UDC 532.64:669.046

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Peculiarities in gas abrasive wear of macroheterogeneous composite coatings reinforced by iron borides for aviation parts

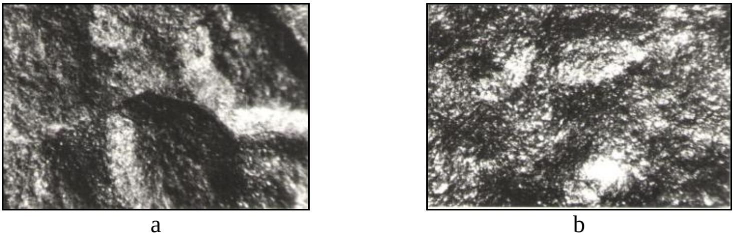
It is shown that the wear resistance of the composite coatings for aviation parts may be enhanced by accelerating interfacial reactions between the filler and the molten binder. The composite coatings produced from rapidly cooled Fe–B–C filler show higher resistance to gas-abrasive wear due to formation of Fe–$Fe_2(B,C)$ metastable eutectics in the structure. As a result of rapid dissolution of the eutectics in the molten binder during infiltration, the strong adhesion at the interfaces of the composite coatings is achieved which prevents the filler from spalling out under the impacts of abrasive.

In the last years, composite coatings have been a matter of active investigation and development [1,2]. These coatings show attractive properties, such as hardness, wear, oxidation, and corrosion resistance due to unique combination of ductile properties of metal matrix and tough properties of reinforcing particles.

Macroheterogeneous composite coatings were fabricated by infiltration at a temperature of 1323 K for 45 min. Cu–20Ni–20Mn alloy was used as binder. The fillers were prepared from Fe–B–C alloys of compositions 9.0–10.0 B, 0.01–0.2 C, the rest being Fe (in wt. %), by mechanical crushing (v_{cool} = 10–20 K/s) or thermocentrifugal atomization of a rotating bar ($v_{cool} = 10^3$–10^4 K/s) [3]. In the first case the filler particles were of irregular shape, in the second case they were spherical. The particle sizes varied from 0.2 to 2.5 mm. After preparation, the major constituents of Fe–B–C fillers were found to be crystals of Fe(B,C) and $Fe_2(B,C)$ phases [4]. The filler content of infiltrated composites was 50–70 vol %. The structure of the composites was studied by quantitative metallographic and X-ray analyses using standard procedures.

The resistance of composites to gas-abrasive wear was determined on a test device in which specimens were fixed with certain angles. Quartz sand particles impacted specimens at an angle of 45°. For each period, the measured erodent quantity was 6 kg. Not less than four tests of 35 mins each were run in ambient air (50-60% humidity, room temperature or 673 K). The specimens were tested against the composite material composed of the ($WC+W_2C$) carbides and Cu-20Ni-20Mn binder.

The structure of composite coatings depends on a cooling rate of Fe–B–C filler during preparation. This of composites reinforced by the filler cooled at 10–20 K/s is characterized by presence of angular shaped particles in a copper-based matrix. The interfacial zones between the filler and the matrix are produced due to dissolution and diffusion processes. Around each particle forms a shell alloyed with Mn and, slightly, Ni, which also differs in a higher iron content vs. that of slowly cooled Fe–B–C filler after preparation [5]. Traces of Fe and B from the reinforcing particles are also revealed in the adjacent matrix. Brittle phases are not observed at the interfaces. At that, the interface width increases at the expense of the layer that dissolves and re-solidifies during the infiltration.



a b

Fig. 1. Worn surface (x25) of the composite coatings reinforced by Fe–B–C fillers cooled at: a – 10–20 K/s; b – 10^3–10^4 K/s

After gas-abrasive tests of the composite coatings, slowly cooled Fe–B–C particles which stand in relief to the surface are observed (Fig. 1, a). Numerous scratches and cracks are revealed in the matrix, and only a few on filler surface. Fe–B–C alloys are hard and tough material. Quartz cannot effectively erode $Fe_2(B,C)$ and Fe(B,C) phases of the filler. But it impinges copper-based matrix making numerous scratches. In addition, matrix wear is accelerated by the plastic deformation. Due to it, appear shallow cracks that can join, which leads to the separation of wear products. Gradual matrix wear around the Fe–B–C particles results in the emergence of the relief. Failure is also stipulated by spalling out of reinforcing particles. Therefore, strengthening of adhesion between the filler and matrix is of a great importance in this case which requires the increase in a dissolution rate of filler's phases in the molten binder during infiltration.

To accelerate interfacial reactions, low-melting phases should appear in the structure of Fe–B–C filler. This result may be achieved for rapidly cooled alloys. Thus, as the cooling rate in producing the filler increases up to 10^3–10^4 K/s, the filler acquires a microcrystalline structure. Depending on the granules diameter, the size of $Fe_2(B,C)$ crystals ranges from 1.0 to 4.5 μm. In addition, the Fe–$Fe_2(B,C)$ metastable eutectics appears along the $Fe_2(B,C)$ boundaries. The metastable eutectics crystallizes because rapid cooling may suppress the formation of equilibrium $Fe_2(B,C)$ phase. As a result, the rest of the liquid is saturated by iron and it may decompose via eutectic reaction $L \rightarrow Fe + Fe_2(B,C)$.

Table 1.

Results of gas-abrasive tests of the composites reinforced by Fe–B–C fillers

Cooling rate of filler, K/s	Relative coefficient of gas-abrasive wear resistance, units	
	273 K	673 K
10–20	0.74±0.17	0.83±0.22
10^3–10^4	0.91±0.08	1.12±0.11

The composite coatings reinforced by the rapidly cooled Fe–B–C particles have the structure featuring so-called “through” infiltration by the metal binder. It means that the contact interaction between the binder and the filler takes place not only at the interfaces of the composite, but inside the reinforcing particles at their $Fe_2(B,C)$ boundaries. So, during the infiltration, non-uniform dissolution of the filler particles in the molten binder is observed. The binder mainly penetrates into the microcrystalline filler along the grain boundaries where the low-melting Fe–$Fe_2(B,C)$ metastable eutectics crystallizes during the atomization. The strong adhesion of the filler with a matrix is attained due to dissolution of metastable Fe–$Fe_2(B,C)$ eutectics.

As a result, the gas-abrasive wear resistance of the composite coatings reinforced by rapidly cooled Fe–B–C filler increases (Table 1). No relief is seen on the surface of composites. Scratches and cracks are observed along the entire worn surface (Fig. 1, b). There are no traces of chipping or spalling out the filler under the impacts of abrasive that are observed on the worn surface of composites reinforced by slowly cooled Fe–B–C filler.

The strong adhesion of the rapidly cooled Fe–B–C filler with the Cu–20Ni–20Mn binder is assured due to higher rates of dissolution of metastable phases during the infiltration. Therefore, no spalling out of Fe–B–C filler is revealed. After the binder solidification, the contact interaction zones form at the interfaces, which contain no brittle phases. Moreover, the hardness of the matrix due to alloying with iron and boron from the particles increases, and it resists to gas-abrasive wear more effectively. Therefore, failure in this case is caused only by cutting and scratching of the surface by abrasive.

Thus, by varying a content of phases in the Fe–B–C filler’s structure which differ in stability under effect of molten metal binder, the interfacial reactions may be controlled during infiltration of macroheterogeneous composite coatings. The resistance to gas-abrasive wear may be ensured by the presence of metastable phases in the filler’s structure provided that an increase of their dissolution rate in the molten binder does not give rise to brittle phases formation at the interfaces. The investigated composite coatings show promise as a way to protect aviation parts from gas-abrasive wear at the working temperatures up to 673 K.

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