Research and development of technology for obtaining small-scale GTE parts from ceramic composite materials by 3D printing

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Abstract. In modern production, direct laser deposition technologies are used to shorten the time of production of a new product at the design and manufacturing stages. The development of technology follows the path of introducing new powder materials and determining rational technological regimes for the formation of a surface layer of specified quality. This work is about study of samples from a cermet composite material (CCM) by direct laser deposition. Technological parameters for defect-free build-up of full-size small-sized parts of gas turbine engines (GTE) are determined. Structures were studied and tests were conducted to determine the mechanical properties of deposited laboratory samples. The technology of full-size small GTE parts manufacturing has been worked out.

1. Introduction

In modern production, the most promising and fast-growing sector is the additive technology sector, the annual the market growth exceeds 25% [1, 2]. One of the intensively developing technologies of additive production of products is the technology of direct laser growth [3]. The use of this technology makes it possible to shorten the time of release of a new product at the design and manufacturing stages.

The development of technology follows the way of introducing new powder materials and determining rational technological regimes for the formation of a surface layer of specified quality, improving the physical and mechanical properties of products, improving the quality and accuracy of the products being formed [4, 5]. The creation of a functional product is possible only in a certain range of laser action, which is selected experimentally for a new powder material.

The main goal of the research of the process of direct laser growing is the selection of rational parameters of the technological process, providing a favorable structure and mechanical properties for increasing the productivity of manufacturing the resulting products.
2. Materials and methods of research

Growing was made on a substrate of steel PCE36 with a thickness of 7 mm. A mixture of powders of composition 95% Inconel 625 + 5% NiTi + TiB2 was used as starting material.

For growing used ytterbium fiber laser LS-3 firm IRE-Pole. The laser radiation was focused using the FLW D30 process head from IPG Photonics. For the formation of gas-powder jet used coaxial cladding nozzle COAX9 production the Fraunhofer ILT. The industrial robot LRM-200iD_7L from Fanuc was used as a manipulator.

The grown rollers were examined by visual and measurement control, as well as optical and scanning electron metallography using DMI 500 Leica microscopes with Thixomet and Phenom PRO X software, respectively.

The hardness was measured on a Buehler Wilson Micromet 6040 hardness tester with Thixomet Pro image analyzer. Compression and tensile tests were carried out on a static universal Zwick / Roell 250 testing machine.

To determine the optimal mode of direct laser growth, the following parameters were varied: the diameter of the laser beam on the substrate, the radiation power, the speed of the laser beam relative to the product, the mass flow of the powder, the magnitude of the vertical and horizontal displacements between the layers and the passages, respectively. The ranges of the parameters used are shown in Table 1.

| Parameters                                | Diameter of the beam in the processing area, mm | Power, W     | Speed of growing of side rollers mm / s | Speed of growing of filling rollers mm / s | Powder consumption, g / min | Shift by X, mm | Shift by Z, mm |
|-------------------------------------------|-----------------------------------------------|--------------|----------------------------------------|------------------------------------------|-----------------------------|----------------|----------------|
| 1,5 – 2,4                                 | 500 – 1400                                     | 10 – 15      | 15 – 25                                | 5,1 – 25                                 | 0,7 – 1,6                   | 0,2 – 0,8       |

3. Metallographic research

3.1. Influence of radiation power and growth rate

The study of the effect of radiation power has shown that low values lead to the formation of non-fusions in adjacent rollers (Figure 1a), high values lead to the formation of cracks (Fig. 1b), and failure of the focusing lens, which leads to unstable formation of the deposited roller (Figure 1c).
According to the results of approbation of regimes, it was found that when the rate of growth of the side ridges, at the place of overlapping of adjacent rollers, is greatly reduced, non-melting occurs. This defect is eliminated either by increasing the radiation power or by increasing the process speed. With a strong increase in speed - there is a tendency to lower the height of the side ridges relative to the central ones. This is due to the fact that in the overlapping areas of two adjacent rollers, the height of the deposited layer is higher than in the center of the roller. There is a formation of the so-called. The barrier for the powder fed into the treatment zone. This leads to the fact that it gets to the bath of the melt less. With increasing sample height, this defect accumulates, and the end roller stops forming. The ratio of velocities ensuring the absence of the described defects is experimentally chosen.

3.2. Effect of powder consumption and vertical displacement of the nozzle after passage

To increase the productivity of the process and the utilization factor of the material, the stability of the growing process by varying the flow rate of the powder and the step of raising the surfacing nozzle in height has been studied. When the consumption of the powder was halved, the height of the grown layer became smaller than the step of raising the nozzle, which indicates instability of the process. When the consumption of powder was reduced by 1.5 times, the stability of the process was maintained. Further to increase productivity, increase the increment in height. With an increase in the pitch of the surfacing nozzle, a transition occurred in the region of a higher concentration of the powder in the focused jet, which led to an increase in the height of the growing layer. However, after passing through the optimal ratio of the parameters, with the increase in the height of the roller, the formation of faulty fusion between neighboring rollers occurred.

Figure 2 shows images of microstructures of samples from an electron microscope, illustrating the effect of powder concentration in the jet as it approaches the focus point of the gas-powder jet.
Figure 2. Structures of samples with different the step of raising a) elevation height 0.2 mm b) elevation height 0.3 mm c) elevation height 0.35 mm.

Figure 3 shows the macrostructures of samples with different increments in the nozzle elevation after passage.

Figure 3. Macrostructure of samples with different the step of raising a) elevation height 0.2 mm b) elevation height 0.3 mm c) elevation height 0.35 mm.

3.3. Selection of technological parameters for growing samples from the CCM

Technological parameters providing a softer regime (D = 1.5 mm, P = 600 W, V = 15 mm / s, G = 5.1 g / min) turned out to be the least productive. The shape of the roller, provided by these parameters, made it possible to produce displacements $\Delta X = 1$ mm, $\Delta Z = 0.3$ mm, which resulted in a productivity of about 200 g / h.

To improve performance, parameters of a more rigid mode were worked out (D = 2.4 mm, P = 1400 W, V = 25 mm / s, G = 25 g / min). The shape of the roller provided by these parameters made it possible to produce displacements $\Delta X = 1.6$ mm, $\Delta Z = 0.8$ mm, which resulted in a productivity of about 1100 g / h. However, when these parameters are transferred from small-sized research samples to full-size demonstration ones, the growing of which is a long non-stop process, the focusing lens has failed several times. This regime also had to be abandoned.

Further, on the basis of the regularities obtained under soft and hard conditions, the parameters (table 2) with satisfactory performance (500 g/h), favorable structure, stable formation of the geometry of the grown samples were calculated.
Table 2. Process parameters for growing laboratory and demonstration samples

| Diameter of the beam in the processing area, mm | Power, W | Speed of growing of side rollers mm / s | Speed of growing of filling rollers mm / s | Powder consumption, g / min | Shift by X, mm | Shift by Z, mm |
|---|---|---|---|---|---|---|
| 2,1 | 1000 | 15 | 25 | 23 | 1,4 | 0,6 |

3.4. Determination of microhardness in samples

To determine the effect of the addition of TiB2 to Inconel 625 powder, microhardness measurements were carried out on grown samples of Inconel 625 powder and a mixture of powders. A micrograph with traces of prints is shown in Figure 4.

![Figure 4. The location of prints on the section.](image)

Table 3. Microhardness of samples

| Point number | Microhardness, HV0.1 |
|---|---|---|
| | Inconel 625 | Inconel 625+TiB2 |
| 1 | 260 | 389 |
| 2 | 269 | 395 |
| 3 | 275 | 411 |
| 4 | 275 | 405 |
| 5 | 284 | 405 |
| average | 273 | 401 |
Table 3 shows that the addition of NiTi + TiB2 powder leads to an increase in hardness by almost 1.5 times.

3.5. Determination of compressive strength and tensile strength

For testing, ingots of a cermet composite material were grown. From the received ingots, samples were prepared for the following tests:

- compressive strength;
- tensile strength;

Figures 5a and 5b show typical stress-strain diagrams obtained during compression and tension.

![Figure 5. $\sigma$-$\epsilon$ diagram of the compression of CCM samples a) compression, b) tension.](image)

Tables 4, 5 show the data obtained as a result of static compression and stretching of samples from the CCM.

**Table 4. Data on the properties of specimens under compression**

| Material | Sample No. | Max relative deformation ($\varepsilon_r$) | Compressive strength ($\sigma_v$), MPa |
|----------|------------|-----------------------------------------|-------------------------------------|
| CCM      | 1          | 0.209                                   | 1835.35                             |
|          | 2          | 0.20                                    | 1805.42                             |
|          | 3          | 0.20                                    | 1823.47                             |

**Table 5. Data on the properties of specimens under tension**

| Material | Sample No. | Max relative extension ($\varepsilon_r$) | Tensile strength ($\sigma_v$), MPa |
|----------|------------|-----------------------------------------|----------------------------------|
| CCM      | 1          | 0.112                                   | 757.62                            |
|          | 2          | 0.094                                   | 714.07                            |
|          | 3          | 0.091                                   | 680.96                            |
To assess the quality of the grown samples, a comparative analysis of the mechanical properties of the research samples from the CCM, obtained using classical technologies (pressing with subsequent high-temperature sintering) was carried out (Table 6).

**Table 6. Mechanical properties of CCM obtained by "classical" and "additive" technologies**

|                      | CCM (obtained by classical technology) | CCM (obtained by additive technology) |
|----------------------|---------------------------------------|---------------------------------------|
| Compressive strength (MPa) | 2100                                  | 1835                                  |
| Ultimate tensile strength (MPa) | 250                                   | 757                                   |

4. Results and conclusions

As a result of the conducted experimental studies, the parameters of the process of direct laser growth from cermet composite materials are determined, which ensure the stable formation of the manufactured product.

The metallographic analysis of the grown samples allowed to determine technological process regimes ensuring the absence of internal defects. The uniform distribution of the ceramic component inside the metal matrix has been established by scanning electron microscopy.

Application of the technology of direct laser growing for the manufacture of products from CCM allowed to increase the tensile strength by 3 times in comparison with the samples manufactured using the pressing technology followed by high-temperature sintering.

Application of the technology of direct laser growing for the manufacture of products from CCM slightly reduces the compressive strength in comparison with the samples produced by pressing technology followed by high-temperature sintering. But, despite this fact, it is worth noting the advantages of the additive method, which consists in automating the process, reducing the time of manufacturing parts and assemblies, increasing productivity in the manufacture of parts of complex shapes, etc.

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