

# Investigation of the structure and microhardness of ‘Mo-Fe-C’ coatings obtained by the electron beam injected in the atmosphere

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**Abstract.** In this work ‘Mo-Fe-C’ coatings fabricated on medium carbon steel by non-vacuum electron beam cladding were investigated. The structure of coatings and transition zones were studied by scanning electron microscopy (SEM). It was shown that an increase of Fe percentage in the cladding mixture led to a decrease of the eutectic volume fraction in the coating and was accompanied by the formation of the gradient structure between the coating and a substrate material. Measurements of microhardness in the cross section of samples revealed that the cladding of a ‘Mo-C’ powder mixture contributed to a 4.5-fold increase of microhardness.

## 1. Introduction

One of the main tasks of mechanical engineering is enhancing wear-resistance of the parts functioning in abrasive wear conditions. The surface layers of parts contacting an abrasive material are subjected to wear. Therefore a rational solution of the tasks is hardening of the product surface.

Formation of high-resistant particles surrounded by a viscous matrix in the surface layers of the work-piece provides high resistance to wear. When cladding wear-resistant coatings, the alloys of a carbide family or carbide-based powders are used. The coatings obtained by cladding with expensive tungsten carbide, (wolfram carbide) WC [1-4], have the highest resistance indices at abrasive wear. However, the carbides of the transition metals, belonging to 4 – 6<sup>th</sup> groups of the chemical elements of the periodic system, possess high hardness and yield to other elements in wear-resistant indices insignificantly. The use of refractory carbides, such as TiC, CrC, TaC, VC, MoC, NbC, as surfacing materials seems a more rational solution [5-12].

Nowadays there is a great number of ways of coating formation using a cladding technique. The best prospective methods refer to cladding with the use of high-energy sources of heating: plasma, laser and electron beam [13-18]. A combination of high productivity of the process of non-vacuum electron-beam cladding along with the possibility of processing large-sized products distinguishes this method from others. Per one beam pass the coatings with thickness of several millimetres are formed. Besides, during inhibition of relativistic electrons a large amount of heat, sufficient for melting of virtually any materials, is emitted, which is why, at further cooling, the synthesis of carbides in the molten pool becomes possible [9].

The aim of the present paper is to study structural-phase transformations, occurring at formation of molybdenum-containing coatings realised by the method of non-vacuum electron-beam cladding.



## 2. Materials and methods

Molybdenum carbides are distinguished by their increased hardness (14 GPa) and melting temperature (2700 °C). At high energy impact as a result of non-vacuum electron-beam cladding a synthesis of molybdenum carbides is possible. Besides, molybdenum, present in steel, enhances steel viscosity, which decreases the embrittlement influence of the clad coatings. Therefore the powders of molybdenum and graphite have been chosen as main alloying elements for the cladding process.

Samples made of 40X steel with dimensions of 50×100×12 mm have been chosen as a basis. The powder mixture, consisting of molybdenum, graphite, iron, and flux – in one case, and molybdenum, graphite, iron, and flux – in the other, was applied to a preliminary smoothed surface of the sample. The pouring density of the powder mixtures amounted to 0.33 g/sm<sup>2</sup>. The ratio of the molybdenum content to the carbon content in the mixture corresponded to 1:1 (at.). The iron powder was introduced into the cladding mixture in order to increase moistening of molybdenum particles in the molten pool in the amount of 30 % wt. The CaF<sub>2</sub> flux was used for protection against oxidation in the process of cladding in the amount of 40 % wt. The chemical composition of the original materials is shown in Table 1.

Non-vacuum electron-beam cladding was conducted at the Institute of Nuclear Physics of the Siberian Branch of Russian Academy of Sciences (SB RAS) named after G I Budker (Novosibirsk) using the electron accelerator, ELV-6. The electron-beam processing of the powder mixtures was realised in a scanning mode. The electron beam energy amounted to 1.4 MeV and the beam current was 28 mA. The sample moved relatively the beam in the direction, which is perpendicular to the plane of beam scanning, at the rate of 1 sm/s.

**Table 1** – Chemical composition of original materials, wt. %.

	C	Mn	Si	P	S	Ni	Cr	Cu	Fe	Mo	O
Steel 40X	0.41	0.86	0.32	0.03	0.02	0.17	1.11	0.16	96.92	-	-
Powder Mo	-	-	-	-	-	-	-	-	-	90.40	9.60
Powder C	100	-	-	-	-	-	-	-	-	-	-
Powder Fe	-	-	-	-	-	-	-	-	98.61	-	1.39

A structural analysis of materials was conducted using the scanning electron microscope, Carl Zeiss EVO 50 XVP. The structure was revealed using a three-percent solution of nitric acid in ethyl alcohol. The element composition of the coatings was determined by the energy-dispersive analyser, INCAX-ACT (Oxford Instruments). For determination of the phase composition of the clad coatings the ARL X'TRA diffractometer was used. The diffraction patterns were registered in increments of 0.05 ° at accumulation time of 3 s.

Durometric properties of coatings, interface regions and the base metal were determined with the use of the microhardness tester of Wolpert Group 402MVD type. The indentation load amounted to 0.98 N. The microhardness measurements were conducted on the basis of the crosscut sections in the direction from the coating surface to the base metal.

## 3. Results and discussion

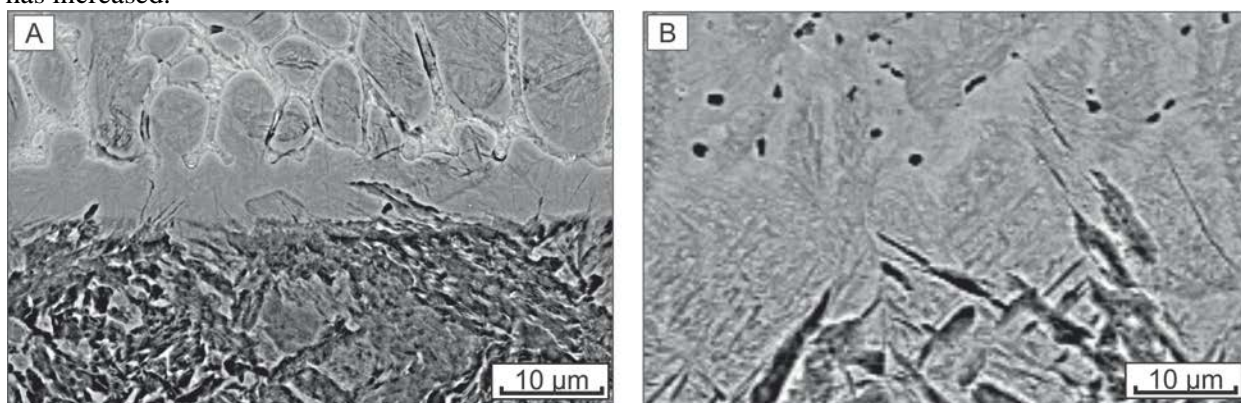
The conducted metallurgical studies have not revealed any cracks, pores in the coatings. The modified layers have the thickness of ~ 2.3 mm at cladding of 'Mo-C' and 'Mo-C-Fe' powder mixtures. Delamination signs along interfacial area 'coating-base metal' were not registered (Figure 1). Additional introduction of the iron into the cladding mixture has reduced the concentration of the alloying elements (molybdenum and carbon) in the alloyed layers. As a result the interfacial area has become more blurred (Figure 1B).

The structure of the clad layer represents an iron matrix, which grains have a dendrite shape. The eutectic, consisting of alpha-iron carbides, excreted along the dendrite boundaries (Figure 2). The volume fraction of eutectic excretions for the coating, obtained by cladding with the molybdenum powder mixed with graphite, amounted to 27.7 %. Hereupon, the reduction in the concentration of the alloying elements in the coating has affected the decrease of the volume fraction of eutectic up to 12.3 %.

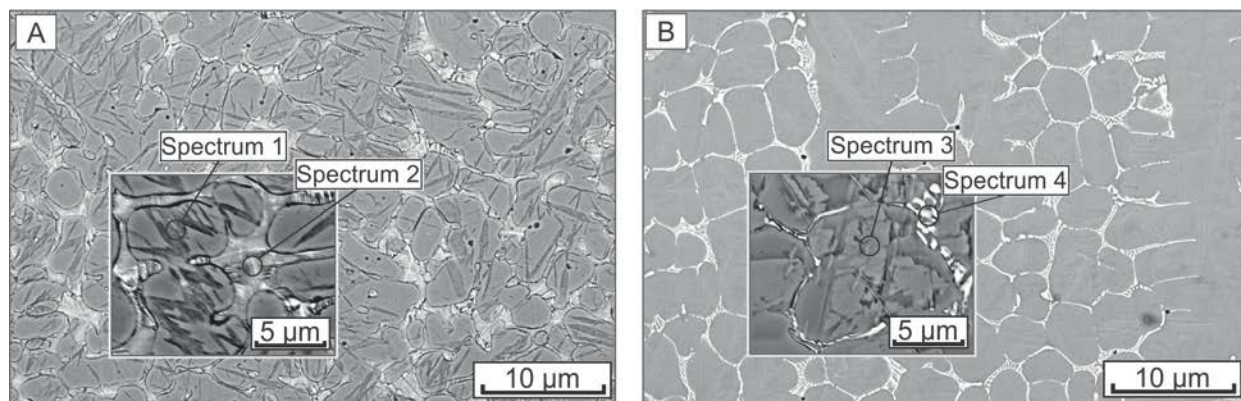
Using the method of the X-ray phase analysis one has fixed four phases:  $\alpha$ -Fe,  $\gamma$ -Fe,  $\text{Mo}_3\text{Fe}_3\text{C}$  and  $\text{Mo}_6\text{Fe}_{11}\text{C}_5$  in both coatings. It is necessary to note that the peaks corresponding to  $\gamma$ -Fe phase in the layer, clad by the 'Mo-C-Fe' powder mixture, are lower in comparison with the second coating. In the 'Ti-C' coating high-alloyed martensite crystals, surrounded by the residual austenite, have grown across the whole volume of dendrites (Figure 2 A).

In the volumes of eutectic in addition to iron and complex carbides, containing iron and molybdenum, there is also oxygen, detected by the X-ray spectral microanalysis method (Figure 2, Table 2). It should be mentioned that the oxygen was detected during the elemental analysis of the initial molybdenum powder, where the oxygen was found probably in the form of a molybdenum oxide (Table 1). During the process of dendrite formation the oxygen was forced out on the grain boundary.

An introduction of the iron into the cladding mixture has resulted in reduction of molybdenum in eutectic. At the same time the quantitative analysis has shown that the amount of carbon has increased (Table 2). These results indicate that in this type of coating the volume fraction of the  $\text{Mo}_6\text{Fe}_{11}\text{C}_5$  phase has increased.



**Figure 1.** Interfacial area of the coating – a base metal for the materials obtained by cladding of the powder mixtures of 'Mo-C' (A) and 'Mo-C-Fe' (B).



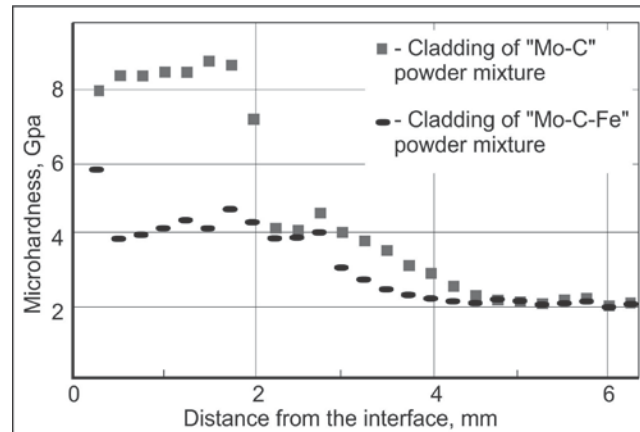
**Figure 2.** The structure of coatings cladded by the powder mixture of 'Mo-C' (A) and 'Mo-C-Fe' (B)

**Table 2** – Elemental composition of local zones of molybdenum coatings.

Element	Fe, at. %	Mo, at. %	C, at. %	Cr, at. %	O, at. %
Zone					
Spectrum 1	78.68	6.53	13.76	1.02	-
Spectrum 2	42.12	22.83	20.78	1.00	13.27
Spectrum 3	83.74	2.59	12.84	0.83	-
Spectrum 4	48.19	15.16	22.02	1.81	12.82

The coating formed on steel by means of electron-beam cladding of the 'Mo-C' powders possesses a microhardness of  $\sim 9$  GPa (Figure 3). The decrease of the volume fraction of eutectic in the molybdenum-

containing coating from 27.7 to 12.3 % has influenced the reduction of the microhardness of up to 4.5 GPa. However, in the second case the hardness of the clad layer is more than two times higher than the hardness of the base material.



**Figure 3.** Microhardness of the materials obtained by means of electron-beam cladding with molybdenum-containing powders.

#### 4. Conclusions

The method of non-vacuum electron-beam cladding of molybdenum-containing layers on steels shows the effectiveness of obtaining of the coatings with the thickness of  $\sim 2.3$  mm with enhanced microhardness. These coatings are remarkable for absence of macroscopic defects in the form of pores and cracks. Structural studies of the modified layers have shown that the introduction of iron into the cladding mixture is accompanied by blurring of the interfacial area – ‘coating-base metal’, but, at the same time, it affects the decrease of the eutectic volume fraction. Electron-beam cladding of the ‘MO-C’ powder mixtures ensures enhanced microhardness of the material up to 9 GPa.

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