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INFLUENCE OF BLOWING AND LOADING OF WORKING SPACE ON MECHANICAL PROPERTIES OF SAMPLES MANUFACTURED USING SLM TECHNOLOGY

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ABSTRACT

At present, for selective laser melting (SLM, Selective Laser Melting), studying the influence of characteristics of blowing and a loading of the working space on mechanical properties of titanium Ti6Al4V alloy is an urgent task. In the work, tensile samples were studied, for which as a result of a different loading of the building space, there was a pause of different duration between the deposition of powder and return of the laser beam. Based on the analysis of the values of mechanical properties, it was found that characteristics of strength of test samples in the area of the inlet nozzle of inert gas blowing have a value by 3–5 % lower compared to the central area of the platform with a range of values of ± 2 %, in the area of the outlet nozzle, the value is lower by 3–5 % compared to the central area, a range of values is ± 10 %. It was found that an increase in the pause from 50 to 65 s leads to a decrease in strength and ductility characteristics by 23 and 10 %, up to 80 s by 33 and 0.7 %, respectively.

KEYWORDS: selective laser melting, blowing, loading of the working space, Ti6Al4V alloy, mechanical properties

INTRODUCTION

Selective laser melting (SLM) technology consists in building a solid object by multicycle surfacing of thin layers of material on previously produced layers. In such processes, the material is subjected to complete melting to provide its joining with the previous layer and the subsequent reusable heating to high temperatures [1, 2]. SLM technology is a relatively new type of metal treatment that allows implementing an accurate fabrication of complex-shape structures [3, 4].

It should be noted that a large number of research is devoted to the issues of selective laser melting and electron beam fusion of powder layer [5–7]. It should be also taken into account, that each piece of equipment has its own technological aspects, one of which is the environment and the processes occurring during printing. For example, the process of fusion by electron beam gun irradiation is carried out in a vacuum environment, and in selective laser melting, in most cases argon (Ar) or nitrogen (N_2), in other — helium (He) is used [8]. If we consider this issue in more detail, it can be said that in the process of fusion as a result of electron beam gun irradiation, in a vacuum environment, the intensity of cooling the melt pool is lower due to the fact that it is affected only by the temperature gradient and crystallization rate [9]. When using an inert medium, to shield the powder layer with laminar gas flows, in the process of selective laser melting, the rate of cooling the melt pool and adjacent layers is additionally affected by gas due to its corresponding physical properties, velocity and flow direction [10]. Thus, the use of rational parameters of velocity control and distribution of gas flow is an additional method of influencing the mechanical properties of a product.

At present, the issues of velocity and flow direction on mechanical properties and density are paid great attention [11–13]. The interest to this issue is caused by such a common phenomenon in the field of printing as the powder ejection into the area of the outlet [14, 15] due to evaporation, picking up and transferring of particles (Figure 1), which as a result can get into the zone of laser beam effect, melt into and affect the density of a finished product. Changes in the inlet flow (nozzle design) lead to changes in the flow in the printing area and in the cooling rate of the melt pool, which also play a role in influencing the quality of a finished product (Figure 2). It should be noted that fabricating parts by this method is in most cases a single or small batch production, which can also have a significant impact on the repeatability of the results. This is associated with the constant change in the cross-section of parts, their quantity and laser beam intensity.

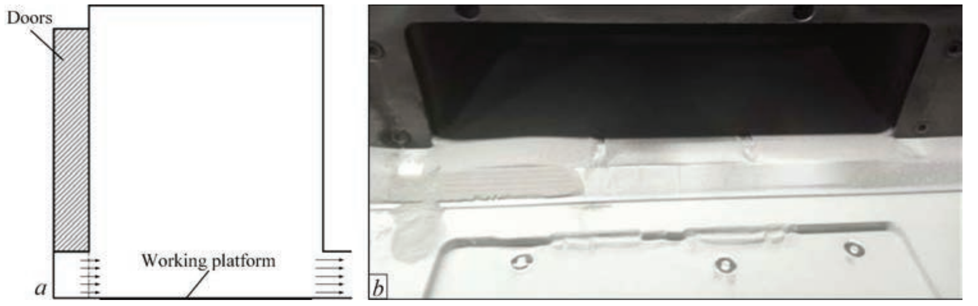

Figure 1. Scheme of outlet and inlet hole location (*a*), ejection of powder particles of Ti6Al4V alloy near the area of inlet hole (*b*)

As a result of the research carried out by the authors of [11], the effect of the inert gas flow on powder particles ejected and returned to the surface of the powder layer during the printing process, which is a general phenomenon in SLM technology, was analyzed. As a result of the study, it was established that the density of parts manufactured by SLM technology was influenced by the morphology of transferred particles. The more important fact is that samples printed by SLM process are not uniform in density due to the effect of gas flow.

In [12] it was established that the uniformity of the gas flow in the SLM process has a significant effect on the density and tensile strength of printed parts. The authors established a rational argon flow velocity in the range of 1.3–2.0 m/s for printing.

Since the authors of [13] did not consider the issue of density and mechanical properties of test samples in real printing conditions (with printing of parts of different cross-section and quantity), the study of witness-samples manufactured in the same printing process together with products is definitely relevant.

It follows from the abovementioned, that the issue of the influence of cooling rate, gas flow circulation and loading of the working space on the density of test samples and mechanical properties is insufficiently studied and is of fundamental and practical importance.

The aim of the work is to study the influence of the working space loading (pause duration between layers formation), velocity and features of the flow circulation on mechanical properties under the conditions of operation of Alfa-150D machine.

MATERIAL AND RESEARCH PROCEDURE

The work examined tensile test samples fabricated in a 3D printing machine Alfa-150D produced by ALT Ukraina LLC [5] from metal powder of titanium Ti–6Al–4V alloy with the following chemical composition, wt.%: A1 – 6.21; V – 4.03; Fe – 0.04; C – 0.1; O – 0.7; N – 0.02; Ti is the base [16], the granulometric analysis is presented in Figure 3.

Alfa-150D 3D printing machine produced by ALT Ukraina LLC with a printing area of 150×150 mm is equipped with an inlet and outlet nozzle for maximum collection of inert gas entering through the inlet nozzle without dispersing it throughout the working chamber. In order to provide inert gas collection and at the same time not to blow powder, the velocity of the flow over the working platform in the printing area was taken to be 1.5 m/s. The working gas is argon with a constant density and temperature. Between the main and auxiliary inlet nozzles, the flow is distributed in such a way that 70 % of the total argon flow rate is on the main nozzle, and 30 % on the auxiliary one. The introduction of the auxiliary inlet nozzle in the upper part of the working chamber led to the fact that dispersion of the flow during its movement from the main inlet nozzle to the outlet is reduced. In this case, the flow has a laminar flowing mode.

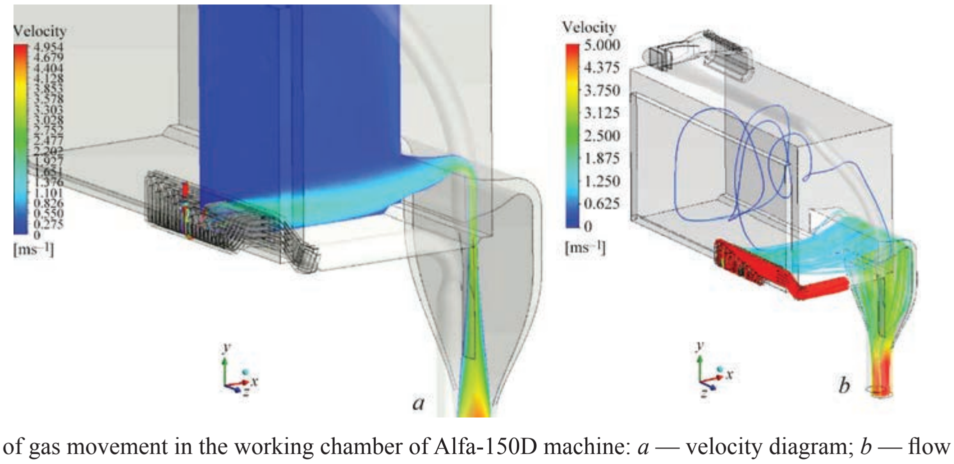

Figure 2. Display of gas movement in the working chamber of Alfa-150D machine: *a* — velocity diagram; *b* — flow lines

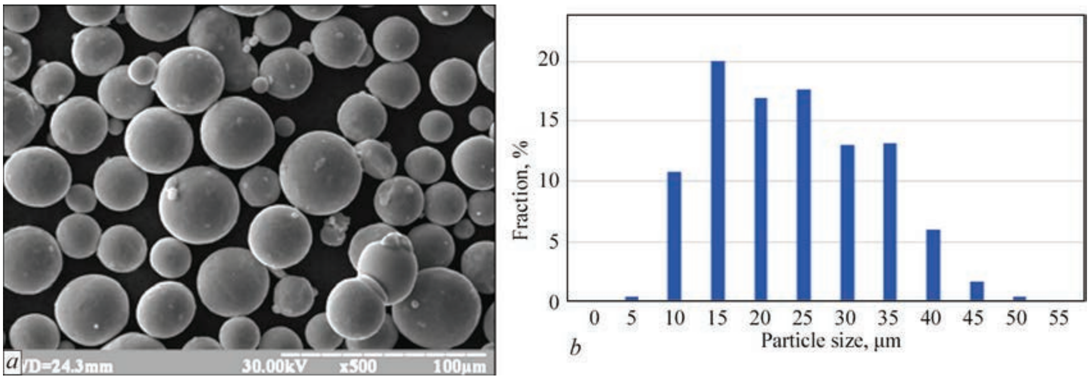

Figure 3. Particles of Ti–6Al–4V initial material at a magnification of 500 (*a*) and results of granulometric analysis (*b*) [16]

The test cylindrical samples for tensile testing with a working zone diameter of 3 mm and a working zone length of 20 mm were produced in the vertical direction (Figure 4). Rational printing parameters were set in [16] with a deposited layer thickness of 40 µm: distance between tracks is 0.03 mm, power is 195 W, beam velocity is 1050 mm/s. Mechanical treatment of samples to finish dimensions was carried out with the use of the HAAS ST10 lathe. The mechanical properties were determined during the tensile test according to the standard procedure in the INSTRON machine.

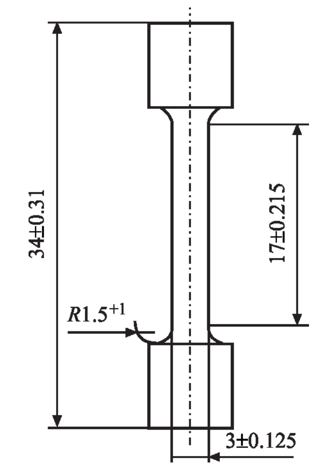

Figure 4. Scheme of location of the place of a controlled stop of printing the test sample

RESEARCH RESULTS

Test samples were made with a full-body part in order to simulate the printing process during operation of the Alfa-150D machine. Depending on the area of a full-body part, there was a pause of different duration between the powder deposition and return of the laser beam, namely: platform 1 — 65 s, platform 2 — 50 s, platform 3 — 80 s, platform 4 — 20 s. On the basis of this simulation, diagrams of the distribution of the printing time of the layer of the working area of the samples were obtained (Figure 5).

From the analysis of the process of samples manufacturing in the working area of the samples (curves along the *Y* axis — 10–20 s, along the *X* axis — layer number 670–787, platforms 3, 4), it was established that with the variable cross-section of parts, the time for the laser to return to the stage of melting the working zone of the samples is reduced by 33 %. It should be noted that during the process of manufacturing parts on the platform 3, printing of the part was completed, and on the platform 4, printing continued without changing the cross-section. From the analysis of the time-layer number dependence, it was established that the completion of printing the main body does not play a role in reducing the time for the laser beam return. Thus, it was established that in the process of

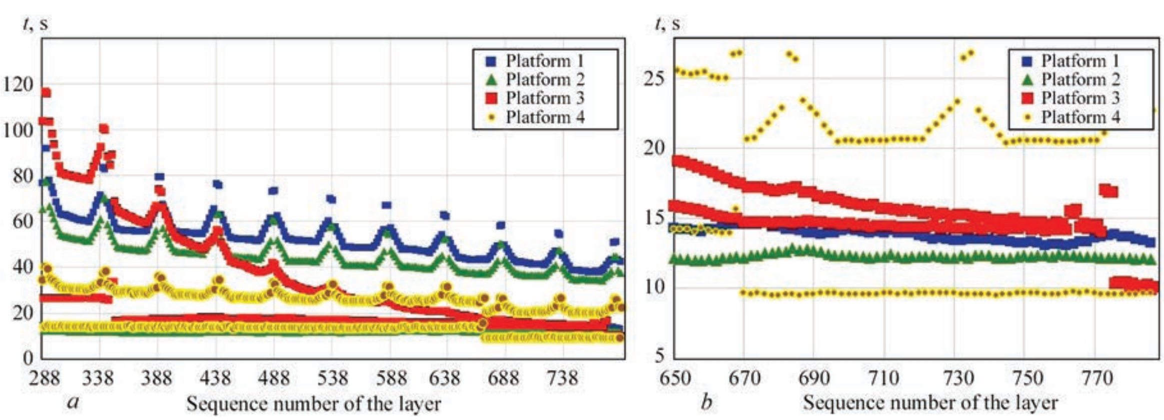

Figure 5. Distribution of time for printing powder layer in the area of the working zone of a tensile sample: *a* — working zone of a test sample from 288 to 787 layer; *b* — working zone of a test sample from 650 to 787 layer; 1 — platform 1; 2 — platform 2; 3 — platform 3; 4 — platform 4

Table 1. Mechanical properties of test samples

Marking	Platform number	Pause duration, s	σ_t, MPa	$\sigma_{0.2}$, MPa	δ, %	ψ, %
1	1	65	1209.7	1093.1	3.3	12.8
2			1168.9	1027.7	3.1	17.6
3			1061.6	997.2	2.0	9.0
4	2	50	1316.1	1178.7	7.0	34.2
5			1313.3	1209.7	7	26.0
6			1305.5	1242.3	9.9	22.3
7	3	80	1237.6	1155.9	4.2	25.0
8			1319.1	1278.8	9.0	28.3
9			1287.5	1201.6	3.2	23.0
10			1316.3	1223.6	5.1	33.9
11			1247.4	1173.0	4.5	28.2
12			1273.3	1188.3	2.1	28.1
13			1342.7	1272.6	7.5	27.3
14	4	20	1380.1	1287.3	2.5	24.3
15			1347.9	1255.7	4.2	23.7
16			1298.9	1178.7	3.6	30.4
17			1345.3	1217.8	4.7	24.3

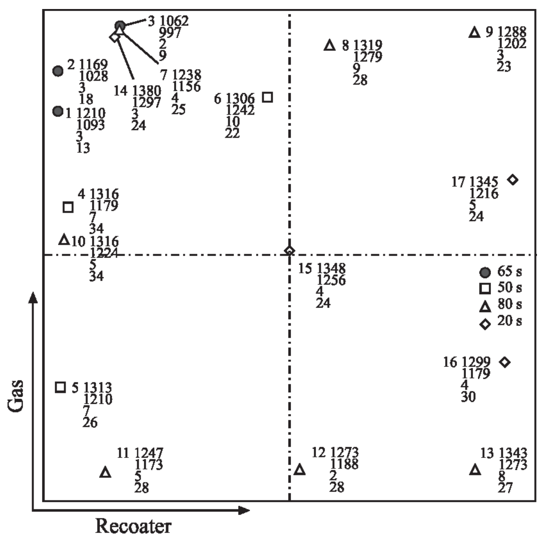

Figure 6. Scheme of samples location on the platform during fabrication: ♦ — 65 s; ● — 50 s; Δ — 80 s; ◊ — 20 s

melting test witness samples, the variable cross-section of a part has a significant influence.

From the results of the analysis of the time-layer number dependence, it was established that the test witness samples of the platforms 1 and 2, depending on the cross-section of a part, are affected by the time of the laser beam return. The printing area of the working zone of the witness sample has a linear nature, and depending on reduction in a part cross-section (platform 2), the change in the time of return is reduced by 18 % for witness samples compared to the platform 1.

Figure 6 shows the location diagram, and the Table 1 shows the values of mechanical properties of the test samples. It should be noted that the samples Nos 3, 7, and 14 were made in the same area of the working platform and differ only in the time of layer deposition and scanning, namely 65, 50 and 20 s, respectively. From the results of research, it was found that with an increase in the time between the deposited layer and the scanning time from 50 s, the strength and ductility characteristics decrease by 23 and 10 %, 33 and 0.7 %, respectively.

As a result of the analysis of the values of mechanical properties, it was established that the strength characteristics of test samples in the area of the inlet nozzle of inert gas blowing have a value by 3–5 % lower compared to the central area of the platform with a range of values of ± 2 %, in the area of the outlet nozzle the value is by 3–5 % lower compared to the central area and have a range of values of ± 10 %. This indicates the influence of the blowing system and the working space loading on the mechanical properties. Thus, it was established that the velocity and circulation of the flow according to the scheme in Figure 2, namely in the area of the output nozzle (Figure 1, *b*), affects obtaining of stable indices of mechanical properties in this area.

CONCLUSIONS

1. As a result of analysis of the values of mechanical properties of the test samples, it was established that their strength characteristics in the area of the inlet nozzle have a value by 3–5 % lower compared to the central area of the platform with a range of values of ± 2 %, in the area of the outlet nozzle, the value is by 3–5 % lower compared to the central area and have a range of values of ± 10 %.

2. It was established that a loading of the working space and the pause between a layer deposition and scanning play a role with an increase in time from 50 s, namely a decrease in the strength and ductility

characteristics at 65 s — 23 and 10 %, 80 s — 33 and 0.7 %, respectively.

3. As a result of research, it was established that a loading of the working space has a significant effect on the mechanical properties compared to the flow rate, but the circulation of the flow plays the greatest role in the area of the outlet nozzle.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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