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INFLUENCE OF A STOP IN THE PROCESS OF MELTING ON MECHANICAL PROPERTIES OF SPECIMENS FROM THE Co–Cr–Mo ALLOY MADE BY SLM TECHNOLOGY

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ABSTRACT

In the modern manufacturing of parts of metal powder, the method of Selective Laser Melting (SLM) has become widespread. In Ukraine, the LLC "Additive Laser Technologies of Ukraine" is engaged in the development of equipment for manufacturing parts of metal powders by SLM technology. Nowadays, for this equipment, the relevant task is the development of a procedure for choosing the parameters of the process of melting metal powder, providing the necessary mechanical and service properties of parts. For the investigations, three experimental cylindrical specimens of Co–Cr–Mo alloy were made in the vertical direction for tensile test according to ISO 6892:2019 — with a diameter of the working zone of 5 mm, with a controlled stop at a height of 18 mm from the beginning of the working zone, the total length of which is 28 mm. As a result of the analysis of the values of mechanical properties, it was found that the ultimate strength of the experimental specimens of Co–Cr–Mo alloy made by SLM technology with a controlled stop during 24 h decreases compared to the specimens made without a controlled stop — by ~13 %, relative elongation — by ~1 % and reduction in area — by ~17 %. It was found that for the experimental specimens with a stop in the manufacturing process, the deviation from the average values was: for ultimate strength ~11 %, relative elongation ~62 % and reduction in area of ~21 %. This is predetermined by failure of one of the specimens at the place of a stop. The use of parts with a production defect (stop) should be significantly restricted respective to a probable significant softening and embrittlement of a product.

KEYWORDS: selective laser melting, controlled stop, Co–Cr–Mo alloy, mechanical properties, density

INTRODUCTION

In the modern manufacturing of parts of metal powder the method of Selective Laser Melting (SLM) has become widespread. This technology is based on layer-by-layer fusion of metal powder particles, in which the melting process is carried out by the movement of laser beam relative to the digital three-dimensional model of an object created.

At present, the main manufacturers of equipment for producing parts by SLM technology are located in Europe and America, for example, the companies 3D Systems (USA), Electro Optical Systems — EOS (Germany), Concept Laser GmbH (Germany) and in other countries of the world. The solutions offered at the market are expensive and require additional purchase of software for various materials, as well as purchase of powder from the manufacturer of equipment.

In Ukraine, the LLC "Additive Laser Technologies of Ukraine" is engaged in the development of equipment for creating parts of metal powders by SLM technology. The advantage of the equipment of the domestic manufacturer is the ability to independently adjust the manufacturing parameters for different materials and to take into account the geometric features of a product (significant change in cross-section, sloping surfaces, etc.).

A large number of publications was dedicated to studying technological aspects of manufacturing parts by layer-by-layer deposition of the powder layer with the following melting [1–4]. The research data are aimed at obtaining high density [5–8], determination of rational parameters [9–12] and their use in parts manufacturing [13–15]. Based on the analysis of the mentioned works, it was found that in most cases a large number of factors play a significant role in the process of manufacturing parts for real printing conditions. But it should be noted that there are a number of reasons causing a stop in the process: reduction in the rate of surfacing a new layer, unevenness of powder surfacing, partial tear of a part due to the curvature, etc. This may play a significant role in changing the end mechanical properties due to different cooling rates and the influence of laminar inert gas flows on a printed layer.

Based on the preliminary studies of the heat-resistant Inconel 718 alloy [16] (used for parts and assem-

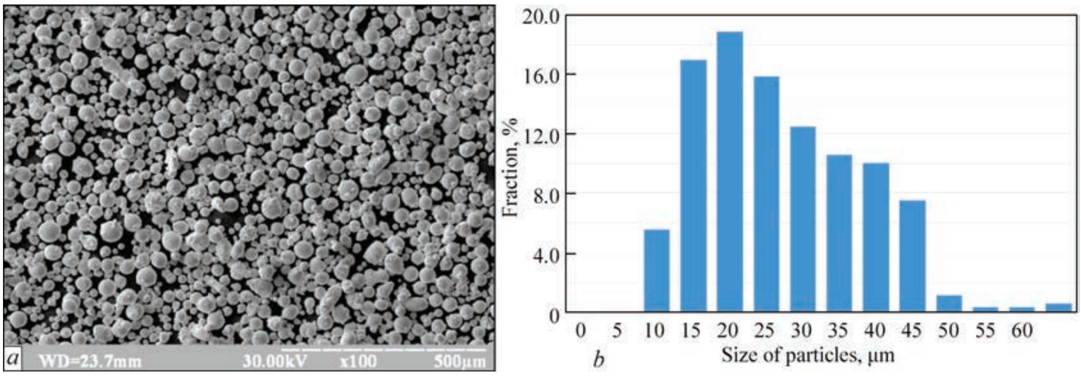

Figure 1. Particles of source material of Co–Cr–Mo at a magnification of 100 (*a*) and results of granulometric analysis (*b*)

blies of aircraft and space purpose), it was fairly clear noted that a stop in printing with the further resumption of the process has no significant influence on mechanical properties (deviation is approximately 5 %), the average level of which corresponded to foreign analogues. Microstructure examinations helped the authors to find an area with a reduced material penetration, located in the zone of a stop.

The problem of the influence of a stop in the process of manufacturing parts by SLM method requires further study, including with the use of other materials in order to determine the level of deviations of mechanical properties and to predict the possibilities of operation of such products. The Co–Cr–Mo alloy is widely used in the dental industry, namely in orthopedics for the manufacture of dental prosthesis with the application of ceramic coating. The use of the Co–Cr–Mo alloy in the dental implantation is predetermined by a high level of values of mechanical properties and indices of wear resistance in combination with a low coefficient of temperature expansion and biocompatibility.

In the work, the studies of the cobalt-chromium Co–Cr–Mo alloy after a stop in the printing process and comparison of the characteristics of the alloy in the state obtained under rational printing conditions were carried out.

The aim of the work is to investigate the influence of a one-time stop in the process of manufacturing a part by SLM technology on mechanical properties of specimens from the Co–Cr–Mo alloy to establish the serviceability of parts that have such a feature.

MATERIAL AND RESEARCH PROCEDURE

In the work, the tensile specimens were studied, manufactured in the 3D printing machine Alfa-150D of ALT Ukraine, produced of metal powder from the cobalt-chromium Co–Cr–Mo alloy with the following chemical composition, wt.%: 17.79 Cr; 12.63 Ni; 2.35 Mo; 0.78 Mn; 0.64 Si; C 0.016, granulometric analysis is presented in Figure 1.

Metallographic sections were made according to standard procedures with the use of diamond pastes. Metallographic examinations were performed with the use of light microscopes Neophot 30 and Axiovert 200M MAT to determine the density of the specimens. The sizes and amount of pores and oxides were calculated using the ImageJ software module. Granulometric analysis was performed in a scanning electron microscope REM 106.

Three experimental cylindrical specimens were made for tensile tests according to ISO 6892:2019 with a diameter of the working zone of 5 mm. In the process of building, the specimens were arranged in the working space in a vertical position; a controlled stop during 24 h was carried out at a height of 18 mm of the working zone, the total length of which was 28 mm (Figure 2). The rational printing parameters were determined in [17]: deposited layer is 20 μm thick: distance between the tracks is 0.1 mm, power is 130 W, velocity of beam passing is 900 mm/s. Mechanical treatment of specimens to finished sizes was carried out with the use of the HAAS ST10 lathe.

Mechanical properties were determined during tensile tests in accordance with the standard procedure in the PHYWE machine.

RESEARCH RESULTS

The studies of the specimens in a polished state showed that they all have a density of about ~99.97 % (Figure 3), in most cases defects are represented by

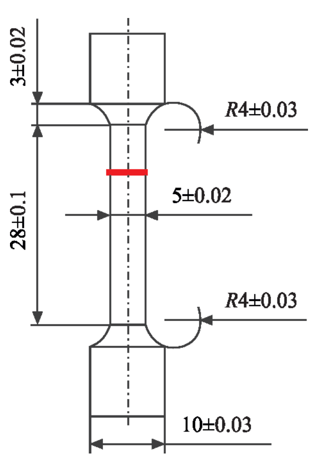

Figure 2. Scheme of location of a place of a controlled stop of printing an experimental specimen

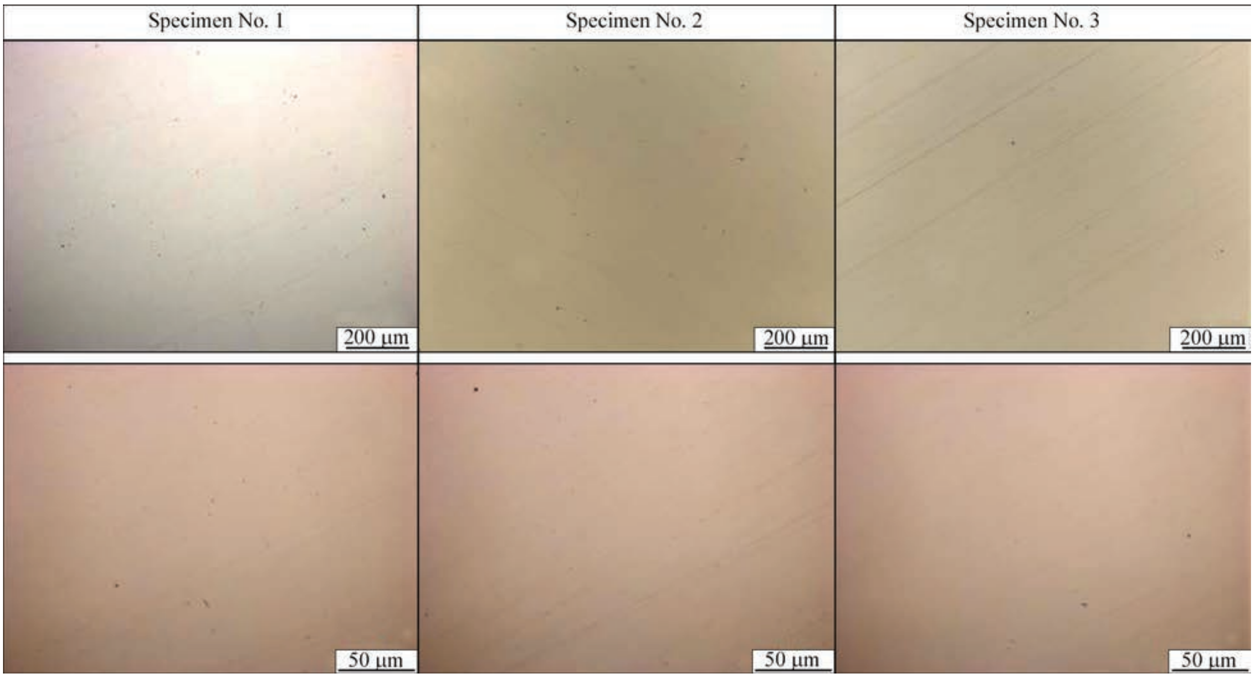

Figure 3. Microstructure of experimental specimens in the zone of stop

Table 1. Mechanical properties of experimental specimens manufactured from the Co–Cr–Mo alloy by SLM technology in the initial state with mechanical treatment of the working zone

Number	State	σ_t, MPa	$\Delta\sigma_y$, %	δ, %	$\Delta\delta_6$, %	ψ, %	$\Delta\psi_6$, %	Source
1	With a stop	1067.6	+5.6	6.9	+0.5	13.9	+14.3	–
2		895.2	–11.1	2.6	–62	9.4	–21	–
3		1060.1	+4.9	11	+37.6	12.3	+3.25	–
Average		1007.6	0	6.86	0	11.9	0	–
4	Without a stop	1157	–0.19	1.8	–74.13	17.9	+23.78	[17]
5		1162	+0.23	8.7	+25	10.1	–30.15	[17]
6		1159	–0.02	10.4	+49.42	15.4	+6.50	[17]
Average		1159.3	0	6.96	0	14.46	0	[17]

separate globular pores with a diameter of 1–2 μm. According to the results of studies, no defects of the influence of a stop on the continuity of the experimental specimens were found at the microstructure level.

According to the results of visual-optical inspection, failure of the experimental specimens Nos 1 and 3 occurred beyond the place of a controlled stop, and the surface of a fracture had a tough structure. It should be noted that failure of the experimental specimen No. 2 occurred in the zone of a controlled stop and had a brilliant fracture with the visible characteristic texture of the tracks (Figure 4).

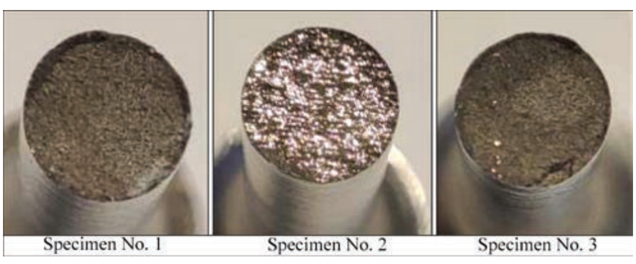

Figure 4. Failures of experimental specimens with a controlled stop

According to the results of the analysis of the values of mechanical properties (Table 1), it was found that the values of mechanical properties of the specimens with a controlled stop undergo changes compared to the initial state without a controlled stop [17].

The comparative analysis of the average values of ultimate strength of all the experimental specimens with a controlled stop allows setting a decrease in values by 13 % compared to the state without a stop in manufacturing. The average values of relative elongation of the experimental specimens with a stop undergo slight changes (~1 % compared to a state without a stop). While analysing changes in the average values of reduction in area, it was found that for the experimental specimens with a controlled stop, a decrease in this characteristic by ~17 % is observed, compared to the specimens without a stop in the manufacturing process. It should also be noted that the experimental specimens with a controlled stop have large discrepancies in values within the framework of the study, namely: ultimate strength –11.1 – +4.9 %, relative elongation –62 – +37.6 %, reduction in area –21 –

+14.3 % compared to the specimens made without a stop –0.19 – +0.23 %, +1.8 – +10.4 %, –30.15 – +23.78 % accordingly. A small discrepancy in values indicates the stability of the process of manufacturing specimens and a heating-cooling cycle in manufacturing. A significant decrease in mechanical properties of the specimen No. 2, which was made with a stop and fractured along the place of its location indicates, that the use of parts with such a production defect should be significantly limited respective to a probable significant softening and embrittlement of a product.

CONCLUSIONS

1. As a result of the analysis of the values of mechanical properties, it was found that the ultimate strength of the experimental specimens with a controlled stop from the Co–Cr–Mo alloy, made by SLM technology, is reduced compared to the specimens made without a controlled stop — by ~13 %, relative elongation — by ~1 % and reduction in area – by ~17 %.

2. It was found that for the experimental specimens in the process of manufacturing, the deviation from the average values was: for ultimate strength ~11 %, for relative elongation ~62 % and for reduction in area ~21 %. This is predetermined by the failure of one of the specimens at the place of a stop.

3. The use of parts with a production defect (stop) should be significantly limited, respectively to a probable significant softening and embrittlement of a product.

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CONFLICT OF INTEREST

The Authors declare no conflict of interest

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