HEAT TREATMENT USING HIGHLY CONCENTRATED ENERGY SOURCES

CHANGE OF STRUCTURE AND PROPERTIES OF CHEMICALLY DEPOSITED Ni-P COATINGS IN FUSION BY CONTINUOUS CO₂ LASER

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Laser amorphization (glazing) of the surface is bound to improve considerably the properties of structural materials since amorphous metallic alloys are better than their crystalline alloy analogs as regards corrosion resistance, strength, hardness, and wear resistance [1]. However, the technical realization of the glazing process is held up by a number of circumstances.

One of the main obstacles to the practical solution of the problem of laser amorphization is the very low vitrifying ability of the traditional materials which cannot be converted into the amorphous state even when fusion regimes with the shortest pulses are used. On the other hand, most amorphizing alloys contain a large amount of nonmetallic elements, have low ductility and are very brittle, and in consequence there are no real prospects that can be used as technical materials. Hence follows that a combination of the bulk properties of structural alloys with the unique characteristics of amorphous phases in the surface layers of products can be attained only by laser alloying by which a single cycle provides jointly for the process of fusion of the vitrifying alloys directly on the surface of the treated part and the subsequent rapid cooling of the alloyed layer by conducting the heat away into the deep-lying layers of the substrate.

Since the suitability of alloys to amorphization is sensitive to the quantitative ratio of the components in them, it is necessary in the realization of the technology of laser surface alloying to endeavor to attain chemical homogeneity of the zone of treatment. The solution of this problem is simplified if the coating intended for fusion not only has an amorphizing composition but is also in the amorphous state, i.e., homogeneous to the highest degree, in regard both to composition and structure. One of the modifications of such coatings are chemically deposited alloys of the system Ni-P: it was shown in [2] that they can be re-amorphized by laser fusion in pulsed regime.

In the present work we investigated the changes of phase composition, microstructure, and microhardness when Ni-P coatings with steel substrate are fused with the aid of a continuous CO₂ laser.

Coatings with specified thickness and concentration Ni-12% P* were deposited from aqueous solutions by the method of [3] on substrates of steel 45 subjected to hardening and high tempering. The thickness of the coatings was varied within the limits 5-50 μm by changing the time of deposition, and it was checked with a thickness meter TsNK-30 or metallographically. Laser treatment was carried out with a continuous CO₂ laser with power density of the radiation 60-100 MW/m² and a scanning speed of 5-20 mm/sec. By changing the conditions of laser radiation we attained different degrees of fusion of the surface layer which was evaluated by the parameter \( K = \frac{h_f}{h_c} \), where \( h_f \) is the maximal thickness of the fused zone and \( h_c \) the maximal thickness of the chemically deposited coating.

The microstructure was investigated under a light microscope MIM-7 and a scanning electron microscope Cambridge Stereoscan S4-10. The zone of laser fusion was etched in a mixture of equal quantities of nitric and acetic acids for 1-3 sec at normal temperature. Microhardness was measured on an instrument PMT-3 with a load of 0.2 and 0.5 N and subsequent statistical processing of the results. The random error in determining \( H \) was calculated for a confidence level of 0.95.

X-ray structural investigations were carried out on a diffractometer DRON-3 in copper Kα radiation with the use of the method of monochromatization of the diffracted beams by an LiF crystal.

*Here and henceforth in this article the content of elements is given in atomic fractions.

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It was established by diffractometric analysis that deposited coatings with atomic fraction of more than 10% phosphorus, independently of the thickness, have an amorphous structure that yields a diffuse pattern of the scatter of x-rays (Fig. 1a). After fusion of coatings by a CO₂ laser with coefficient \( K = 3.3 \) the nature of the diffraction spectra undergoes a qualitative change: on the diffractograms of the irradiated specimens there appear distinct interference lines (Fig. 1b) which can be grouped into two systems. The first system contains highly intense lines whose mutual relative disposition is characteristic of phases with fcc lattice. The second system has low-intensity maxima situated at angles of reflection \( 2\theta < 55° \). Interpretation of the results of diffractometric analysis showed that the intense lines correspond to solid solution based on \( \gamma \)-Fe with lattice period \( a = 0.355 \text{ nm} \). The lines of the second system are satisfactorily correlated with the key maxima of nickel phosphide \( \text{Ni}_3\text{P} \) or of the isostructural compounds with more complex composition of the type \((\text{Ni, Fe})_3\text{P}\).

A comparison of the data of Fig. 1a and b shows that there is no diffusion halo or even traces of it, which would indicate that the structure of the laser-treated zone contains an amorphous component. Hence follows that treatment of coatings of Ni-12% P by continuous laser radiation in a regime of deep fusion \( (K = 3.3) \) does not cause the effect of reamorphization, and the alloyed layer assumes a crystalline structure.

The obtained result is logical because when the surface layer is deeply fused, its composition is strongly enriched with matrix elements and deviates substantially from the composition of the vitrifying coating. This conclusion is confirmed by a comparative qualitative analysis of the concentration of nickel and iron in the neighboring fused and nonfused parts of the zone affected by the laser (Fig. 2). When we compare the photographs obtained with a microscope Cambridge Stereoscan S 4-10 in characteristic nickel and iron \( K_{\alpha} \) radiation (Fig. 2) we may conclude that treatment with a large parameter \( K \) is accompanied by a substantial decrease of nickel content and an increase of the amount of iron in the fused sections.

A lowering of the coefficient \( K \) to 1.3-1.5 manifests itself in reduced contrast of the electron micrographs obtained in characteristic nickel \( K_{\alpha} \) radiation. Also, in the diffraction spectra of the zone of laser fusion the lines corresponding to the phosphide \( \text{Ni}_3\text{P} \) become substantially thicker. That the fused layer contained a small amount of iron was established in the investigations by scanning electron microscope, and also from the lattice period \( (a = 0.353 \text{ nm}) \) of the solid solution.

When the depth of fusion is reduced by changing the regime of laser treatment to values of \( K \) close to unity, it leads to a state in which the chemical composition of the coating of