ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

Research Of The Quality Of Obtaining Stocking From Stainless Steel By Selective Laser Sintering.

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ABSTRACT

The technology for the production of powder products by the method of selective laser sintering (SLS) makes it possible to obtain materials using the energy of laser radiation to fuse the powder particles while maintaining the solid core, which leads to the formation of interparticle contacts in the presence of a liquid phase. Such a technology, ensuring minimal shrinkage of the layers in the absence of particle conglomeration, would allow obtaining a given porosity of the products while maintaining the structure and phase composition of the starting material. Layer-by-layer synthesis technology allows reproducing products with a high degree of accuracy, as well as providing a homogeneous structure and improved mechanical characteristics. However, for the quality of the products obtained, it is important to control the mechanism of structure formation, and, as consequence, mechanical properties. The article considers the factors affecting the quality of the billet produced using the SLS method. The main types of defects in the manufacture of parts by the SLS method are considered.
Keywords: The Additive Technologies (AT), 3D technology printing, the selective laser sintering (SLS), x-ray control, a tomography, quality, defects, "green technologies", environmentally friendly production, thermal, diffusive, kinetic, rheological processes.

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ISSN: 0975-8585

INTRODUCTION

The study of SLS processes involved domestic and foreign scientists:

V.M. Dovbysh, M.A. Zlenko, M.D. Krivilev, S.P. Murzin, A.P. Nazarov, A.A. Popovic, A.A. Saprykin, I.Yu. Smurov, V.Sh. Sufiyarov, E.V. Haranzhevsky, I.V. Shishkovsky, I.A. Yadroittsev, C.D. Boley, Chee Kai Chua, C. Coddet, A.V. Gusarov, Kai Zeng, S.A. Khairallah, J.P. Kruth, Maarten Van Elsen, T. Ozel, A. Riemer, A.M. Rubenchik, J. Sienz, E.M. Weissman, Xiaoze Du and others.

Analyzing the work of scientists, we can distinguish the following current research areas: 1) Development of a methodology for designing the manufacture of parts by selective laser sintering. 2) Development of the SLS technology and selection of the optimum treatment regime for the powder layer. 3) Metal powders of high-temperature alloys on a nickel basis are of particular interest. These alloys are widely used in aircraft engine building, in the manufacture of the main components of the hot tract of gas turbine engines, in particular, the combustion tubes of combustion chambers.

The essence of manufacturing billets by the method of selective laser sintering consists in layer-by-layer sintering of powder materials with the help of a laser beam (Fig. 1) [4].

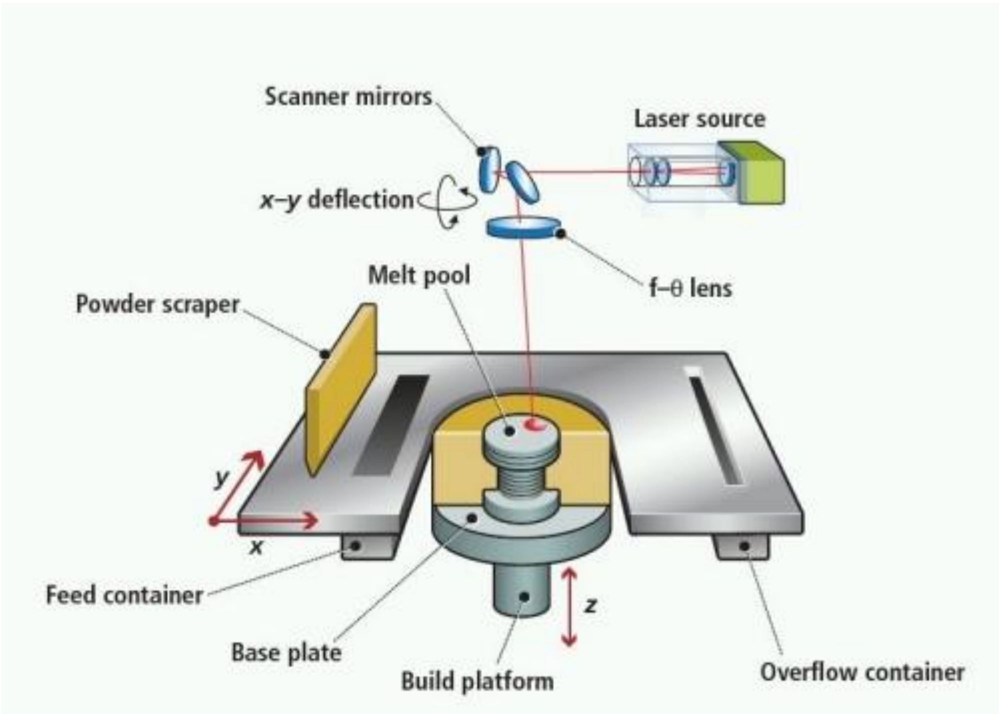

Figure 1: Production of products by selective laser sintering method

The laser beam sinters powder layer by layer in a powder bin. The powder is supplied in a thin layer and spreads over the entire surface with a blade or knife. The laser beam looks through and melts the powder, which will include the first layer of what it will build. The next layer will be built in sequence, immersing the construction platform at a distance of one building layer to place the next layer of powder on top of the first layer built.

The technology of layer-by-layer synthesis allows to reproduce products with a fine precision and also provides uniform structure and the improved mechanical characteristics [5-8]. In process powder material, primary spherical shape is used. Also a number of requirements are imposed to raw powders: by the size, the pour density and viscosity. Sintering of powder particles occurs layer by layer under the action of laser radiation on a substrate of various materials. As a result, the particles are fused, the substrate descends one level down and the process repeats [9].

In the process, sintering parameters such as laser intensity, holding time, laser power, pulse frequency, laser beam scanning speed, protective atmosphere are monitored. In the layer of powdered material, a modeled product is formed, the properties of which depend on the parameters of the laser radiation. The quality of the sintered layers is characterized by the minimum deviation from the nominal sizes, the most achievable efficiency, uniform density, thickness of the processed layer [10].

However, theoretical and experimental studies of physicochemical processes occurring in powder materials under intense external influences (temperature, pressure, electromagnetic fields, etc.) are still one of the attracting attention and comprehensively developed fields of chemical physics and physics of a solid.

High-speed heating, inherent in laser action in SLS processes and integrated with technology, opens up opportunities for studying the features of thermal, diffusion, kinetic, rheological and mechanical processes, in states far from equilibrium.

The flow of a particular mechanism is determined by the energy of the interfacial interaction at the solid-melt interface.

Unlike sintering technology, where powders are heated to below the melting temperature of the main component for the implementation of the atom diffusion mechanism [11], the formation of a dense structure and, as a consequence of the high values of the mechanical properties of the material being synthesized, will be determined by the process of complete penetration of each individual powder particle, by welding it to the underlying layer.

The melting process is ensured by determining the optimal range of processing parameters boundaries when scanning with a laser beam a powder layer.

However, at production of details by SLS method various defects can emerge.

The following types of defects are most common [12]. 1. Porosity. This type of defect has the greatest effect on the fatigue characteristics of the material and is the source of crack growth in the part. It was established in [13] that in layer-by-layer technologies pores can be distributed inside the volume of the main material, between the inner hatching area and the outer boundary of the produced part, or in the surface layer of the part being synthesized. 2. Stratification and internal stresses. The stratification of the synthesized material is caused by the formation of cracks between adjacent layers (interlayer delamination). The process of formation of a stratification occurs due to the appearance of high values of internal stresses, exceeding the strength of the bond between the upper and lower layers [14]. In [15] one of the cases of material stratification is presented, such as the partial separation of the workpiece from the construction platform. 3. Clotting. The process of clotting the material when scanning with a laser beam occurs when molten metal powder particles solidify into spheres instead of layers, which is a serious obstacle for interlayer binder. [12]. In work [16], the results of a study of the effect of the clotting process in SLS are presented, where it was found that this phenomenon increases the roughness of the surface layer of the product being synthesized, a large number of pores is formed between the fused metal particles, and the clotting process can prevent the powder metering system from moving to the treatment zone. 4. Microstructural inhomogeneity. The SLS process is characterized by a local high-temperature energy supply for a very short time of exposure of the laser beam to the material being processed, which has a significant effect on the microstructure of the material [12].

Microstructural heterogeneity adversely affects the mechanical and functional properties of the part and includes: impurities, grain size, crystallographic texture. Impurities are inclusions, contamination from other materials, and the formation of an oxide film [16].

The results of a study of the influence of unmelted metal powder particles on the mechanical properties of a material were presented in [17].

It is considered that not completely melted particles are sources of the lowered material durability due to the lack of mechanical communication between synthesizable layers of a detail. Process of production of products by SLS method is influenced by a set of factors. Some of them are defined by the main properties of powder compositions.

Control factors include technological modes of the SLS process, for example, scanning speed, laser radiation power, scanning step, type of hatching by a laser beam, which are selected to obtain high-quality products. The microstructural inhomogeneity is largely determined by the processes associated with the interaction of the laser radiation spot with the powder material. An investigation of the influence of various parameters of the SLS process on the structure of the synthesized material for various powder compositions was presented in [18, 19].

Most of the studies have shown the dependence between the energy density of the laser beam and the density of the synthesized material on the quality of the resulting product.

The purpose of this work is to study the factors affecting the quality of blanks produced by selective laser sintering.

To achieve the goal, the following tasks were accomplished:

1) Determine the factors affecting the quality of the billet obtained by selective laser sintering.
2) Determine the effect of laser radiation on the quality of the sintered part.
3) Study the interaction of particles at the solid-melt boundary.

MATERIALS AND METHODS OF RESEARCH

Selective laser melting was carried out with the EOSINT M280. The subject of the study were samples of stainless steel powder EOS Stainless Steel PH1, obtained by laser recrystallization of powder material. Chemical composition of powder following: Fe (basis), Cr (14-15.5%), Ni (3.5-5.5%), Cu (2.5-4.5%), Mn (max of 1%), Si (max of 1%), Mo (max of 0.5%), Nb (0.15-0.45%), C (max of 1%). This type of steel is characterized by high corrosion resistance and excellent mechanical properties, especially in the dispersion-hardening state.

Manufacturing with standard parameters and 20μm thickness of the build layer, the parts are completely fused.

The granulometric composition of the powder was carried out on a laser particle analyzer "Microsizer-201C". The average size of the powders in a given fraction is 63 μm. Powders have a spherical shape (Fig. 2) with the presence of satellites on the surface (Fig. 3). The results are shown in Table 1.

Table 1: Granulometric composition of powder PH1

Particle size, μm	Content,%
<5	0,6
5-10	0,7
10-20	8,7
20-30	29,7
30-40	28,3
40-50	17,1
50-60	8,2
60-70	3,5
70-80	1,5
80-90	0,7

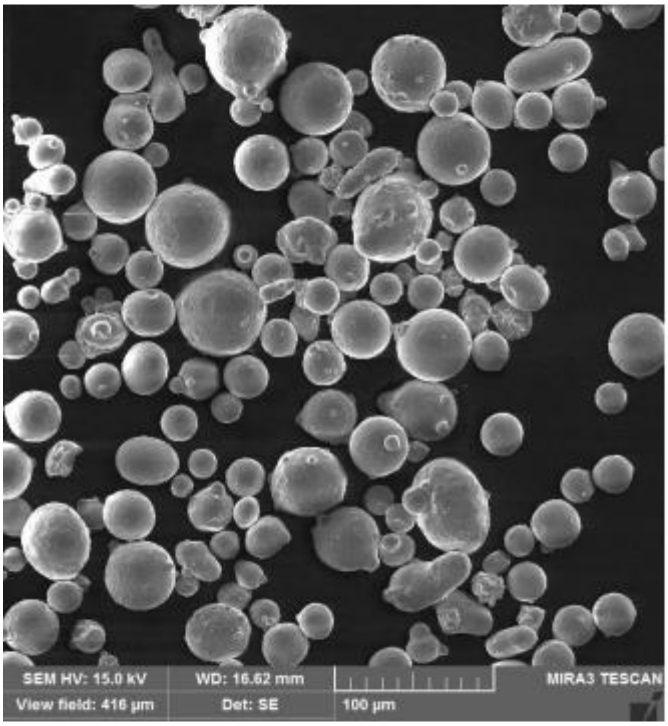

Figure 2: Type of powder of the PH1 brand

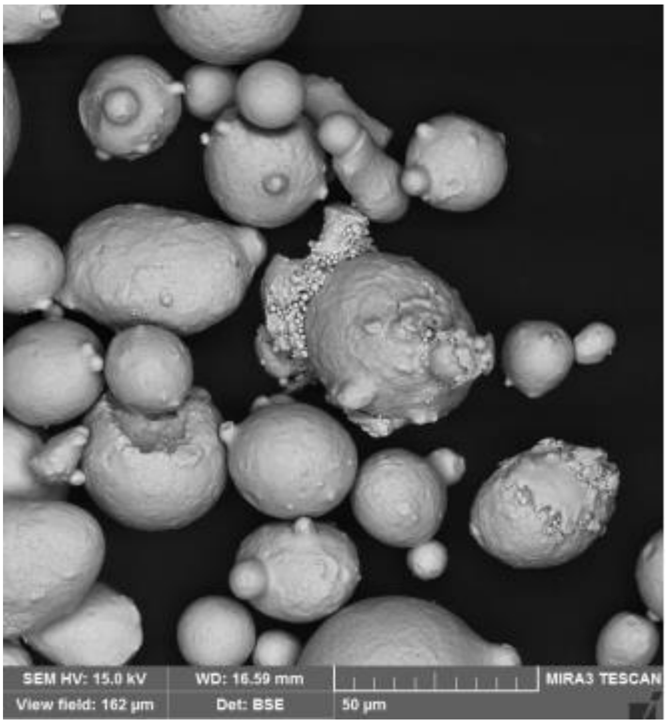

Figure 3: a type of powder of the PH1 brand (with existence of satellites)

For the SLS process, parameters were chosen that make it possible to obtain a continuous object with a minimum content of pores.

The parameters at which SLS was conducted are given in Table 2.

Table 2: The main parameters under which the SLS process was conducted to grow stainless steel parts PH1

The main parameters under which the SLS process was conducted to grow stainless steel parts PH1					
model	operating area, mm	the build step, µm	laser power, W	productiveness, cm^3/h	material
EOSINT M280	250x250x350	20-200	400-1000	20-35	PH1

The process was carried out in a nitrogen medium. The heat treatment was carried out at a temperature of (482 ± 10) ° C, an exposure time of 4 hours, cooling in air.

Quality control of the surface layer of the billet was carried out on the equipment. The contourograph T-8000 is a device for testing the roughness and surface contours of the Hommel Tester T8000-RC200-800 (Figure 4) and the DIP-1 microscope.

Figure 4: The contourograph T8000

RESULTS AND DISCUSSION

During laser sintering, a laser beam, with a diameter such as 100 µm, locally melts the top layer of the powder on the powder web. The laser will be partially absorbed by the metal powder particles, creating a molten layer that very quickly solidifies, using the laser radiation energy to surface fuse the powder particles while maintaining the solid core, which leads to the formation of interparticle contacts in the presence of the liquid phase. Such a technology, ensuring minimal shrinkage of the layers in the absence of particle conglomeration, would allow obtaining a given porosity of the products while maintaining the structure and phase composition of the starting material.

Layer-by-layer synthesis technology allows reproducing products with a high degree of accuracy, as well as providing a homogeneous structure and improved mechanical characteristics. However, for the quality of the products obtained, it is important to control the mechanism of structure formation, and, as consequence, mechanical properties. In SLS technology, materials heated by laser radiation reach the liquid phase during melting. Figure 5 shows the main stages of the change in the shape of a powder particle when laser radiation is processed.

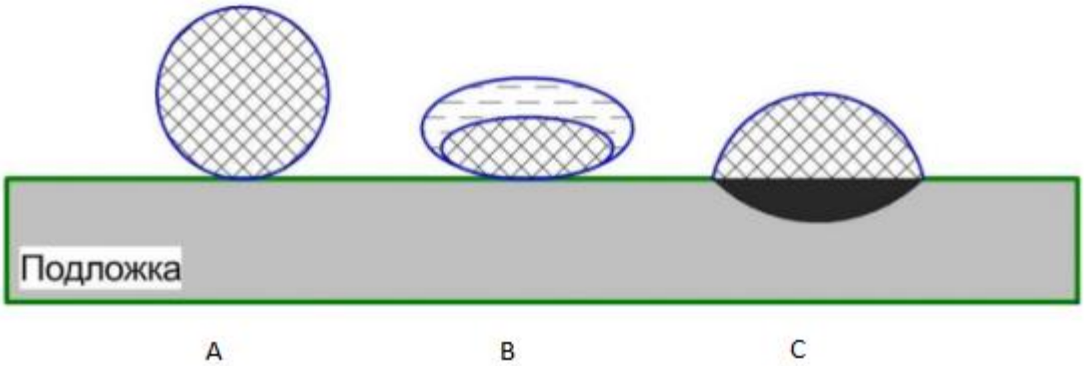

Figure 5: The main stages of the change in the shape of powder particles in SLS

A. - solid phase of the powder in the initial state; B. - the formation of the liquid crystal phase upon melting of the powder; C. - recrystallization of the powder, formation of a dense structure.

It should be noted that in the SLS process, the crystallization of the powder material takes place under conditions of ultrafast cooling rates from the liquid state (105 ... 106 K / c), and when laser treatment of adjacent areas already recrystallized material undergoes reheating. This influence largely determines the performance characteristics of the future part.

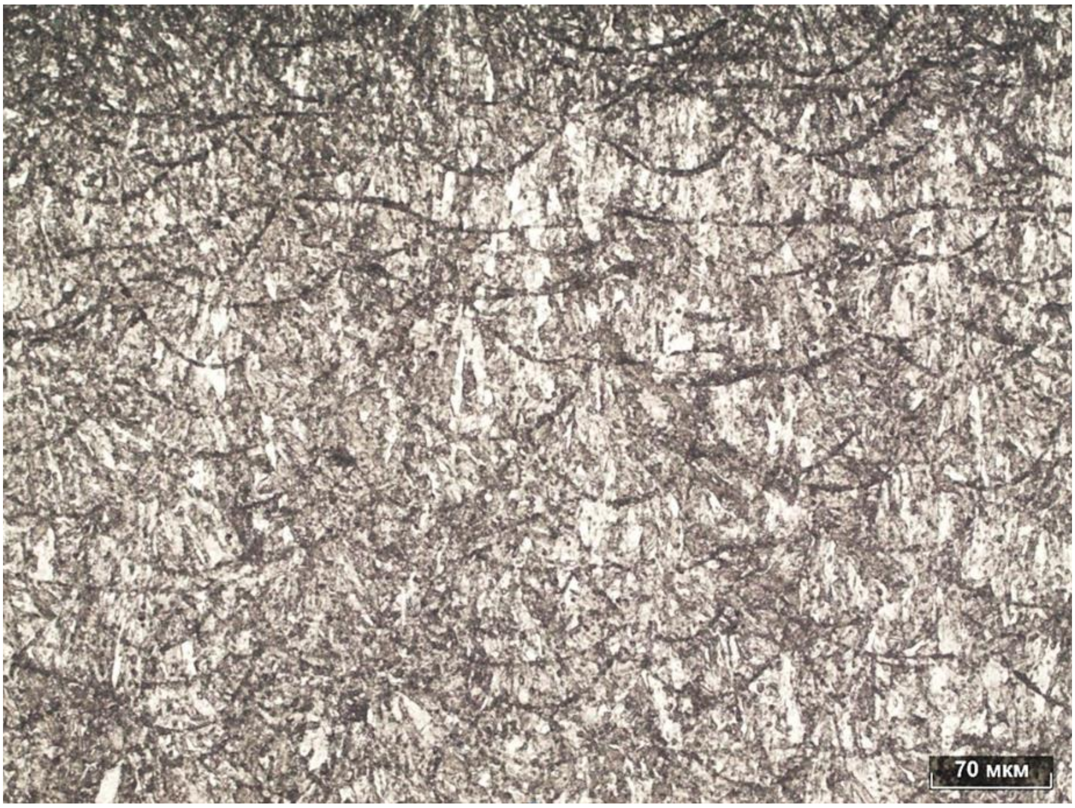

Figure 6: Microstructure of the PH1 alloy

The studies were aimed at correlating the main process parameters, such as the laser beam power, throughput, the build step, which have a significant influence on the dimensional features of the material, such as the height and width of the preform layer, as well as the quality of the surface layer and the penetration depth of the laser beam.

And at this stage it is very important to monitor the quality of the sintered powder layer [20-22].

ISSN: 0975-8585

In Figure 7, you can see the surface layer of the workpiece made of stainless steel.

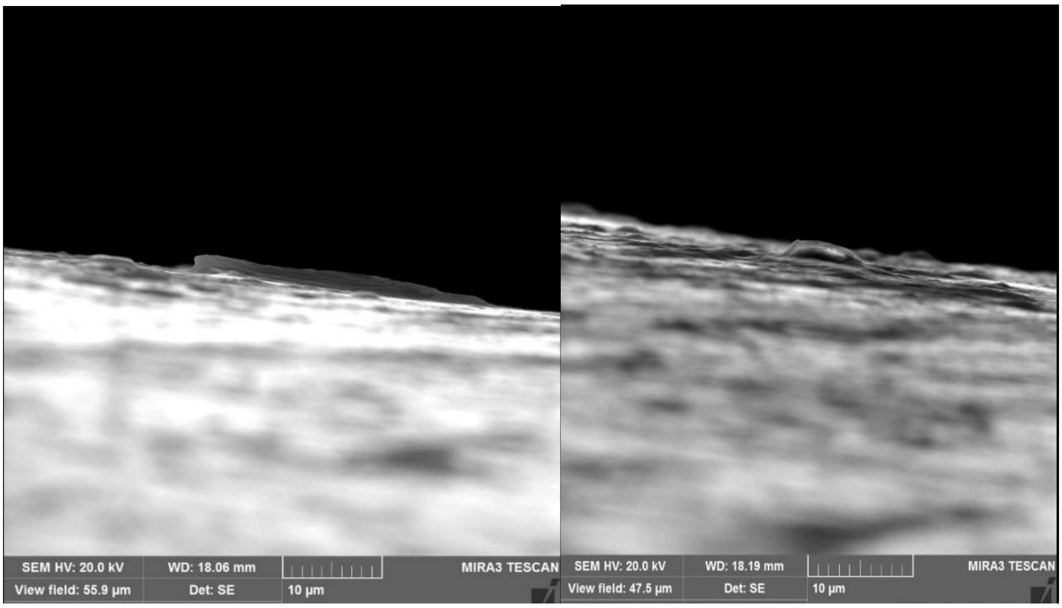

Figure 7: Surface layer of the workpiece

When monitoring the quality of the blank by the method of computed tomography, a defect in the form of a darkening characteristic of discontinuity was found (Fig. 8).

a) b)

Figure 8: The inconsistency revealed in computed tomography
a) Surface after hydroabrasive treatment; b) Surface after selective laser sintering of the powder.

Investigating the microstructure of samples of stainless steel products made using the SLS method, one can see that they have defects that can be classified as pores and shells. The reason for this is the surface tension under the action of which the melt tends to reduce the free surface energy by forming pores (Fig. 9).

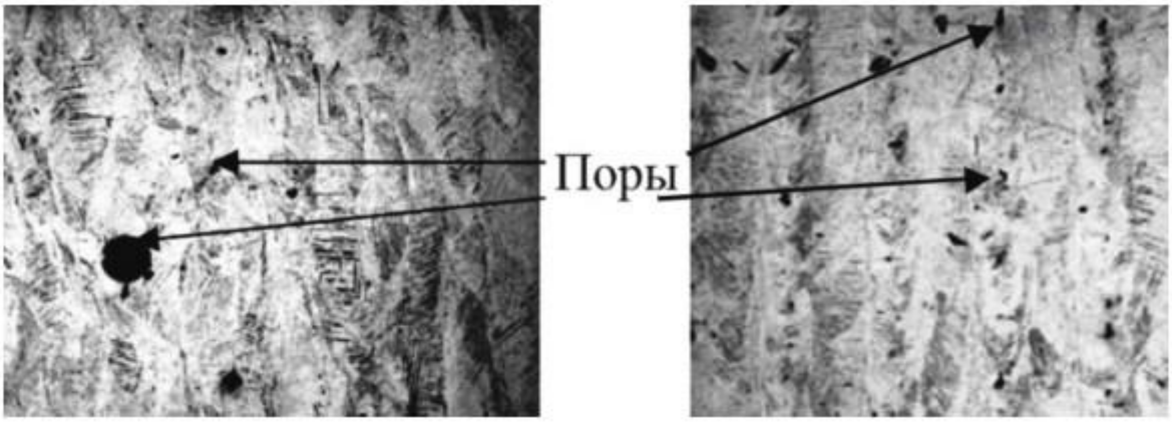

Figure 9: Pore formation

The SLS process traditionally acts through atomic diffusion and the binding of structural powder components at temperatures well below the melting point, then melts with a laser, thus enveloping the powder through capillary forces.

CONCLUSION

For each production, the criterion for the quality of any product is the formation of a stable, dense (no voids and pores) structure having a regular geometric shape and a good metallurgical connection with the substrate.

There are no optimal process parameters that work in all cases. Differences in wall thicknesses, height and angles can lead to thermal concentrations leading to, for example, phase conversions, residual forces or recrystallization.

Before the direct production of a particular product, it is necessary to search for and optimize the parameters of each selective laser melting process.

As a rule, from the whole range of factors affecting the quality of the part, these are: temperature, laser power, scanning speed, powder layer thickness, and other factors.

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