Structure and Wear Resistance of the Coatings on the Basis of M2 Steel Obtained by Electron-Beam Deposition

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Abstract – Features of structure formation of the coatings on basis of M2 steel obtained by multipass E-beam vacuum deposition were investigated. It was established that multimodal size distribution \(d_1 = 3.8 \mu m, d_2 = 0.65 \mu m, d_3 < 0.25 \mu m\) of reinforcement particles was formed in the carbide subsystem of hardened layer. The volume fractions of secondary carbides \(M_6C\) and residual austenite of matrix can be changed in the wide range depending on the deposition thermal cycle. Wear resistance of the coatings increased with the growth of quantity of residual austenite through \(\gamma \rightarrow \alpha'\) martensitic transformation and presence of disperse secondary carbides in the volume of matrix grains.

The correlation between wear resistance of steels, alloys and their mechanical properties has a quite intricate character. It is especially typical for heterophase materials: cemented carbides, carbide-steels and coatings on their basis [1–3]. A number of different factors have influence on their wear resistance. There are: volume fraction, size, shape and phase composition of reinforcing particles; binder phase free path, matrix phase composition, dissolved reinforcing particles quantity, the presence of residual austenite and its capability to phase transformation under external action. Materials present better both abrasive and sliding wear resistances by grinding the reinforcing phase to nano- and substructural state.

However it doesn’t succeed to maintain the initial disperse structure by coating deposition, for example on the basis of WC–Co [3]. It leads to higher wear rates of deposited coatings as compared with their sintered counterparts. Investigations that are restricted by work [6] show that it is possible to obtain the homogeneous age-hardened structure in volume of hardened layer by E-beam deposition. This structure has a bimodal size distribution of reinforced particles that allows their wear resistance improvement. The purpose of this work is clear: to influence of temperatures that occur in material by multipass E-beam deposition on phase-structure composition and wear resistance of coatings on the basis of HSS M2.

The high-speed steel M2 powder with dispersity 50…350 \(\mu m\) was used for electron-beam (E-beam) vacuum deposition. Four-pass coating was deposited on flat low-carbon steel substrates with dimensions 30×200 mm (thickness \(h\)) was changed in the range of 5…40 mm). The power of electron beam was changed subject to number of pass: first pass – 4050…4300 W, second – 2900…3200 W, third – 2160…2300 W, fourth – 2000…2100 W. Electron beam diameter, peripheral length and substrate movement speed weren’t changed and amounted to 1 mm, 20 mm, and 2.8 mm/s correspondently.

The thermocouple was placed into the centre of base metal substrate for temperature measurement by E-beam deposition. It was situated close by deposited metal (0.5 mm). Three-body abrasive test was used for abrasive wear resistance definition.

Figure 1, \(a\) shows the dependence of base metal substrate temperature on their thickness by E-beam deposition thermocycling (4 passes). It is evident that temperature reached 830…840 \(^\circ C\) for minimal substrate thickness (5 mm) after four passes and only 430…450 \(^\circ C\) for its maximal thickness. Analysis of thermokinetic diagram of supercooled austenite decay [7] allowed to define temperature area (830…500 \(^\circ C\)) at which disperse secondary carbides (\(M_6C\) type) are extracting from austenitic matrix. On the basis of this dates it can propose with confidence that in deposited coatings which substrate was heated over 500 \(^\circ C\) it can most probably expect the maximum quantity of disperse secondary carbides that extracted from austenitic matrix.

According to dates of \(\mu X\)-ray analysis deposited coating has a chemical composition like this: (in wt.%) Fe – 1.34 C – 5.94 W – 1.35 V – 4.0 Cr – 5.37 Mo. Joint analysis of microstructure and X-ray dates confirms that the reinforcing phase is represented by \(M_6C\) and VC carbides. \(M_6C\) carbide has two morphological types (Fig. 2, \(a\)). The first type is the reticular eutectic carbides with mean size is 3.8 \(\mu m\) situated on the solid solution grain boundaries. The second morphological carbide type is disperse (\(< 0.25 \mu m\) eqiuxed carbides situated inside of austenitic matrix grains.

The variation of secondary carbides volume fraction against substrate thickness is presented on the Fig. 1, \(b\). It is evident that their maximum quantity was extracted in hardened layer deposited on base metal substrate with thickness about 21 mm that were heated to intensive carbide extraction temperatures (600…700 \(^\circ C\)) [7]. Vanadium carbide is presented by separate round discharges (white particles) generally situated near the eutectic carbides of \(M_6C\) type (Fig. 2, \(b\)). The mean size of vanadium carbide particles is 0.65 \(\mu m\) and their volume fraction doesn’t exceed 0.7…0.9%. Coating matrix is presented by martensite-austenitic mixture. Martensite volume frac-
tion is changed as a curve line with minimum (Fig. 3, a) subject to base metal substrate thickness.

![Graph](image1)

\[ Y = 901.5 - 20X + 0.21X^2 \]

![Graph](image2)

The analysis of dependence of relational wear resistance coefficient variation on coating hardness has a complicated character and doesn’t conform traditional views: if the coating is harder, it will have better wear resistance. Consequently, the main factors that have an influence on wear resistance of high-speed steels besides hardness are quantity, character of distribution and size of carbides [8–10], matrix structure state and capability of metastable austenite to martensitic transformation by external actions [2]. It is well known [11] that better wear resistance of cast high-speed steels in comparison with deformed ones is accounted for by the presence of hard eutectic carbides framework on the solid solution grains boundaries in their structure. Eutectic carbides framework in conditions of oxidation and abrasive wear is more efficiently than single detached carbide particles.

Disperse carbide discharges are necessary for preservation the grain volumes of soft matrix from abrasion. Analysis of literature deals with volume composites WC–Co [4, 5], shows that matrix free path is decreased increasing the hardness by transition from the micro to nanocrystalline carbide structure at the same cobalt content. Wear resistance is increased dramatically at both sliding and abrasive wear. This effect is accounted for by carbide grains size and binder free path reduction that limits selective wear and following carbide grains chipping [4, 5]. There is a hope that two morphological carbide types (reticulate discharges on the grain boundaries and ultrafine-disperse carbides on the boundaries and in volume of solid solution) in hardened layer significantly differed by sizes (multimodal distribution: \( d_1 = 3.8 \), \( d_2 = 0.65 \) and \( d_3 < 0.25 \) μm) allow to increase its wear resistance.

Martensitic transformation of metastable austenite matrix under external loads can be the additional factor for wear resistance improvement [2]. Last investigations of deformation character and destruction of composite materials point out the main role of binder phase in material plasticity providing. The composite plasticity increase is established by binder capability to relax the stress raiser, to pass the load to carbide particles and to provide the braking of crack development at carbide destruction. It can be realized only with phase-structure transformation in matrix. Unlike sliding this deformation mechanism allows to move crystal lattice atoms on interatomic distance forming the new crystal structure under stress action in the every small volume of material such as thin interlayers between carbide particles.

Figure 3, b shows the dependence of relative wear resistance coefficient variation on martensite volume content in matrix. It is evident that this relationship has an obvious minimum when the martensite content approximately equals to 85% from the total matrix volume. Wear resistance increased on the left side.
Modification of Material Properties

Wear resistance increasing on the right side of minimum is established most probably with growth of total quantity of solid components in deposited coating. There are carbide particles and initial matrix material. Wear resistance of these coatings grows in conditions of purely abrasive wear, but the strong spread of $K_i$ values by point-to-point transition (Fig. 3, $b$) is observed. In conditions of impact abrasive wear when the cracks will intensive develop by interaction, wear resistance of this coatings will fall because of significant crumbling of large volumes of brittle coating material.

Figure 3, $c$ shows the effect of base metal substrate thickness on the quantity increment of $\alpha'$-phase in surface coating volume after wear test. It is shown that there is an increment of deformation martensite quantity in surface coating volume (10 µm) after wear test in the range of base metal substrate thickness 13...21 mm. Judge by microhardness variation and X-ray layerwise analysis layer depth of $\gamma \rightarrow \alpha'$ transformation and substructure changes doesn’t exceed 40...50 µm.

Analysis of relationships that are presented in Figs. 1, $b$ and 3 allows to conclude that with growth of residual austenite quantity wear resistance of coatings is increased by $\gamma \rightarrow \alpha'$ martensitic transformation intensity and presence of disperse secondary carbides in the matrix grains volume. It is safe to say that increment of residual metastate matrix austenite quantity will propose the improvement of coatings wear resistance.

References