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IMPACT OF THE DETONATION GAS SPRAYING MODE ON THE PHASE COMPOSITION AND ADHESIONAL STRENGTH OF Ti-Si-C COATINGS

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The work considers the research results of the phase composition and strength characteristics of detonation coatings based on Ti-C-Si, which obtained for different values of the volume of filling the detonation barrel with an explosive acetylene-oxygen mixture. It was determined that with an increase in the volume of filling the detonation barrel with an explosive mixture up to 70% of the coating are mainly consist of TiC phases. Since Ti_3SiC_2 powder heated to high temperatures partially decomposes into TiC as a result of high-speed shock interaction. The results of X-ray phase analysis showed that a low degree of decomposition of Ti_3SiC_2can be achieved under filling the barrel with an explosive mixture of 50% and 60% and the coatings mainly consist of Ti_3SiC_2 phases with a low TiC content. This is due to the fact that the heating temperature of the sprayed powder increases with increasing in the degree of filling of the detonation barrel with an explosive acetylene-oxygen mixture. It was determined that an increase in the volume content of the TiC phase in the coating composition leads to a decrease in the hardness of the Ti-C-Si coating. The results of the research of the adhesive strength of coatings showed that the effect of the volume of filling the detonation barrel with an explosive mixture on the adhesive strength is negligible. Moreover, all coatings based on Ti-C-Si, obtained by the detonation method, showed good adhesive strength.

Keywords: detonation spraying, titanium carbosilicide, steel, phase, adhesion.

Introduction

The creation of wear-resistant coatings on rubbing surfaces is one of the most effective and economical time-tested areas for increasing the durability of partš operating in conditions of contact wear. Detonation spraying [1,2] and HVOF-spraying [3] among the coating methods have obvious superiority compared to plasma spraying and other spraying methods due to the high speed of flight of particles and lower operating temperature. Detonation spraying of coatings from powders is based on the use of the energy of the explosion of a fuel-oxygen mixture and is known as a promising method for producing coatings from various materials with good adhesion [4]. A higher particle velocity allows a higher density and adhesion strength of the detonation coating. A key advantage of the detonation spraying method is the ability to precisely control the amount of explosive gas mixture used for each shot of detonation gun, which allows you to change the degree of thermal and chemical effect of detonation products on the particles of the sprayed powder [5,6]. Chemical interactions can occur between the individual phases of the composite particles depending on the composition of the acetylene-oxygen explosive mixture, on the O_2/C_2H_2 ratio, and on the nature of the gas carrier [7,8]. Therefore, recently, it has become increasingly interesting to obtain detonation coatings from binary and ternary phases belonging to the Ti-Si-C system. Nanocomposites based on Ti-Si-C are especially relevant, since it is shown that these nanocomposites combine known mechanical strength and low friction coefficient with high conductivity and low contact resistance [9-11]. The question of how to deposit coatings with high adhesive strength based on Ti_3SiC_2 is still open by considering their tribological application.

In connection with the foregoing, the aim of this work is to study the impact of detonation gas spraying on the phase composition, adhesive strength and hardness of Ti-Si-C coatings.

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1. Materials and methods of research

Ti_3SiC_2 coatings were obtained by the method of detonation spraying on the surface of U9 steel. The chemical composition of the powder: Ti - 74 wt.%; SiC - 20 wt.%; C - 6.0 wt.%. The particle size of the powder is up to 40 μm. U9 steel was sandblasted in order to improve the adhesion strength of the coatings before applying the coatings. The distance between the treated surface of the sample and the detonation barrel was 500 mm. The diameter of the straight barrel was 20 mm.

The CCDS2000 detonation complex was used to obtain coatings, which has a system of electromagnetic gas valves that regulate the supply of fuel and oxygen, as well as control the purge of the system (Figure 1). An acetylene-oxygen mixture was used as a combustible gas, which is the most popular fuel for detonation spraying of powder materials. Spraying was carried out at a ratio of acetylene-oxygen mixture O_2/C_2H_2 = 1.856. The volume of filling the barrel with an acetylene-oxygen mixture was varied from 50% to 70%. Nitrogen was used as a carrier gas.

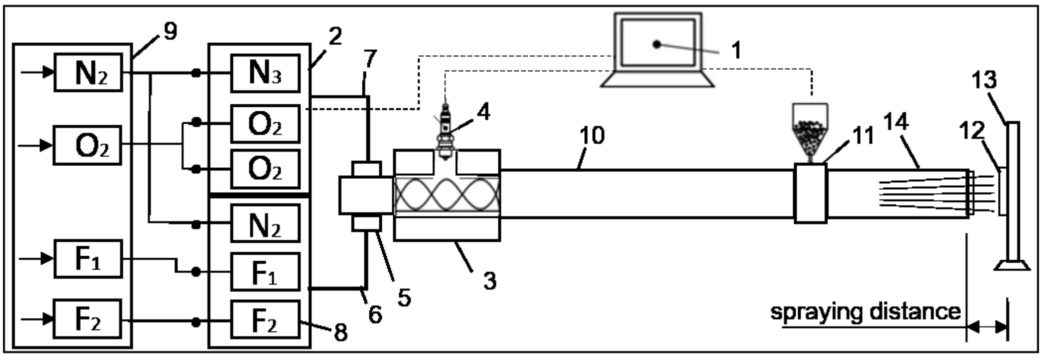

Fig.1. Principled schematic diagram of the CCDS2000 detonation complex:
1 - control computer, 2 - gas distributor, 3 - mixing-ignition chamber, 4 - spark plug, 5 - barrel valve, 6 - fuel line, 7 - oxygen line, 8 - gas valves, 9 - gas supply unit, 10 - indicated part of the barrel, 11 - powder dispenser, 12 - workpiece; 13 - manipulator, 14 - the muzzle of the barrel

The research of phase composition of the samples was studied by X-ray diffraction analysis on X'PertPro diffractometer by using CuKα-radiation[12]. The surveywas carried out in the following modes: tube voltage U = 40 kV; tube current I = 20 mA; exposure time 1s; survey step 0.02º. The scratch tester CSEM MicroScratchTester was used to study the adhesion characteristics of coatings by the "scratch" method. Scratch testing was carried out at a maximum load of 30 N, the rate of change of normal loading on the sample - 29.99 N/min, the indenter displacement rate - 9.63 mm / min, the scratch length - 10 mm, and the tip curvature radius - 100 μm.

Nanoindentation is a universal method for identifying patterns of the mechanical behavior of materials in the surface layers of coatings. The mechanical properties (Young's modulus, hardness) were investigated using a NanoScan-4D Compact compact nanohardness meter for the resulting coatings. Experiments were carried out at a load of 200 mN. The load – unload rate was 3mN / min. The dependence of the penetration depth on the applied force at the stages of loading and unloading was determined by the Oliver – Farr method [13].

2. Research results and its discussion

Figure 2 presents the diffraction patterns of Ti_3SiC_2 powder and Ti-Si-C system coatings obtained with a barrel filling volume of 50% to 70%. The results of x-ray phase analysis of the powder showed that the powder consists of the phases Ti_3SiC_2 and TiC. A decrease in the intensity of Ti_3SiC_2 diffraction lines and an increase in TiC intensity are observed in the diffraction patterns of Ti-Si-C coatings, which indicates partial decomposition of the Ti-Si-C system and is consistent with the data [14]. A decrease in the intensity of diffraction lines in the Ti-Si-C system is observed after detonation sputtering due to deintercalation of silicon from Ti- Si-C lattice layers [15-18], since silicon planes have weak bonds with Ti–C planes. This fact can be explained that the Ti-Si-C system lost a certain amount of silicon due to its high "volatility" as a result of detonation deposition [19]. The results of X-ray phase analysis showed that a low degree of decomposition of Ti_3SiC_2can be achieved with a 50% and 60% filling volume of the barrel of the explosive mixture. A decrease in the intensity of diffraction peaks of Ti_3SiC_2 With an increase in the volume of filling the detonation barrel by 70% is observed as a result of decomposition of the powder into TiC. Ti_3SiC_2 powder decomposes due to high-speed shock interaction of heated to high temperatures in a detonation wave stream.

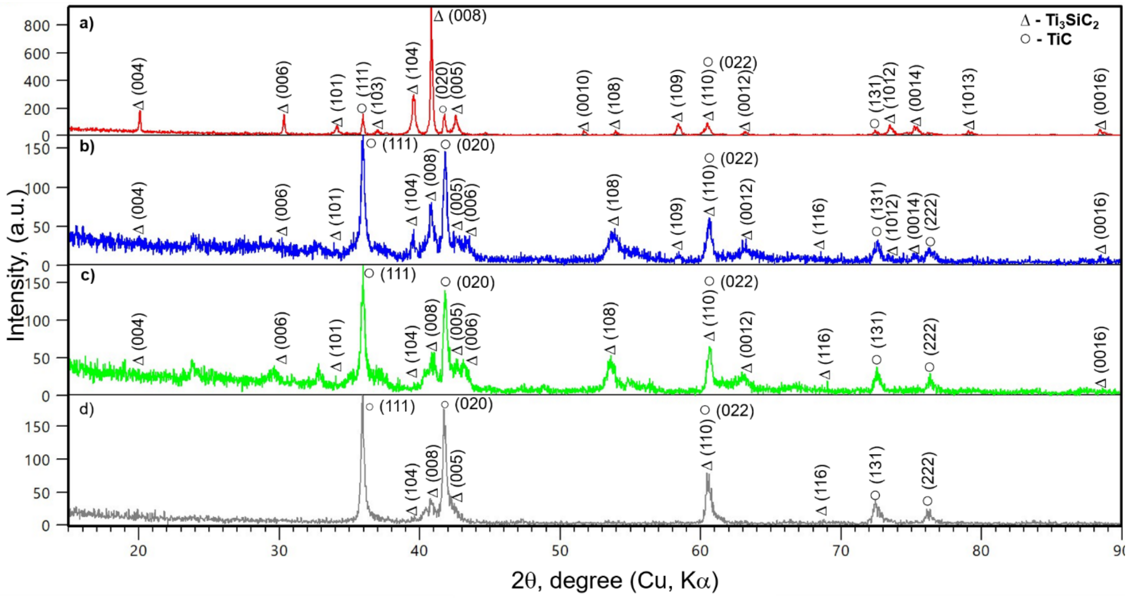

Fig. 2. Diffraction pattern of Ti_3SiC_2 powder (a) and Ti-Si-C coatings obtained at different volumes of filling the detonation barrel with an acetylene-oxygen mixture: 50% (b), 60% (c) and 70% (d)

One of the main factors determining the quality of the coating is adhesion. Figure 2 shows the results of testing the adhesion strength of coatings by scratch testing. The moment of adhesive or cohesive destruction of the coating was recorded after testing visually using an optical microscope equipped with a digital camera, as well as by changing two parameters: acoustic emission and friction force. It should be noted that not all recorded events associated with the destruction of the coating describe the actual adhesion of the coating to the substrate. Registration of various parameters during the testing process allows you to record the various stages of coating failure. So, L_{c1} denotes the moment of the appearance of the first crack, L_{c2} - peeling of the coating areas, L_{c3} - plastic abrasion of the coating to the substrate [20].

We can find that the intensity of crack formation and their development in the sample upon scratching by the type of change in the amplitude of acoustic emission (AE).It can be seen that the first crack is formed at a load of L_{c1}= 12 N. Further, the process continues with certain cyclicity for Ti-Si-C coatings obtained with a detonation barrel filling volume of 50% and 60%. Each formation of a chevron crack (Figures 3a, 3b) is accompanied by a corresponding peak in acoustic emission. The partial abrasion of the coating to the substrate was judged by a sharp change in the growth rate of the friction force. This occurred at a load of L_{c3}= 29 N, which is also confirmed by visual observations fixing the color change of the sample material at the bottom of the scratch (Figures 3a, 3b). Such a value of L_{c3} indicates a high adhesive strength of adhesion of the coatings to the substrate. The appearance of chevron cracks (Figures 3c) is observed at a load of L_{c1}= 8 N for a Ti-Si-C system coating obtained with a 70% fill volume. It can be argued that the cohesive fracture of the sample coating occurs at 8 N, and its adhesive failure at 26 N according to the results of

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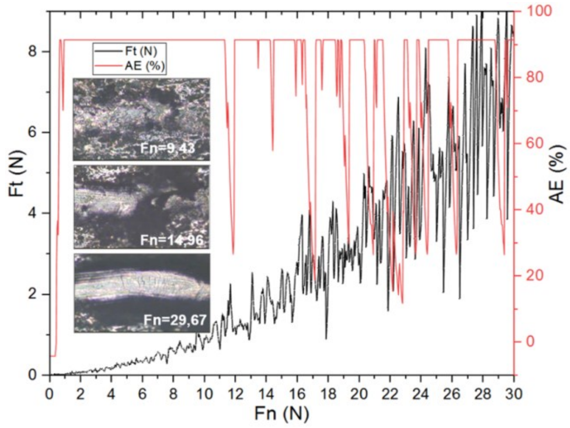
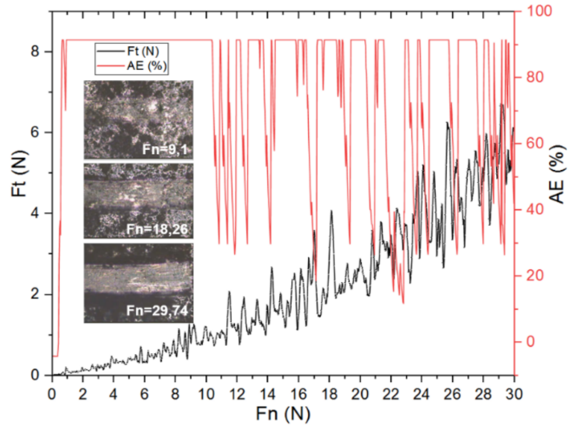
adhesive tests. This is explained by the fact that the Ti-C system has a higher rigidity; therefore, it is natural to expect minimal elastic and intense plastic deformation during adhesive testing [21].



a)



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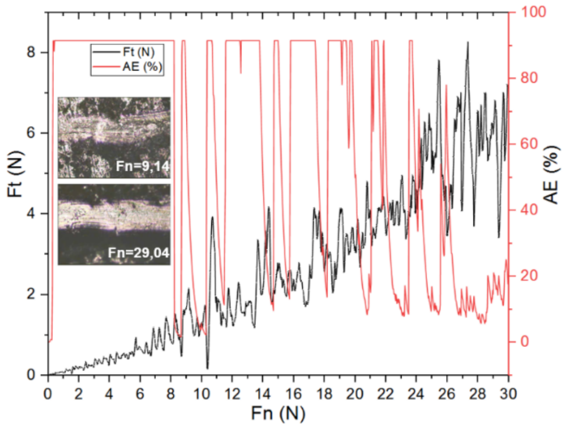
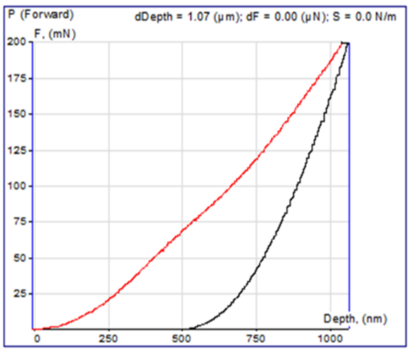


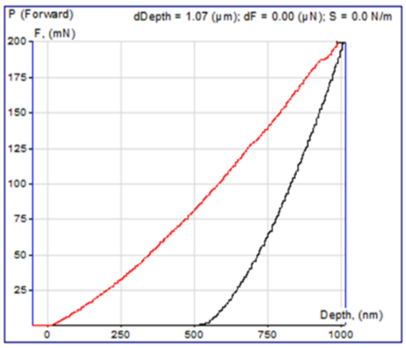
c)

Fig. 3. Results of a scratch-test of Ti-Si-C coatings obtained at different volumes of filling the detonation barrel with an acetylene-oxygen mixture: a) 50%, b) 60% and c) 70%.

The research results of the mechanical characteristics of the obtained coatings were carried out by the Oliver-Farr method. Typical dynamic loading-unloading diagrams are shown in Fig.4.



a



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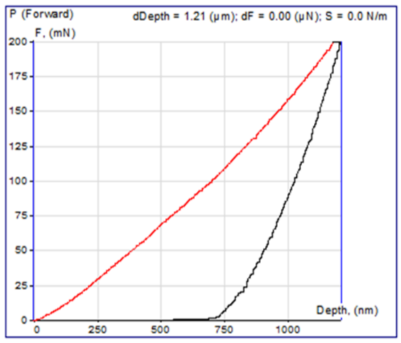

c

Fig. 4. Load-unloading curves for Ti-Si-C coatings obtained at different volumes of the detonation barrel fillings: a) 50%, b) 60% and c) 70%.

An analysis of the loading and unloading curves shows that the penetration depth of the nanoindenter in the case when the detonation shaft is filled with acetylene-oxygen mixture by 50% and 60% less than 70% filling. We can conclude that the elastic stiffness of the coatings during filling is 70% (Figure 4 c) higher than the others (Figures 4a and 4b) according to the analysis of the indentation curves. According to the results of X-ray phase analysis, a coating with a high TiC phase content is formed with an increase in the volume of filling of the detonation barrel with an acetylene-oxygen mixture by 70%. Thus, the results of nanoindentation and scratch testing are agreed in a good way and confirm the TiC formation, which has a higher rigidity than Ti_3SiC_2. The values of hardness and elastic modulus of the test samples obtained from the analysis of the load-unloading curve are shown in table 1. Coatings with a high Ti_3SiC_2 content have a higher hardness compared to the coating with the predominant TiC phase as can be seen from Table 1.

Table 1. Results of nanoindentation

Coatings	Occupancy, %	H_{IT}, GPa	E_{eff}, GPa
Ti-Si-C	50	10.07 ± 1.63	232.36 ± 51.61
	60	10.01 ± 2.31	245.96 ± 44.05
	70	7.51 ± 0.50	198.99 ± 17.70

Conclusion

An experimental study of the imact of the detonation gas filling mode on the phase composition and strength characteristics of Ti-Si-C system coatings was carried out in this work. It is shown that the phase composition of detonation coatings can be significantly changed relative to the phase composition of the initial powders, depending on the volume of filling the detonation barrel with an explosive acetylene-oxygen mixture. It was determined that coating mainly consist of TiC phases under increasing in the volume of filling of the detonation barrel with an explosive mixture up to 70%, since the Ti_3SiC_2 powder partially decomposes into TiC in the detonation wave stream due to the high-speed shock interaction of heated to high temperatures. The results of X-ray phase analysis showed that a low degree of decomposition of Ti_3SiC_2can be achieved when filling the barrel with an explosive mixture of 50% and 60% and the coatings mainly consist of Ti_3SiC_2 phases with a low TiC content. It is connected due to the fact that the heating temperature of the sprayed powder increases under increasing in the degree of filling of the detonation barrel with an explosive acetylene-oxygen mixture. High temperature helps decompose Ti_3SiC_2 powder into TiC. It was determined that an increase in the volume content of the TiC phase in the composition of the coatings leads to a decrease in the hardness and cohesive strength of the Ti-C-Si coatings. The research results of the adhesive strength of coatings showed that the impact of the volume of filling the detonation barrel with an explosive mixture on the adhesive strength is negligible. Moreover, all coatings based on Ti-C-Si, obtained by the detonation method, showed good adhesive strength.

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