The Influence of Selective Laser Melting Process Parameters on the Structure and Properties of Products Made from Metal Powders of Domestic Manufacture

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Abstract. Rational selective laser melting modes have been established for the manufacture of parts from domestic powder of steel grade 20H13. The properties of PR20H13 powder have been studied using the methods of granulometric analysis. The physical and mechanical properties of samples manufactured using rational modes of selective melting have been determined.

1. Introduction
According to the European Powder Metallurgy Association (EPMA) [1], additive production is a branch of powder metallurgy which continues to grow at a rapid pace. The continuous developmental grown of additive production is associated with its ability to make products with specific properties that cannot be manufactured other methods, such as lattice implantable materials that biologically act on bone tissue. Additive production provides technologically effective product design by solving problems such as reducing labor intensity, cost, material consumption and the energy resources required to manufacture the product [2; 3].

To date, the range of imported and domestic metallic powders used in additive manufacturing is limited. However, this is not due to the lack of powders with a spherical shape of particles: their industrial production began in the late 30s of the twentieth century and has been used to manufacture filters and other porous products [4]. This is due rather to the lack of technological fabrication processes using concentrated energy flows. Therefore, it is necessary to develop technological additive production processes using a wide range of powder materials. Fabrication based on selective laser melting (SLM) involves manufacturing products from metal powders using one or more lasers selectively melting or melting particles on a substrate, layer by layer in a closed chamber [5]. The goal of this work is to expand the range of domestically produced metal powders for the manufacture of products using selective laser melting method in accordance with the quality requirements for parts of particularly complex shape, bearing in mind the rational scope of the process. The goal of this work is to expand the range of domestically produced metal powders for the manufacture of products using selective laser melting method in accordance with the quality requirements for parts of particularly complex shape, bearing in mind the rational scope of the process.
2. Research Methodology

In this work, the material studied is corrosion-resistant chromium steel of the martensitic class and of grade 20H13 (analogues: AISI 420, EN X20Cr13, DIN 1.4021). The chemical composition of the steel is 0.16–0.25 % C, 12.00–14.00 % Cr, ≤ 0.80 % Si, ≤ 0.80 % Mn, ≤ 0.030 % P, ≤ 0.025 % S. This steel is used for parts that are not subject to concentrated stress and work in environments with only slightly aggressive wear. Metal powder of brand 20H13 (PR20H13, fraction 0–40 μm) is manufactured by POLEMA JSC by dispersing molten metal with a jet of compressed gas. The dispersed (particle size) composition of PR20H13 was determined on an OCCHIO500nano image analyzer (manufacturer OCCHIO SA, Belgium) using the static image analysis method in accordance with ISO 13322-1. The real-time particle morphology of PR20H13 was determined using a scanning electron microscope (VEGA 3 LMH TESCAN, Czech Republic) employing scanning electron microscopy according to State Standard R 54597. Selective laser melting of the materials studied was carried out on an industrial EOS M 280 installation (manufactured by EOS GmbH, Germany) and an experimental setup for SLM (ALAM) with the following technical characteristics: wavelength – 1070 nm, beam divergence – 0.2°, pulse duration and relative intensity – continuous radiation, maximum power – 200 watts. The physical and mechanical properties of the samples were determined by standard methods in accordance with State Standards. The characteristics of mechanical properties (modulus of normal tensile elasticity and mechanical properties of the samples were determined by standard methods in accordance with State Standard 9450. The density of the samples was determined by hydrostatic weighing on a Mettler Toledo XP504 scale with an accuracy of 0.001 g/cm³. The method for determining the hydrostatic weighing density was based on determining the mass difference between samples in air and liquid, using Ethanol as the working fluid. Gas porosity was evaluated on 4 mm² panoramic images according to State Standard 1583 using a Carl Zeiss AxioObserver.D1m optical microscope. Image processing was performed using the Thixomet Pro program. The volume fraction of pores, their size distribution, and the total porosity score were evaluated.

3. Research Results and Discussion

Studies of powder particle size distribution gave the following results: the average particle diameter was \(x_{k,0} = 20.47 \mu m\), where the total content of particles not corresponding to the size of the main fraction corresponded to 8.02 %. The particle size distribution of PR20H13 is described by the law for a normal Gaussian distribution. Form factors (descriptors) were used to describe the size of the projections and the shape of the particles [7]. The shape factors were determined based on the maximum frequency distribution. Since the elongation \(El = 0.230\) tends to zero, and the roundness \(C = 0.725\) to one, the typical shape of the PR20H13 particles is spherical. According to roughness calculation results \(Rg^2 = 0.003\) and bluntness \(Wv = 0.913\), particles PR20H13 have a high surface purity and no sharp edges. Thus, PR20H13 particles are characterized by a spherical shape, high fluidity, microcrystalline structure, an equiaxial morphology and a small number of satellites (Figure 1).
Figure 1. (a) Graphic representation of measurement results for particle content in a sample depending on their size; (b) the microstructure (2.98 k × and 13.8 k ×) of the PR20H13 particle surface.

In order to determine the influence of SLM process parameters on the structure and properties of the products, experiments were carried out to make tracks from the PR20H13, varying the laser power, scanning speed and thickness of the powder layer. Laser power was varied from 40 to 120 W at scanning speeds from 50 to 150 mm/s. The thickness of the powder layer applied to the substrate was 50 μm. The track length (molten bath) was 15 mm for all experiments. In each experiment, the height of the track above the substrate, the depth of the penetration zone, the width of a single track, the width of the penetration zone, and the wetting angle of the substrate in the laser irradiation zone were analyzed. As scan speed increased, the width of a single track varied from 234 microns to 112 microns, i.e., the track width decreased with increasing scan speed. Track formation ceases to be stable at a scanning speed of 80 mm/s, a laser power of 40 W and a layer thickness of 50 μm. In this case, droplets are formed. With a laser power of 40 W, substrate melting was not observed at a scanning speed of 50 mm/s, i.e., the laser power was sufficient to melt the powder, but the energy contribution was insufficient to melt the upper substrate layer and form a common melt pool. At this laser power, the amount of powder involved in track formation decreases. For a layer thickness of 50 μm and a laser power of 80 W, stable single tracks from PR20H13 can be formed at scanning speeds of $v_s = 50–120$ mm/s (Figure 2). Microstructural analysis of the tracks was conducted. As a result of parametric analysis, modes were selected that provide high-quality and stable tracks.

According to the metallographic analysis results, it was found that the average grain diameter in the samples did not exceed 2 μm, which corresponds to the 15th point (fine-grained group). At high magnifications, cells with an oriented structure characteristic of the SLM method can be seen. In the manufacture of samples from PR20H13 using the SLM method, a tempering mechanism occurs from the liquid state. Dendrites do not have second-order axes on the microstructures of the samples after the SLM method. Non-metallic inclusions and traces of intergranular corrosion were not found. The pore size does not exceed 0.01 mm, score 3, the volume fraction of the pores is in the range of 0.05 ... 0.1 %. The average value of the roughness parameter was $R_z = 12.97 ± 2.02$ (Ra $1.70 ± 0.19$) μm (Figure 3). The microhardness over the sample thickness remains almost unchanged. The average value was 474 ± 7 HV$_{0.1}$.
Figure 2. (a) The geometric characteristics of a single track in the cross (lower) section and from above (above) the alloyed layer: the track height above the substrate; the depth of substrate penetration to the underlying layer; single track width; penetration zone width; the wetting angle of the substrate with the melt in the zone of exposure to laser radiation; (b) Powder 20H13, thickness of the applied powder layer 50 μm, laser power 80 W, scanning speed 50 mm/s; magnification: 5 and 20 ×. Samples on the construction plate after manufacture using the SLM method.

Figure 3. (a) Microstructure of sample magnification: 1000 ×; (b) Microstructure of the sample surface after the SLM magnification: 7000 ×; (c) Reconstructed three-dimensional image of the sample surface area.

The behavior of steel 20H13 obtained using the SLM method under the influence of a gradually increasing load was determined by the stress-elongation diagram (Figure 4).

Figure 4. (a) Dependence of stress on strain. (b) Appearance of destroyed specimens.
The basic characteristics of the mechanical properties of $E$, $R_{p0.2}$, $R_m$, $A$ according to the results of static tests for 20H13 steel obtained using electroslag remelting methods with heat treatment and SLM are given in Table. 1. A comparative analysis of the results of mechanical testing of specimens from 20H13 steel obtained using the SLM method and traditional heat treatment shows an increase in the tensile strength and yield strength of the samples manufactured by the SLM method, the relative elongation decreases.

Table 1. Physical and mechanical properties.

| Standards Documentation | State of control samples | $E$ [MPa] | $R_{p0.2}$ [MPa] | $R_m$ [MPa] | $A$ [%] | Hardness | Density g/cm$^3$ |
|-------------------------|--------------------------|-----------|------------------|------------|--------|----------|----------------|
| — SLM                   | SLM                      | 208917.5  | ±1024.5          | 863.98     | ±7.38  | 1584.09  | ±3.58         |
| — Hardening + tempering | —                        | 635       | 830              | 10         | 197-126 HB | 7.7 [8]   |

4. Conclusions and Recommendations

The work involved the selection and analysis of powder material for research. It was shown that the properties of the PR20H13 powder correspond to the properties recommended for additive production. The density of the samples obtained by the SLM method corresponds to the density of cast specimens from 20H13 steel. Optimally selected modes for the SLM process demonstrate an increase in the strength characteristics and hardness of 20H13 steel compared to traditional technologies due to the fact that the hardening mechanism was implemented from the liquid state [9].

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References

[1] https://www.epma.com/additive-manufacturing
[2] Grigor'ev S N i Smurov I YU 2013 Perspektivy razvitiya innovacionnogo additivnogo proizvodstva v Rossii i za rubezhom Innovacii 10 ss 76–82
[3] Grigor'ev S N, Gusarov A V, Okun'kova A A, Protasov K E i Hmyrov R S 2015 O celesobobraznosti profilirovaniya puchka v tekhnologiyah selektivnogo lazernogo spekaniya i plavleniya Fizika i himiya obrabotki materialov 3 ss 80–87
[4] Libenson G A, Lopatin V YU i Komarnickij G V 2001 Processy poroshkovoj metallurgii (Moskva: MISIS)
[5] ISO / ASTM52900-15, Standard Terminology for Additive Manufacturing – General Principles – Terminology, ASTM International, West Conshohocken, PA, 2015, www.astm.org
[6] Tarasova T V, Filatova A A, Kotoban D V i Ableeva R R 2017 Laboratornye raboty po kursu «Additivnoe proizvodstvo» (Moskva: FGBOU VO «MGTU «STANKIN») s 54
[7] Nowotny St Tarasova T V Filatova A A and Dolzhikova E Yu 2016 Methods for Characterizing Properties of Corrosion-Resistant Steel Powders Used for Powder Bed Fusion Processes Materials Science Forum 876 pp 1–7 (https://doi.org/10.4028/www.scientific.net/MSF.876.1)
[8] Tumanov A T 1975 Aviacionnye materialy (Moskva: ONTI)
[9] Tarasova T V, Gusarov A V, Protasov K E and Filatova A A 2017 Effect of Thermal Fields on the Structure of Corrosion-Resistant Steels Under Different Modes of Laser Treatment Met Sci Heat Treat 59 pp 433–440 (https://doi.org/10.1007/s11041-017-0168-z)