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# Obtained of powder coatings by detonation spraying

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In this work, consider the aspects of obtaining powder coatings that possessing certain working properties obtained by detonation spraying. Experimental research were carried on the effect of technological parameters of the detonation spraying process on the phase composition and properties of Ti-Si-C coatings. It is determined that when the volume of filling the detonation barrel with an explosive mixture increases to 70% in the detonation wave flow, the  $Ti_3SiC_2$  powder partially decomposes into TiC consequently the high-speed shock interaction of heated to high temperatures. Installed that when filling the barrel with an explosive mixture of 50% and 60%, a low extent of decomposition of  $Ti_3SiC_2$  powder can be achieved. It is determined that an increase in the volume content of the TiC phase in the composition of coatings bring to a decrease in the hardness of the Ti-C-Si coating.

**Keywords:** detonation spraying, coating, phase, nanohardness.

## Introduction

Nowadays, high-speed coating technologies have a significant interest, which is characterized by high performance, universality, simplify of automation, and almost practically unlimited size of coated surfaces. High-speed spraying methods can substantially expand the capabilities of traditional gas-thermal coating spraying, used to protect components from wear and corrosion. To gas-thermal high-speed methods for obtaining coatings, include methods of detonation, High Velocity Air-Fuel plasma (HVOF) and High Velocity Oxygen Fuel (HVOF) spraying [1-3]. Among them, prospective is detonation spraying. Detonation spraying

is one of the methods of gas-thermal spraying of coatings, which is carried out using a special detonation barrel filled with an explosive gas mixture. For formation of the coating, a powdered sprayed material is used. During the detonation process, the powder particles are accelerated to high speeds (up to 1000 m/s), their melting and deposition on the sprayed surface. The advantages of this method are low porosity of the coating, high bond strength with the base of the processed part, low thermal impact, which allows avoiding undesirable thermal stresses and warping even thin-walled parts of complex construction [4].

## The essence process of the detonation spraying

The essence of the method of detonation spraying (DS) is elementary: in a water-cooled tube (barrel) filled with a gas explosive mixture, the sprayed powder particles are placed, after which the detonation is excited in the gas [5]. The spraying process occurs at speeds in excess the speed of sound, and is itself cyclical, which is why during spraying there is not a large return of heat to the surface of the substrate because there are small pauses between shots. Each cycle is an injection under pressure of an air-fuel mixture, which in most cases consists of acetylene ( $C_2H_2$ ) and oxygen ( $O_2$ ), after mixing, the explosion is initialized by setting it on fire (spark), due to the limited space of the oxidation-reduction reaction (OVR), this mixture is detonated, and a shock wave is generated, which transfers the sprayed particles to the substrate (realized the mechanism-shock pressing). The cycle ends after the installation purges with protective gas, mainly nitrogen ( $N_2$ ), to clear the remaining undirected particles, as well as to prevent a "blowback" in which the flying from combustion products, due to the pressure difference inside and outside the products, are sucked back, which can lead to failure and destroying of the spraying equipment [6, 7].

The key advantage of the detonation spray method is the ability to accurately control the amount of explosive gas mixture used for each shot of the detonation gun, which allows changing the degree of thermal and chemical effects of the detonation products on the particles of the sprayed powder [3-7]. Depending on the composition of the acetylene-oxygen explosive mixture, the  $O_2/C_2H_2$  ratio, and the nature of the gas carrier, chemical interactions may occur between the individual phases of the composite particles [8]. These advantages of detonation coatings served as a stimulus to search for their rational application in industry.

In this regard, the detonation method of coating represents considerable interest.

## Installation scheme

Knowing the characteristics of the sprayed material is necessary to understand the principle of operation of the installation that carries out the process of detonation spraying. It should be noted that since the creation of the first installations, the principle of their operation has not undergone significant changes, which cannot be said about some components of the spraying apparatus itself (nozzles, powder

dispenser, etc.) [9, 10]. The automation of the process has improved largely: the elimination of the human factor, due to the introduction of software, improving the accuracy of surfacing, due to the improvement of individual parts of the installation and optimization of the deposition processes. A new generation of Computer-Controlled Detonation Spraying CCDS2000 has been developed for a more flexible change of spray parameters in ISIL SB RAS [11, 12]. The principle of operation is shown in Figure 1 and is as follows [13]. Directly from the gas cylinders, a mixture of gases is fed through the valve block 9, which enters the combustion chamber 3, at the same time, a powder suspension is applied from the powder dispenser 11 to the space of the barrel 10 under pressure, and then, thanks to the ignition device 4, ignition occurs. As a result, the mixture is detonated and moved towards the nozzle 14, where the path is picked up and accelerated by the sprayed particles. As a result, get the formed coating 12 on the substrate 13. Control unit 1 controls the entire spraying process, from the supply of flammable gases and powder dosing, to the movement of the sprayed billet itself [13] using a 3D manipulator.

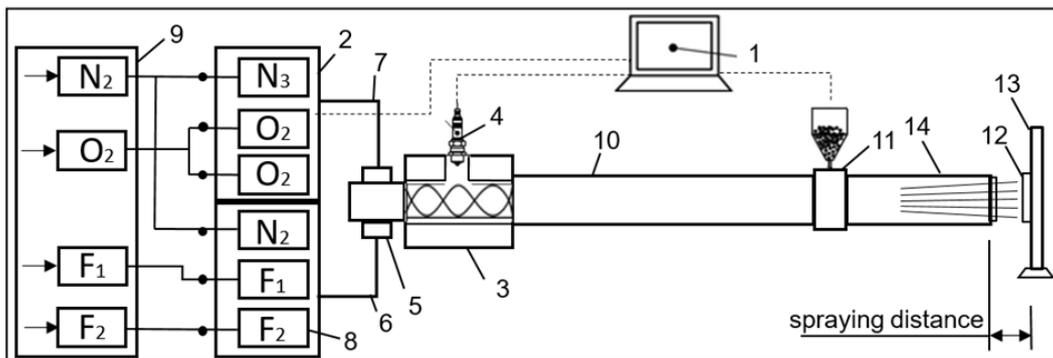


Figure 1. Principled schematic diagram of the CCDS2000 detonation complex: 1 - control computer, 2 - gas distributor, 3 - mixing-ignition chamber, 4 - spark plug, 5 - barrel valve, 6 - fuel line, 7 - oxygen line, 8 - gas valves, 9 - gas supply unit, 10 - indicated part of the barrel, 11 - powder dispenser,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

## Computer-Controlled Detonation Spraying CCDS2000

During detonation spraying, the ability to control the composition and structure of coatings is determined by the level of control of the deposition parameters, so attention is paid to the design features of the Computer-Controlled Detonation Spraying CCDS2000 system used in this work. The main elements of the complex are shown in the Figure 2 (a, b, c). The complex has a precision system of gas supply and powder feeding with computer control.

The complex has a number of distinctive features that allow you to effectively control the spraying process. The gas supply to the mixing-ignition chamber is carried out through replaceable stream with calibrated holes using fast-acting FESTO valves with a response time of 3-4 msec. [14]. The program controls the apparatus, the interface of the "Cycloramas Editor». The charge of the explosive mixture in this installation is dosed with an accuracy of at least 5%, and the powder (mass  $\approx 50$  mg) is fed into the barrel radially and sprayed in the barrel



Figure 2. Detonation complex CCDS2000: a) working body (gun) consisting of a barrel, a gas distribution unit and powder dispensers; b) the control unit on the basis of the industrial computer; c) the gun is complete with a 3-coordinate manipulator.

with localization of the order of the barrel diameter. This makes it possible to verify model calculations with good accuracy [15].

Except for the installation itself, the set of equipment for detonation spraying also includes a noise-insulating cabin (the process itself occurs at a noise level of about 140 DB), an operator control unit (installed outside the place), a cooling, and filtration and exhaust system. Besides, working gases are installed ballons in a separate room [11-15]. All of the above forms the concept of the detonation spray installation infrastructure.

## Phase composition and nanohardness of detonation coatings

Experimental researches were conducted on the effect of technological parameters of the detonation spraying process on the phase composition and properties of Ti-Si-C coatings [16-20]. The experiments were carried out based on the Scientific research center «Surface Engineering and tribology» of the non-profit limited company "Sarsen Amanzholov East Kazakhstan University" on the industrial computerized detonation spraying complex CCDS 2000 [21].

Preliminary results showed that the phase composition and properties of detonation coatings highly depend on the technological parameters of spraying. Based on the preliminary results, we found that by varying the technological parameters of coating, such as the percentage of barrel filling, the ratio of the gas mixture and the delay time between shots, it is possible to control the structure, phase and chemical composition, and, accordingly, the properties of  $Ti_3SiC_2$ -based coatings [20].

As a fuel gas, acetylene-oxygen mixture was used, which is the most popular fuel for detonation spraying of powder materials. For  $Ti_3SiC_2$  coatings, the volume of filling the barrel with an acetylene-oxygen mixture was variables from 50% to 70%. Nitrogen was used as a carrier gas.

The research phase composition of the samples was studied by x-ray diffractometer X'PertPro using  $CuK\alpha$  -radiation [22, 23]. The measurement of hardness and modulus of elasticity was determined by indenting on the nanohardometer "NanoScan-4D compact" in accordance with GOST R 8.748-2011 and ISO 14577. The tests were performed at a load of 100 mN.

## Results and discussion

Figure 3 shows diffractograms of  $\text{Ti}_3\text{SiC}_2$  powder and Ti-Si-C coating obtained at filling the barrel volume of 50% to 70%. On the diffractograms of Ti-Si-C coatings, there is a decrease in the intensity of  $\text{Ti}_3\text{SiC}_2$  diffraction lines and an increase in the intensity of TiC, which indicates a partial decomposition of the Ti-Si-C system and is consistent with the data [24]. Decrease in the intensity of diffraction lines in the Ti-Si-C system due to deintercalation of silicon from Ti-Si-C lattice layers [25, 26], since the silicon planes have weak connections with Ti-C planes. The results of x-ray phase analysis showed that a low degree of decomposition of  $\text{Ti}_3\text{SiC}_2$  could be achieved by filling the barrel of the explosive mixture by 50% and 60%. When the filling volume of the detonation barrel is increased by 7% in the detonation wave flow,  $\text{Ti}_3\text{SiC}_2$  powder decomposes due to high-speed shock interaction of heated to high temperatures.

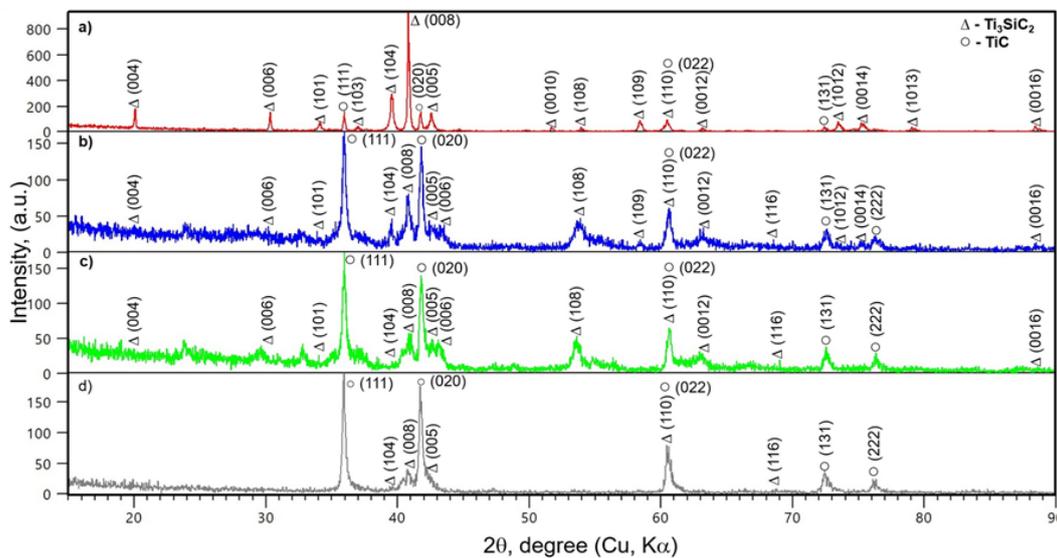


Figure 3. Diffractogram of powder  $\text{Ti}_3\text{SiC}_2$ : a) and Ti-Si-C coatings obtained at different volumes of filling the detonation barrel with acetylene-oxygen mixture: filling degree 50% b), filling degree 60% c) and filling degree 70% d).

From the analysis of load and unloading curves can be seen the penetration depth of the nanoindenter in the case of the volume of filling the detonation barrel with a mixture of acetylene-oxygen is 50% and 60% less than in the case of filling by 70%. Based on the analysis of the indentation curves can be concluded that the elastic stiffness of coatings during filling is 70% larger (Figure 4 d) compared to the other (Figure 4 (a, b)). According to the results of x-ray phase analysis, when the volume of filling the detonation barrel with acetylene-oxygen mixture increases by 70%, a coating with a high content of the TiC phase is formed. Thus, the results of nanoindentation are in good correspondence with the results of x-ray phase analysis and confirm the formation of TiC, which has a higher rigidity compared to  $\text{Ti}_3\text{SiC}_2$ .

The values of the hardness and modulus of elasticity of the  $\text{Ti}_3\text{SiC}_2$  samples obtained from the analysis of the load-unloading curve are shown in Table 1. Apparently from Table 1, coatings with a high  $\text{Ti}_3\text{SiC}_2$  content have higher hardness compared to the coating with the prevailing TiC phase.

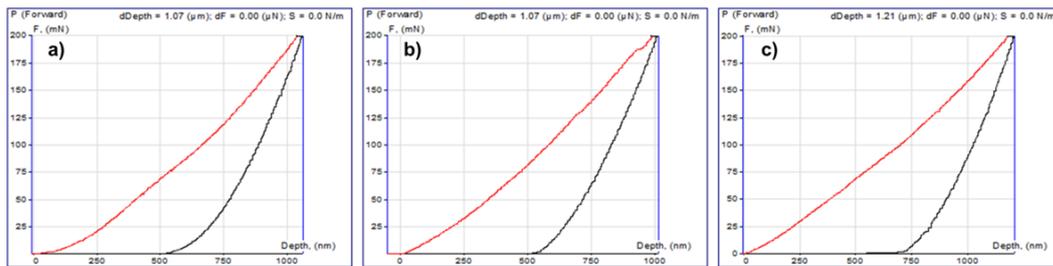


Figure 4. Load-unloading curves for Ti-Si-C coatings obtained at different filling volumes of the detonation barrel: a) filling degree 50%, b) filling degree 60% and c) filling degree 70%.

Table 1.

The results of nanoindentation.

Coating	Filling degree, %	Nano hardness, GPa	Young modulus, GPa
Ti-Si-C	50	$10.07 \pm 1.63$	$232.36 \pm 51.61$
	60	$10.01 \pm 2.31$	$245.96 \pm 44.05$
	70	$7.51 \pm 0.50$	$198.99 \pm 17.70$

## Conclusion

The technology CCDS realised on the CCDS2000 detonation complex allows applying strong dense functional coatings from a wide range of materials to various substrates. Detonation coatings are used in a wide variety of fields of technology and scientific experiment. The range of workpiece is continually expanding, and methods and equipment for detonation spraying are continuously improved, opening new perspectives and areas of application of this technology.

Experimental research of the influence of the detonation gas filling mode on the phase composition and strength characteristics of Ti-Si-C coatings. It is shown that the phase composition of detonation coatings can be considerably 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 is determined that when the volume of filling the detonation barrel with an explosive mixture increases to 70% in the detonation wave flow, the  $Ti_3SiC_2$  powder partially decomposes into TiC consequently the high-speed shock interaction of heated to high temperatures

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