Optimization of laser melting parameters of martensity-aging steel powder

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Abstract. In this work, we investigated the possibility of manufacturing parts by selective laser melting of heat-resistant steel. The study of the structural-phase composition of the powder material by X-ray spectroscopy was carried out, and the particle size distribution was studied by scanning electron microscopy. Powder material was melted at an industrial facility for selective laser fusion, and the parameters of laser melting were optimized for experimental samples. Information on the nature of the current melting processes was obtained as a result of analyzing the geometric characteristics of laser irradiation zones. The structure of the formed material, pores and microcracks were revealed using metallographic analysis.

1. Introduction

At present, additive technologies are increasingly used in various industries. One of the promising technologies for additive manufacturing is the technology of selective laser melting (SLM) [1,2]. This method is suitable for the manufacture of steel injection molds. The mold can be grown together with cooling channels of arbitrary configuration, which cannot be done with conventional machining methods.

The SLM process consists in layer-by-layer fusion of powder material using laser radiation. Initially, metal powder is loaded into the working chamber, then it is leveled into a layer several tens of micrometers in size, after which, using laser radiation with certain characteristics, the powder layer is processed in accordance with a previously created three-dimensional model of the product.

Various problems arising in the development of SLM technology require deep study at different levels: theoretical — constructing a detailed model of the process, and practical — conducting experimental research on the selection of optimal parameters for growing products from certain powders [3-7].

One of the most important factors affecting the quality of the final product can be considered the processing mode. In selective laser melting, the controlled characteristics are the radiation power and the scanning speed of the laser beam. With incorrectly selected characteristics, the part is deformed during the construction process, warpage occurs, and porosity appears. Porosity depends both on the material and on the parameters of the melting regime [8-10]. At the same time, to reduce the internal porosity of the product, heat treatment and pressure treatment methods are used, including HIP (Hot Isostatic Pressure) – hot isostatic pressing [11]. The materials used in selective laser melting are metal powders of titanium, tungsten, various steels, etc. Product cultivation takes place on a special platform,
which is called the substrate. Most often, the substrates have a rectangular shape, consist of a material similar in characteristics to the material from which the product is grown. Before starting the cultivation process, they undergo special machining. It can be carried out in various ways, for example, using a dog-sanding apparatus. Processing actions are performed to increase the adhesion of the substrate and powder granules. The substrate has a strong influence on the formation of the initial layers during the SLM process; under certain characteristics of the penetration, the used material and the substrate penetrate and mix, which in turn has an additional stabilizing effect during melting [12-15].

2. Methods  
As a material, powder material of the brand PR-07H18K9M5T of Russian production was used. This material is an alloy of steel, characterized by outstanding heat resistance, which allows it to be used for the additive production of various forming components, followed by conformal cooling for injection molding. This powder composition was obtained in several melts by gas atomization, subsequent spheroidization of the powder, subsequent averaging and sieving into a fraction of 20-40 microns.

The obtained powder material was melted at a selective laser melting unit (Concept Laser M2 Cusing, Germany) equipped with a 400 W Yb: YAG fiber-optic diode pump operating in continuous generation mode. Powder material was applied to the surface of a specially prepared steel substrate, the thickness of the powder layer was 30 μm. The resulting surface was irradiated with a laser, the radiation wavelength was 1.06 μm. Processing was carried out without the use of additional heating, in a nitrogen atmosphere.

To reduce the level of internal stresses in the samples, a scanning strategy patented by Concept Laser GmbH was used (Fig. 1). The scanning surface was divided into 5 × 5 mm squares and treated with a laser beam in a random order, with 90° rotation in adjacent squares and with a 1 mm shift between the layers [16,17]. This allows the manufacture of large parts with a minimum level of internal stress.

![Figure 1. Heat transfer process in powder materials: 1 - laser radiation, 2 - heated surface, 3 - heat transfer zone of powder granules, 4 - micro-granules of powder.](image)

During the work, visual inspection was carried out using an optical microscope. The criterion that determines the satisfactory quality of processing when choosing an exposure mode was the state of the formed surface. Information on the nature of the current melting processes was obtained as a result of the analysis of the geometric characteristics of the laser exposure zones. On an optical microscope, surface images of the samples were obtained, followed by image processing in Altami Studio. The formation of a uniform molten layer is possible only with the formation of a sufficient amount of the liquid phase of the metal, therefore, optimization of laser melting parameters is carried out. Adjustable parameters were laser radiation power and scanning speed. Several heats were carried out with variable power parameters (from 100 to 200 W) and beam scanning speeds (from 500 to 1600 mm / s). Thus, the optimal set of melting parameters can be distinguished: power 180 W, scanning speed 600 mm / s. When exposed to less energy, the powder is collected in droplets, poor wettability of the components of the composition is expressed, when the energy is exceeded, intense burning of the material with characteristic dynamic gas formation occurs.
3. Results and Discussion
The particle size distribution of the powder material was studied by scanning electron microscopy. Particle sizes are in the range of 20-40 μm, particles are mainly spherical in shape.

![Figure 2. SEM images of powder material.](image)

The structural phase composition of the powder material was studied by X-ray spectroscopy on a D8 ADVINCE instrument (BRUKER, Germany). The results are presented in Fig. 3.

![Figure 3. The structural phase composition of the powder material.](image)

The phase composition of the powder and the SLM sample is a solution of alloying components (Ni, Co, Cr, Ti, Mo) in iron, while such intermetallic compounds as FeNi, CoFe, Fe₀.₇Ni₀.₃, FeNi, Fe₀.₈₅Mo, Fe₀.₈Ti₀.₂ are also present. In the SLM sample, in comparison with the initial powder, there was a shift towards the solution, i.e. part of the amount of two-component intermetallic phases was dissolved in iron; the content of the FeNi phase also increased with a sharp decrease in the content of the Fe₀.₇Ni₀.₃ phase.

Used powder steel refers to maraging steels, in which intermetallic phases increase the strength and hardness of the material, and their number can be increased due to aging [18-20].
Table 1. The composition of the powder material before processing and after.

|          | Powder  | SLM     |
|----------|---------|---------|
| Fe       | 29.16%  | 60.02%  |
| Fe$_{0.7}$Ni$_{0.3}$ | 37.51%  | -       |
| FeNi     | 6.67%   | 17.73%  |
| CoFe     | 14.57%  | 12.00%  |
| Cr       | -       | 2.63%   |
| Fe$_{0.85}$Mo$_{0.125}$ | 2.56%   | 2.36%   |
| Fe$_{0.8}$Ti$_{0.2}$   | 3.75%   | 2.14%   |
| Ni       | 4.05%   | 3.11%   |

The structure of the formed material, pores, and microcracks were detected by metallographic analysis. To obtain microphotographs of the obtained sections, a metallographic microscope was used.

**Figure 5.** Microphotographs of transverse sections of the obtained samples.

The photographs of microsections show that when using laser melting with a 200-watt-pumped powder, pores with a diameter of 5–50 μm are formed in the sample body, while such pores are not observed at a pump power of 180 μm.

**Figure 6.** Microphotographs of transverse sections of the obtained samples at a power of 180, a speed of 600 mm/s.

In fig. 6a is an end section of the obtained sample (several layers are shown in side view), Fig. 6b horizontal section (in the plane of the layer in the case of SLM). The deposited layers in cross section have the form of hemispheres with a linear size of 70-100 μm.

Based on the data obtained, conclusions were drawn about changes in the chemical and phase composition, the nature of the distribution, and changes in phase states. SLM promotes the dissolution of iron-based intermetallic phases, which can somewhat reduce the strength characteristics of the material, however, it is possible to restore the amount of intermetallic compounds during aging of the samples.
4. Conclusions
As a result of the work, several swimming trunks with variable power parameters (from 100 to 200 W) and beam scanning speeds (from 500 to 1600 mm/s) were carried out. An optimal set of melting parameters was determined: power 180 W, scanning speed 600 mm/s. When exposed to less energy, the powder is collected in droplets, poor wettability of the components of the composition is expressed, when the energy is exceeded, intense burning of the material with characteristic dynamic gas formation occurs. Conclusions were drawn about changes in the chemical and phase composition and changes in phase states.

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