Optimization of laser surfacing technological parameters to composite coatings WC/INC625

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Abstract. Single laser tracks of the WC/INC625 composition in a wide range of concentrations of the carbide phase obtained by laser surfacing at various values of the technological parameters of the process are studied. Based on the results of quantitative metallographic analysis, promising compositions of coatings were selected and intervals of technological parameters were established. The modes allowing to obtain objects without cracks, with minimal porosity and a given geometry of the laser track cross-section were determined.

1 Introduction

Composite coating technologies make it possible to obtain parts with such important surface properties as high wear resistance and corrosion resistance in a large temperature range, heat resistance and heat resistance, etc. [1-3]. The methods of plasma and detonation spraying used for these purposes have some disadvantages, for example, they have an intense thermal effect on the product, and also have a lot of macrodefects in the coating, and the process of coating synthesis by ion-plasma methods requires expensive equipment [4-6].

One of the alternative ways to obtain composite coatings is surfacing. Surfacing of composite coatings is used in manufacturing of new parts or in repair and restoration, thereby providing a high economic effect and increasing the service life of parts of a wide range [1, 7]. Currently, laser surfacing is the most promising method for obtaining coatings from composite materials. It has the following advantages: minimal thermal influence that does not cause significant warping of the product, locality of heating of the part, high dimensional accuracy, as well as a minimum number of macro- and micro-defects [8-11].

Laser surfacing is a high-performance, and also a universal process in terms of the thickness of the coating obtained and the possibility of using various materials (for example, complex alloys based on iron, cobalt, nickel, etc.) [8, 12]. This technology makes it possible to obtain multicomponent coatings with high wear-, thermal- and other impact resistance [8, 13, 14]. The equipment for the implementation of laser surfacing is equipped with such laser sources as gas, diode or optical fiber. Diode laser sources are the most suitable for surfacing, since the energy distribution density is the most uniform [15, 16]. The used technologies for applying functional composite coatings based on the Inconel 625 (INC625) nickel alloy are

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not sufficiently perfect, as they are accompanied by possible disadvantages, such as cracks and porosity [17-20].

To obtain high-quality coatings that meet the requirements for the absence of cracks, minimal porosity, good adhesion to the base material, it is necessary to choose the correct ratio of the proportion of carbide in the matrix. In addition, by changing the composition (i.e., the volume fractions of the components) of the composite, it is possible to control the structural characteristics of the coating material that determine its operational properties. The first stage of optimization of the technological process of laser surfacing is the selection of single laser tracks (tracks) without cracks, with the minimal porosity and with a geometry that ensures the absence of defects when applying tracks. This stage of optimization was performed in this work.

The aim of this work is to optimize the composition and technological parameters of obtaining composite coatings based on Inconel 625 nickel alloy reinforced with WC carbide particles applied by laser surfacing for the synthesis of objects with the required level of operational properties and the minimum number of defects.

2 Methodology and materials of the experiment

The object of research in this work is a composite material, the matrix of which is the Inconel 625 nickel alloy, and the reinforcing element is $WC–W_2C$ particles. In the compositions of the samples to be considered further, the content of tungsten carbide particles varies from 10% to 90%. The size of the matrix powder is 63-100 microns [21-25], and its chemical composition is presented in Table 1. Method of preparation: plasma melting and centrifugal spraying [20-22, 26]. Melting range: 1310…1360°C. The material retains its physical properties at both low and high temperatures and resists oxidation at elevated temperatures up to 1000°C [21].

Table 1. The chemical composition of Inconel 625 powder according to ASTM B214 [25].

The concentration of elements, mas. %					
Ni	**Cr**	**Mo**	**Nb**	**Fe**	**The rest**
58.0–63.0	20.0–23.0	8.0–10.0	3.0–5.0	Less than 5.0	Less than 2.0

The particle size of $WC-W_2C$ powder is 45…106 microns [25, 10]. The chemical composition of this powder is presented in Table 2. The method of obtaining this powder is melting and grinding, and then spheroidization using plasma compaction [25, 26]. Powder hardness: 2700… 3100 $HV_{0.1}$. The operating temperature is less than 500°C [23].

Table 2. The chemical composition of WC powder according to ASTM B214 [25].

The concentration of elements, mas. %			
W	**C**	**Fe**	**The rest**
The base	3.7–4.2	Less than 0.5	Less than 0.2

Insstek MX-Grande machine was used for the synthesis of samples. The samples were single laser tracks. The laser power values used and the scanning speeds are shown in the Table 3. The diameter of the laser spot d in all modes was 1.8 mm. Depending on the composition of the composite material, the powder feed rate varied.

Table 3. Parameters of the laser surfacing models.

V, mm/min.	**P, W**			
400	400	600	800	1000
600				
800				
1000				

The content of the carbide phase and nickel alloy as a percentage and the feed rate in grams per minute is given in Table 4. A cross-section was examined in each sample.

Table 4. The powder feed rate.

Composition of WC – INC625, vol. %	**Feed rate, g/min.**
10 – 90	15.26
20 – 80	16.67
30 – 70	17.87
40 – 60	18.97
50 – 50	20.14
60 – 40	21.25
70 – 30	22.37
80 – 20	23.284
90 – 10	24.382

Methods of structural analysis. The structure of the composite material after surfacing and powders of the starting materials (WC and INC625) was studied by metallographic analysis methods. Two sets of samples were prepared for study on an optical or laser microscope: the first set is samples of the cross-section of a composite material on a metal substrate, the second is the initial powders. Metallographic analysis of the first set was performed on an Olympus GX53 microscope at magnification of ×50 and ×200.

X-ray structural analysis is a method of studying the structure of a substance by the distribution in space and the intensities of X-ray radiation scattered on the analyzed object [15]. Diffraction analysis was performed on a D8 ADVANCE from Bruker AXS diffractometer using filtered Cu K_α-radiation.

X-ray phase analysis of WC powder was carried out when shooting in the range of diffraction angles $2\vartheta = 20\text{-}140$ degrees with a step of $\Delta 2\vartheta = 0.02$ degrees and an offset of 0.3 sec. at the point. The following slot system was used: a motorized 0.5 mm slot on the tube. Soller slots with a distance between the plates of 2.5 mm on both the tube and the detector. During the shooting, the sample rotated at a speed of 60 rpm.

The X-ray analysis of Inconel 625 powder was carried out with the same parameters, but the diffraction angle was equal to $2\vartheta = 30\text{-}100$ degrees.

The microstructure of WC and INC625 powders (size and morphology) was studied using an Olympus 3D measuring laser microscope OLS4100. With this microscope, it is easy to make non-contact three-dimensional observations, as well as to obtain information about the surface profile, measure the thickness of translucent coatings, etc. With the help of a laser scanning microscope, it is possible to obtain an image of sections of the object of study, that is, WC and INC625 powders. This is possible because the laser focuses on a given depth of the object under study and takes a layered image of a micro-object with high contrast. Consequently, it becomes possible to study the structure of the object more precisely. And the software can put all the information into a 3D model of this object.

3 The results of experiments and discussion

3.1 Results of quantitative metallography

To select the optimal mode of laser surfacing and the composition of the composite material, we will analyze the obtained tracks. Objects for further investigation must meet the following conditions: $f = h / L$, with $1/5 < f < 1/3$; $d = P / (h + P)$, with $0.1 < d < 0.4$; $L > 1.7$ mm; angle $\theta < 90^o$; no cracks; porosity less than 1%. Figure 1 shows the geometric characteristics of the shape of the deposited track.

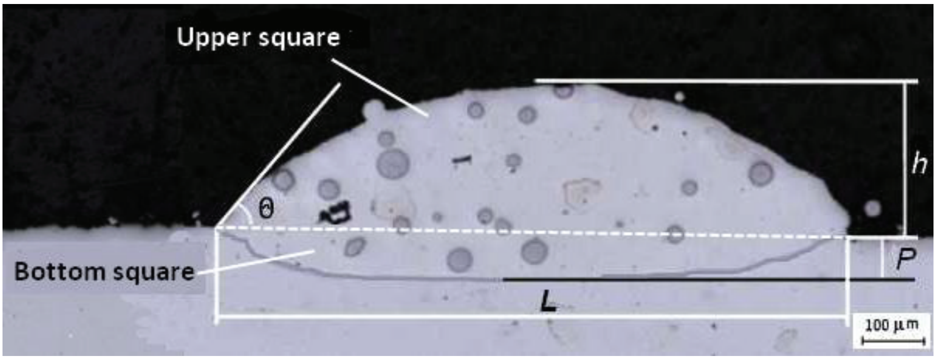


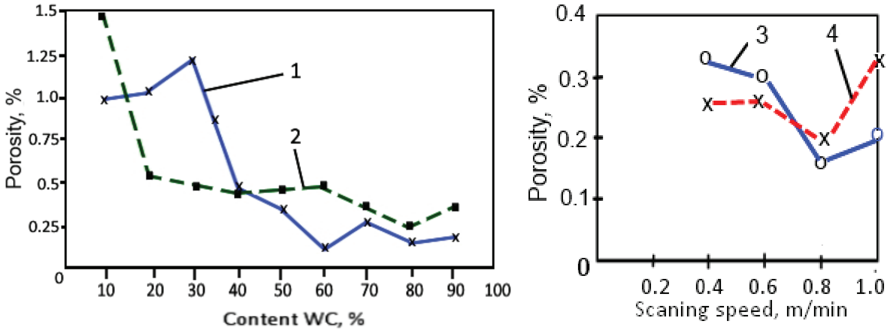
Fig. 1. The sample of track of the composition 30 % WC – 70 % INC625. The power of 1000 W and the scanning speed of 0.8 m/min. (×50).

The results of studies conducted at a power of 1000 W with a scanning speed of 0.8 m/min. are presented in Table 5. And the dependence of porosity on the composition and on the scanning speed for samples of the composition 40% WC – 60% INC625 are shown in Fig. 2.

Table 5. Conditions for selecting the surfacing mode.

Composition of WC – INC625, vol. %	f, units	d, mm	L, mm	Porosity, %	θ	The presence of cracks
1	2	3	4	5	6	7
10 – 90	0.26	0.25	1.96	0.72	–	–
20 – 80	0.27	0.24	2.08	0.66	–	–
30 – 70	0.24	0.27	2.08	0.39	–	–
40 – 60	0.21	0.29	2.08	0.25	–	–
50 – 50	0.23	0.29	2.14	0.67	–	–
60 – 40	0.26	0.28	2.17	0.11	–	+
70 – 30	0.29	0.45	1.89	0.09	–	–
80 – 20	0.26	0.43	1.92	0.47	–	+
90 – 10	0.25	0.36	2.07	0.24	–	+

Note: The column 6, whose data is the «+» sign, which shows that the angle is greater than 90 and the «–» sign is the angle less than 90. The column 7, in which «+» means that there is a crack, «–» - there is no crack.



a b

Fig. 2. Porosity dependence on composition *(a)* and scanning speed for the sample 40% WC – 60% INC625 (*b*): 1 – P = 800 W, V=0.4 m/min.; 2 – P = 400 W, V = 0.6 m/min.; 3 – P = 600 W; 4 – P = 1000 W.

Based on the results obtained from Table 5 and Fig. 2, the following conclusions can be drawn:

- composite coating of 90% WC and 10% INC625, applied by laser surfacing, should not be used, as it is most susceptible to cracks;
- for compositions containing 70% and 80% tungsten carbide particles, there is no optimal coating mode, since two or more conditions are not met;
- composite coatings containing 10% WC and 20% WC are impractical to use due to the small amount of carbides, since their mechanical properties will not differ much from the source material;
- the optimal mode of laser surfacing is coating with a power of 800 W and 1000 W and a scanning speed of 0.8 m/min.

The volume fraction of WC in the selected modes from Table 5 was calculated in the Olympus Stream Basic program. The result is presented in Table 6. A graphical explanation for calculating the volume fraction is shown in Fig. 1.

Table 6. The WC powder parameters.

Composition of WC – INC625, vol. %; power; scanning speed	Upper square, mm^3	Bottom square, mm^3	Total square, mm^3	The square of carbides, mm^3	The content of WC, %
30 – 70; 1000 W; 0.8 m/min.	0.735	0.27	1.005	0.05	5.2
40 – 60; 1000 W; 0.8 m/min.	0.601	0.325	0.926	0.08	8.74
50 – 50; 1000 W; 0.8 m/min.	0.64	0.355	0.995	0.174	17.49
60 – 40; 1000 W; 1,0 m/min.	0.467	0.336	0.803	0.213	36.53

Thus, it can be seen from Table 6 that there is significantly less tungsten carbide in the matrix than previously indicated.

3.2 The results of X-ray analysis

Figure 3 shows a radiograph of WC – W2C powder with phase decoding and interplant distance.

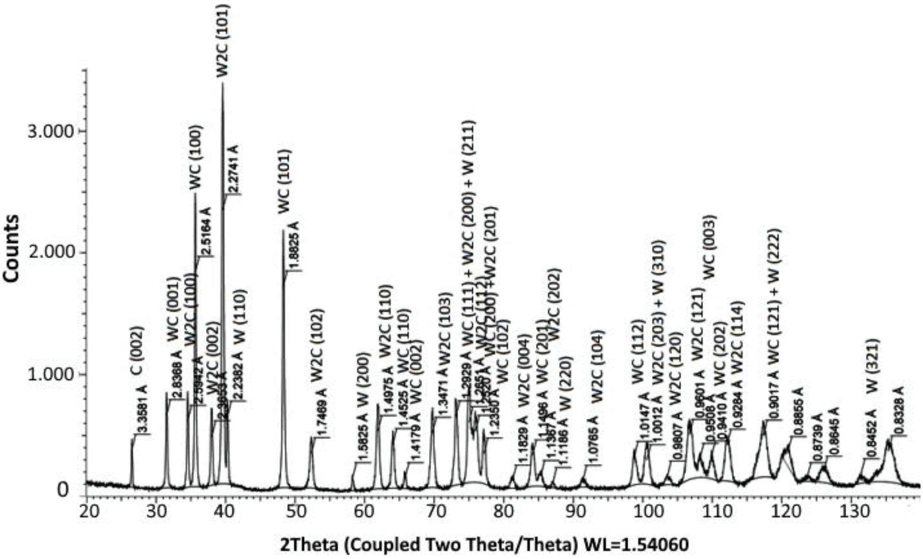


Fig. 3. Radiograph of WC – W_2C powder.

From the X-ray image (Fig. 3), we can conclude about the phase composition of the powder. The powder consists of such phases: W - volume-centering crystal lattice; WC and W_2C - hexagonal crystal lattice. Figure 4 shows a radiograph of Inconel 625 powder with phase decoding.

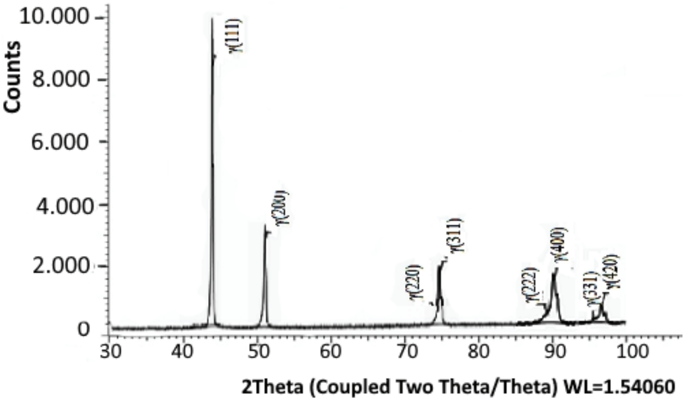


Fig. 4. Radiograph of Inconel 625 powder.

On the X-ray image (Fig. 4), all diffraction reflections from the FCC crystal lattice of the γ-solid solution are observed, there are no other reflections. Thus, the only phase present in Inconel 625 powder is γ.

When studying the structure and microstructure of the WC/INC625 composite material obtained by laser surfacing, it was found that the volume content of WC in the composite is less than stated [23-26]. It is likely that the tungsten carbide particles were dispersed to a greater extent during the feeding process than the nickel alloy particles. With an increase in the content of carbides, the number of defects (pores) becomes smaller up to a certain WC content, then the number of defects increases again. The most preferred for laser surfacing is a composite material with a content of 40% WC and 60% INC625 with a scanning speed of 0.8 or 1.0 m/min. and a power of 800 or 1000 W.

4 Conclusions

1. Composite coating of 90% WC and 10% INC625, applied by laser surfacing, is not recommended for further use due to the presence of cracks.

2. For compositions with a tungsten content of 70% or 80% WC, there is no optimal coating mode, since two or more conditions are not met.

3. Composite coatings containing 10% or 20% WC are impractical to use due to the small amount and uneven distribution of carbides, since their mechanical properties will not differ much from the source material.

4. It was found that the composite material with a content of 40% WC and 60% INC625 with a scanning speed of 0.8 m/min. or 1.0 m/min. and a power of 800 W or 1000 W is the most preferable for laser surfacing.

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