Formation of Nanosized Lamellas of a Hardening Intermetallic Phase in the Powder Ni-based Coating Deposited by Microplasma Spraying on Steel Substrates

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Abstract. This paper presents new results of studying the structure-phase compositions of Ni-based powder coating, deposited by Microplasma Spraying onto steel substrate by transmission electron microscopy (TEM), scanning electron microscopy (SEM), and X-ray diffraction (XRD). It is shown that we have managed to obtain the predicted specific structure with nanosized lamellas of intermetallic phases due to the appropriate proper selection of modes of additional microplasma processing. As a result, the microhardness of the coating has been increased by 1.25 times.

1. Introduction

Among the various existing plasma spraying processes for surface protection against corrosion and wear, Microplasma Spraying (MPS) is very beneficial for the deposition of coatings on small parts or with high accuracy [1,2]. However, a number of challenges still remain in the field of microplasma coating. The most important among them is the problem of the formation of coatings with specified structure and properties. Usually we have to use combined methods of plasma spraying including the deposition of powder on the substrate and the additional treatment of the coated surface by irradiation. Additional processing of the powder plasma coatings by irradiation is used to melt the coating in order to reduce its roughness and increase the homogeneity of its structure. This is reported in previous work [3,4]. We also proposed an alternative approach to the choice of additional processing as shown in our past works [5,6]. The selection of additional treatment modes has been based on the results of
simulation of temperature fields in the "coating-substrate" system under heating by a moving plasma source. We have indicated the precipitation in the coating during additional irradiation of the phases with defined morphology and composition that could increase the coating’s microhardness.

The purpose of this study is to use microplasma and additional surface treatment to form a nickel based coating with the desired microstructure, i.e. lamellas of the intermetallic phase.

2. Materials and Methods

The 100 µm thick coatings from PG-19N-01 powder (Ni-based powder alloy with addition of Cr (14...20%), B (3.5%), Si (4.3%), Fe (7%), C (0.8%)) were deposited on Steel 3 substrates (Fe – base, C - 0.25 %, Mn – 0.8 %, Si – 0.37 %, P < 0.045%) by MPS.

The microplasma deposition of powders onto steel substrates was carried out with the help of “MPN-004” micro-plasma deposition unit (produced by E. O. Paton Electric Welding Institute, Ukraine). The powder is fed in a stream of argon onto a substrate.

The modes of microplasma deposition: a laminar plasma jet; the diameter of the spray spot (1...8) mm; the power of plasma source 2 W; the powder flow rate 2 kg/hour; the travel speed of the plasma jet 0.008 m/s.

The additional treatment of the samples by a plasma jet was carried out at power density of 2.0·10⁹ W/m² with 0.006 m/s of the plasma jet travel speed.

Experimental methods of analysis include Transmission Electron Microscopy (TEM) by JEOL JEM-2100 with Energy Dispersive Spectrometry (EDS) INCA Energy TEM 350, Scanning Elec tion Microscopy (SEM) by JEOL JSM-6390LV, X-ray diffraction (XRD) by X’Pert PRO. Gatan M-691 Precision Ion Polishing System was used to prepare TEM foils by the Ar ion sputter etching method. Microhardness test of the samples was performed with LM-700 digital microhardness meter.

3. Results and Discussion

The XRD results shows up to about 10 vol.% of CrNi₃ phase with fcc crystal lattice (a = 3.55 Å) is formed. This is whilst the original powder coating does not contain this phase (figure 1).

The microhardness of the coating in average is 6.0± 0.5 GPa, and that of the substrate is 1.4 ± 0.1 GPa. After additional pass by a plasma jet the CrNi₃ phase volume fraction increased by 5 vol. % of (figure 1), and the coating microhardness increased by 7.5 GPa (figure 2).

![Figure 1. Phase composition of investigated materials](image-url)
The analysis of the coating by TEM method showed that the CrNi$_3$ phase is released in the form of nanoscale lamellae (figure 3a) from the fcc coating matrix ($\gamma$-phase, solid solution on Ni-base with parameter $a = 3.5(8)$ Å) consisting of crystallographically disoriented, approximately equiaxed grains with a diameter of about 50 nm (figure 3b).

These results are of significance due to the followings: firstly, the coating consists of the ductile base with fcc lattice type which is reinforced by lamellas of hard and heat-resistant intermetallic phase. It gives the possibility of creating a protective coating having a combination of properties such as thermal stability, high hardness and good ductility at the same time. This is also noted in the work of other researchers [1,2]. Secondly, we proposed an alternative approach to the choice of modes of additional processing. As the authors of papers [3, 4] have noted, an additional treatment of powder plasma coatings by irradiation results in melting of the coating. This consequently improves the homogeneity and adhesion to the substrate results in the melting of the coatings. The use of relatively low power densities of the plasma source in our study allowed the hardening of the coating due to the phase transformations which take place at lower temperatures. However, our proposed approach is not universal and requires a thorough and further analysis of the coating material and desirable and possible phase transformations.
4. Conclusions

The laboratory samples with protective powder coatings deposited by the microplasma according to the recommended modes onto steel substrates have been obtained; and it was established experimentally that the coatings have the predicted structure-phase composition, namely the nanograin Ni-based solid solution with precipitations of strengthening intermetallic lamellas of CrNi$_3$ -phase which provide the coating’s high microhardness.

TEM and XRD methods confirmed a 4% increase in the volume fraction of CrNi$_3$ phase in the coating after additional microplasma irradiation.

It is established that microhardness of the coatings after additional processing is 1.25 times higher than that of the same coatings before irradiation, and 5 times higher than that of the substrate.

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