

Investigation of the Influence of Direct Metal Deposition Modes on Microstructure and Formation of Defects in Samples of Heat Resistant Alloy

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Abstract. The article discusses the influence of technological modes of the DMD method on the macro- and microstructure of a heat-resistant nickel-based alloy to use this technology for heat-resistant materials in the manufacture of parts for combustion chambers in gas turbine plants.

Introduction

In the aerospace and energy industry, products are widely used, the parts of which are made of high-temperature alloys. Such details include flame tubes, discs, blades and turbine housings [1]. Usually, blanks for these parts are obtained by such methods as casting, metal forming and powder metallurgy methods [2]. This requires the manufacture of expensive equipment (foundry, die), the design and manufacture of which takes a long time [3, 4]. In this case, the mass of the initial billet made of the heat-resistant alloy can be 10-15 times greater than the mass of the finished part, and the waste obtained in the foundry cannot always be reused. The chips obtained in the process of machining require special technologies for recycling.

Additive technologies (AT) make it possible to obtain products of complex geometric shapes, which are impossible to obtain by traditional methods. This reduces the nomenclature of parts and the time to receive the finished product. Additive manufacturing allows you to immediately produce blanks directly from 3D models obtained from a CAD system by layer-by-layer addition of materials, without the need for design and manufacture of additional equipment.

The use of additive technologies in the production of gas turbine engines makes it possible to produce blanks by melting a metal powder or wire and obtaining a continuous solid-phase structure of functional components of engines [5, 6]. The use of AT makes it possible to obtain products with high mechanical properties, the quality of which depends on many technological parameters of the process. A distinctive feature of the additive production of metal products in comparison with foundry is the possibility of obtaining a homogeneous fine-grained structure by acting on the initial material of a point source of supplied energy and high crystallization rates, which makes it possible to avoid defects in the structure characteristic of high-chromium and intermetallic nickel alloys. However, rapid crystallization in the local volume contributes to the formation of other characteristic defects, such as lack of fusion and pores with insufficient energy supply and cracks from the action of thermal stresses in the case of its excess.

The mechanical properties of parts obtained by additive technologies strongly depend on the size and shape of the metal powder grains, as well as the geometry and parameters of the formation of the surfacing bead [7]. Depending on the temperature and power load of the parts to which they are subjected during operation, the requirements for the microstructure for parts made of heat-



resistant alloys will be different. For example, during the takeoff regime, the turbine disk is exposed to high loads and experiences low-cycle fatigue; therefore, a fine-grained equiaxed microstructure is required to increase the fatigue strength [8, 9]. To ensure improved mechanical properties in castings, directional solidification technology is used, in particular, for turbine blades of gas turbine engines, methods of producing monocrystalline blades are used. Monocrystalline castings have enhanced mechanical properties due to a reduction in the number of transverse grain boundaries or their complete elimination [10].

The most promising technology for the manufacture of billets of large-sized parts from heat-resistant hard-to-machine steels and alloys is the direct energy deposition, when the product is formed from a metal powder supplied by a gas-powder jet into the zone of exposure to a laser beam (L-DED) [11, 12, 13]. Among the disadvantages of this method are high roughness, as well as defects such as discontinuities in the form of looseness, pores and adhesions.

The aim of this work is to study the influence of technological parameters of the L-DED process on the microstructure of chromium-nickel alloy samples and minimizing the appearance of characteristic defects.

Materials and methods

Material. In the course of the research work, the heat-resistant alloy Inconel 718 was used. Samples made of metal powder (the particle size of the main fraction is 40-150 μm) using the L-DED technology have the shape of a parallelepiped with dimensions of 80x30x12 mm. The chemical composition of the heat-resistant powder Inconel 718 was determined using a TESCAN VEGA 3 scanning electron microscope, the results of microspectral analysis are shown in Table 1.

Table 1. Results of microspectral analysis of heat-resistant powder of alloy Inconel 718

Element	Ni	Cr	Si	Mn	Nb	Al	B	Ti	Mo	Fe
Percentage	52.26	19.22	0.0	0.17	5.3	0.75	0.00	0.99	2.92	0.11
Standard	50.0- 55.0	17.0- 21.0	<0.35	<0.35	4.75- 5.5	0.2- 0.8	0.006	0.65- 1.15	2.8- 3.3	balance

Sample Making. The samples under study were made on a robotic L-DED machine developed at Samara University, consisting of a six-axis industrial robot-manipulator Eidos A12 with an additive module and a pedestal on which the growing process was carried out.

Argon was used as a protective and transport gas, which was supplied to the deposition zone at a flow rate of 4 L/min and 10 L/min, respectively. For a better heat exchange processes in the workpiece, the deposition process was carried out on a low-carbon steel substrate, and a sacrificial layer 10 mm high was added to the sample to equalize the deposition conditions. After growing the samples, they were separated from the build platform and processed to a size of 80x20x12 mm. Table 2 shows the parameters of the mode of laser fusion of powder material.

Table 2. Modes of L-DED of powder material

L-DED mode parameter	L-DED parameter value			
	Sample 1	Sample 2	Sample 3	Sample 4
Laser power, W	1400	1600	1700	1800
Powder consumption, g/min	32	29	20	46
Deposition speed, mm/s	20	20	23	40
Layer step, mm	0.4	0.4	0.6	0.4
Track width, mm	1.6	1.6	1.6	1.6

Metallographic Investigation of Sample Material. During external examination of the samples, fusion beads were clearly visible, the width of which was from 1.5 to 1.7 mm. The metallographic analysis was carried out on metallographic specimen prepared along the growth direction of the samples. Additionally, thin sections were made in the transverse direction with respect to the direction of growth of the samples in the middle part with respect to the height of the samples. Etching of specimen was carried out in Vasiliev's reagent (CuSO₄ - 5 g, H₂SO₄ - 1.4 ml, HCl - 50 ml, H₂O - 40 ml). The macrostructure of the samples obtained by the L-DED method in modes 1...4 is shown in Fig. 1.

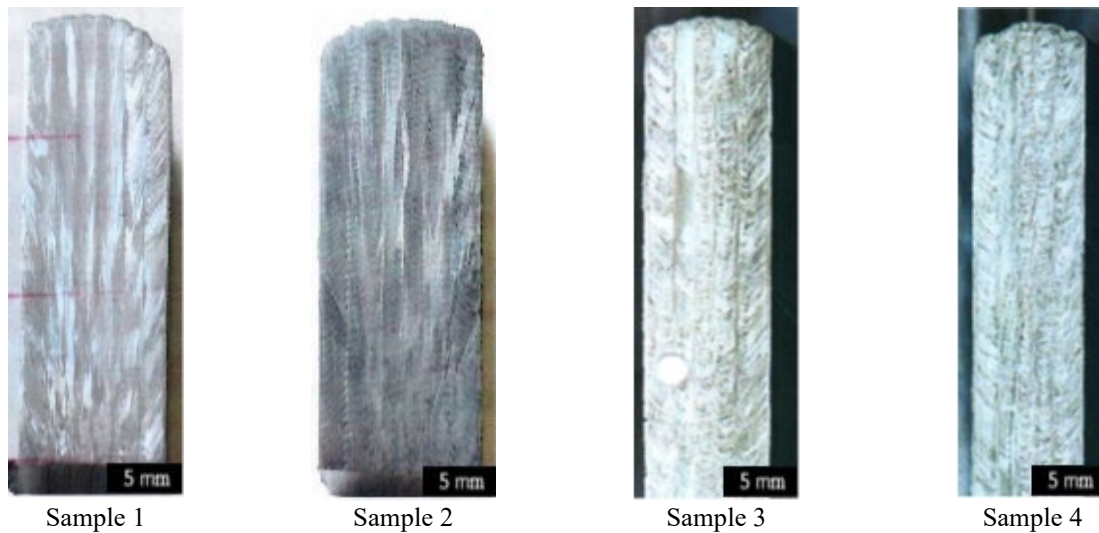


Fig. 1. Macrostructure of samples obtained by the L-DED method in modes 1...4

Microanalysis of specimen without etching revealed that the material of all samples contains small discontinuities in the form of looseness, pores and seals (Fig. 2). The total porosity of the material of the samples is: in samples No. 1, 2 - up to 0.015 mm, in samples No. 3, 4 - up to 0.01 mm.

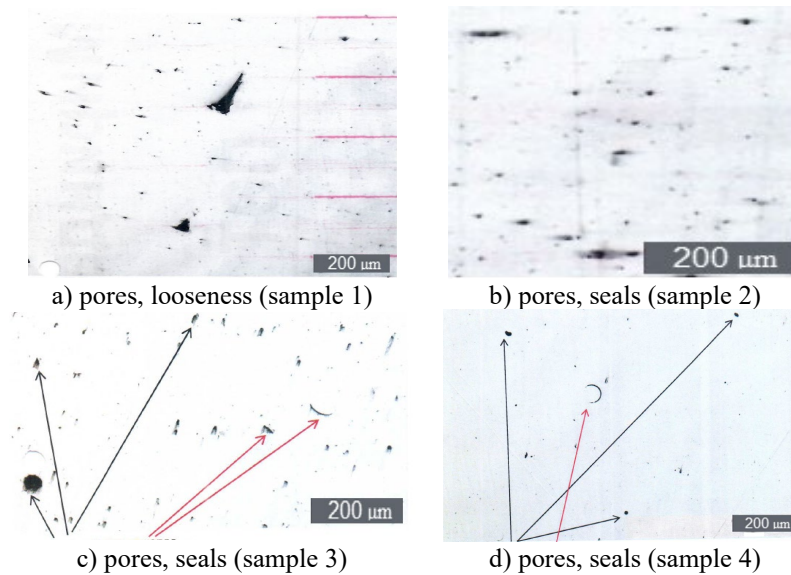


Fig. 2. Defects in sample material

After etching, cracks with a length of 0.05 to 1.1 mm were found in all samples, located along the boundaries of individual grains at a distance of 0.6 to 2.0 mm from the side surfaces. Samples 1, 2 have single cracks in the central part. The track structure is noticeable in sample No. 1, and in sample No. 2 the tracks are practically indistinguishable.

Results and discussion

Microstructure. The analysis of the microstructure of the samples, obtained with an optical microscope, was carried out. It was revealed that the microstructure of the Inconel 718 alloy is mainly represented by columnar dendrites, which grew continuously during the deposition of subsequent layers. An increase in the length of dendrites occurs in the direction of surfacing, which is explained by the co-directional temperature gradient, which creates thermodynamic conditions for solidification. It is obvious that the size of the melt pool and the characteristics of compaction of the material as a result of a decrease in its porosity and the number of non-melts (solders) differ significantly depending on the laser power. With an increase in the laser power, the depth and width of the melt pool increase, and the bonding properties of the adjacent layer increase with a constant lateral step, as a result of which the relative density of the sample increases. At the same time, the heat-stressed state increases, which increases the likelihood of cracking. At low laser power, the energy absorbed by the powder is insufficient. This leads to a mismatch in the required temperature in the melt bath and complicates the melting of the powder and the penetration of adjacent layers, which is a necessary condition for the formation of a stable bond between the layers being fused. In addition, due to the high dynamic viscosity of liquid metal at low temperatures in the molten bath, convection deteriorates and the flowability of the melt decreases, which makes it difficult to remove mixed gases and contributes to the formation of pores. At optimal laser power, the dynamic viscosity of the melt is sufficient to provide convection and gas removal from the melt bath, as a result of which the number of pores becomes minimal.

Laves phases are harmful phases, since they are very fragile compounds, and their morphology and size strongly affect the properties of the alloy [14]. The formation of Laves phases is greatly influenced by the parameters of the laser, especially the power and speed of the beads deposition [15].

Conclusion

Having studied the results of the research carried out, the following conclusions can be drawn:

1. Large discontinuities such as looseness, pores and seals were not found in the material of the samples. The maximum size of single discontinuities is: looseness - 0.03x0.06 mm, pores - from 0.03 to 0.05 mm, seals - 0.13...0.17 mm.

2. The maximum pore size is: in samples No. 1, 2, - up to 0.015 mm, in samples No. 3, 4 - up to 0.01 mm.

3. In the material of samples 1, 2, 3, cracks with a length of 0.05 ... 1.1 mm were found, located along the boundaries of individual grains at a distance of 0.6 ... 2.0 mm from the side surfaces.

Analysis of the L-DED technological modes shows that the most preferred fusion mode is mode 4. The main defects for mode 4 are single pores up to 0.03 mm. In this regard, we select the values of the 4th technological mode as the basic mode.

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