

Technological features manufacture samples of stainless steel 316L by Selective Laser Melting on the machine Melt Master3D-550.

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Abstract. In this work we consider obtaining high-density powder samples from austenitic stainless steel 316L, on the first national experimental layered build-up equipment by the method of selective laser melting (SLM) Melt Master3D - 550. The equipment description is given. Morphometric properties of the original powdered material is studied. Continuous unit vectors (tracks) and high-density samples with the relative density of 97% are obtained during the experiments. The laser radiation energy contribution is estimated to compare the conditions for obtaining samples with different technological parameters. In course of the study of the sample properties the dependence of density on the specific energy is revealed. Moreover, the influence of technological parameters on the microstructure and microhardness of the samples is established. The obtained data are compared with the results of other studies on similar foreign facilities.

1. Introduction

At present, high-technology production trends of such industries as machinery, electric energy (including nuclear), oil and gas, medical show great interest in additive technologies of making products with complex shapes from metal and ceramic powder materials. Additive manufacturing with the selective laser melting (SLM) is a layer-processing technology by local melting of metal powder materials with laser energy, which makes it possible to obtain high-quality products with complex shapes immediately, i.e. the subsequent final processing in most cases can be completely excluded.

Over the past decade of the development of additive technologies a large number of research papers which describe obtaining samples and products from various types of stainless steel with the selective laser melting have been published. As a rule, the authors give the following main technological parameters that affect the quality of the obtained products and samples [1, 2]:

- original metal powder: chemical composition, shape and size distribution of particles, thickness of the melted layer for each production cycle;
- laser radiation source: type, capacity, space-energy beam parameters (radiation intensity distribution, the size of the laser beam spot in the melting zone as a result of its divergence);
- characteristics of the production process: scan speed, type of a protective gas environment, choice of the type and parameters of the scan strategy on each melted layer.

In the papers [3-5] the samples of stainless steel 316L are studied. The experiments were carried out on the selective laser melting (SLM) Phenix Systems PM100. The source of the laser radiation in this equipment is the ytterbium fiber laser YLR-50 CW at the wavelength of 1075 nm and a maximum



output power $P = 50$ W. The size of the laser spot on the surface of the powder layer was about 70 microns. SLM was carried out in a closed chamber filled with nitrogen to prevent oxidation. The operating temperature in the chamber was kept at 80°C .

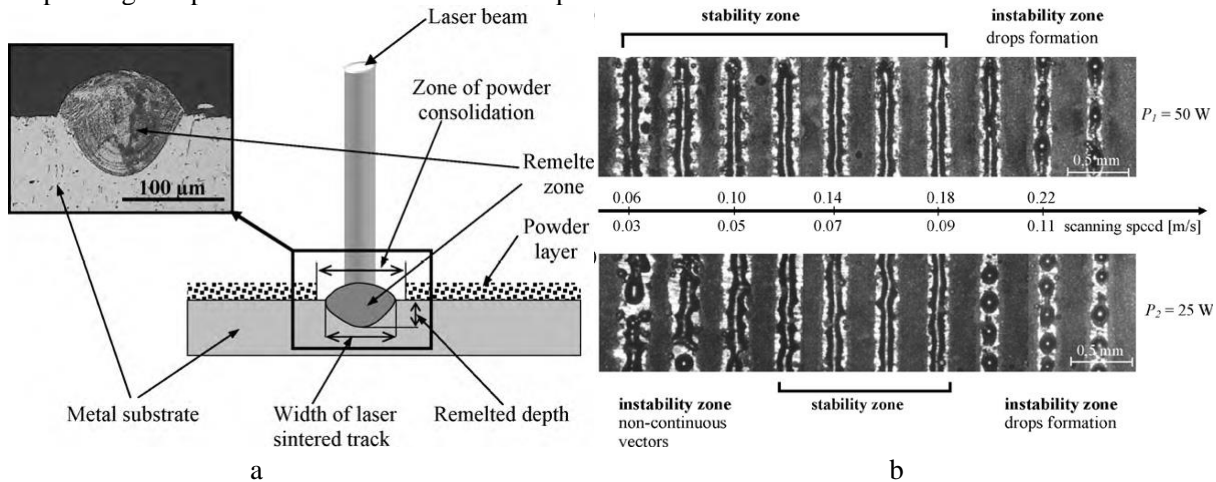


Figure 1. Tracks: (a) - cross-section of the track [4]; (b) - melted tracks from austenitic stainless steel [2].

The authors of the papers [3,4] describe the traces on the of stainless steel building platform at the laser power of 50 W and 25 W at various scan speeds in the range from 0.06 to 0.24 m / s and from 0.03 to 0.12 m/s respectively. The thickness of the powder layer was 50 microns. Figure 1 (a) shows a cross sectional view of the track indicating width, consolidation zone and the depth of melting zone. Figure 1 (b) shows photographs of the tracks made in different technological modes.

The authors of the paper [5] obtained bulk samples by combining the methods of "two zones" and "cross-hatch" with the following parameters: the laser power of 50 W, layer thickness of 40 microns, the scan speed of 0.12 m / s, the hatching step of 120 microns. The results of the mechanical tests of samples are shown in Table 1. The analysis of the mechanical properties of the samples produced by the SLM method from the powder of stainless steel (SS) 316L showed excellent mechanical properties matching cast materials.

Table 1. Mechanical properties of the SLM samples [5].

Properties of the sample	Way of the sample production	
	SLM	Casting
Tensile strength (MPa)	436±60	480-560
Yield strength (0.2%) (MPa)	366±50	170-290
Elongation (%)	9±2	40

The above-mentioned papers show the possibility of obtaining products from powders of austenitic stainless steels by SLM method on the basis of Phenix Systems PM100, Concept Laser GmbH M1. This article considers the production of high-density samples from stainless steel 316L on the first Russian equipment of layer build-up with the method of selective laser melting Melt Master3D550.

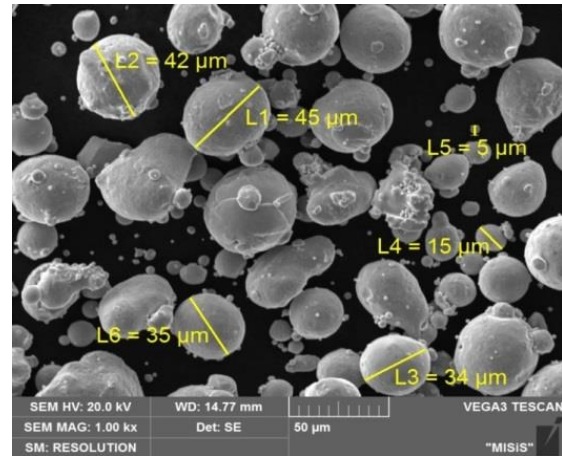
2. Experiments

The experiments were carried out on MeltMaster3D550, which external design is given in Figure 2. The main specifications of Melt Master3D550 are shown in Table 2, which, for comparison, also shows the parameters of similar imported facilities. In our experiments stainless steel 316L powder was used. Figure 3 shows photographs of the powder particles. The figure shows that the particles have a rounded shape. The estimates of the index of the powder particle geometry were obtained; the estimated average value was 1.5 with a standard deviation of 0.5. The particle size of the powder was in the range of 10 - 90 microns and the average particle size was 40 microns.

Table 2. Main characteristics of the facilities of different manufacturers producing layered products.

Equipment	SLM 500HL	EOS M400	X line 1000R	MeltMaster ^{3D} 550
Maximum sizes of the building platform (mm)	500×280×325	400×400×400	630×400×500	550×450×450
Laser, number, pcs. / Power, kW / type	2×0,4 (2×1,0) ytterbium fiber	1 / 1,0 / ytterbium fiber	1 / 1,0 / ytterbium fiber	1 / 1,0 / ytterbium fiber
Building rate (cm ³ /h)	up to 70	-	10-100	15-100
Layer thickness (μm)	20-200	-	30-200	20-250
Spot diameter (μm)	80-150/700	90	-	50-700
Scan speed (m/s)	up to 15	7,0	-	up to 15

The following technological parameters of the SLM process for obtaining sample were used: the scan speed from 100 to 1000 mm / s and laser power from 154 to 491 watts. The samples were made as a rectangular parallelepiped with dimensions of 3x3x15 mm. The thickness of the layers during the sample building was 200 micrometers. The same hatch was made for all the samples with a simple one-pass strategy. The selective laser melting process of the samples occurred in a nitrogen atmosphere, residual oxygen at the concentration less than 0.07%.

**Figure 2.** External design of MeltMaster^{3D}-550.**Figure 3.** Morphological characteristics of the steel powder particles 316L.

3. Results and discussion

3.1 Measure of the track width

During the building of bulk samples one of the important parameters is a hatching step. To determine the right step for a given layer thickness the continuous tracks were obtained from a single layer of the same thickness as that of the samples (200 microns). To obtain the tracks the main parameters were the following: power from 379 up to 530 W and scan speed from 60 to 100 mm/s. The width of the tracks was measured by the microphotos. The hatching step was calculated on the basis of the following equation (1):

$$h = 0,7 \times b \quad (1)$$

where h – hatching step, b- track width.

The calculated value of the hatching step is 180 microns.

3.2 Dependence of the sample density on SLM parameters

For comparing the conditions of sample building with different technological parameters, it is necessary to determine the contribution of specific laser energy. The sample density measurement results made under different technological SLM modes are shown on the diagram of the dependence of sample density on the specific energy (Fig. 4).

The evaluation of the specific laser energy for each tested sample was carried out according to the following formula (2) [6]:

$$E_{sp} = \frac{P}{V \cdot d} \quad (2)$$

where P - laser radiation power, V - scan speed, d - spot diameter.

The analysis of the dependences of sample density on specific energy showed that when the energy changes from 1 to 3 J/mm² the density increases dramatically, but at the same time the density value is less than 90%. When increasing the specific energy from 3 to 12 J/mm² there is an increase in density, but with a less dependence. The further increase in specific energy does not lead to the increase of the sample density actually. It can be also concluded that the optimum value of the specific laser energy is 8 - 15 J/mm². These values are consistent with the published data in the above-mentioned papers, and have a similar dependence of the sample density on the introduced specific energy [7]. When the samples are separated from the building platform the following result was reached: a group of samples made in the range of the input specific energy from 0.8 to 1.9 J/mm² was not welded to the platform.

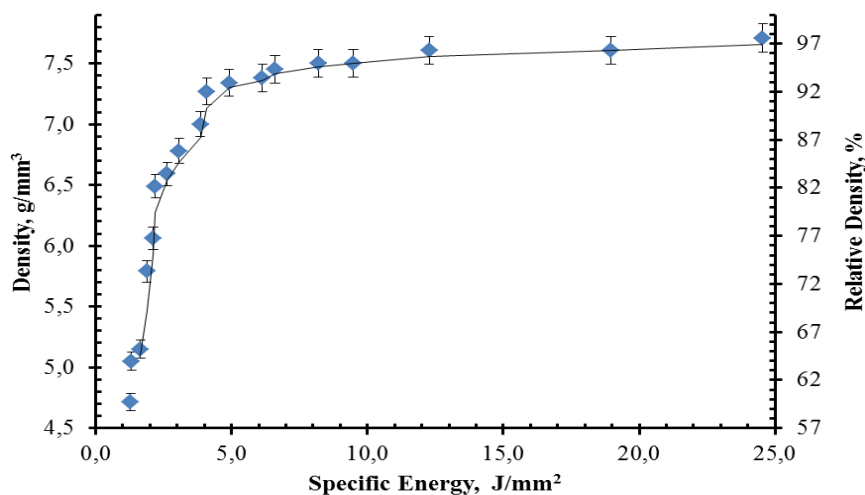


Figure 4. Dependence of the sample density on the input specific energy.

3.3 Microstructure Research

The results of microstructure studies of samples made with specific energy up to 3.0 J/mm² showed the presence of open macropores (shells) of more than 150 microns (Figure 5 (a)). For samples made with the input specific energy from 3.0 to 8.0 J/mm² pores of a 100 micron were typical. Furthermore, the the samples produced by the SLM method have a layered structure. The samples made with the input specific energy from 8 to 12 J/mm² were characterized by the presence of micropores.

The samples obtained at the input specific energy from 12 to 25 J/mm² have micropores and tracks of repeated melting. The pore distribution in this case is random. Figure 5 (b) shows the typical microstructure of micropores and repeated remelting of the example of the sample obtained at the input specific energy of 19 J/mm². All the samples found multidirectional dendritic segregation and fine-grained area. This structure is due to the rapid cooling of the molten pool and directed crystallization during selective laser melting.

Moreover, the element composition analysis of the sample with a density of 95% from the theoretical density obtained at the input specific energy of 12 J/mm². The results of the studies showed that there was no oxygen and oxides in the sample indicating little (less than 0.07%) oxygen in the working atmosphere.

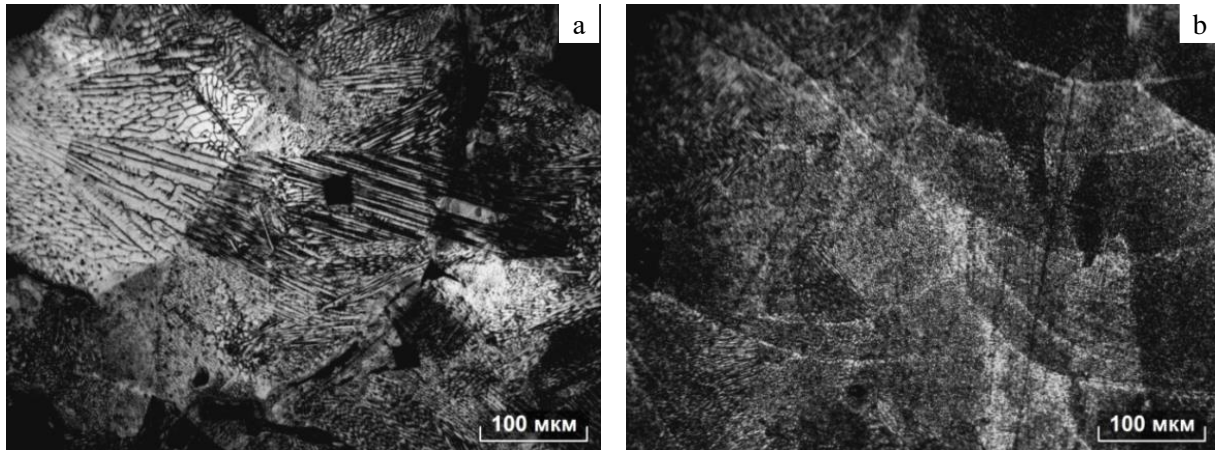


Figure 5. Typical microstructure of samples with macropores.

3.4 Microhardness

The measurement results are presented in the diagram of sample microhardness dependence on the specific energy of the SLM process (Figure 6). As seen from Figure 7 the microhardness of the samples obtained at the input specific energy of 8.2 J/mm² and 24.6 J/mm² is almost identical (the difference is less than 1%). This confirms that the optimal range of the value of the specific energy is 8 - 15 J/mm² for the layered synthesis process by SLM. Since the microhardness and density dependence on the technological SLM parameters is similar it can be concluded that the main reason of the sample microhardness increase with the increase of the specific energy of the powder melting is the decrease of the pore volume fraction.

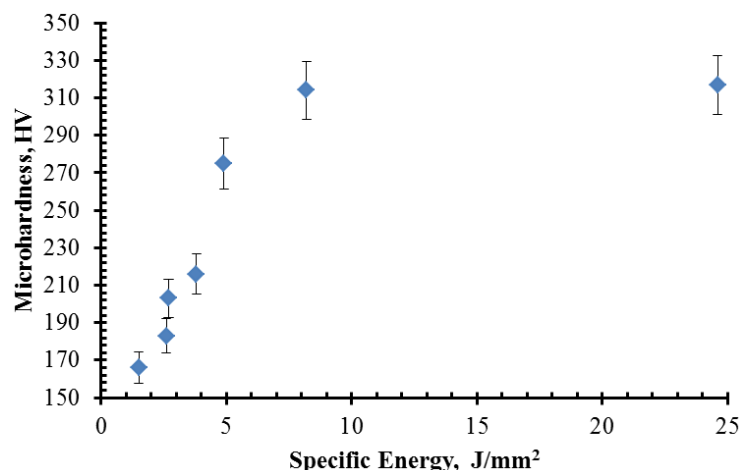


Figure 6. Dependence of microhardness on the parameters of SLM process.

4. Conclusions

The production of the first set of samples has shown the fundamental possibility for obtaining high-density samples from austenitic stainless steel 316L on layered selective laser melting MeltMaster3D-550 equipment.

In the course of continuous tracks study the right hatching step was calculated. At the thickness of the powder layer of 200 microns the right step between the adjacent passes of the laser must be 180 microns.

The study Identified dependencies of the sample density on the laser radiation power and scan speed. A more narrow range of input specific energy from 8 to 15 J/mm² is described.

The interrelation of the input specific energy and sample density has been set. The studies have shown that the dependence of the sample density on the input specific energy is consistent with the data presented in the paper [7].

The microstructural studies have revealed the dependance of selective laser melting parameters on the density, microstructure and microhardness of the samples. The samples from the steel 316L with the density more than 95% have the microhardness of about 315 HV.

Acknowledgments

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