

Research of post-processing approaches for parts obtained by the method of selective laser melting

A A Voznesenskaya¹, D A Kochuev¹, R V Chkalov¹, A V Kireev¹, V V Morozov¹

¹Vladimir State University named after A. G. and N. G. Stoletovs, Vladimir, Russia

E-mail: 2obk@bk.ru

Abstract. In this work, samples were obtained from the powder of heat-resistant steel by the method of selective laser melting. Samples were heat treated in a muffle furnace. Also, a number of samples were subjected to hot isostatic pressing. The microstructure of the formed material, pores and microcracks were detected by metallographic analysis. The graphs of the structural-phase composition of the powder material before and after melting, as well as after the post-processing methods were obtained. Based on the data obtained, conclusions were made about the effect of thermal post-processing on changes in the nature of the distribution of defects and changes in the microstructure, as well as on changes in the structure-phase composition.

1. Introduction

Selective laser melting (SLM) is one of the methods of additive technology, which involves layer-by-layer fabrication of parts from a powder material using laser radiation. One of the current applications of SLM technology is the production of molds or small inserts for large molds. One of the most interesting features of these techniques is the possibility of complex internal cooling after the surface of the part, which can lead to a reduction in the cooling time of plastic-injected parts by more than 30%. The use of additive technologies in the foundry industry allows us to “grow” casting models and molds that could not be made using traditional methods, and also significantly reduces the production time of model tooling. The use in the process of vacuum casting of forms and models obtained using additive technologies made it possible to reduce the time of manufacture of pilot, prototypes and, in some cases, mass production, dozens of times.

Due to significant temperature gradients and not optimal modes of technology, the formation of defects is possible: there are stresses, deformations, inaccuracy of sizes, cracks, delamination, porosity [1]. There are many post-processing methods to reduce or eliminate defects [2, 3]. For example, methods of pressure treatment, including HIP (Hot Isostatic Pressure) - hot isostatic pressing, are used to reduce the internal porosity of the product [4]. The purpose of this work was to identify patterns of formation of the microstructure and changes in the phase composition during selective laser melting and the applied post-processing methods.

2. Experimental work

The material used was powder material of the brand PR-07H18K9M5T. This material is an alloy of steel, characterized by outstanding heat resistance characteristics [5], which allows it to be used for the additive production of various formative components with subsequent conformal cooling for injection molding [6]. The particle size distribution of the powder material was studied by scanning electron microscopy (SEM). Particle sizes are in the range of 20-40 microns, particles are found both spherical and oblong with some defects (Fig. 1).



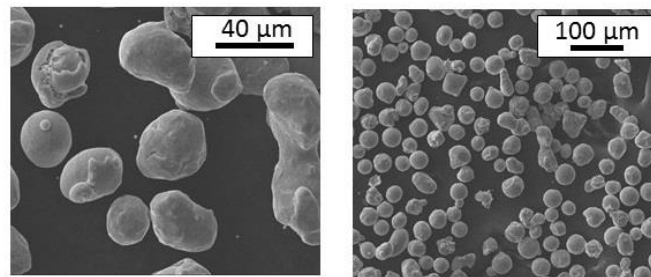


Figure 1. SEM photographs of steel powder material.

Samples were obtained from the powder material on a selective laser melting facility (Concept Laser M2 Cusing, Germany) equipped with Yb:YAG 400 W fiber-optic laser. The powder material was deposited on the surface of the 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 . The diameter of the laser beam on the treated surface was 50 μm . The treatment was carried out without the use of additional heating, in a nitrogen atmosphere. Samples were grown at a power of 180 W and a scan rate of 600 mm/s.

Next, the samples were subjected to heat treatment in a Nabertherm muffle furnace, with the possibility of fixing the necessary heating intervals. The treatment was carried out as follows: the temperature increased to 940 $^{\circ}\text{C}$ for 2 hours, then the stabilized temperature was maintained for 7 hours. The whole process was carried out in argon. Then there was a smooth cooling to room temperature. Also, a number of samples were subjected to hot isostatic pressing with a pressure of 1800 bar in argon. Processing took place according to the following scheme: heating with a step of 10 degrees per minute to 940 $^{\circ}\text{C}$, holding for 7 hours, cooling occurred at a speed of 10 degrees per minute to 150 $^{\circ}\text{C}$, then to room temperature. A graphic representation of the post-processing options is depicted in Figure 2.

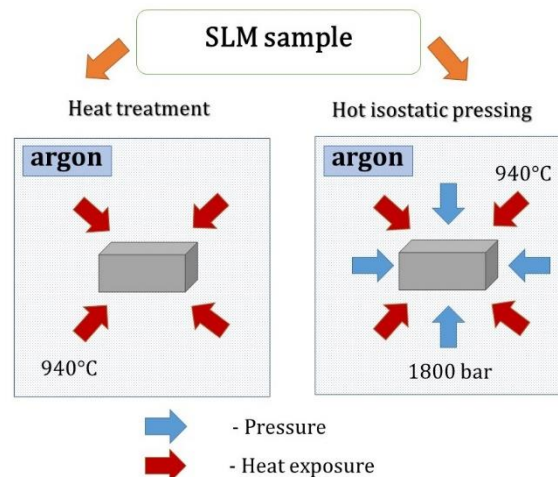


Figure 2. Scheme of heat treatment and isostatic pressing.

3. Research

The structural-phase composition of the powder material was studied on a D8 ADVINCE instrument (BRUKER, Germany). The results are presented in Fig.3 and 4.

The phase composition of the powder and SLM sample is a solution of alloying components (Ni, Co, Cr, Ti, Mo) in iron, while such intermetallic compounds as FeNi, CoFe, Fe_{0.7}Ni_{0.3}, FeNi, Fe_{0.85}Mo, Fe₀ are also present .8Ti_{0.2}. In the SLM sample, a shift towards the solution occurred in comparison with the initial powder, i.e. part of the number 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 Fe_{0.7}Ni_{0.3} phase.

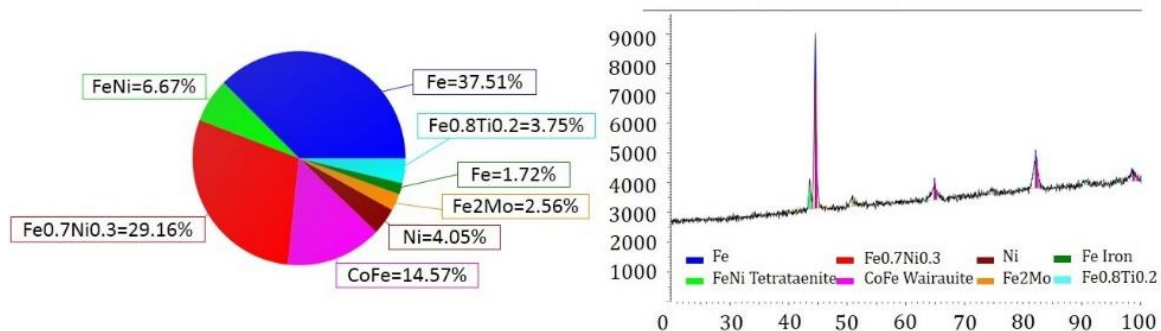


Figure 3. Structural-phase composition of the powder material.

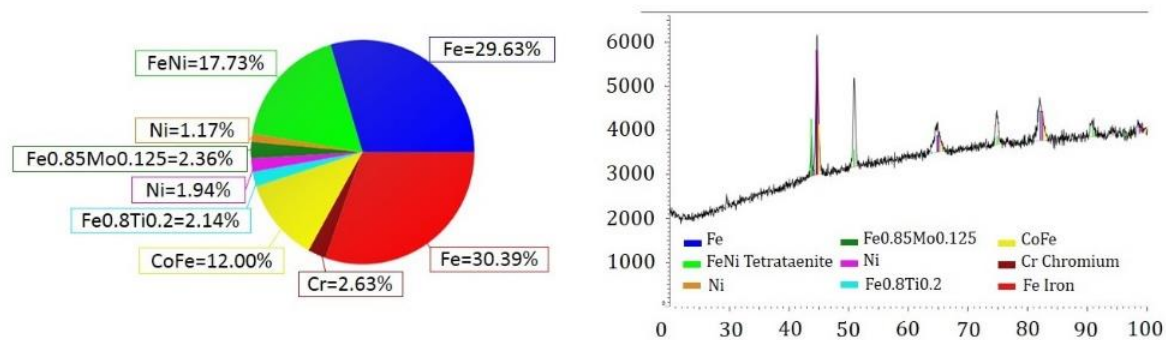


Figure 4. Structural-phase composition of the sample SLM

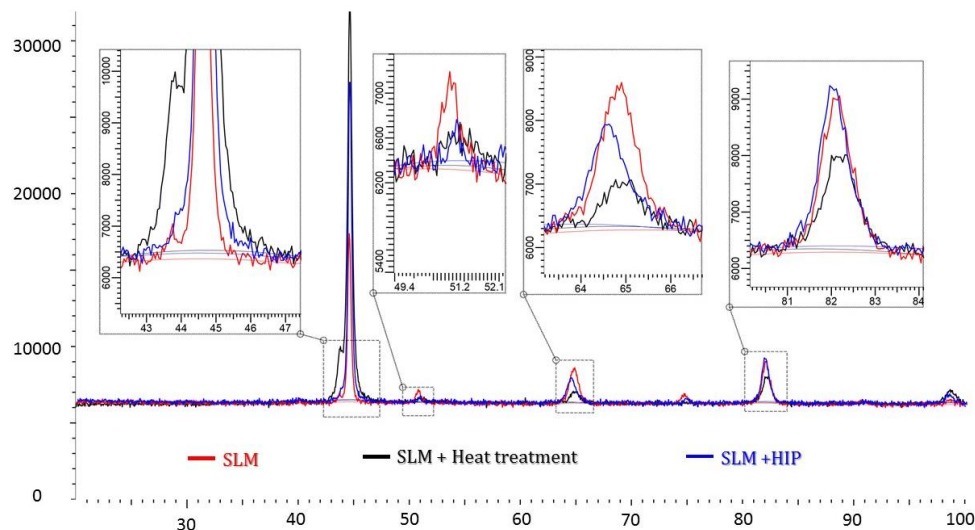


Figure 5. Structural-phase composition of all samples.

Figure 5 shows iron — blue color of peaks = α -iron = ferrite = cubic body-centered, green color = γ -iron = austenite. Iron up to $t = 911^\circ\text{C}$ has a body-centered cubic lattice (K8), in which the packing density of atoms is 68%, is designated as α -iron. The lattice parameter of α -iron is $a = 2.86 \text{ \AA}$. When heated above 911°C , iron changes the crystal lattice to face-centered cubic (K12), the packing density of atoms of which is 74%, denoted γ -iron [7]. The γ -iron lattice parameter is $a = 3.64 \text{ \AA}$. Thus, we observe a solid solution of the main components with austenite release (in the furnace), and at HIP (although the temperature was also high (above 911°C)), γ -iron did not precipitate.

To obtain micrographs of the structure of the sections obtained, a metallographic microscope was used. Images of the surface of the samples were obtained, followed by image processing in the Altami Studio program.

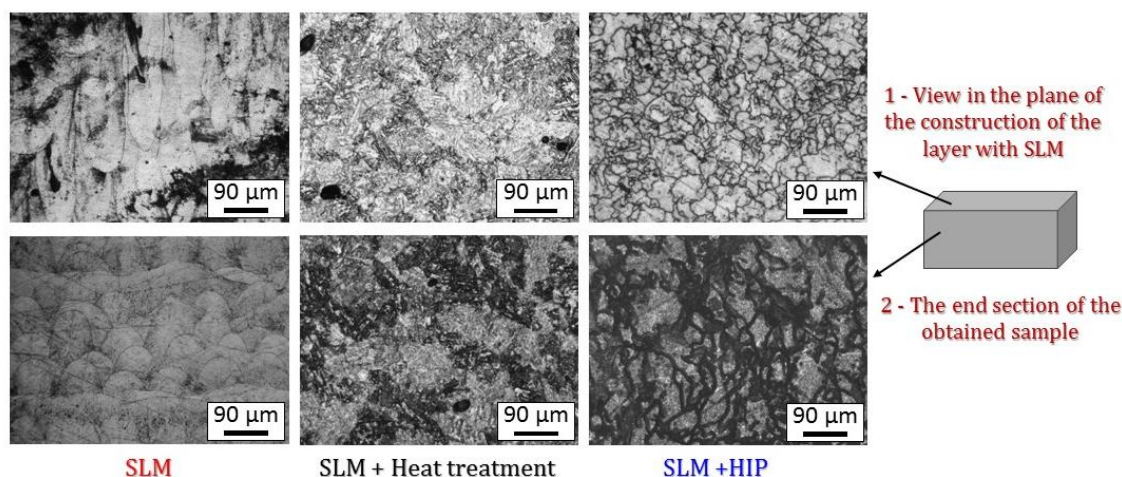


Figure 6. Microstructure of samples.

In selective laser melting, a microstructure is observed consisting of submicron cells growing along the direction of the crystal towards the center of the molten bath. After heat treatment, the cell boundaries become less noticeable, and after pressure treatment, a mosaic microstructure is formed.

4. Conclusion

Thermal post-processing of SLM samples was carried out using a furnace and an isostatic press. A change in the phase composition and a change in the phase states of the powder material and the fused samples, as well as the samples after post-processing, are noted. There is a solid solution of the main components with the release of austenite after heat treatment, and γ -iron does not occur at HIP. Also during the study of the microstructure of the samples before the post-processing and after revealed pronounced changes.

Bibliography

- [1] Alexandrov S, Usov S, Voznesenskaya A, Zhdanov A, Kochuev D and Morozov V Research of the absorption of laser radiation by powder materials 2019 *J. Phys.: Conf. Ser.* **1164** pp 012001
- [2] Röttger A, Geenen K, Windmann M, Binner F and Theisen W Comparison of microstructure and mechanical properties of 316 L austenitic steel processed by selective laser melting with hot-isostatic pressed and cast material 2016 *Materials Sci. and Eng.: A* **678** pp 365-76
- [3] Kreitchberg A, Brailovski V and Turenne S Effect of heat treatment and hot isostatic pressing on the microstructure and mechanical properties of Inconel 625 alloy processed by laser powder bed fusion 2017 *Materials Sci. and Eng.: A* **689** pp 1-10
- [4] Yadroitsev I and Smurov I Selective laser melting technology: From the single laser melted track stability to 3D parts of complex shape 2010 *Phys. Proc.* **5** (B) pp 551-60
- [5] Grobelny P, Furmanski L and Legutko S Selected Parameters of Surface Topography of Hot Working Tool Steel (1.2709) Manufactured with the Use of 3D Print 2017 *Sci. Bulletin Series C: Fascicle Mechanics, Tribology, Machine Manufacturing Technology* **31** pp 36-39
- [6] Preez W, Pereira M and Williams M Application of laser additive manufacturing to produce dies for aluminium high-pressure die-casting: general article 2012 *South African J. of Industrial Eng.* **23** (2) pp 147-58
- [7] Kashchenko M, Vereshchagin V and Aristova N Dislocation nucleation centers at the reverse $\alpha - \gamma$ martensitic transformation in iron alloys 1993 *Metal Phys. and Metallography* **75** (2) pp 38-43