The peculiarities of surface cladding by laser metal deposition of AISI304 steel

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Abstract. The study of the cladding process with the laser metal deposition (LMD) equipment was carried out. The experimental results of the tracks formation on the surface of AISI 304 stainless steel are presented. The technological regimes of LMD are shown, samples of coatings are obtained, measurements of the geometric characteristics of the samples are carried out.

1. Introduction

It is known that the equipment used for the additive synthesis of products using the laser metal deposition technology (LMD) can be used to perform metal deposition operations on the product surface and, in particular, to repair worn or damaged parts [1]. This paper presents the study results of the process of creating coatings on the surface of austenitic steel with LMD equipment. The creation of products in the LMD technology occurs by sequential deposition of individual tracks. Each track is formed by the interaction of laser radiation with a stream of powder and a previously applied material (or substrate) [2–4].

2. Experimental setup

Experimental setup, figure 1, includes a 400 W ytterbium doped fiber laser 1 (LC-400-V, NTO IRE-Polus), the radiation of which is focused by a laser head 2 (Precitec YC52). The manipulator 4 (Kuka KR10 900-2) moves the substrate 3 relative to the position of the beam. The powder feeder 5 (GTV PF 2.1LC) incorporates a feed disk 6, the rotational speed of which determines the mass flow rate of the powder.

The scheme of laser radiation interaction with a gas-powder mixture (GPM) and a substrate is shown in figure 1(b). The coaxial flow of the GPM is heated by the focused laser radiation. \( B \) is the distance from the substrate to the waist of the laser beam and \( D \) is the distance from the bottom surface of the nozzle to the substrate. The distance from the nozzle to the minimum size cross section of the GPM flow \( C \) is 11 mm. The position of the focus of the laser beam \( B \) was changed independently of the change in \( D \) by moving the collimating lens of the laser head 2 in the vertical direction. The quality and productivity of the LMD process can vary significantly depending on the parameters \( B \), \( C \), and \( D \) [5].

The powder of austenitic steel PR X18H9, the analogue of AISI 304 steel, with a carbon content of about 0.09% was used in these experiments. The granulometric composition of the powder was (40...100) microns. Substrates of 40x10x4 mm³ in size of 304 steel were used.
Figure 1. Scheme of the experimental setup: 1 – laser, 2 – laser head, 3 – substrate, 4 – manipulator, 5 – powder feeder, 6 – feeder feed disk (a) and the scheme of mutual disposition of the substrate, ring nozzle, GPM and laser beam (red lines) (b).

In the first series of experiments, a single track 34 mm long was deposited on each substrate for the given technological parameters $B_z$, $C_z$ and $D_z$, as well as scanning speed $V$ and laser power $P$. Speed $V$ was varied within (800...1100) mm/min. The parameter $B_z$ took the value 6 mm, 8 mm and 9 mm in different series of experiments, the distance $D_z$ was changed from 10 mm to 13 mm. The mass flow rate $G_0$ of the powder ranged from 5.6 g/min to 12.5 g/min. The experiments used the maximum power of 400 watts. The flow rate of the feeder was 15 nl/min, the protective gas pressure was 0.6 MPa, the protective gas flow was 10 nl/min.

Figure 2. The dependence of mass productivity on the synthetic parameter of the location of the substrate relative to the nozzle and the focus of laser radiation $D_z * 10 + B_z$. The data are given for different values of the mass flow rate $G_0$: 1 – 15.6 g/min; 2 – 12.5 g/min; 3 – 8.4 g/min; 4 – 5.2 g/min. Scan speed $V$: 800 mm/min (a) and 1000 mm/min (b).

Mass performance $G$ was evaluated, which was defined as:

$$G = (\delta m \cdot V) / L, \text{ [g / min]},$$

where $\delta m$ is the increase in the mass of the substrate, $V$ is the scan speed, $L$ is the length of the track.

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The obtained values of $G$ are shown in figure 2 depending on the synthetic parameter of the location of the substrate relative to the nozzle and the focus of the laser radiation $D_z \times 10 + B_z$ for different values of the mass flow rate. In figure 2(a) mass production data are given for a scan speed of 800 mm/min, in figure 2(b) – for 1100 mm/min. The mass productivity $G$ increases with increasing powder consumption and with decreasing scanning speed. The highest $G$ values for the same $G_0$ and $V$ correspond to $D_z$ values of 11 mm or 12 mm.

3. Results and discussion

The cross-sections of samples with a deposited track are shown in figure 3 at different values of the parameter $D_z \times 10 + B_z$ in the case of a speed of $V = 800$ mm/min and a flow rate of $G_0 = 8.4$ g/min. As we see from figure 3, for the purposes of coating, the following process conditions can be chosen ($D_z = 12$ mm; $B_z = 9$ mm) and ($D_z = 13$ mm; $B_z = 6$ mm). They are selected by the criterion of the maximum ratio of the width of the track to its height and a sufficient depth of penetration. In some cases, excessive penetration of the substrate is observed, which can lead to an increase in internal stresses and distortion of the part. Previously, numerical modeling was carried out, which allows to determine the ratio of the width of the track to its height depending on the process parameters [6].

Figure 3. Cross-section of the deposited track. The parameter $D_z \times 10 + B_z$ value is specified.

Table 1. Cross section of the deposited tracks. The scale is 300 microns.

| $V$, mm/min | $G_0$, g/min | $D_z$, mm | $B_z$, mm | $V$, mm/min | $G_0$, g/min | $D_z$, mm | $B_z$, mm | $V$, mm/min | $G_0$, g/min | $D_z$, mm | $B_z$, mm |
|-------------|--------------|-----------|-----------|-------------|--------------|-----------|-----------|-------------|--------------|-----------|-----------|
| 800         | 12.5         | 13        | 6         | 1100        | 8.4          | 11        | 8         | 1100        | 15.6         | 12        | 6         |

The dependences of the averaged values of the $T*$ on the power $P$ for different values of $B_z$ and velocity $V$ are shown on figure 3(a). The standard deviation of the brightness temperature is shown in figure 3(a) and was near 1.5 % of the measured value. The dependences of the mass rate of powder $G$ on the power $P$ under the same other conditions are shown on figure 3(b) for $V=350$ mm/min. The intensity of laser radiation on the substrate surface increases with decreasing in $B_z$, and melt temperature increases as shown on figure 3(a). However, the decreasing transverse size of the laser beam on the substrate in this case leads to a decrease in the mass rate $G$, figure 3(b).

Samples of coatings were obtained in a multi-track regime. Figure 4 shows the result obtained using the technological regime with the parameters specified in tables 1 and 2. Overlap at 0.7 mm step was about 30%. The vertical step was 0.3 mm; in total, 2 layers were successively deposited to the
substrate. Thus, choosing the required technological regime, you can obtain a coating of the required thickness with a sufficiently high material denseness.

| $G_0$, g/min | $D_z$, mm | $B_z$, mm | Width, µm | Height, µm |
|-------------|-----------|-----------|-----------|------------|
| 8.4         | 12        | 9         | 1186      | 360        |
| 8.4         | 13        | 6         | 1132      | 280        |
| 12.5        | 13        | 6         | 1091      | 265        |

**Figure 4.** Cross section of the deposited metal (the scale is 300 microns).

4. Conclusions
The experimental results of the study of coatings creating process on the surface of austenitic steel with the laser metal deposition equipment are presented. The technological regimes of LMD are shown, samples of coating on a metal surface are obtained, measurements of the geometric characteristics of the samples are carried out from the obtained images of the cross sections of the samples.

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