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Segregation of atoms of the eutectic alloys Fe-Mn-C-B at friction wear

M.I. Pashechko*, K.C. Lenik
Education Technical and Information Department, Lublin University
ul. Nadbystrzycka 38, Lublin 20-618, Poland
* Corresponding author: E-mail address: pashechko@hotmail.com

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Properties

ABSTRACT

Purpose: Wear resistance of eutectic alloys based on the Fe-Mn-C-B-Si-Ni-Al-Sc system was studied.
Design/methodology/approach: The surface alloys were obtained by plasma surfacing of steel disks with previously prepared powder alloys. Atomic segregation in the eutectic coatings due to wear was studied by Auger-spectroscopy.
Findings: An increased content of C, B, Si at a friction surface was revealed. Oxygen diffusion from the atmosphere into the coating was not detected.
Research limitations/implications: Probably, that is due to the B and Si atoms segregation upon friction, and formation of B_2O_3 or system B_2O_3 - SiO_2 is possible in the surface layer. Under some friction conditions they become more soft or liquid. The latter lowers the friction coefficient to values similar to these in liquids.
Originality/value: The obtained results allowed to reveal a new effect in tribology of the Fe-Mn-C-B-Si-based dispersionally reinforced composite eutectic alloys: intensive diffuse processes occurring upon wear, leading to the C, B and Si contents increase in the friction surface.
Keywords: Working properties of materials and products; Segregation; Eutectic alloys Fe-Mn-C-B

1. Introduction

Iron-, nickel-, cobalt-, and SiC-based coatings are hard coatings commonly applied by thermal spray processing [1,2]. Typical compositions of these coatings include Ni-Cr-Si-B-C, Co-Cr-W-C and Fe-Mo-C. Although the Ni- and Co-based coatings have good corrosion resistance, Fe-based coatings are often used in place of the Ni- and Co-based coatings because the Fe-based coatings are less expensive [1]. Therefore, Fe-30Mo-2C (Diamalloy), Ni-17Cr-2.5Fe-2.5Si-2.5B-0.15C (Metco) and Co-30Cr-12W-2.4C (Stellite) coatings were selected because of their superior wear corrosion properties and that they can be easily deposited on cast substrates. The Stellite coatings had the best corrosion resistance. The wear of the lining material was lowest when it slid against the Stellite coated disk and the highest coefficient of friction was observed for the Metco coated disk [3].

The processes of surface segregation of C, Si and Al atoms on friction of the Fe-C, Fe-Si, Fe-Al, Cu-Al, Cu-Sn alloys has been described in Ref. [4]. It was noted that the influence of the segregation of carbon atoms on the friction properties of steel is ambiguous. On the one hand, the presence of carbon in the friction surface reduces the adhesive interaction of the contacting solids. On the other hand, it may reduce the efficiency of lubrication. Modification of the mechanical properties of the surface layer by wear may also occur, due to the Ioffe, Rebinder, Roskoe, and Kramer effects [4]. The features of the surface layer structure and their influence on the selective transport of copper atoms were investigated by the low angle X-ray scattering [5].

It was observed that the material in the friction layer may become plastic or friable depending on the presence of active or non-active substances presence [4]. The visual plasticits is due to the lowering of the potential barrier to be overcome by dislocations moving toward the surface of the solid.

2. Experimental

Structural - chemical investigations of secondary structures formed by wear of eutectic coatings, were carried out by Auger-spectroscopy using a JAMP-10S (JEOL) instrument. The specimens were cut out as segments from disks with external diameter of 50 mm. The concentrators were put on the segments at opposite to a friction surface's side. The segments were fractured in vacuum. The analysis was carried out at points situated along the fracture surface from the depth of the specimen towards is the friction surface.

The surfaces were cleaned by ultrasonic treatment in a powder dispenser followed by ionic treatment in a vacuum unclear. In the latter case the accelerating voltage was about 10 kV, the current 1 μA, the pulsing voltage 5 V, and the residual pressure 5×10^{-7} Pa. Quantitative analysis was accomplished using the element sensitivity factors for pure metals. Ionic bombardment of the analysed area by an argon ion beam (accelerating voltage ~3 kV, ion current 10^{-5} A) was performed before recording the spectra. Typical areas (according to chemical structure) were selected for recording of the spectra. They were located by statistical analysis of the sets of the measured spectra. In addition, a reflected electron method was used. A detector forming an image depending on the composition of the analysed surface was applied.

The elemental distribution was studied by "Superprobe -733" apparatus.

The measurements of a wear resistance of the eutectic coatings on the steel 45 samples were carried out in a disk - disk (50 mm) apparatus with a sliding friction rate and engagement factor of 0.2. The loading pressure were 4, 8 and 15 MPa, the sliding speed was 1 m/s, the test time was about 6 hours. Lubricant AMG10 was used in the experiments. Samples of steels-45, -52 and -54 HRC were applied as counterbodies. The wear resistance of the samples was determined by weighing and by profilometry.

The eutectic wear-resistant coatings were obtained from the relative powder alloys by plasma spraying with UPU-3D equipment (Russian) [6].

3. Results

The wear resistance investigations of the manufactured materials showed, that the friction couple "eutectic coating - steel 45" was characterized by the highest wear resistance (Fig. 1). It should be noted, that the eutectic alloys were from 2 to 10 time more wear-resistant in comparison with coatings obtained from the powder alloys PG-SR3 and PG-10N-01 (a powder - analogue 10009 "Borotak", CASTOLIN, Switzerland) (Fig. 1) [1,6].

The coating structure obtained from a Fe-Mn-C-B-Ni-Al-Sc alloy powder consisted of complex alloyed parlite (matrix phase), manganese iron carbide $Fe_{0,4}Mn_{3,6}C$ (reinforcing phase) and iron boron precipitates Fe_2B (dispersion phase) (Fig. 2,3).

The change in Fe, Mn and C ratio in the powder alloy structure essentially affects the mass ratio of the matrix and reinforcing phases and assists creation of the coatings with pre-eutectic, posteutectic and eutectic structures. The increase in Fe or Mn content in the alloy structure as compared to the base eutectic structure results in enrichment of the liquid phase by atoms of these elements. This leads to an increase of concentration of complex alloyed parlite or manganese iron carbide $Fe_{0,4}Mn_{3,6}C$ in the structure of the coating [6]. These data permit the optimum relationship between wear resistance of the both hard and damping matrix phases to be produced.

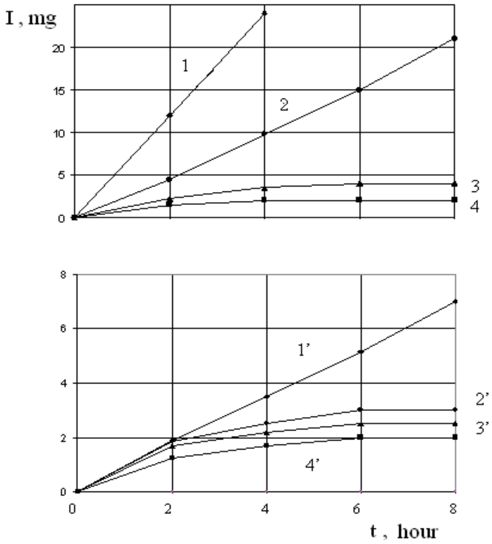

Fig. 1. Wear kinetics of eutectic coatings (1-4), obtained by plasma surfacing in powder alloys PG-SR3 (1), PG-10N-01 (2), PG-12N-01 (3), FMI-14 (4) and counterbody in steel-45 (1`-4`) on lubrication

The required chemical structure of a composite alloy as well as its phase composition and properties, are determined by a medium's destroying influence on the surface. The later can be oleaginous, abrasive, oleaginous-abrasive, etc.

The decrease of microhardness of the eutectic basis shifts the area of maximum wear resistance to higher contents (up to 60-95 %) of the redundant hard inclusions. The results obtained (and also the analysis of the friction surface) indicates that the friction energy is accumulated in a subsurface layer. It creates a power field, promotes a considerable increase in the amount of defects in a crystalline lattice, specifically dislocations. These phenomena appear in more plastic ferrite component of the eutectic and lead to work hardening and fatigue processes. The $Fe_{0,4}Mn_{3,6}C$ laminae and fine-dispersed particles of harder Fe_2B and Cr_7C_3 phases are obstacles to the motion of dislocations and prevent their accumulation and transformation into volume defects (pores, cracks). Due to a high degree of the eutectic components dispersity, the processes mentioned above are localized in interlaminated eutectic regions 1-5 microns in width.

It can be noted that damping matrix properties at the abrasive wear process are less important as those at the sliding friction.

Thus, the influence of the eutectic coating structure on their wear resistance has been revealed. It has also been found that the coatings with pre-eutectic structure exhibited the highest wear resistance under sliding friction, whereas the coatings with hard phase components (up to 60-95 %) are preferable under percussive-abrasive wear conditions. At the same time, less hard coatings can be more wear-resistant. The wear resistance of coatings increases proportionally to the hardness in abrasive wear. The greater plastic and mild is the eutectic in the investigated loading region, the greater part of friction energy it absorbs and the more it is capable to relax the tensions. Accordingly, the minority of friction energy would be spent for fatigue processes in the hard phase components.

Atomic segregation at wear of Fe-Mn-C-B-Si-based coatings alloyed by Ni, Cr, Al and micro amounts of Sc was studied by

Auger-spectroscopy. A considerable increase in the C, B, and Si content has been revealed in the friction surface. The content of carbon increases from 2.4 to 2.7, the boron from 8.8 to 33.0 and silicon from 3.0 to 11.4 at. % (Fig. 4). The peak shape of the carbon spectrum indicates that the carbon remains in a free (amorphous) state in a free (amorphous) state. The main specific feature of the friction process was absence of the oxygen diffusion from air into the coating depth.

The diffusion of oxygen to a depth up to 5 to 20 microns was observed only in samples doped with Ni and Cr. However, its maximum local content of approx. 1.3 at. % testifies that no significant oxide formation occurs within the eutectic coatings.

We can conclude that a continuous oxide film is not formed either on the friction surface or within the alloy.

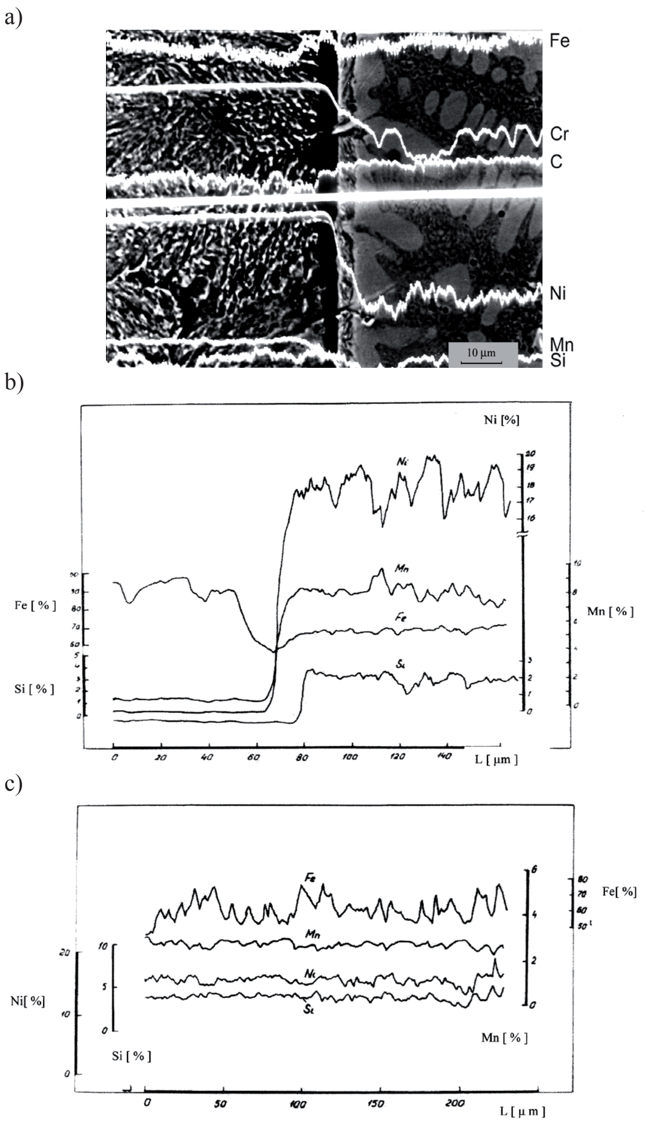

Fig. 2. Microstructure and distribution of elements (×1000) in eutectic coating on steel-45 (a,b) and in powder alloy (c)

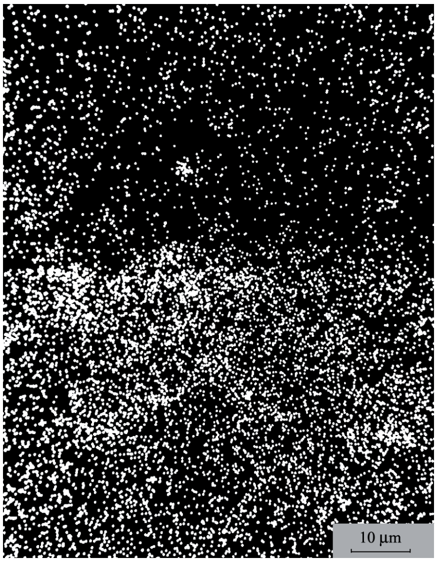

Fig. 3. Distribution of carbon's atoms in eutectic coating on steel-45 (×1000)

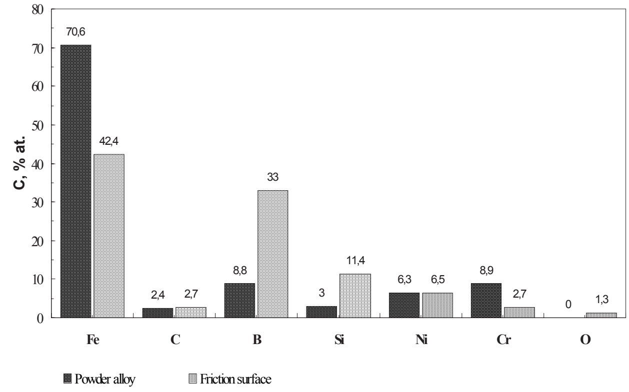

Fig. 4. Distribution of elements on a friction surface and in a powder alloy of the Fe-Mn-C-B-Ni-Al-Sc system

4. Discussion

Formation of oxide phases of the B_2O_3-SiO_2 system is possible in the friction surface. The melting temperature of this system increases from 731 K (M. T. of boron oxide) to 2000 K. (M T. of the SiO_2) (Fig. 5).

Probably, that is due to the B and Si atoms segregation upon friction, and formation of B_2O_3 or system B_2O_3 - SiO_2 is possible in the surface layer. Under some friction conditions they become more soft or liquid. The latter lowers the friction coefficient to values similar to these in liquids.

In its turn, the carbon provides lubrication of the friction surface and decreases the friction coefficient.

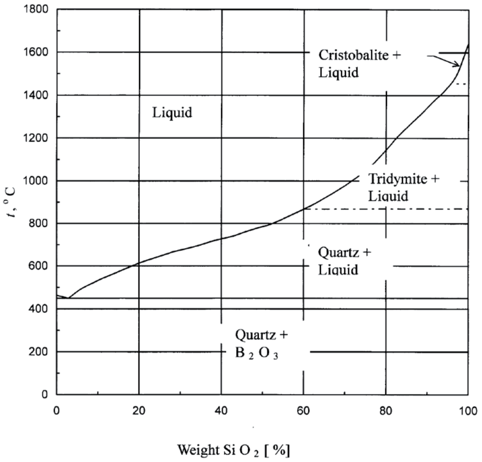

Fig. 5. Phase diagram of the B_2O_3-SiO_2 system

Taking into account that the melting temperature of B_2O_3 is 723 K and the B_2O_3-SiO_2 system 7123-1923 K, we conclude that temperature in the friction area reached 723-773^{0}C. A melted film of B_2O_3, B_2O_3-SiO_2, formed upon friction, serves as a lubrication. It prevents the temperature increasing on the friction surface above the melting temperatures of B_2O_3 or composite system B_2O_3-SiO_2. The film, which has been formed was named 'Servovit' (Serve for life).

5. Conclusions

The obtained results allowed to reveal a new effect in tribology of the Fe-Mn-C-B-Si-based dispersionally reinforced composite eutectic alloys: intensive diffuse processes occurring upon wear, leading to the C, B and Si contents increase in the friction surface. The boron and silicon oxides formation are most likely to occur. At the same time carbon has been found to exist in the free state. All these factors lead to a decreasing friction coefficient, and, accordingly, to an increase in wear resistance.

References

[1] B. Bhushan, B.K. Gupta, Handbook of Tribology: Materials, Coatings, and Surface Treatments, McGraw-Hill, New York, 1991.

[2] J.B.C. Wu, J.E. Redman, Hardfacing with cobalt and nickel alloys, Welding J. 73 (1994) 63-68.

[3] M.K. Stanford, V.K. Jain, Friction and wear characteristics of hard coatings, Wear 251 (2001) 990-996.

[4] D. Bakley., Surface phenomena on adhesion and friction interactions. (1986).

[5] L.M. Rybakova, L.I. Kuksionova, Structure and wear resistance of metals. Mashinostroyeniye, Moscow (1982).

[6] M.I. Pashechko, V.M. Golubetz, M.V. Chernetz, Preparation and friction resistance of eutectic coatings. Naukova Dumka, Kyiv (1993).