

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