Selective Laser Melting of Metal Powder Of Steel 316l

V G Smelov 1,2,3, A V Sotov 1,2, A V Agapovichev1 and T M Tomilina 2

1Samara State Aerospace University (National Research University), Moskovskoe sh. 34, Samara, 443086 Russia
2Institute of Mechanical Engineering named after A.A. Blagonravov of Russian Academy of Sciences, Russia
3e-mail: sotovanton@yandex.ru

Abstract. In this article the results of experimental study of the structure and mechanical properties of materials obtained by selective laser melting (SLM), metal powder steel 316L was carried out. Before the process of cultivation of samples as the input control, the morphology of the surface of the powder particles was studied and particle size analysis was carried out. Also, 3D X-ray quality control of the grown samples was carried out in order to detect hidden defects, their qualitative and quantitative assessment. To determine the strength characteristics of the samples synthesized by the SLM method, static tensile tests were conducted. To determine the stress X-ray diffraction analysis was carried out in the material samples.

1. Introduction

Today 3D-printing is a fast developing technology that produces three-dimensional objects directly from digital models through additive process, typically by precipitation and "cured in place" successive layers of polymers, ceramics or metals. Unlike traditional production processes associated with subtraction, for example, a cutting process or shaping techniques, such as stamping, bending and molding, AT connects the material layers to create a final product. Originally, this technology was conceived as a method for producing prototypes, but currently additive manufacturing has improved to the extent that they are increasingly used to obtain the finished product. Therefore there are high demands on the quality of the synthesized material to details grown.

Selective laser melting technology (SLM) is a fast growing technology that allows to produce metal parts in a short time. Interest in the technology is growing from year to year. At the moment, there are several well known works devoted to the study of physical and mechanical properties and structure of the samples obtained by the SLM. For example, in works [1-3] studies on the impact of the mode selective laser melting refractory metal powder on the structure of the material are presented.

The essence of SLM technology is the layer-by-layer manufacturing of a detail in which the heat source is a laser. Schematic diagram of the process is shown in figure 1. Construction of part 1 occurs on the high-platform 2. The platform is a plate approximately 20 mm thick attached by screws to the piston 3. The piston is responsible for moving building platform by an amount equal to the thickness of the layer construction. Accuracy of the piston affects the physical and geometric characteristics of the articles produced and typically is ± 0,005 mm [4]. The metal powder enters the zone via constructing recoater (dispenser) 4. From the main hopper 5, which is a building material, the powder
is dosed via a screw recoater. Recoater then, moving horizontally, delivers a new batch of powder to the growing area and levels it with silicone blade 6. Process openings 7 serve to collect metal powder which does not participate in the fusion process, the powder is stored in bottles with the possibility of further sieving. After laying a new layer laser processing is implemented where the laser through a system of mirrors 8 9 scans the powder layer, fusing it with the previous layer. Build process itself takes place in a sealed chamber filled with an inert gas (argon, nitrogen). The process is cyclical and repeats until the product is completely finished.

![Diagram of SLM process.](image)

Figure 1. Diagram of SLM process.

The aim of this study was to conduct a comprehensive study of the structure of the sample material obtained by selective laser melting (SLM) of powder metal steel 316L. The results of the study of the surface of the powder particle morphology are presented in the article, as well as 3D X-ray quality control of the samples grown, conducted static tests of cylindrical samples in tension.

2. The methodology of the study
The objects of research are samples grown from the metal powder 316L of stainless steel on the 3D machine SLM 280HL. The manufacturer of the device is a German company SLM Solutions. Infrared fiber laser with a wavelength of 1075 nm and a maximum power of 400 watts is used to alloy powder. The laser is operated in a continuous mode. This machine has an open system that allows the use of powders for the manufacture of parts of one's own production. Construction of the detail is carried on a metal platform, the maximum dimensions are up to 280x280 mm. To prevent oxidation and combustion of the powder particles during the process of forming the monolayers working chamber filled with inert gas, wherein the oxygen content does not exceed 0.2%.

Before the process of growing samples on 3D machine as input control, the morphology of the surface of the powder particles was studied, particle size analysis was carried out. Metal powder steel 316L, a Russian analogue is 03H16N15M3 stainless steel was used as a building material. The study of the powder was carried out using a metallurgical microscopes METAM LE-31.

3D X-ray quality control of the samples grown was performed to detect hidden defects, using microfocus X-ray inspection system with CT function on the basis of X-ray machine Nikon Metrology.
XT H 225. X-ray system XT H 225 is an X-ray camera, suitable for working with objects in real-time, as well as for computed tomography objects. In this system, it is possible to create a difference in the X-ray gun potential of up to 225 kW X-ray power to 225 watts. In conjunction with a flat panel high-definition receiver, the system provides high-contrast images.

To determine the strength properties of the samples obtained by selective laser scanning state standard GOST 1497-84 “Tensile Test Methods” was used [5]. This standard establishes methods for static testing of products stretching. For tensile tests were selected samples of type VII number 3. The diameter of the cylindrical part of the working sample to test was 8 mm, the initial sample gauge length 40 mm, working length 52 mm.

3. Results and discussion

In selective laser melting technology strict requirements are imposed for metal powders on the quality of the surface of the particles, and particle size distribution. Figure 2 shows the results of the study of the surface morphology of 316L powder. It can be seen that the particle surfaces have sufficiently correct spherical powder particles in a small amount of visible growths. The formation of these nodules is associated with powder preparation technology, in this case, the metal powder was obtained by gas atomization of the melt [6-8]. Another important criterion for assessing the validity of the powder for SLM is the size of grains of powder. Figure 2b shows a histogram of particle size distribution of the powder particles of steel 316L. It is seen from the analysis that the average particle diameter is about 15 ... 60 mm, which satisfies the requirements for SLM technology powders.

![a) The surface morphology of the powder particles; b) The size distribution of the powder](image)

**Figure 2.** Study of metal powder steel 316L.

To study the structure and mechanical features of SLM parts, cylindrical samples have been designed. Then, in a special software product that came with the 3D machine model samples were positioned on the construction platform of 100x100 mm. The smaller size of the platform is justified by decrease of powder flow supplied to the laser beam scanning area. To prevent shear parts, its buckling during printing, as well as for ease of separation of the final product were raised platform construction parameters and configuration support material in the form of thin-wall block designs.

Samples grown on 3D car were sent to the X-ray control of the structure of the resulting material. Scanning of the sample was subjected to a median of about 17 mm in size. Presence of internal pore size of 38 ... 41 mm was found in the manufactured details. Figure 3 shows the results of computed tomography, arrows mark pores formed in the cross section of the samples.
To determine the strength properties of the components synthesized by the SLM, cylindrical samples according to GOST 1497-84 were designed and manufactured on SLM 280HL. The surface roughness of the grown parts is quite high, requiring the introduction of additional machining on a lathe [9-12]. Diagram of the process tests the force-elongation is shown in figure 4.

![3D X-ray inspection of the structure of grown material samples.](image)

**Figure 3.** 3D X-ray inspection of the structure of grown material samples.

Results of mechanical testing of tensile specimens grown in 316L steel metal powder and comparison with the properties of the samples obtained by casting technology are presented in Table 1.

| Technology | Strength limit, $\sigma_u$, MPa | Yield strength $\sigma_y$, MPa | Relative elongation, $\varepsilon$, % |
|------------|-------------------------------|-------------------------------|-------------------------------------|
| SLM        | 579                           | 455                           | 50                                  |
| Casting [13]| 485                           | 170                           | 40                                  |

**Table 1.** The values of the mechanical parameters of the molded and grown material.
It is seen that the ultimate strength of SLM samples is 15% above with respect to the tensile strength of cast samples. This result can be explained by the presence of the borders like those of "micro-welded seams" (MWS-borders). Crystallographically and chemically these boundaries are quite different from the "normal" grain boundaries. MWS-boundary has significant difference in the chemical composition of the base material and has a significant effect on the kinetics of deformation processes. MWS-borders create effective stoppers for the movement of lattice dislocations and an additional contribution to the strengthening of the material [2].

Significantly different is yield strength of the samples from the samples obtained by casting (about 63%). This significant increase in yield strength indicates that plastic deformation will develop in SLM samples at high strain. Ceteris paribus grown items will withstand heavier loads, in contrast to parts obtained by casting.

To determine the internal stress in the material of the grown samples, X-ray diffraction analysis was carried out. The XRD patterns are shown in figure 5, the values are summarized in table 2.

![Steel 316L Radiographs obtained by SLM.](image)

**Figure 5.** Steel 316L Radiographs obtained by SLM.

**Table 2.** Breakdown of diffraction patterns.

| HKL  | B₀, mm | B₀, mm | E₀, kg/mm² | R, mm | 2θ° | θ° | tgθ | σII, MPa |
|------|--------|--------|-------------|-------|-----|----|-----|----------|
|      |        |        |             |       |     |    |     |          |
| Defomed state | 111 | 3,0 | 4,0 | 21000 | 180 | 51,6 | 25,8 | 0,483 | -603     |
|       | 200 | 4,5 | 6,0 |         |     | 60,3 | 30,15 | 0,583 | -750     |
|       | 220 | 5,0 | 6,0 |         |     | 89,9 | 44,45 | 0,981 | -386     |
|       | 311 | 7,0 | 9,5 |         |     | 111,6 | 55,8 | 1,471 | -436     |
| Initial state | 111 | 4,9 | 4   | 21000 | 180 | 51,6 | 25,8 | 0,483 | +543     |
|       | 200 | 6   | 6,6 |         |     | 60,2 | 30,1 | 0,581 | +301     |
|       | 220 | 7   | 6,5 |         |     | 90  | 45   | 1,000 | +437     |
|       | 311 | 11  | 9   |         |     | 111,6 | 55,8 | 1,471 | +396     |
Table 2 shows that the displacement of the lines has not been identified, i.e. macrostresses are absent. Microstresses of type II are present and have a negative value in comparison with the initial state of the material. Presence of type II microstresses can point to inhomogeneous heating or cooling of the powder during sintering. Tensile and compressive stresses, appearing at the same time lead to plastic shear, which result in residual microtension.

4. Conclusion
1. As an input control, morphology of the surface of the metal powder particles of steel 316L was studied and the particle size distribution analysis implemented. Results showed that the particles have a spherical shape, a small amount of powder particles has visible growths. Histogram of the particle size distribution of the powder is also created and the average size was 37 microns that corresponds to standard.
2. The structure of the samples obtained by selective laser melting metal powder steel 316L was investigated. 3D X-ray quality control of manufactured samples showed that the material has internal pores of 38 ... 41 mm.
3. Mechanical properties of synthesized samples have been determined, where the tensile strength of 579 MPa yield strength of 455 MPa, elongation of 50%. Comparison with a molded sample showed that the tensile strength and yield strength SLM samples are 15% and 63% more respectively.
4. To improve the properties of material of details manufactured by SLM, further studies on the influence of heat treatment on the quality of the material structure and mechanical properties are required.

Acknowledgements
This work was supported by the Russian Science Foundation (project no. 15_19_00284) in the experimental part concerning the investigation of mechanical parameters of the 316L stainless steel manufactured by selective laser melting.

Samples for testing were manufactured on the equipment of CAM technology common use center (RFMEFI59314X0003). This work was supported by the Ministry of education and science of the Russian Federation in the framework of the implementation of the Program «Research and development on priority directions of scientific-technological complex of Russia for 2014-2020».

References
[1] Sufiarov V Sh, Popovich A A, Borisov E V and Polozov I A 2015 Selective laser melting of heat-resistant nickel alloy Tsvetnye Metally. Vol. 2015, Issue 1, pp 79-84
[2] Grjaznov M U, Shoshin S V and Chuvildeev V N 2012 Effect of mesostructural hardening of steel 316L during stratified laser alloying Bulletin of the Nizhny Novgorod University named after N. Lobachevsky. №5 (1) pp. 45-50
[3] Grjaznov M U, Shoshin S V and Chuvildeev V N 2014 Physical and mechanical properties and structure of the alloy Inconel 718, obtained by layering laser fusing technology Bulletin of the Nizhny Novgorod University named after N. Lobachevsky. №4 (1) pp 99-104
[4] Nazarov A P 2013 Features of machine design for selective laser sintering Vestnik MSTU “STANKIN” № 1 pp 76-79
[5] GOST 1497-84 1986 Test methods for stretching Moscow: Publishing House of Standards. 36 p
[6] Zlenko M A, Popovich A A and Mutylin I N 2013 Additive technologies in mechanical engineering SPb.: Publishing house of the Polytechnic University. 222 p
[7] Riemera A, Leudersa S, Thönea M, Richarda H A, Tröster T and Niendorfd T 2014 On the fatigue crack growth behavior in 316L stainless steel manufactured by selective laser melting Engineering Fracture Mechanics. Vol. 120 April pp 15–25
[8] Smelov V G, Sotov A V and Agapovichev A V 2016 Recovery Technology Features of Aerospace Parts by Layering Synthesis Key Engineering Materials. Vol. 684, pp. 316-322
[9] Fangxia X, Xinbo H, Shunli C and Xuanhui Q 2013 Structural and mechanical characteristics of porous 316L stainless steel fabricated by indirect selective laser sintering Journal of Materials Processing Technology. Vol. 213 Issue 6 June pp 838–843

[10] Vdovin R A and Smelov V G 2014 Elaboration of a casting defects prediction technique via use of computer-aided design systems International Journal of Engineering and Technology (IJET). Vol. 6 Issue 5 Oct-Nov pp 2269-75

[11] Smelov V G, Sotov AV and Murzin S P 2016 Particularly selective sintering of metal powders by pulsed laser radiation Key Engineering Materials. Vol. 685 pp. 403-407

[12] Olakanmia E O, Cochranea R F and Dalgarnoc K W 2015 A review on selective laser sintering/melting (SLS/SLM) of aluminum alloy powders: Processing, microstructure, and properties Progress in Materials Science. Vol. 74 pp 401–477

[13] http://goodner.ru/services/info/marks/316l-ti.