Forming of Multifunctional Coats by Vacuum-Free Electron Beam Surfacing and Thermal Treatment of this Coats[1]

T.A. Krilova*, I.M. Poletika*, M.G. Golkovski**, and M.V. Perovskaya*

*Institute of Strength Physics and Material Science, 2/1, Academichesky ave., Tomsk, 634021 Russia
Phone: +7(3822) 28-68-58, Fax: +7(3822) 49-25-76, E-mail: poletika@list.ru
**Budker Institute of Nuclear Physics, 11, Academician Lavrentiev ave., Novosibirsk, 630090 Russia

Abstract – One-layer and two-layer surfacing of chromium powder mixtures and chromium carbide onto St3 low-carbon steel in different mixing proportions using the relativistic electron beam has been carried out. The surfaced layers have been subjected to heat treatment in the form of tempering and quenching. The structure and phase composition of the surfaced layers before and after the heat treatment have been investigated by the methods of metallography, TEM, X-ray phase analysis and microanalysis. The conclusions on the nature of the property formation of coatings – hardness, wear-resistance, corrosion-resistance, crack-resistance and beam-strength have been made. It was established that wear-resistance of surfaced layers cannot be characterized only by hardness, but the formed structure pattern as well. Corrosion resistance depends on amount of chromium in the source powder mixture. It increases with increasing the component ratio Cr/C in surfacing mixture. Optimal surfacing conditions were matched that allow achieved the coats on steel St3 having high levels of all investigated properties simultaneously. It is shown that the applied method of surfacing is high technological, as it allows to form coatings on the surface of low-carbon steels, which in their initial condition possess higher mechanical properties than after their standard thermal treatment.

1. Introduction

During their service life, various mechanical and machine components should sustain deteriorating environmental factors such as corrosion, abrasion, both static and impact loading, heat degradation, etc. Comparatively new environmental relativistic electron beam surfacing method has been developed to enable protection of the metallic surfaces. Such an approach allows melting practically any refractory material, providing deep penetration of electrons into metals, high processing rates and simple feeding of the alloying additives. Therefore, this method is feasible both for quenching [1] and surfacing the mechanical components [2].

The objective of this paper is to obtain both wear- and corrosion resistant coatings on low-carbon steels using the environmental electron beam surfacing as well as characterize them for structure, phases, flexure strength and effect of standard heat treatment thereof.

2. Materials and methods

Electron accelerator ELV-6 has been used to obtain both single- and double-layer coatings from pure chromium carbide Cr_3C_2, Cr_3C_2/Cr mixture of weight ratio 1 and 2 (regimes 2 to 5) on sheets of low-carbon steel St3.

Heat treatment has been carried out using laboratory SSHOL oven. The samples were coated by lime before being tempered at 650 °C for 1 h, heated to 850 °C for 0.5 h and then quenched in water. Optical microscope NEOPHOT as well as TEM instrument EM-125 has been used to examine the microstructure of samples. Phase composition was analyzed using X-ray diffractometer DRON-2M. The distribution of chromium in the build-up layers was determined using X-ray microanalyzer CAMEBAX. For microhardness test we used PMT-3 instrument and abrasive wear resistance was determined using the free abrasive particles method according to GOST 23.208-79.

Corrosion resistance was determined by measuring the weight losses on keeping the samples in nitric acid. Flexure test on both surfaced and control samples were performed using Instron 1185 test machine operating at loading speed 1.7 μm/s.

3. Results and discussions

Microstructure of surfaced layer is composed of solid solution dendrites and eutectic grains (Fig. 1).

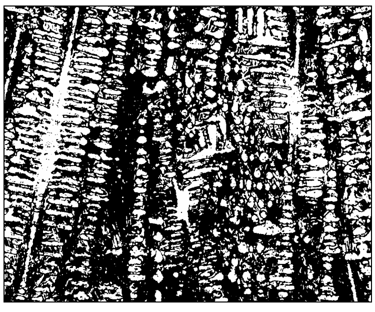

Fig. 1. Microstructure of double-layer coating for Cr_3C_2/Cr = 1, × 500

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The microanalysis shows that chromium is distributed nonuniformly across the microstructure with sharp oscillations in the chromium content in either solid solution or eutectics. According to X-ray diffractometry, both solid solution and eutectic grains are based on austenite. In addition, the presence of two carbides of the types Cr_7C_3 and $Cr_{23}C_6$ was detected. As shown, the basic hardening phase Cr_7C_3 precipitated in the surfaced layer deposited using the source carbide mixture of Cr/C < 2 weight ratio. Along with the above-indicated phases and using the SAED method, we detected also some amounts of CrC, Cr_3C, as well as traces of σ-phase (FeCr). Such a composition may characterize the non-equilibrium microstructure of the electron beam surfaced material.

There is no uniformity in distribution of microhardness numbers across the coating section (Fig. 2) due to the microstructural inhomogeneity.

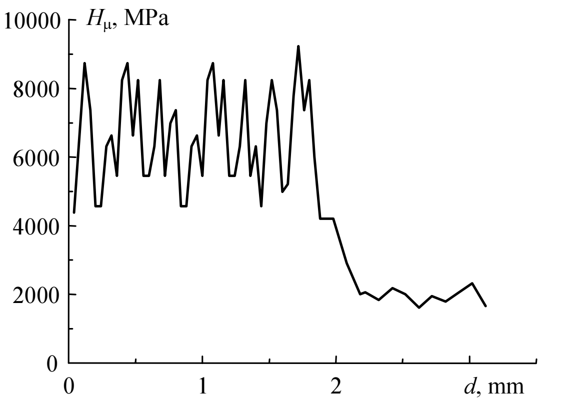

Fig. 2. The distribution of microhardness numbers in the coating, $Cr_3C_2/Cr = 2$

The mean microhardness number grows with the chromium carbide content in the source mixture (Fig. 3, *a*) and correlates both with the volume content of eutectics and chromium content in both phases.

The wear tests in Fig. 3, *b* show that the wear resistance does not necessarily depends on the coating hardness, in fact, these values do not, even correlate to each other. One can see from Fig. 3, *a* that the wear resistance is impaired in spite of high hardness of double-layer coating resulted from the increasing content of eutectics. It follows from this fact that increasing the carbide content is reasonable only until reaching some limit, here 40%. The higher carbide content may change the wear mechanism from abrasion to brittle fracture. Therefore, high hardness is not the only criterion for developing the hardfacing coatings.

The results of corrosion tests are shown in Fig. 3, *c* where corrosion resistances of the coatings in nitric acid (curves *2*, and *3–6*) are lower those of stainless steel 12X18H10T grade (curve *7*) but higher that of St3 (curve *12*). The resistance is enhanced by adding more chromium to the source mixture. The corrosion rate slow down on testing the samples for 5 h due to passivation by $(Cr,Fe)_2O_3$ film.

It follows from the analysis of the test results that most efficient bifunctional single-layer coatings on St3 are obtained from the source powder mixtures of $Cr_3C_2/Cr = 2/1$.

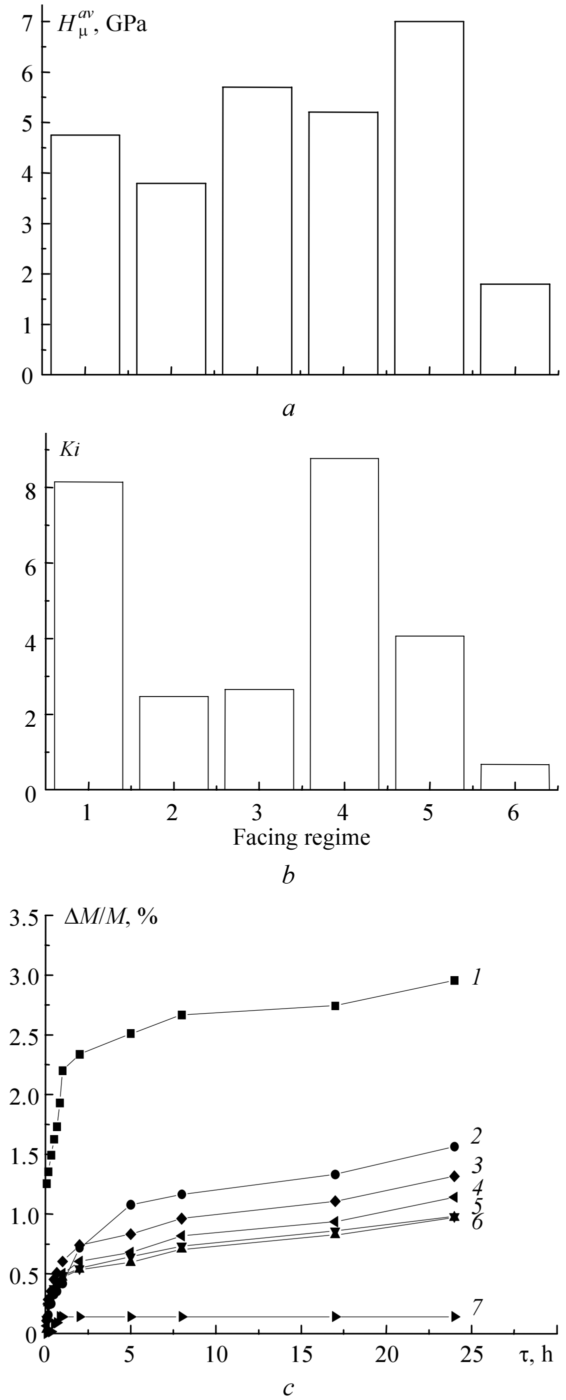

Fig. 3. Mean microhardness level (*a*), wear resistance (*b*), and time-dependent weight losses of samples in nitric acid corrosion test (*c*) vs. processing regime

Wear resistance is impaired by depositing the mixture of $Cr_3C_2/Cr = 1$ composition since the hard phase content is reduced. When double-layer coatings are deposited, too many carbides precipitate in the austenite matrix thus reducing the overall fracture toughness of the eutectics and facilitating the brittle fracture in wear.

Although surfacing the substrate material by pure carbide Cr_3C_2 serves to enhance the wear resistance, the corrosion resistance is reduced thereon due to the lack of chromium in the solid solution.

The X-ray phase analysis of the tempered samples shows only the presence of α-Fe while no γ-Fe peak is observed. The Cr_7C_3 content grows sufficiently as compared to the first deposition whereas its hardness is reduced. TEM images show decomposition of austenite and precipitation of perlite-like strictures consisting of α-phase platelets and $(Fe,Cr)_7C_3$ carbides. The eutectic grains suffer diffusion-controlled $\gamma \rightarrow \alpha$ transformation, coarsening of Cr_7C_3 carbide platelets and extra precipitation of nanosize $M_{23}C_6$ carbides.

Quenching the samples gives the coating's hardness of the same level as hardness of the first deposited coating before any heat treatment was carried out. Phase analysis shows the presence of α-phase (martensite) as well as Cr_7C_3 and $Cr_{23}C_6$. Quenching from the temperature 850 °C initiates martensite transformation in solid solution, further coarsening of $(Fe,Cr)_7C_3$ particles, and partial $(Fe,Cr)_7C_3 \rightarrow M_{23}C_6$ transformation.

Eutectic grains suffer $\gamma \rightarrow \alpha$ transformation both by martensitic and diffusion-controlled mechanisms as well as the precipitation of nanosize $M_{23}C_6$ carbides.

The fracture pattern of a sample after the flexural strength test shows only the main crack, which propagates being driven by comparatively low stress (Fig. 4). The fracture mechanisms may be elucidated by initiation of secondary cracks which stop in the substrate metal.

Tempering serves both to higher pre-fracture strain limit and yield strength for all hardfaced samples as compared to simply coated ones. The fracture pattern of coated samples shows many small spiral cracks instead of the main one. Rather high ductility of the base metal serves to dulling the crack tip and stopping its further development. The hardfacing coating after tempering and quenching from 850 °C demonstrates a lot of brittle isolated cracks of high energy. Furthermore, many cases of spalling are observed at the coating/substrate interface.

Abrasive wear tests of the heat treated samples demonstrated that wear resistance is reduced by a factor of 4 to 5 as compared to the initial deposition both for tempered and quenched samples. Changes in strength, ductility and wear are related to the peculiarity of structures formed. On tempering, the wear resistant austenitic phase is substituted by ferrite and in quenching the hard martensitic phase precipitates thus reducing strength, ductility and wear resistance by a high risk of brittle fracture.

4. Conclusion

The results of this work enable a conclusion that the relativist electron beam hardfacing is a high technology that allows obtaining structurally non-equilibrium hypoeutectic coatings on the low-carbon steel substrates. These coatings demonstrate their strength, ductility and wear resistance being much higher those of obtained on alloys of same composition using the standard heat treatments such as tempering and quenching.

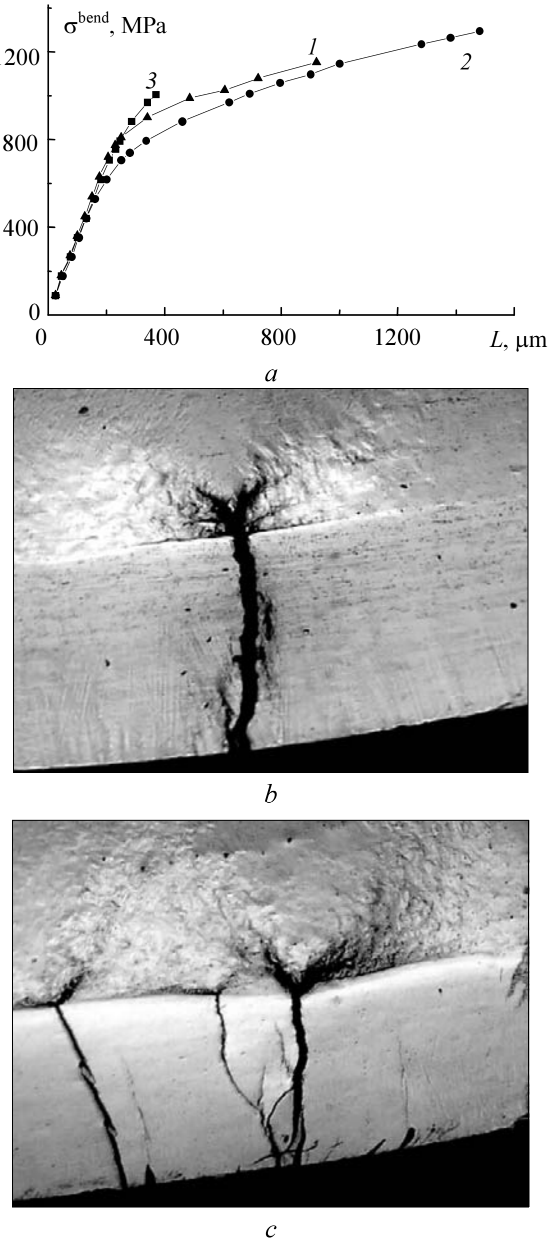

Fig. 4. Bend stress vs. bend deflection (*a*) of coated samples (*1*), on tempering 650 °C (*2*) and after quenching 850 °C (*3*); fracture pattern of non-treated coating (*b*), quenched and tempered coating (*c*), × 50

References

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