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PRODUCTION OF WEAR-RESISTANT COMPOSITE MATERIALS BY THE METHOD OF HIGH-ENERGY INDUCTION IMPACT

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ABSTRACT

The use of a high-energy effect makes it possible to control the rates of heating and cooling, which, under certain conditions, leads to the production of maximum non-equilibrium structures. The control of the structure formation of materials of a given composition, in conditions far from thermodynamic equilibrium, makes it possible to provide the required durability of the working zone of the product when exposed to high contact and dynamic loads under conditions of abrasive, shock-abrasive and impact wear. Technologies that ensure the regulation of the structure formation of materials, due to the rates of heating and cooling, in conditions of high-energy heating, make it possible to use materials of a given composition to form the required set of properties, taking into account the nature of wear. The main difference between such heating and heating by external heat sources is that heating occurs directly in the metal due to the electromagnetic field created by the inductor. The aim of this work is to develop technological parameters for obtaining wear-resistant composite materials with a given set of physical and mechanical properties, obtained by the method of high-energy induction exposure using metal powders of a given composition. In the course of the work, the technological modes of obtaining layered composite materials with a given structure and properties were established, taking into account the nature of wear. The studies carried out have shown that a decrease in the time of high-energy induction exposure during the production of a composite material provides a high hardness (55-58 HRC) and wear resistance under conditions of abrasive wear. An increase in time leads to a decrease in hardness to 43-45 HRC, which increases the wear resistance when exposed to impact loads.

Keywords: composite material, induction heating, wear resistance.

INTRODUCTION

The use of a high-energy effect makes it possible to control the rates of heating and cooling, which, under certain conditions, leads to the production of maximum non-equilibrium structures. The control of the structure formation of materials of a given composition, in conditions far from thermodynamic equilibrium, makes it possible to provide the required durability of the working zone of the product when exposed to high contact and dynamic loads under conditions of abrasive, shock-abrasive and impact wear. Technologies that provide regulation of the structure formation of materials, due to the rates of heating and cooling, under high-energy heating conditions make it possible to use materials of a given composition to form the required set of properties, taking into account the nature of wear [1-5].

One of the ways to obtain layered composite materials is to apply to the base component a metal melt obtained from a powder mixture under conditions of induction (Figure-1).

The use of this technology makes it possible to control the structure formation of the material, which ensures the formation of a given set of physical and mechanical properties, taking into account the operating conditions. I use a metal charge of the same composition [6-13].

Therefore, the purpose of this work is to develop technological parameters for obtaining wear-resistant composite materials with a given set of physical and mechanical properties, obtained by the method of high-energy induction exposure using metal powders of a given composition.

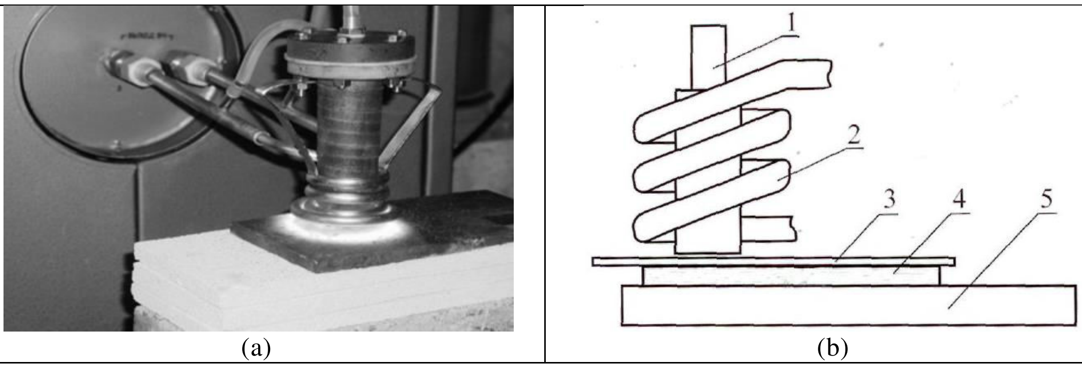
MATERIAL AND METHODS

Based on the analysis of wear-resistant materials [5, 7, 14, 15, 16] to obtain experimental samples of a layered composite material, PGS-27 alloy was used in the form of a metal powder (Table-1) mixed with boron-containing flux in an amount of 20%. Low-alloy steel 9MnSi5 was used as a component of the base of the composite material.

Obtaining the composite material was carried out using a high-frequency induction transistor type UVG 2-25, with a working frequency range of 44-66 kHz. General view and diagram of the technological process are shown in Figure-1.

Table-1. Chemical composition of PGS-27 metal powder.

Brand metalpowder	**Chemicalcomposition, %**					
	C	**Cr**	**Ni**	**Si**	**Mn**	**Fe**
PGS-27	2,5-3,5	25,0-31,0	3,0-5,0	2,8-4,2	0,5-1,5	base



(a) (b)

Figure-1. Obtaining a composite material at a high-frequency induction unit UVG 2 - 25; a - general view; b - scheme: 1 - ferrite core; 2 - turn inductor; 3 - charge; 4 - componentbase; 5- table.

Studies of the influence of technological modes on the formation of the structure and properties of a composite material were carried out using the following techniques and research equipment:

- metallographic-by electron microscopy using electron microscopes JEOL JSM 7001F, "HITACHI TM-1000" and optical microscopy using a light microscope "Carl Zeiss Axio Vision";
- energy dispersive and chemical analysis in a JEOL JSM 7001F scanning electron microscope equipped with an energy dispersive spectrometer from Oxford Instruments;
- hardness analysis on the TK-2M device by the Rockwell method.

The use of high-energy induction heating in the production of layered composite materials makes it possible to control the depth of penetration of the base component due to the thickness of the skin layer, which is determined by the formula:

$$\Delta = \sqrt{\frac{2\rho}{\omega\mu\mu_0}}\text{, m} \qquad (1)$$

where $\omega = 2\pi f$ –is the cyclic frequency of the generator, μ is the magnetic permeability of the substance, μ_0 is the magnetic constant, ρ - is the specific resistance of the substance.

Obtaining the minimum penetration depth of the base component allows you to preserve the original chemical composition of the deposited material. The energy dispersive analysis carried out made it possible to trace the change in the chemical composition in the cross-sectional plane and to determine the nature of the interaction of the highly alloyed deposited material with the material of the base component, as well as the chemical composition of the phases present.

The spectral line shown in Figure-2 passes through three zones of the test specimen: the deposited layer (left) - the interface - the base component. The interspectral distance is 1 µm. The chemical composition of the spectra under study is shown in Table-2, based on the results of which a graph of changes in the concentration of alloying elements along the interface and adjacent areas was built (Figure-3).

Table-2. The chemical composition of the studied spectra.

Spectrum No	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Number of alloying elements, %											
Si	0,85	0,77	0,75	0,77	0,61	0,58	0,46	0,38	-	-	0,33
Cr	11,51	11,31	11,15	10,64	9,58	7,04	2,92	1,13	0,68	0,53	0,47
Mn	0,72	-	-	-	-	0,6	0,63	0,75	0,87	0,75	0,74
Ni	-	0,77	0,79	0,78	-	-	-	-	-	-	-

Analysis of the change in alloying elements shows a sharp decrease in the chromium concentration in the range of 5-7 spectra and the absence of nickel in 5 and subsequent spectra. Since chromium and nickel are absent in the base component, such a change indicates that the interface thickness is in the range of 2-4 µm, and its formation occurs due to the adhesion of the molten metal powder to the solid-phase base component and the diffusion of alloying elements into the boundary zone. At the initial stage, diffusion proceeds mainly along the grain boundaries, and later, at temperatures close to the solidus point of the metal powder, the character of diffusion of elements changes and transforms from intercrystalline to bulk (frontal), which leads to the leveling of the interface surface.

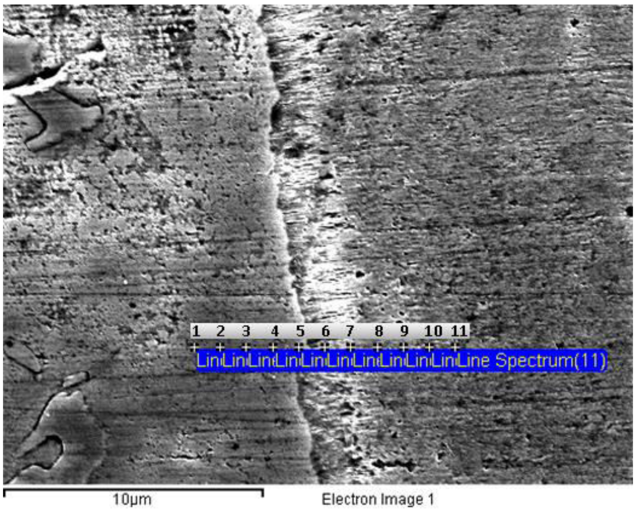


Figure-2. Energy dispersive analysis line.

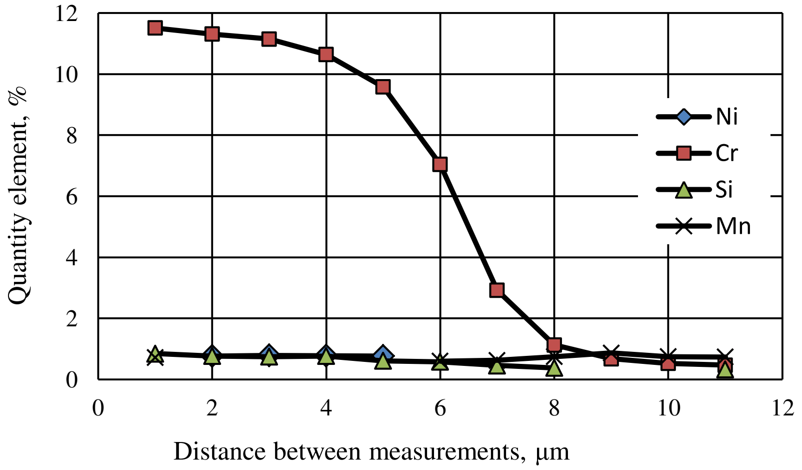


Figure-3. Change in the concentration of alloying elements in the investigated area.

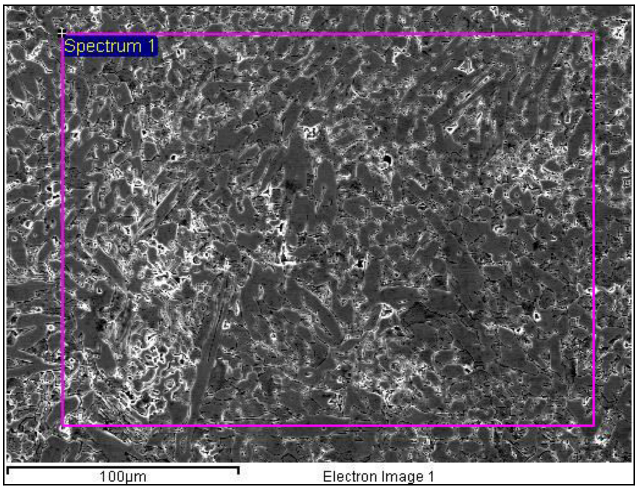


Figure-4. Spectrum for determining the chemical composition of the resulting layer.

As the exposure time to high-energy induction heating increases, the temperature of the base component increases and diffusion processes intensify. According to the calculation

$$D = 13{,}8 \cdot \exp\left[-\frac{31600}{T}\right],\ \mathrm{cm^2/s} \qquad (2)$$

where T is the temperature, K, the diffusion coefficient of chromium into steel, at a temperature of about 1573 K (solidus temperature of the metal powder), is 2.6 · 10-8 cm^2/s.

The formation of an interface with a thickness of 2-4 µm makes it possible to draw conclusions about the minimum or complete absence of penetration of the base metal, and, therefore, the chemical composition of the deposited layer does not change, which makes it possible to predict the structural-phase composition and properties of the resulting composite material. The chemical composition of the deposited layer, presented in Table-3, was determined by the volume spectrum (Figure-4) with an area of 0.04 mm^2, including a set of phases. Analysis of the data obtained showed that the chemical composition of the deposited layer corresponds to the composition of the original metal powder (Table-3).

Based on this correspondence, it can be assumed that in the process of high-energy induction heating with a certain current frequency and duration of exposure, no melting of the base component occurs.

Table-3. The chemical composition of the deposited layer.

Chemical composition, %					
C	**Si**	**Cr**	**Mn**	**Fe**	**Ni**
3,18	0,58	30,60	0,59	61,79	3,52

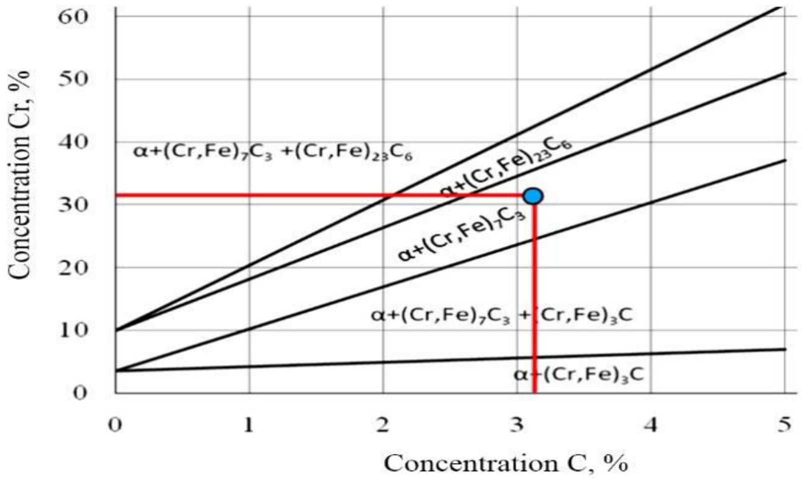
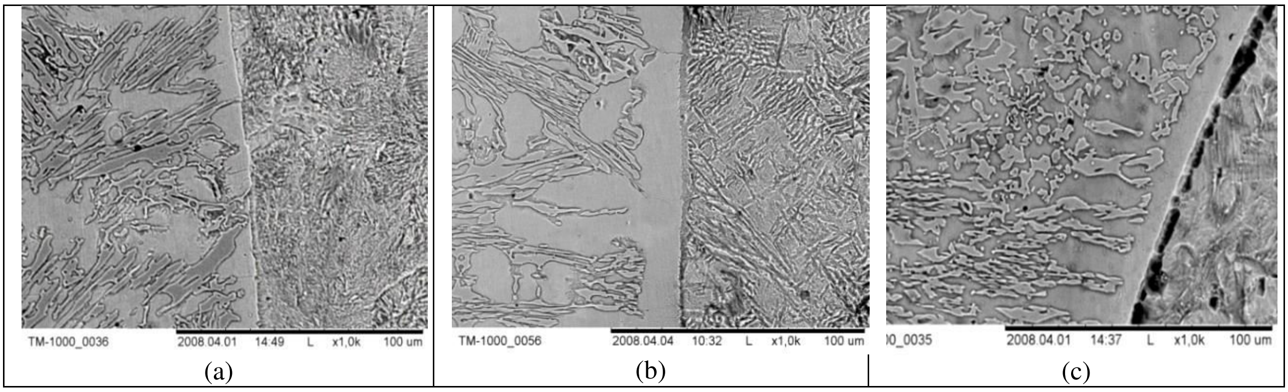


Figure-5. Isothermal section of the Fe - Cr - C phase diagram.

Hardness is an indirect criterion for evaluating wear resistance under abrasive wear conditions. The hardness of the materials used depends on the type, size and amount of the carbide phase. According to the isothermal section of the Fe - Cr - C diagram (Figure-5), carbides of the (Cr, Fe)$_7$C$_3$ type are formed in the structure of the deposited layer, the hardness of which is higher than the carbides of the Me$_3$C type.

Studies of the influence of technological modes on the formation of the structure and properties of the formed layer showed that when a layer is obtained from a melt of a metal powder with a workpiece movement speed relative to the inductor of 6.5 m/h, the interface between the components of the composite material is not very thick and is practically degenerate into a line, and the resulting carbide phase has a dispersed structure (Figure-6, *a*). With a decrease in the speed to 5 m/h (Figure-6, *b*), a depletion of the section of the obtained layer close to the interface with the carbide phase is observed, as well as an increase in its thickness. This difference in structure is obvious and is associated with a longer exposure time to high energy induction heating. Obtaining a layered composite material at a speed of 8-9 m/h leads to the appearance of defective areas at the interface (Figure-6, *c*), which is explained by the insufficient time of interaction of the molten charge with the solid-phase component of the base.



(a) (b) (c)

Figure-6. Influence of speed on the formation of the layer structure (in the left corner), structure and size of the interface: *a* - 6.5 m/h, *b* –5 m/h, *c* - 8-9 m/h.

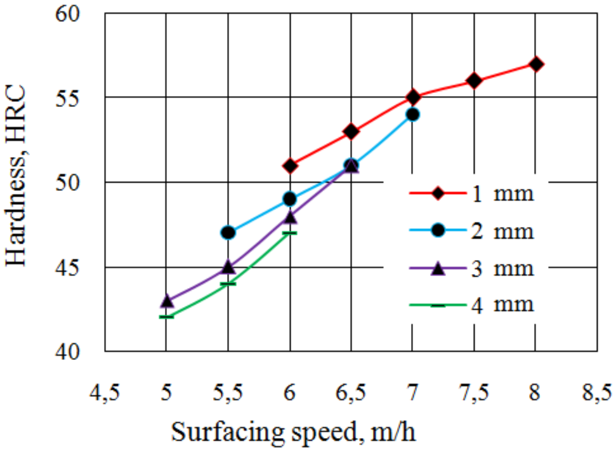


Figure-7. Dependence of the hardness on the surfacing speed, with different layer thickness.

An increase in the thickness of the layer being formed, as in the case of a decrease in the rate, leads to an increase in the time of exposure to high-energy induction heating, complete dissolution of carbides in the liquid phase, and stronger heating of the base component, which leads to an increase in the size of the carbide phase. The change in hardness, depending on the deposition rate and layer thickness, is shown in Figure-7. It is shown that a decrease in the rate and an increase in the layer thickness contribute to a decrease in hardness. Finely dispersed carbides, evenly distributed in the metal matrix, provide maximum hardness values of 55-58 HRC. Obtaining high hardness is possible with a layer thickness of no more than 1-2 mm and is necessary under the condition of abrasive wear, and when exposed to impact loads, high hardness contributes to the embrittlement of the material.

Obtaining a layered composite material at reduced speeds of 5-6.5 m/h and a deposited layer thickness of more than 3 mm increases the service life of products operating under shock loads by reducing the hardness of the deposited layer to 43-45 HRC.

CONCLUSIONS

The regularities of the structure formation of a layered composite material, which determine the formation of mechanical and operational properties, during induction heating have been established. A decrease in the time of high-energy exposure contributes to the formation of dispersed carbides of the $(Cr, Fe)_7C_3$ type. The resulting layer is characterized by increased hardness (55-58 HRC) and wear resistance under abrasive wear conditions. An increase in the heating time leads to an increase in the size of the carbide phase; the hardness of the layer decreases to 43-45 HRC. The duration of induction heating is determined by the speed of movement of the resulting layered composite material relative to the inductor and the thickness of the deposited layer. The results obtained allow us to conclude that the use of high-energy induction heating makes it possible to obtain layered composite materials with a given set of physical and mechanical properties depending on the nature of wear, using materials of the same composition.

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