Laser melting of powder materials with developed morphology of granules

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Abstract. In this paper, we consider the possibility of increasing the efficiency of laser melting by changing the morphology of the powder. To change the absorptivity of the granules, the treatment of the material was carried out by the mechanical action of the abrasive material on the metal powder base. As a result of grinding the powder composition in a planetary mill, the surface and shape of the granules were greatly altered, and a developed microrelief was formed. This was recorded with the help of scanning electron microscopy. Experiments on the fusion of the synthesized powder material took place on an installation equipped with an iterbium fiber laser operating in a continuous mode of radiation generation. The formation of a layer in the cross section was studied. It is noted that the developed developed morphology of the powder granules absorbs laser radiation to a much greater extent than the smooth surface, thereby increasing the efficiency of laser melting. The use of this method made it possible to significantly reduce the energy of laser radiation necessary for fusing the powder.

1. Introduction

Currently, additive technologies are actively developing around the world. The multilayered laser melting of metallic powder compositions is one of the directions. The popularity of the application of this method of synthesis of details is growing every day. This can be attributed to the high flexibility of production (from the time of creation of the 3D model to the time of its production an insignificant time passes), with the possibility of modulating the properties of the obtained was done by changing the concentrations of various powders used. A small amount of production waste and minimal subsequent machining are also attractive aspects of layer-by-layer technology.

The essence of the selective laser melting method lies in the metered supply of powder to the laser radiation impact region, then the formation of a part of a given geometry occurs, or a certain coating is applied from the fused powder particles. The accuracy of the manufacture of parts depends on the thickness of the forming layer (usually it is from 50 to 100 μm) [1]. This is due to the size of the spheres in the powder used and the features of the focusing system. The most common is powders with the size of granules from 20 to 60 microns. Modern trends in mechanical engineering require reducing the particle size of the powder to 10 microns, which will increase the accuracy of processing (synthesis of the part or the formation of coatings), reduce the porosity of the resulting material.

In modern industry, more often than not metal alloys are used and metal-ceramic compositions. Various materials (alloying additives) are used for their production, they are introduced into the metal matrix both directly in the melting process (as a result of the action of high temperatures they form a connection with the base metal powder), and it is possible to directly introduce ceramic elements,
carbides, nitrides, oxides [2]. With this approach, the contribution of chemical reactions to the synthesis of the part does not take place, and the effect of laser radiation on such a powder results in the melting of particles with a minimal transition of the material to the vapor-gas phase. Excess gas formation in the process of laser melting of powder materials occurs from the excess energy generated as a result of the different absorbing capacity of metals and introduced impurities. When various ceramic components are introduced into the composition, there are many difficulties associated with different melting points, wetting of the surface by metals, phase transition of the materials used [3].

Aluminum powder is very popular in the aircraft and space industries. Despite its popularity, in the case of layered laser synthesis, there are a number of problems that significantly complicate the work with this material. For example, low absorptivity and the formation of a stable oxide film lead to increased porosity and brittleness of the resulting part. In the literature, no data have been found concerning the increase in the absorptivity with the use of aluminum powders for processing with laser radiation with a wavelength of 1.06 μm. Reducing the surface roughness can reduce the absorbing capacity. Dependence of the reflection coefficient on the angle of incidence and its magnitude are different for a well polished and rough surface were considered in [5, 6]. The developed morphology of the powder granules absorbs laser radiation to a much greater extent (80-90%) than the smooth surface [7].

The aim of this work is to investigate the effect of the morphology of the powder granules on the energy expended on the fusion of a portion of the powder material. The application of this approach will allow to equalize the energy threshold leading to reflow of granules of various materials, to ensure uniform reflow due to a change in the absorption coefficient of laser radiation for each material of the powder composition. This approach is also possible to use when using powder materials with a large dispersion of the components of the compositions.

2. Experimental work

The processed materials used aluminum powder. The classical powder for additive technologies has a spherical shape and a smooth surface. To change the roughness of the granules, the material was processed in a planetary mill with the introduction of abrasive material - corundum. Preparation of the powder material was as follows: the aluminum powder is loaded into a planetary mill together with corundum powder and grinding bodies of spherical shape. The abrasive powder undergoes mechanical influence of both grinding bodies and metal granules, which contributes to its grinding. Particles of metal in the process of processing are modified due to the force action of the working bodies of the mill. The impact of working bodies is carried out with a force exceeding the compressive strength and the shear of the particle material, both corundum and aluminum, which contributes to a change in the structure of the aluminum powder. As a result of grinding the powder composition in a planetary mill, the surface and shape of the granules were greatly altered, and a developed micrelief was formed. Before laser sintering, the morphology of the surface and the granulometric composition of the powders were studied before and after machining in a ball mill. The results were obtained using a Quanta 3D scanning electron microscope (Figure 1).
The photo of the SEM (Figure 1) shows that the particles of Al powder have an almost ideal spherical shape and a smooth surface, and the particles of the modified Al + Al2O3 powder have a complex, ambiguous shape (Figure 2). The developed morphology of the powder granules must absorb laser radiation to a much greater extent than a smooth surface [4]. The macroscopically rough surface of Al + Al2O3 powder is a large number of microscopic sections oriented at different angles to the direction of light wave incidence, characterized by different reflectance values. In this case, light scattering by the surface will be observed, multiple reflection on the elements of the formed relief [8]. Thus, a more complete absorption of the incident radiation is achieved. The average particle size of the powder material is Al-75 μm, Al + Al2O3 80 μm. During processing, the pellets are subjected to mechanical action, and if the treatment regime is observed, the average size of the particles remains practically unchanged.

To obtain a fused layer, a Laser M2 Cusing (Germany) selective laser melting unit with a capacity of 400 W was used. A powder composition was applied to the surface of the metal substrate, the thickness of the powder layer was 100 μm, then the surface formed was subjected to continuous laser action (Figure 3), the radiation wavelength was 1060-1070 nm, the beam diameter was 120 μm, the treatment was carried out in 1 layer in a protective medium.
During the action of laser radiation, a liquid phase is formed, followed by rapid cooling and solidification due to the contact of the fusion region with the substrate. The constant heat load on the material being processed does not occur in view of the high locality of the action of laser radiation [9]. Power parameters were selected to form a layer of fused powder material without cracks, pores and other defects. The most uniform layer of Al powder was formed at 150 W, (Al + Al2O3) - 80 W, the scanning rate was unchanged. When exposed at a lower energy, the powder is collected in droplets, the wettability of the components of the composition is poor; when the energy is exceeded, intense combustion of the material takes place with a characteristic dynamic gassing. Thus, it can be noted that during processing Al + Al2O3 powder was melted at a power much lower than the aluminum powder without first modifying the surface of the granules. Earlier, [10] considered the introduction of carbon into a powder composition, which is a material with good absorption of laser radiation at a wavelength of 1.06 μm. Corundum used as an abrasive material has an absorption coefficient much lower. Thus, by the nature of the processing of powder materials, it can be concluded that the composition of the abrasive used does not make a tangible contribution. In the process of fusing the powder material, when forming a homogeneous melt bath, the particles of the abrasive material leave the surface without remaining in the bulk of the solidified metal.

3. Research
The criterion determining the satisfactory quality of treatment when choosing the exposure regime was the condition of the formed surface. During the work, visual control was carried out using an optical microscope (Figure 4). Modes leading to the formation of pores, cracks, hail formation, uneven melting in the material of this work are not considered.
To detect defects, the structure of the formed material was examined in a cross section. The resulting microsections were examined using a metallographic microscope MMN-2. Samples were ground, polished to a mirror surface, and then etched with a reagent for 10 seconds to help identify the microstructure. On a sample with pure Al, a fine-grained structure is observed, no porosity is observed. On the sample Al + Al2O3 there are needle or columnar crystals growing in the direction of intense cooling. There is a significant number of cracks and low adhesion resistance to the substrate when new layers are formed. The second sample is characterized by a much smaller thickness of the layer formed. This is probably caused by the presence of an excessive amount of corundum, which prevents the wetting of the components of the composition with each other [11]. Probably, the smaller thickness of the formed layer is caused by intensive gassing of aluminum oxide and as a result of interaction with laser radiation, which subsequently led to the "scattering" of the powder granules. The formation of a layer without cracks in its structure suggests that the time for the exit of corundum particles beyond the volume of the melt bath is sufficient. Poor adhesion to the substrate and to the subsequent layers that are formed indicates the need to heat the substrate [12-14]. This approach is likely to increase the crystallization time of the melt. Increasing the temperature of the system will improve the wettability of the formed melt bath of the hardened previous layer. The use of heating is periodically described in a number of sources as a way of reducing the defects of the formed part. In this case, additional heating will also facilitate the release of the abrasive components outside the melt bath. In the process of laser processing of aluminum powder material, the amount of aluminum oxide formed can be reduced using additional components that bind oxygen. It was not possible to study the mechanical properties of the material obtained for hardness, tensile / compression, in view of the small thickness of the layer formed and the weak adhesive resistance to the surface of the plate.

4. Conclusion
The result of the work done is the reduction of the necessary energy to melt the modified powder material. This modification can, if necessary, increase the speed of the selective laser melting process. A change in the morphology of the surface of the granules made it possible to reduce the energy of formation of a uniform roller from the powder by almost half, which is a very tangible contribution to the performance of the operation. When corundum is used as an abrasive material to change the morphology of the surface of the powder granules, the structure of the formed welded layer has pronounced cracks along the interface of contact with the substrate surface. Considered reasons for crack formation can be low adhesion resistance of microcrystals of corundum with aluminum, various coefficients of thermal expansion of materials, poor wettability of corundum with aluminum during the formation of melt baths, high cooling rate of the reflowing area. The possibility of changing the absorption capacity of granules of a powder composition by mechanical modification of the surface of granules is qualitatively shown. Increasing the effectiveness of this approach is possible by improving the technology of changing the morphology of the surface, by selecting the optimal type of abrasive
material, as well as quantitative and fractional composition. It is possible to combine both mechanically modified granules of the composition and pellets containing carbon. When laser treatment of this powder mixture, it is possible to oxidize carbon with oxygen, thereby reducing the amount of aluminum oxide, both at the boundary of the processed tracks, and between the layers. This approach can be applied to the use of powder materials with a large dispersion of the size of the components of the compositions, which will also increase the productivity of this operation by using larger granules. Increasing the absorption coefficient of laser radiation by large granules will increase the homogeneity of the melt bath being formed without increasing the laser radiation power. Later it is planned to continue work in the direction of modification of powder materials, both with the use of mechanical action, and with the use of various additives that help to increase the necessary characteristics of the material being formed. Modification of the powder material is possible.

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