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WEAR-RESISTANT OF AMORPHOUS-CRYSTALLINE COATINGS

The results of research of amorphous-crystalline coatings under friction in the absence of lubrication are presented. It is established that the amorphous-crystalline composition of the composition with the optimal combination of structural components has high wear-resistant properties.

The structural-phase composition of coatings was studied and it was found that the amount of amorphous phase is up to 71%, and the phases that are localized in separate parts of the matrix have a microcrystalline structure. Separate zones enriched in boron and representing fine inclusions of the type Fe_2B, FeB, AlB_2 and intermetallic structures of the Fe_2Al_5, $FeAl_3$ type are established on their X-ray diffraction patterns. The electrograms from the friction surface were studied and it was found that the structure of the surface films has a finely dispersed structure. This structure consists of a mixture of phases of coating materials and products of their interaction with the environment. A complete microfractional model is formed by the surface amorphous-crystalline phase. The metallographic analysis and profilogram of friction surfaces testify to the

absence of damage and establishes that mechanochemical wear is the main process in the whole range of tests. [dx.doi.org/10.29010/083.8]

Keywords: *amorphous-crystalline coatings; friction; wear resistance; detonation spraying.*

Introduction

The processes of friction, wear and lubrication are one of the most actual spheres of research in tribology, since their theoretical and practical methods study the operation of machines and mechanisms of modern technique.

The phenomena that are associated with the problems of friction and wear are in correlation with the surface properties of the materials. The use of protective wear-resistant coatings is an effective method of providing surface strength for tribomaterials.

Presently, due to sufficient simplicity and productivity, the technology of creating amorphous-crystalline materials, based on quenching hardening. Detonation spraying, which is used in the work, has great potential for solving this problem and is an alternative technology [1]. In this article, tribotechnical properties of amorphous-crystalline coatings based on iron with alloying with aluminum and boron, were researched. By the method presented in [1], technological conditions for creating amorphous-crystalline coatings are established.

Using the phase equilibrium diagram, it is established that the components of the composition that are being studied are melted congruently and have a narrow homogeneity field. Also, it is emphasized that detonation spraying creates optimal conditions for obtaining eutectic compounds in a metastable state and has advantages over traditional methods of quenching hardening.

The aim/purpose of the wor is to determination of the laws of resistance to wear of the amorphous-crystalline coating of the Fe-Al-B system when loaded by sliding friction.

Methods

Proverbially that the choice of research methods is important for studying the relationships between the properties of coatings, their structure and the influence of external influences that determine the operational reliability of the friction system. Possibilities of methods and instruments significantly determine the reliability of knowledge about the laws and processes that occur when contact surfaces friction. A study of the surface layer in which activation processes occur in friction and which affect the basic form of wear was made by the methods of probe raster electron microscopy on "Camscan" (accelerating voltage 25 kW, beam current 200 mA). The ZAF-L/FLS program was used for the chemical analysis of the surface structures of the localization zones and their constituents. To study the state of the friction surface, the electron diffraction method (electron diffractometer type EMP-100) was used.

Tests for wear were carried out under conditions of friction without lubrication along the end-to-end circuit on annular samples of heat-treated steel 45 in a UMT-1 plant using the standard procedure.

In studying the processes of friction and wear under similar conditions, detonation coatings were tested from a tungsten-containing alloy VK15 and based on iron alloyed with aluminum, silicon and carbon. The thickness of the sprayed coatings in all cases was 0.20–0.30 mm. The hardness is measured on the PMT-3 device.

Results

In Fig. 1 shows the dependence of the wear rate on the speed under a constant load (8.0 MPa).

To study the nature and patterns of structural changes that determine the high resistance to wear of the coatings of the Fe-Al-B system (graph 3) on a microanalyser, the distribution of elements over the thickness of the deposited layer was studied. Analysis of the coating material was carried out at a probe diameter of 10 μm, the results indicated the presence of a transient diffusion zone of the order of 15–20 μm with a variable concentration of elements. When comparing prints taken in absorbed electrons and in X-rays, it was impossible to compare these structures, which indicates its heterogeneity in composition. The discrepancies in the chemical composition confirm the heterogeneity of the fine-dispersed structure, which coincides with the modern concepts of the nature of amorphous and amorphous-crystalline composites [2]. Radiographic studies of the phase composition showed that the coating contains a solid solution based on Fe, fine-dispersed borides Fe_2B, FeB, AlB_2 and iron aluminides of Fe_2Al_5 type. Also in the surface layer, chemical compounds Al_2O_3, Fe_2O_3 and oxide of complex composition of FeAlO type were detected.

The wear resistance of the Fe-Al-B system, as indicated by the experimental graphs, is better than almost the entire range of speed for a fixed load, better than VK15 type coatings. This, in our opinion, is due to the creation of optimal heterogeneous long-life thin-film structures with a high level of self-organization and

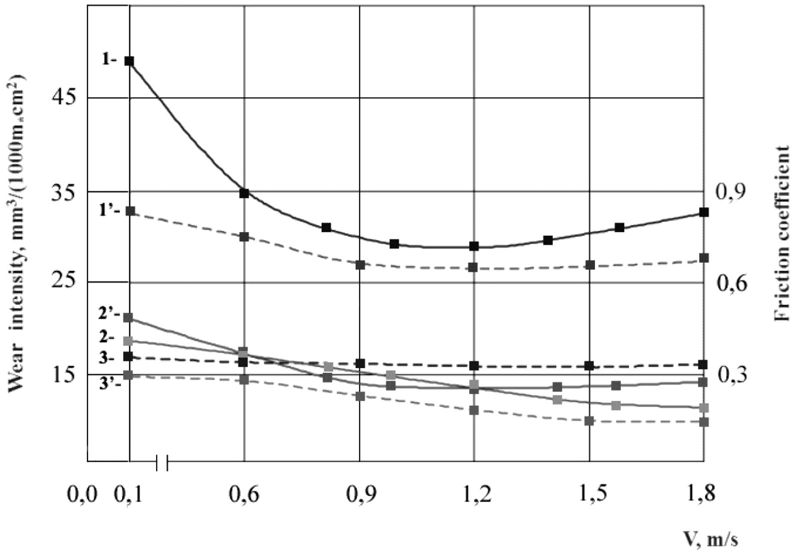


Fig. 1. Dependence of wear rate (1, 2, 3) and coefficient of friction (1', 2', 3') on the sliding speed of coatings: 1 – based on Fe (Fe-Al-Si-C); 2 – type VK15; 3 – amorphous-crystalline Fe-Al-B system

Table 1

Mechanical properties of Fe-Al-B coatings

Composition, %			E, Н/мм	σ_T, Н/мм²	m	HV, МПа
Fe	Al	B				
75	15	10	181500	3010	2,61	1250
65	27	8	182600	2250	2,87	1380
35	32	13	195100	3980	3,20	1410

structural adaptability. The amount of amorphous phase is from 65% to 71%.

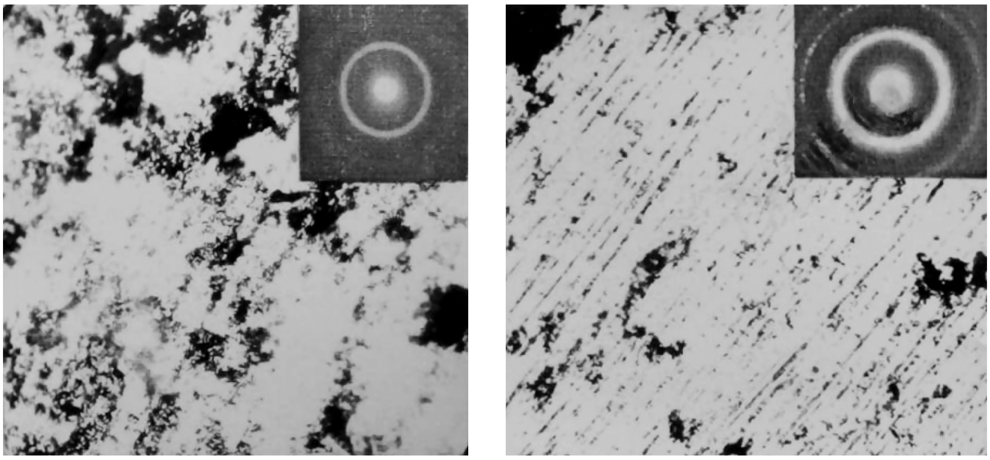
Table 1 presents the results of studies of the mechanical properties of iron-based detonation coatings that contain fine-dispersed particles of crystalline refractory borides and aluminides.

The yield strength (σ_T) was determined from the angle of residual bending of flat samples with a sprayed coating. The presence of strain hardening was established. The degree of strengthening (m) was determined according to [3]. For a linear relationship, the increment of σ_T should not exceed 2.5% with an increase in the degree of plastic deformation by 1%. For amorphous materials, the value is $m < 2.5$. Table 1 indicated the values of m, which are calculated for the test coatings. Analysis of the data in the table indicates that the hardness of coatings decreases with decreasing iron content, and aluminum (together with boron) increases sharply. At the same time, the introduction of up to 32% of Al and 13% of B increases the value of σ_T, the Young's modulus and the strain hardening coefficient also increases and exceeds the limit values for amorphous alloys (E = 180000 N/mm² and m = 2.5), which confirms the presence in the structure crystalline phases [4].

Discussion

Electron microscopy of coatings showed (Fig. 2a) that in the amorphous structure, along with the halo, the diffuse reflections of crystalline planes are visible. Referring to Fig. 2b, the electron diffraction pattern contains clear reflexes to the microcrystalline structure, which consists of crystals of borides (Fe_2B, FeB) and α-solid solution based on iron. The above crystals have a size of 0.15–0.20 μm and a globular shape.

According to the structural-energy hypothesis, microstructures and electron diffraction patterns are presented, reflecting the kinetics of the decay of the amorphous structure and the formation of ultra-crystalline inclusions. This, in our opinion, is due to insufficient cooling speed and an increase in the sliding speed. As a result, the operating temperature rises, which activates the coagulation and recrystallization



a b

Fig. 2. Friction surfaces and electron micrographs of the structure of coatings of the Fe-Al-B system:
a) the electron-diffraction pattern of the initial state (×70000);
b) the electron-diffraction pattern after the tests – V = 1.5 m/s, P = 8.0 MPa (×70000)

processes that occur at various scale levels and, correspondingly, the appearance of bitmap reflexes on the electron diffraction patterns. We note that the surface amorphous-crystalline layer prevents direct contact of interacting surfaces, reduces the adhesion component of friction forces, helps localize plastic deformation, and is not accompanied by significant energy expenses.

Thus, the transformation of secondary structures can be considered as elementary mechanisms for the adaptation of surface layers in the process of structural adaptability of the friction system. On the one part, due to statistical regularities, the phases of formation and fragmentation of secondary structures in different areas of contact surfaces do not coincide, but their additive distribution represents a stable structural-temporal state. On the other part, the formation of the structure of the surface layer is not indeterminate, but is controlled by the minimal principles of dissipative processes [5]. That is, it can be argued that if the structure can adapt under given friction conditions, then this will necessarily happen. In detail, if there is any distribution of secondary tribostructures that corresponds to the state, then the material will adapt, and the friction parameters will be minimal.

Over the entire test range, which simulate the work of sliding friction parts, high tribotechnical properties of the detonation coatings of the Fe-Al-B system have been established. Thermal effects induce diffusion processes that regulate the destruction of the surface and provide high wear resistance, due to the formation of zones with different elements of composition and short-range order. This has the greatest effect on the properties of surface tribostructures due to the increase in the quantity of the nanocrystal component.

In the end, we emphasize that the development of tribotechnical materials for coatings should be oriented towards the domestic raw material base. Despite the economic situation in Ukraine, further research to optimize the conditions for the use of these materials is a necessary component of the technical and social development of our country.

Conclusions

1. The structural state and wear resistance of detonation amorphous-crystalline coatings are studied. The mechanical properties of the coatings are researched and the optimum content of the components is determined to provide maximum wear resistance. In this case, the values of yield strength, Young's modulus and degree of strain hardening of the studied coatings are better than amorphous materials due to the established presence of fine-crystalline phases.

2. It was found that the coatings of the Fe-Al-B system consist mainly of an amorphous matrix with fields of fine-dispersed crystalline components. The mechanism of the decomposition of amorphous structures in surface layers and the formation of fine-crystalline phases in secondary tribostructures are presented. These phases increase the surface strength and wear resistance of amorphous-crystalline coatings.

3. It has been established that a thin-film amorphous-crystalline structure of surfaces reduces the adhesive component of the frictional force. Also, the plastic deformation of the above structure occurs without large heat expenses and minimizes the energy loss.

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ИЗНОСОСТОЙКИЕ АМОРФНО-КРИСТАЛЛИЧЕСКИЕ ПОКРЫТИЯ

Изложены результаты исследований аморфно-кристаллический покрытий в условиях трения при отсутствии смазки. Установлено, что аморфно-кристаллический состав композиции при оптимальном сочетании структурных составляющих обладает высокими износостойкими свойствами.

Изучен структурно-фазовый состав покрытий, при этом отмечено, что количество аморфной фазы составляет до 71%, а фазы, локализующиеся в отдельных участках матрицы, характеризуются микрокристаллическим строением. На рентгенограммах от них установлены отдельные зоны, обогащенные бором и представляющие собой тонкие включения как типа Fe_2B, FeB, AlB_2, так и интерметаллидные структуры типа Fe_2Al_5, $FeAl_3$. Исследованы электрограммы от поверхности трения и, отмечено, что структура поверхностных пленок имеет тонкодисперсное строение и состоит из смеси фаз материалов покрытия и их продуктов взаимодействия с окружающей средой. При этом полную микрофракционную модель формируют поверхностная аморфно-кристаллическая фаза. Металлографический анализ и профилоргафирование рабочих поверхностей свидетельствует об отсутствии повреждений и устанавливает, что во всем диапазоне испытаний ведущим видом изнашивания является механохимический. [dx.doi.org/10.29010/083.8]

Ключевые слова: *аморфно-кристаллические покрытия; трение; износостойкость; детонационное напыление.*

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