Evaluation of microstructure and physical and mechanical properties of bulk parts obtained from Russian and German steel powder by selective laser melting

Usov S.1, Tochilin I.2, Voznesenskaya A.2, Zhdanov A.2,
1 "TSZP" Limited Liability Company "TSZP", Moscow, Russia
2 Vladimir State University named after A. G. and N. G. Stoletovs, 87 Gorky, Vladimir, Russia

E-mail: zhdanov@vlsu.ru

Abstract. In this work, a comparative analysis of steel powder materials of Russian and German production is carried out. Samples were obtained by selective laser melting at various melting parameters. X-ray diffraction analysis was carried out, the microstructure of the obtained samples was analyzed by optical microscopy, and hardness of the samples was studied.

1. Introduction

Selective laser melting technology (SLM) allows you to produce parts that are optimized as much as possible in terms of mass and strength, with complex geometry, including conformal channels, which is not achievable with classical processing methods [1]. The use of selective laser melting is a new opportunity to optimize costs and increase production efficiency [2]. SLM technology is a complex process for forming parts from an ultrafine powder composition. Layer-by-layer synthesis involves the growth of a part in an inert gas medium, the part is heated in the area of laser exposure and nonequilibrium cooling in other zones, which leads to uneven metal shrinkage. Obtaining a part that meets all the necessary physical and mechanical requirements is the result of choosing the correct material characteristics and laser radiation exposure parameters [4-6]. 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 [7]. Pore formation is characteristic of regions with insufficient energy contribution, where the melting is sluggish, and the resulting gas bubbles do not have time to float, but remain in the metal in the form of pores. Moreover, the nature of the formation of the melt is highly uneven, in which the formation and evolution of gases occurs, both during the formation and solidification of the bath of the melt. The materials used in selective laser melting are metal powders of steels, aluminum alloys, titanium, etc. [1].
2. Experimental work

In this study, powders based on iron of Russian (powder 1) and German (powder 2) production were used. These powder materials are used in the production of conformal cooling mold inserts for injection molding, as well as functional components, using SLP methods. The chemical composition is presented in Table 1.

Table 1. The chemical composition of the powders.

| Mass fraction of elements, % | Powder 1 | Powder 2 |
|-----------------------------|----------|----------|
| Fe                          | 0.07     | 0.03     |
| C                           | 0.75     | 0.14     |
| Si                          | 2        | 1.0 - 1.1|
| Mn                          | 16 - 18  | 16.5 - 18.5|
| Cr                          | 10 - 14  | 10 - 13  |
| Ni                          | 2 - 3    | 2.0 - 2.5|
| Mo                          | 0.02     | 0.03     |
| S                           | 0.03     | 0.045    |
| P                           | 0.03     | 0.10     |
| O                           | No more  | -        |

Samples were obtained at a Concept Laser M2 Cusing industrial laser selective melting facility (Germany), equipped with a 400 W ytterbium fiber laser operating in a continuous generation mode with an “open” laser sintering control system that allows varying the process parameters over a wide range. The thickness of the powder layer was 40 μm. The resulting surface was subjected to laser irradiation, the radiation wavelength was 1.06 μm. The diameter of the laser beam on the treated surface was 50 μm. Processing was carried out without the use of additional heating. The working space is located in a nitrogen environment. Adjustable parameters were laser radiation power and scanning speed. Several melts with variable power parameters (from 100 to 200 W) and beam scanning speeds (from 500 to 1600 mm / s) were carried out.

The patented principle of building objects in a system similar to ConceptLaser, used as one of the tools involved in the implementation of this work, allows reducing the number and size of pores. It is called stochastic exposure technology (Fig. 1).

![Figure 1. Scan strategy.](image)

3. Research

A study is made of the distribution of particle size of the powder material by scanning electron microscopy (SEM) (Fig. 2).
Figure 2. SEM images of powder materials.

In powder 1, particles with a size of about 40 μm make up a large proportion, the particles are predominantly spherical in shape, but deformed particles are also found. In 2 powders, a larger dispersion of particles from 20 to 40 microns is observed, while the particles also have a spherical shape.

X-ray diffraction analysis was performed on a D8 Advance (Bruker) diffractometer (Fig. 3, 4).

Figure 3. Structural-phase analysis of powder samples 1.

The phase composition of powder 1 and a sample of SLP from powder 1 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 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 dissolved in iron, the content of the FeNi phase also increased with a sharp decrease in the content of the Fe0.7Ni0.3 phase. The hardness of the samples was 29-34 HRC.

Samples from powder 2 correspond to a solution of chromium, nickel, and other components in iron, without precipitation of other individual phases (Fig. 4). The hardness of the samples was 25-27 HRC.
Figure 4. Structural-phase analysis of powder samples 2.

The study of pores, microcracks, and shrinkage defects is detected by obtaining a thin section and etching of the transverse and longitudinal surfaces of the sample with subsequent examination using optical microscopy (Fig. 5).

Figure 5. The microstructure of the obtained samples from powder 1 and powder 2.

The resulting images show clear contours of the cellular structure characteristic of samples obtained by selective laser melting. Pores are also observed.

4. Conclusion

In this work, experimental data were obtained comparing two powder materials based on iron of similar fractional and chemical composition, produced in Russia and Germany. Samples were obtained by selective melting at various melting parameters. Samples from powder 1 have a hardness higher.

5. References

[1] Shishkovsky I V 2016 Basics of additive high-resolution technologies (SPb: Pete.)
[2] Smurov I Yu et al. 2011 Vestnik MGTU Stankin vol 2 № 4 pp 144-146
[3] Kostritsky V V et al. 2013 Bulletin of Polotsk State University. Series B, Industry. Applied Science № 3 pp 97-101
[4] Grigoryev S N et al. 2015 J. Metallurgy and heat treatment of metals. №10 pp 5
[5] Kostenkov S N et al 2011 Bulletin of Udmurt University. Physics and Chemistry Series pp 13-23
[6] Jordan V I 2013 Proceedings of the Altai State University vol 1-1 (77) pp 167-171
[7] Yan S J et al. 2014 Materials Science and Engineering: A. vol 612 pp 440-444
[8] Voznesenskaya A et al 2018 J. Phys.: Conf. Ser. 1109 012056
[9] Alexandrov S et al. 2019 Journal of Physics: Conference Series. IOP Publishing, vol 1164 №1 pp 012001