INFLUENCE OF TECHNOLOGICAL FACTORS ON THE FORMATION OF AMORPHOUS PLASMA-SPRAYED COATINGS

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We investigate the influence of technological factors of the process of pulsed plasma spraying (in particular, of the composition of plasma-forming gases and magnetic fields) on the formation of amorphous coatings. It is experimentally established that the formation of coatings in the presence of a magnetic field applied in the region of spraying favors the formation of amorphous coatings and, thus, increases their adhesion to the base. The application of argon-hydrogen mixtures as plasma-forming gases make it possible to obtain homogeneous coatings with elevated contents of the amorphous component.

The comparative analysis carried out in [1] and our own investigations demonstrate that the method of pulsed plasma spraying has significant advantages over the well-known technologies of application of massive amorphous coatings, namely, high cooling rates (required for the formation of amorphous coatings), high temperatures of heating of particles of powders in plasma jets (required for the application of refractory powder materials), strong pulses of pressure observed in the process of interaction of heterogeneous jets with the base (necessary to improve the adhesion of coatings and decrease their porosity), and the application of inert gases as plasma-forming gases (this enables one to decrease the degree of oxidation of the material of coatings and guarantee the required transformation of the powder into the material of coatings). At the same time, high potentialities of the method of pulsed plasma spraying are poorly investigated up to now. In particular, to guarantee the maximum possible content of the amorphous component, it is necessary to determine the optimal technological parameters of the process of spraying. The present work is devoted to the investigation of the influence of the composition of plasma-forming gases and magnetic fields on the formation of coatings with amorphous structure.

Coatings were sprayed in an “Impulse-M” experimental and commercial installation with updated coaxial plasma accelerator [2]. For spraying, we used PG-10N-01 and PT-19N-01 commercial nickel powders and new Fe-Mo-Cr-B powder alloys [3]. Metallographic and structural analyses were carried out with a DRON-3 diffractometer, a MIM-8 microscope, and a “Camebax MB-1” X-ray microanalyzer. To evaluate the amount of the amorphous phase according to the data of metallographic analysis, the experimental results were subjected to statistical processing.

It is known that external magnetic fields with an induction of 10–20 T facilitate the formation of the amorphous structure of metallic multicomponent melts in the process of their rapid cooling by increasing their ductility over the value required for the transition to the amorphous state (10^{12} \text{ Pa} \cdot \text{sec}) [4]. This means that it is quite promising to use external magnetic fields for the formation of amorphous plasma-sprayed coatings. Magnetic fields of different intensities (3–8 kA/m) were induced in the spraying region on the surface of the base (workpiece) by electromagnets. For intensities lower than 3 kA/m, there influence of the magnetic field on the structure of coatings is insignificant. The magnetic field intensity of 8 kA/m is close to the upper limit of our technical possibilities.

In the process of pulsed plasma spraying in magnetic fields, the results of durometric and structural analyses reveal the formation of the areas of coatings located near the base (with a width of about 150–250 \text{ \mu m}) that are not susceptible to etching even by strong metallographic agents and have anomalous microhardness. If PG-10N-01 powders are sprayed in the magnetic field, then the structure of the coating forms near the base is homogeneous, with predominance of the light phase. Against the background of the light phase, one can readily detect dispersed microcrystalline inclusions (Fig. 1a). The data of X-ray diffraction and microscopic X-ray spectral analyses show that this phase is amorphous. In the absence of magnetic fields, coatings consist of alternating layers of light amorphous and dark microcrystalline components (Fig. 1b).

Fig. 1. Microstructure (×800) of coatings made of PG-10N-01 powders with a degree of dispersion of 20–40 μm in the presence (a) and in the absence (b) of a magnetic field applied to the base.

A similar situation is observed for Fe–Mo–Cr–B alloy sprayed in the magnetic field but the width of the relevant zone is somewhat smaller (150–200 μm).

To explain changes in the structure of coatings induced by the action of magnetic fields, we performed special X-ray diffraction analysis. We studied the influence of magnetic fields on the structure of coatings with a thickness of 100–150 μm (close to the working thickness). As follows from the comparison of the X-ray photographs of coatings applied in the presence and in the absence of magnetic fields, magnetic fields are responsible for a noticeable decrease in the height of the peaks of crystalline phases accompanied by an increase in their width and an enlargement of the range of angles of reflection where it is possible to observe the diffuse halo. Similar changes in the diffraction patterns attributed to an increase in the amount of amorphous component are also recorded for coatings based on nickel and iron (Fig. 2).

Changes in microhardness across the thickness of sprayed layers mean that magnetic fields applied to the spraying region may be responsible for the opposite effects in alloys with different chemical compositions, namely, for Ni–Cr–B–Si alloys (PG-10N-01 and PT-19N-01 powders used in the present work are alloys of this type), the microhardness of the zone adjacent to the base slightly decreases. At the same time, the microhardness of Fe–Mo–Cr–B alloys increases. This can be explained by the fact that the mean microhardness of the coating is determined by the fractions of its amorphous and microcrystalline components. For Ni–Cr–B–Si alloys, the microhardnesses of the amorphous and microcrystalline components of the coating are equal to 5.8–6.0 GPa and 6.5–7.5 GPa, respectively. As the distance from the base increases, the amount of the amorphous phase in the coating decreases as a result of changes in the conditions of heat removal through the sprayed layer caused by the deceleration of the process of cooling. This promotes an increase in microhardness. In the presence of magnetic fields, the amount of the amorphous phase increases and the curve of microhardness becomes smoother.