Formation of aluminum alloy parts with working internal cavities by selective laser melting

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Abstract. The great difficulty in synthesizing parts by selective laser melting lies in the formation of high-quality internal surfaces of workpieces. High quality is understood as the absence of defects in the form of shells, pores, partially fused powder granules, forming a rough surface. This task is especially relevant when obtaining parts by selective laser melting of aluminum alloys powders. The main problem is the great complexity or impossibility of their mechanical post-processing. Thus, in the manufacture of parts with working internal cavities used for the flow of liquids and gases, the presence of defects is completely unacceptable. In this paper, we studied the formation of defects in the internal surfaces during the process of obtaining objects by selective laser melting, in particular, the sticking of granules of powder material on the formed surface under various processing conditions. Variable parameters were scanning speed and laser radiation power. Data on the behaviour of the growth of a multilayer object depending on the variable parameters are obtained. The groups of samples of different shapes obtained under different melting conditions are considered.

1. Introduction

Additive laser technologies are technologies that can be used to create functional parts by layer-by-layer melting of microparticles of powder by laser radiation. In the manufacture of parts by selective laser melting, a number of physical processes are observed, such as heating, melting of the powder material and instant hardening with the formation of the necessary layer of the resulting part. It is also worth paying attention to the physical processes that are directly important for growing defect-free parts. Due to significant temperature gradients, non-optimal processing conditions, the formation of the following defects is possible: stresses, deformations, size inaccuracies, cracks, delamination, and porosity occur. The heat generated by the laser beam must be quickly removed / dissipated in the volume of the part from the molten bath to prevent the formation of residual stresses. For this reason, the thermal conductivity of the materials of the created part must be sufficiently high. To reduce the amount of unwanted heat, thereby reducing the residual stress [1], resort to optimizing of the part construction mode. When the thermal stress exceeds the material strength, plastic deformation occurs. The deformation of the part hanging elements is also due to the absence of supporting structures designed to fix the deposited layer with the previous layers [2]. Supports play an important function in constructing a part of complex geometric shape [3-5], for example, incorrect calculations of supporting structures and location of the part on substrate can lead to increased thermal stress, and as a result to the defects formation, warpage of the part, or the impossibility of its synthesis [6,7].
The aim of this study is to search for processing regimes using selective laser powder melting, which allows to create parts with holes or internal channels to easily remove supports, reduce deformations of resulting part and the roughness of internal surfaces.

2. Materials and Methods
The experimental samples were obtained by selective laser melting using an optical fiber laser with a maximum power of 400 W and a beam scanning system. Metal powder material of an aluminum alloy AlSi10Mg with an average fractional composition of 30 μm, mainly spherical, was deposited on the surface of the substrate. The powder layer with a thickness of 40 μm was subjected to continuous laser irradiation: the radiation wavelength – 1070 nm, the diameter of laser beam on the treated surface – 120 μm. For focusing, an optical system with an F-Theta lens was used. The key parameters were scanning speed and laser power. In order to ensure uniform heat exposure and reduce internal stresses, the following scanning strategy was chosen: the scanning area was divided into small areas and processed by a laser beam in a random order. To exclude oxidation of the material during laser processing, the workspace was located in a protective nitrogen gas environment.

Due to the complexity of manufacturing parts with internal channels, the shape of the samples (figure 1A) was chosen in such a way as to study the process of surface growth of parts in holes and channels with a diameter of more than 7 mm [8]. The model is a 15x15mm cube with a through hole of 10 mm. The number and thickness of the supporting structures should be minimized in order to reduce the mechanical processing time and to exclude the possibility of forming supports in hard-to-reach areas [9].

![Figure 1. 3D models of prototypes.](image)

To study the quality of inclined surfaces, we chose the form shown in figure 1B. This model demonstrates the roughness of the side surfaces formed as a result of volumetric heating of the grown part in contact with powder material, as well as the quality of the formed surface in the absence of heat removal (supporting structures). The growth of the samples occurred from bottom to top along the Z-axis.

3. Results
Three groups of samples were obtained under various processing conditions for forms A and B. The first group of samples was fabricated at various powers (from 200 W to 400 W) at a constant speed of 2000 mm/s (figure 2 and figure 3).
Figure 2. Group of samples No. 1 of a cubic shape, formed at different power and constant scanning speed of 2000 mm/s.

The cubic samples obtained at a power of 400 W turned out to be the most fragile and crumbled upon separation from the substrate (as can be seen in figure 2). Samples obtained at a power of 300 and 350 W, also have defects in the form of cracks. In the holes of these samples, an increase in unmelted and adhering powder particles is observed, which is unacceptable in the manufacture of parts with internal hard-to-reach channels. Visually, the highest quality can be considered samples obtained at a power of 200 and 250 watts.

Figure 3. Group of samples No. 1 with inclined surfaces, formed at different power and constant scanning speed of 2000 mm/s.

When considering a group of samples with inclined surfaces, a decrease in roughness with a decrease in power from 400 W to 200 W can be noted, which is clearly shown in figure 3.

The second and third groups of samples (figures 4 and 5) were manufactured at a beam scanning speed of 1000 to 2000 mm/s and with a constant power of 250 and 200 W, respectively.
Figure 4. Groups of samples No. 2 and No. 3, formed at different scanning speed and constant power.

At a power of 200 W and a speed of 2000 mm/s, samples were obtained that have the smallest roughness of the inner surface of the cylindrical channel; in other modes, fused granules of powder material are observed. The quality of the inner side surfaces of all samples was the same. The upper surface was rougher than the side. In the group of samples with inclined surfaces, as in the samples of the first group, a decrease in roughness is observed with a change in speed from 1000 to 2000 mm/s (figures 5, 6).

Figure 5. Groups of samples No. 2 and No. 3, formed at different scanning speed and constant power.

The smallest surface roughness is observed at a power of 200 W and a scanning speed of 2000 mm/s, which corresponds to the regime with the smallest thermal effect. Both types of samples have the same defects – fused granules of powder material located on internal surfaces. The formation of spherical structures at the interface between the melt and the powder material is associated with poor wetting conditions and loss of bonds between the melt and the contact area.
Two defects that often occur during the formation of overhanging surfaces are scale and warping [10]. In the case when laser processing occurs in the zone of the melted layer, the thermal conductivity is high, however, when the laser processes the boundary powder layer, the thermal conductivity becomes much lower than that of the solidified fused layer zone. Heat removal is possible only in the sample volume, since the thermal conductivity of the powder material layer is ten times less. Significant thermal effects are observed at a lower scanning speed and higher laser radiation power. In this case, heat from the affected area does not have time to be absorbed by the volume of the formed part, granules fuse with each other, heat deficiency occurs, granules melt only in the contact area, the formation of a continuous structure does not occur, which is shown in figure 3 and figure 6. The described effect is most pronounced in the construction of thin-walled horizontal elements. The energy consumption is much greater when the laser beam processes the powder layer than the solidified melt, which leads to an increase in the volume of the melt and immersion of powder particles in it. For the aforementioned reason, a scale will form and the surface of the part (especially the lower region) formed by laser melting of the overhanging layer will be of poor quality.

4. Conclusion
The studies carried out allowed to determine the necessary set of parameters for layer-by-layer production of a volumetric part from powder aluminum alloy. The best quality of the obtained internal channels surface and external inclined surfaces was noted at a power of 200 W and a scanning speed of 2000 mm/s. In other cases, formed surface contains inclusions of adhering particles of the powder material, a distortion of the geometric shape of the part is observed. Thus, the need for the correct determination of the heat load during the preparation, orientation and construction of the part model is revealed. The creation of thin-walled elements containing internal channels, the mechanical processing of which is difficult, requires the selection of the optimal formation mode. The processing sample mode should be determined depending on the geometry of the part, it is necessary to give preference to modes with minimal thermal load.

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Figure 6. Optical images of groups No. 2 and No. 3 samples surfaces.
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