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STRUCTURE AND TRIBOTECHNICAL PROPERTIES OF THE PLASMA SPRAYED COATINGS BASED ON THE COMPONENTS SiC-Al_2O_3 WITH THE STEEL COUNTERFACE WITHOUT LUBRICANTS

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The structure of the coatings, made of the composition material, containing the wear resistant component SiC-Al_2O_3 and metallic binder on the basis of iron that is acquired in the result of batch mixture milling in the steel vessels, deposited by the plasma spraying method on mild carbon steel has been researched. Tribotechnical properties of the acquired coatings within the conditions of friction in air without lubricants have been investigated. Features and regularities of wear mechanisms have been detected.

Key words: coating, ceramics, wetting, millings, plasma vapor deposition (PVD), wear resistance.

Introduction

The great amount of technological methods of coating deposition enables to have the composition and properties of superficial layers be efficiently effected. All available technologies of superficial modification are grounded on different physical and chemical phenomena of process realization, the energy sources for its activation and distribution depth of modifying elements diffusion in the superficial layers. Frequently coatings, made of the same modifying elements, but being deposited by the different technological methods, have the principally different properties, due to the change of interaction scale factor and level of effecting energy on the system “coating - substrate”. Therefore this research is devoted to the study of structure formation phenomenon, wear resistance and wear mechanisms of coating made of components silicon carbide – alumina with the metallic phase on the basis of iron that is deposited by plasma spraying technique.

Review of the latest relevant publication

Many researchers are very interesting in silicon carbide coatings, as a very efficient action for surfaces protecting of machines elements from wear, corrosion and thermal influence. Serious technological problems of silicon carbide coating deposition are known: silicon carbide activity, recrystallization growth of grains, porosity and low adhesion to the surface and all this compelled the researchers to study newer and newer physical and physical-chemical phenomena enabling to avoid these negative phenomena. Thus, in article [1] the silicon carbide coating that are deposited from the gaseous phase are suggested. Researchers of article had developed [2] a deposition method of silicon carbide coating and films with the high technical performances on the basis of melt (or steams) interaction of silicon and carbon, created in result of hydrocarbon molecules spallation. In article [3] silicon carbide coatings were deposited by the chemical deposition from the steam phase of methyl-chlorine-silane with hydrogen. In published research [4] coating were deposited by the same method, but superficial layers with the enhanced content of carbon were fixed. For coatings deposition by the plasma spraying method the application of the heterogeneous components with the activating elements is required [5].

Previously, compact ceramics on the basis of the SiC-Al_2O_3 system had been researched, which has revealed a high level of tribotechnical properties and, thus, series of technological actions for the acquisition of high-dense, fine-grained and heterogeneous systems had been investigated [6]. After that a series of researches on the study of this ceramics possibility application as protective wear resistant coatings had been held, that’s why the number of tasks on optimization of composition and application of different methods with purpose of acquisition of wear resistance of the value that is approximately close to wear resistant of compact material have been solved. Thus, an attempt of the metallic binder introduction had been committed, both as pure dopant and jointly with the refractory component [7-8], and different gas-flame methods of the coating deposition had been applied. So in article [7] it was found that the coatings deposited have very low adhesion to the steel surface due to the very low content of iron based phases and their adhesive destruction takes place when already loaded by 5 MPa pressure. In article [8] the content of silicon carbide phase and density of coatings were considerably increased due to complication of batch mixture preparation process, but the level of tribotechnical properties had not been substantially improved. Application of gas-flame methods, which have short time high temperature action on components of batch mixture and substrate in the process of deposition that must effect on level of properties of deposited coating is of great scientific interest.

Research aim

Acquisition of wear resistant coatings made of the system (SiC-Al_2O_3)-FeSi by the plasma spraying method, testing of these coating on wear resistance without the lubricants and detection of their wear mechanisms is the aim of this study.

Experimental procedure

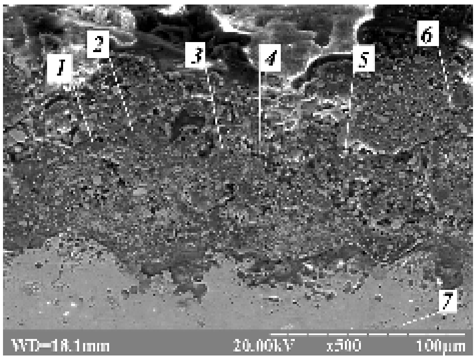
Preliminary, powders of alumina (ТУ 6-09-2486-77) of average size of 40 - 45 micrometers and silicon carbide 64C (ГОСТ 26.327–84) of average size 45 - 50 micrometers within the batch mixture of content 50 % SiC – 50% Al_2O_3 has been mixed in the steel vessels with the steel milling bodies in the planetary mill "Санд-1" in the acetone substance in the steel vessels of the 32 hours duration. Acquired batch mixture has been dried and sifted through sieve. By methods of chemical analysis the amount of iron millings has been held, which appeared to be of 19,3 wt. %. Acquired batch mixture has been pressed at the temperature of 1540 ^oC for the ceramics components conglomeration with the metallic binder, after that the batch mixture has been milled and sifted to the particles size from 63 up to 130 micrometers. The coatings have been deposited on the plasma spraying machine: "ОПУ-3Д", where the optimum deposition modes of plasma coatings on coating thickness and integrity. For the acquired composition the following modes has been detected. Plasma formative gas is the Ar+H_2 mixture. Transporting gas is Ar. Argon consumption is 45 litres/minutes. Deposition distance is 130 mm. Current strength of plasma formative burner is 500 A. Voltage between electrodes is 65 V. Coating had been deposited on plate for the adhesion test, residual stresses and metallographic researches of thickness 100 micrometers. Deposition on pins for the test friction machine "pin-on-disk" had been done of thickness 200 micrometers.

Structure of plasma coatings of the composition material (SiC–Al_2O_3)-FeSi by method of electronic microscopy on the scanning electron microscope РЭМ-106И and on the X-ray diffractometer ДРОН-3,0.

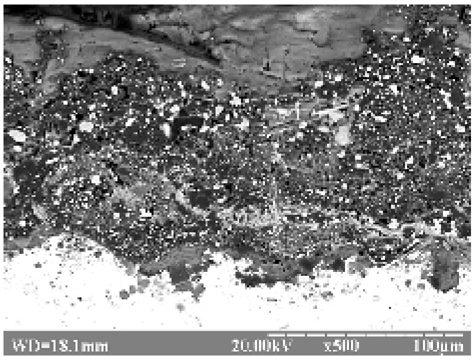
Composition plasma sprayed coating of the system (SiC-Al_2O_3)-FeSi has been tested on friction machine on the "pin-on-disk" together with the steel counterface, without the lubricants (on method described in [7]) in range of sliding speeds of 2 - 7 m/s and loading of 2-6 MPa. Specimen friction surfaces with coatings had been examined on the scanning electron microscope РЭМ-106И and on the X-ray diffractometer ДРОН-3,0.

Experimental results and discussion

General pattern of coating is shown on fig. 1 on three images: in back scattered electrones (fig. 1, a); in secondary electrones (fig. 1, b) and topographical research of surface (fig. 1, c).



a



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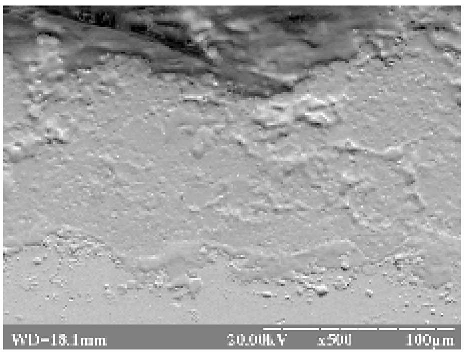


c

Spectra	C	O	Al	Si	Fe
Spectrum 1	48,52	-	-	51,48	-
Spectrum 2	43,13	-	-	56,87	-
Spectrum 3	-	52,05	47,95	-	-
Spectrum 4	-	55,00	44,99	-	-
Spectrum 5	-	-	-	24,00	75,98
Spectrum 6	-	-	-	20,00	79,95
Spectrum 7	0,01	-	-	-	99,97

Fig. 1 – SEM microstructure of plasma sprayed of system (SiC–50%Al_2O_3)– FeSi, images of backscattered (a) secondary (b) and surface topography (c) with electron microprobe analysis of phasesc specified at. %

From the first image the following can be seen, that coating is a heterogeneous layer of the thickness 100 micrometers, consisting of three phases and closely adjoining to the steel substrate. Adhesion force of this coating is 10 MPa. In the secondary electrons (fig. 1, б) on the image white color phases are rendered, which have a metallic structure (the coating contains about 15 - 20 % of them), because they have the greater conductivity and intensively emit the secondary electrons. The topographical research of coating cross section surface enables judgment about coating porosity which makes more than 10 %. It should be emphasized that the structure of plasma coating is very similar to the structure of detonation coating made of the same composition [7]. A coating microstructure (fig. 1) is composition material, consisting of matrix on the basis of alumina, where the SiC particles are evenly distributed. Possible pores in ceramics are filled by phases on the basis of iron, which composition is iron silicides (see table to the fig. 1). It was confirmed by the X-ray phase analysis, which has detected the SiC, Al_2O_3, $Fe_{1,34}Si_{0,66}$, Fe_3Si phases in coating. The thickness of coating had been changing within the range of 100 - 150 micrometers. The size of ceramic inclusions is in the range from 4 up to 7 micrometers.

So as the wear resistance of gas-flame silicon carbide coatings had been previously researched [7, 8], thus plasma sprayed silicon carbide coatings of the system (SiC-Al_2O_3)-FeSi had been tested on wear resistance in conditions, which are described in these articles for detection of applicability domain of acquired new coatings.

The tribotechnical tests had been held on two ways: having the constant load 4 MPa, studied the friction speed effect had been studied and having the constant speed 7 m/s, the loading effect had been studied on the wear rate and friction factor accordingly.

The results of tribotechnical tests of composition plasma sprayed coatings having the constant load are the following, with the increase of sliding speed the wear rate is reducing from 60,2 micrometers/km at speed of tests 2 m/s to 34,89 micrometers/km at 7 m/s. These values two times exceed the results of test of steel specimens (fig. 2, a).

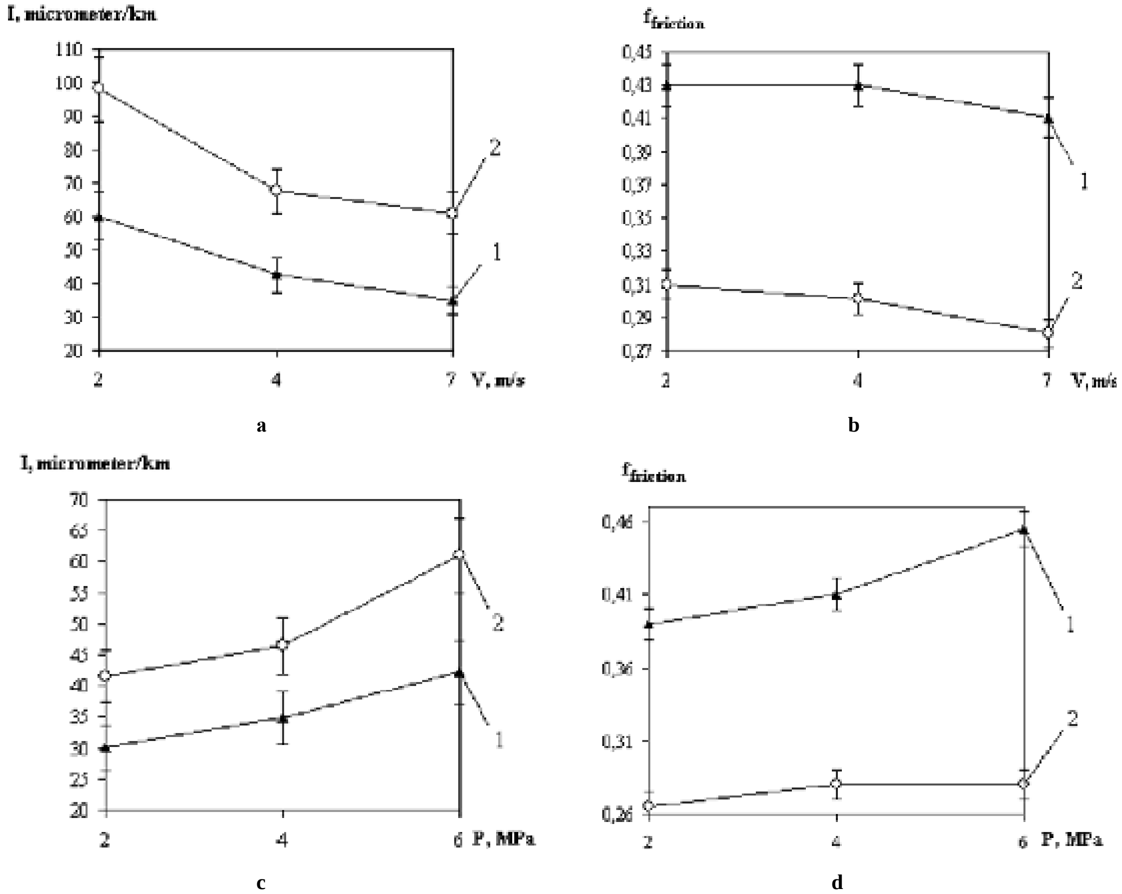
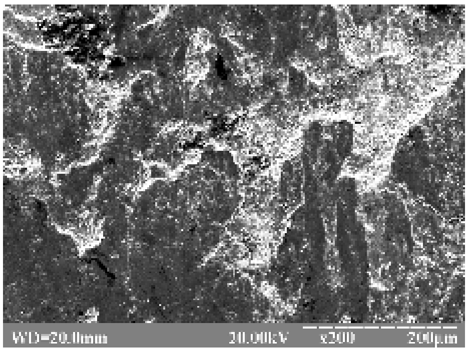


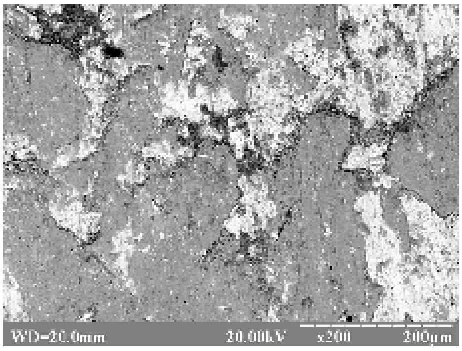
Fig. 2 – Diagram of wear rate and friction factor of speed (a, b) and loading (c, d):
1 – plasma sprayed coating (SiC-Al_2O_3)-FeSi;
2 – hardened steel 45

Friction factors during testing of coatings depending on the friction speed are changing in limits from 0,43 to 0,41 (fig. 2, b). Tests of coated specimens at the constant speed 7 m/s are the following (see fig. 2, c), that having increased the loading the wear rate is raised from 30,1 micrometers/km at P = 2 MPa up to 42,16 micrometers/km at P = 7 MPa. The wear rate of steel specimens having the loading increased is sharply increasing from 41,6 micrometers/km up to 61 micrometers/km. Thus, in the most heavy duty conditions of test the wear rate of coated specimens is two times less than this figure of the specimens of the hardened steel 45. Friction factor of plasma coating with boosting of loading from 2 to 7 MPa had been increased from 0,39 to 0,455 (fig. 2, d). Thus, the developed coating in the specified testing ranges can be classified as frictional. The wear rate of couterface during tests did not exceed 15 micrometers/km.

For justification of the acquired results of specimen friction surface with coating that had been tested in extremely hard conditions of friction (V = 7 m/s, P = 6 MPa) were examined on the scanning electronic microscope РЭМ-106И in the back scattered, secondary electrons and topographical reflection. A structure of friction area of composition coatings is the diphase pattern, consisting of two areas (fig. 3, a - c).



a



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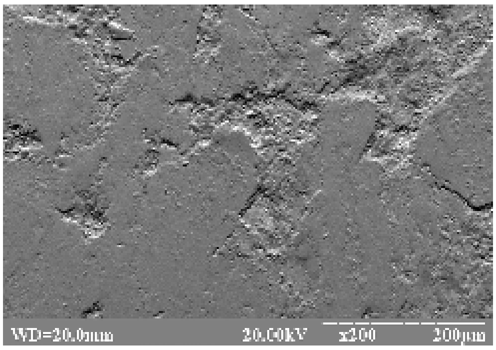
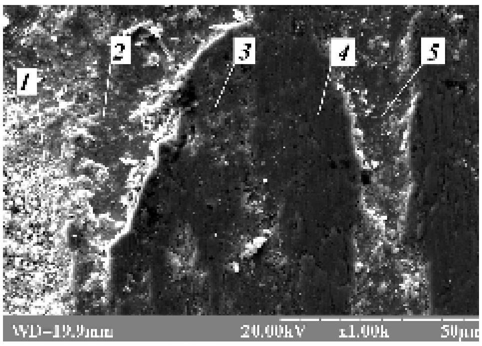
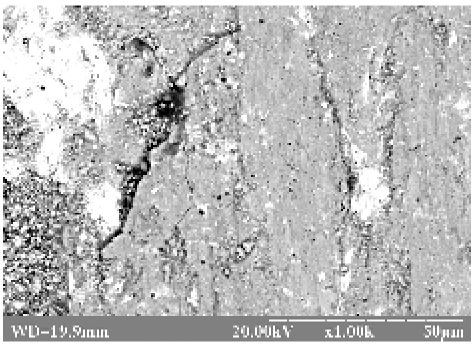


c

Fig. 3 – SEM images of friction surfaces of plasma sprayed coatings of the system (SiC-Al_2O_3)-FeSi, zoom 200:
a – in back scattered electrones;
b – in secondary electrones;
c – surface topography



a



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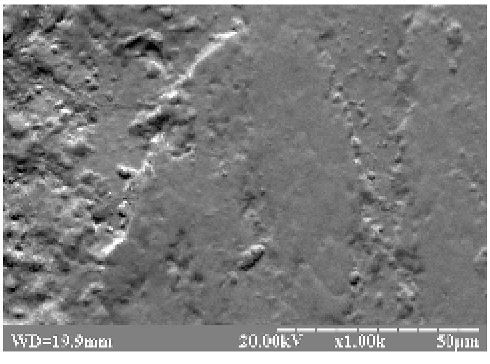

c

Spectra	C	O	Al	Si	Fe
Spectrum 1	0,02	-	-	33,01	66,97
Spectrum 2	0,04	-	-	27,01	72,95
Spectrum 3	-	41,19	20,88	10,77	27,16
Spectrum 4	-	43,48	12,45	18,89	25,18
Spectrum 5	0,03	-	-	31,01	68,96

Fig. 4 – SEM microstructure 1000 zoom of the friction track area of the plasma sprayed coating in back scattered (a) in secondary electrons (b) and surface topography (c) with electron microprobe analysis of phasesc specified at. %

At that, as results of topographical analysis has shown (fig. 3, a, c) in the contact ledges the most intensive loading is held by the dark areas of structure. As a result of more detailed electron microprobe analysis zooming the image in 1000 times it was established, that dark areas are the mixtures of silicon, aluminium and iron oxides that is confirmed by additional X-ray phase analysis. Light areas are inferior iron silicides (spectra 3 and 4 fig. 4) with traces of dissolved carbon. Probably, namely they play a positive part in the improvement of adhesive performances of coating to the steel substrate in the case of the plasma spraying of this composition, so as a result of detonation technique deposition [7] a coating applicability domain had been restricted namely by the poor adhesive properties. However due to application of plasma praying method the coating wear resistance had been reduced due to the more active interaction of silicon carbide with iron based phases having the high temperature influence [7], that can justify extremely high porosity of coating.

Thus, as a result of friction surfaces analysis of composition plasma sprayed coating against the steel counterface without the lubricants the oxidizing mechanism of wear and forming on surface friction of spotty areas of glassy films of the triple oxide mixtures: oxides of aluminium, silicon and iron. The application of plasma spraying method enabled substantially improvement of coating adhesion to the steel surface, but thus its wear resistance had been reduced due to the porosity increase and reduction of silicon carbide phases content. The friction factor of the coating had been also substantially gown.

Conclusions

1. New composition ceramet plasma sprayed coating of the system (SiC-Al_2O_3)-FeSi on mild carbon steel had been acquired. A structure of these coatings is the composition ceramic matrix of Al_2O_3 where the SiC grains and inclusions of iron based phases of silicides type are evenly distributed. A coating thickness is changing within the limits of 100 - 150 micrometers.

2. Tribotechnical performances of plasma sprayed coatings in the wide range of loading - speed descriptions have been tested, it is established, that within the most heavy duty modes of tests (P = 4 MPa and V = 7m/s) the coating wear rate is 42,16 micrometers/km, that in the 1,5 times exceeds wear resistance of the steel. Wear mechanisms of these coating and maximum loading-speed modes of these coatings wear resistance had been detected.

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Довгаль А.Г. **Структура и триботехнические свойства плазменных покрытий на основе системы SiC-Al_2O_3 в паре со стальным контртелом без смазочных материалов.**

Получены принципиально новым путем керамические композиционные покрытия SiC-Al_2O_3, которые содержат металлическую составляющую железа, не введенную в начальную шихту в форме порошка, а которые получены в результате размола компонентов шихты в стальных барабанах со стальными размольными телами. Исследована возможность плазменных покрытий из этой керамико-металлической системы на стальных деталях элементах для их поверхностного восстановления и упрочнения. Определены оптимальные режимы нанесения покрытий из этого материала плазменным методом. Используя метод электронной растровой микроскопии и микрорентгеноспектральный анализ, рентгенофазовый анализ изучена структура покрытий из материала композиции, содержащей износостойкую составляющую SiC-Al_2O_3 и металлическую связку фаз на основе железа, полученных в результате размола шихты, в стальных барабанах на средне углеродистой стали. Определены триботехничесике свойства покрытий в условий трения без смазочных материалов на воздухе в паре со стальным контртелом и определены пределы использования полученных покрытий. Используя методы растровой электронной микроскопии поверхностей трения полученных покрытий исследованы особенности и закономерности механизмов их изнашивания.

Ключевые слова: покрытие, керамика, смачивание, намол, плазменное напыление, износостойкость**.**