Optimization of laser cladding parameters of nickel-based metal powder for creation a heat-resistant coating

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Abstract. Optimization of laser deposition of nickel aluminide was carried out to obtain a single track of high quality. The structure of single tracks was investigated. Based on the data obtained, a multilayer structure was deposited and a study of the distribution of elements was carried out.

1. Introduction

Currently, additive technologies are intensively developing due to their unique capabilities for the layer-by-layer production of functional products and coatings from various metals and alloys. Additive technologies are widely used in many areas of production, such as automotive industry, medicine, aerospace [1–3].

The traditional approach to studying the influence of various parameters of the additive manufacturing process is to study the finished product, which consists of many layers. In addition to the significant production time of such parts and its cost, the most important limitation of this method is that the initial shape of the molten bath and the initial state of the solidified structure in the real process of additive manufacturing are hidden by subsequent passes that partially remelt the underlying layer. Thus, single track deposition experiments based on studies of other similar processes, such as laser welding[4,5], are used as a replacement in some studies aimed at a deeper understanding of the process of molten pool and single-track formation. A study was made in [6] about similar trends in the characteristics of the melt pool of a single track, the deposited layer and multilayer deposition of a nickel-based heat-resistant alloy using the SLM technology. This shows that single track experiments are a useful experimental tool for understanding the effect of process parameters on molten pool formation and for generating process flow charts.

A promising material for use in aircraft construction is an alloy based on the Ni3Al intermetallic compound. High strength, resistance to oxidation and thermal stability make it possible to use alloys based on nickel aluminide in the manufacture of heavily loaded critical parts of gas-turbine engines for aviation and transport purposes, gas-turbine power plants[7–10]. Ni3Al alloy is been produced in the form of PN85Y15 powder, consisting of spherical granules. Work on laser cladding of this powder is of a single nature, in [11] PN85Y15 powder was fused on the camshaft cams of an automobile engine. However, it was not possible to achieve a satisfactory structure of the deposited layer due to internal defects. As far as the author know, a systematic study of the dependence of the deposited layer characteristics on the conditions of laser surfacing of PN85Y15 powder has not been carried out.
The purpose of this work is to experimentally study the effect of processing parameters on the characteristics of single tracks during laser cladding of PN85Y15 powder and to search for processing conditions that allow obtaining heat resistant coatings.

2. Experimental Technique

In the work, Ni₃Al alloy was used in the form of PN85Y15 powder with a fractional composition of 20-63 microns. The powder was deposited onto a 12Kh18N10T stainless steel substrate 50x50x5mm in size. The thickness of the applied layer was 400 microns. The chemical composition of the powder is shown in Table 1.

Table 1. Chemical composition of PN85Y15 powder

|   | Ni, %  | Al, % | Fe, % | C, % |
|---|--------|-------|-------|------|
| wt| 85-87  | 12-15 | 0.2   | 0.07 |

The surfacing of single tracks was carried out in a protective argon atmosphere on an automated laser technological complex of the «Siberia» series, which includes a CO₂ laser with a power of up to 8 kW. Laser radiation with a wavelength of 10.6 μm was focused using a ZnSe lens into the interior of the material, onto the surface and above the material.

Parameters such as laser power (from 500 W to 1500 W), focus position relative to the powder layer (from -30 mm to +30 mm), scanning speed (from 5 to 45 mm / s) were varied.

The geometric characteristics of single tracks were measured using an Olympus LEXT OLS 3000 optical confocal microscope.

The study of the microstructure was carried out using a scanning electron microscope (SEM) Zeiss EVO MA 15.

3. Results and Discussion

For deposition of multilayer structures, it was decided to use modes which allow to obtain the highest quality of single tracks.

Four most important quality criteria for a single track were selected:
1) Lack of pores, cracks.
2) Reducing the mixing of the base metal and the weld metal.
3) Minimum penetration depth of the substrate.
4) The shape factor of the track (the ratio of the height of the track to its width) should be no more than 0.3-0.5, which will ensure high adhesion strength of interlayer adhesion when surfacing multilayer objects [12].

At the beginning of the work, the problem of practical search for optimal deposition modes was solved. During that process the dependence of the geometric dimensions of a single track on the scanning speed was discovered. Thus, the width, height of the track, as well as the substrate penetration depth decreased with increasing speed (Fig. 1).
An increase in the power of laser radiation also led to an increase in the geometric dimensions of a single track, which is associated with an expanding molten pool due to the greater amount of energy imparted to the powder layer. A characteristic dependence of the shape of single tracks with an increase in the laser power can be observed in Fig. 2.
Figure 2. Optical images of cross-sections of single tracks obtained at laser power values of 500, 1000, 1500 W.

During the study of single tracks, they were also analyzed by scanning electron microscope and an analysis of the distribution of elements was carried out, as a result of which mixing of the substrate material with the deposited powder was revealed, which is evidenced by the presence of iron in a single track in Fig. 3.
In Figure 4 clusters of equiaxed grains of different contrast can be noted, which indicates a different direction of grain formation. In the lower half of the figure, closer to the substrate, more elongated crystals can be seen, which shows a difference in the metal cooling processes in different zones of a single track. Near the substrate, the gradient is directed vertically, from the substrate to a single track, which indicates more efficient heat transfer from the melt pool to the substrate. In the upper zone, the temperature gradient during surfacing is co-directed with the movement of the laser; therefore, the grains are elongated along the direction of surfacing. The grain size was measured, the average diameter is 5 microns.

Based on the data obtained from the study of single tracks, several modes were selected for surfacing multilayer objects (4 mm wide, 8 layers high), during surfacing of which the position of the tracks in the next layer shifted relative to the previous layer by ± 0.5 mm. The obtained samples were cut across and polished in order to prepare them for research with SEM.

Elemental analysis of multilayer structures (Fig.5) also revealed mixing of the substrate material with the deposited sample in the first layers, which should ensure good adhesion between the substrate and the coating.
Figure 5. SEM image of elements distribution in a multilayer structure
a) Nickel, b) Ferrum

Figure 6. Elemental analysis area

Elemental analysis was carried out in the central part of the multilayer structure (Fig.6), the composition is shown in Table 2.

|       | Ni, % | Al, % | Fe, % | Cr, % |
|-------|-------|-------|-------|-------|
| wt    | 72.86 | 13.67 | 10.62 | 2.85  |
| at    | 62.29 | 25.42 | 9.54  | 2.76  |

The aluminum content remained at the level of the original powder, but part of the nickel was replaced by iron, as a result of mixing with the substrate. Based on the composition in at% - it can be assumed that the phases NiAl, Ni₅Al₃, Ni₃Al were formed in the course of crystallization, however, to study the phase composition, more detailed studies are necessary.
Figure 7. Change in the number of pores in a multilayer structure with an increase in the amount of energy imparted to the powder layer

Figure 7 shows how an increase in the amount of energy imparted to the material increases the porosity of the sample, which can reduce the thermal conductivity of the coating, leading to less heating of the protected material.

4. Conclusions
In this work, a search and study of the optimal modes of surfacing of PN85Yu15 powder were carried out.

Experimental data have been obtained on the dependence of the geometric characteristics of the tracks on the parameters of laser cladding.

The effect of scanning speed on the geometric dimensions of single tracks has been studied.

The possibility of obtaining porous coatings based on Ni3Al has been investigated.

The possibility of creating heat-resistant coatings from Ni3Al has been investigated.

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