DETONATION SPRAYING AND ITS POTENTIAL IN DEPOSITION OF FUNCTIONAL COATINGS

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Abstract

The new generation equipment created in LIH SB RAS, the detonation complex CCDS*2000* (Computer Controlled Detonation Spraying), permits to coat different substrates with a wide range of materials. CCDS*2000* can work on various gas fuels (acetylene, propane-butane, MAPP, etc.). The properties of the resulting coatings are presented, and the examples of detonation spraying utilization in aviation motor-building, oil- and gas industry and other industrial branches are given, as well as in the developing of scientific equipment.

Key words: detonation spraying, gas mixture, detonation complex, coatings.

Introduction

The gas detonation phenomenon is commonly known and is used in different technologies, in particular in the detonation spraying (DS). This technology appeared in the mid 20th century in the USA [1], and a bit later in Russia [2]. Since then, it is applied in machinery and other fields of industry in order to produce functional coatings, increase part lifetime, and recover parts. The review of publications related to DS is given in [3, 4]. The work unit of the DS facility includes the tubular barrel in which the detonating combustion of the gas mixture fuel + oxidizer takes place; this process yields the products with the temperature up to 4500 K and mass velocity behind the detonation front up to 1300 m/s. Powder particles are injected into the barrel, and then heated normally up to melting point and accelerated to velocity of about half a kilometer per second under the action of a high-speed gas flow. When particles collide with a substrate, a strong and dense coating is formed. Advantage of the DS over another gas-thermal methods (plasma and gas-flame spraying, HVOF, HVAF) is the high adhesion and low porosity of the resulting coatings, besides, sprayed parts do not lose their shape.

The present paper is focused on the peculiarities of the detonation complex CCDS*2000* enabling to have the high-quality coatings, and presents the properties of some coatings and their application.

1. Detonation complex CCDS*2000* and used fuels

Many year research of the gas detonation in LIH SB RAS enabled to create the equipment of new generation, the detonation complex CCDS*2000* (Computer Controlled Detonation Spraying) [5 – 7], which permits to deposit the wide range of materials on different substrates. Main elements of the complex are shown in Figures 1a, b, c. The working unit (gun) can also be set on an industrial robot (Figure 1d). Fig. 2 schematically shows the DS process. Opposite to the other thermal spray technologies, DS is an impulse process consisting of a sequence of cycles (shots). Usually, during the spraying, the facility makes up to 10 cycles per second, though the CCDS*2000* complex provides the cycling rate up to 50 sec^{-1}, and an impulse detonation engine can be based on it [8]. The complex features a number of peculiarities permitting controlling the spraying process effectively. The gases are supplied into the mixing-ignition chamber through replaceable jets with calibrated holes with the use of fast valves FESTO having an operating time of 3 - 4 msec. The pressure stabilizer with the excessive pressure above 0.11 MPa in the supporting cavity provides the sonic gas outflow from the jets. This enables a precise metering of the components in the detonating mixture by means of opening and closing of respective valves upon the preset program. There is a capability to create the lengthwise stratified charge, when detonating mixtures of different content are formed in different tube sections. It is especially important when the main (working) charge in the barrel is a hardly initiated gas mixture, and, for its reliable initiation, a layer of an easily initiated mixture in the barrel breech end is made (the booster charge).

Figure 1. Detonation complex CCDS*2000*: a) working unit (gun) containing the barrel, gas distribution unit and powder feeders; b) control unit based on an industrial computer; c) the gun assembled together with 3-coordinate manipulator; d) the gun on the industrial robot

The specially designed mixing-ignition chamber [5] enables to mix effectively the supplied gas components and create the detonation front right immediately on the chamber-barrel interface. It permits reducing the barrel length as compared to the detonation facilities of previous design, where the detonation front emerges on the distance sometimes occupying the essential part of the barrel. Shorter barrel length resulted in the smaller gun, so it can be mounted on the industrial robot (see Figure 1d).

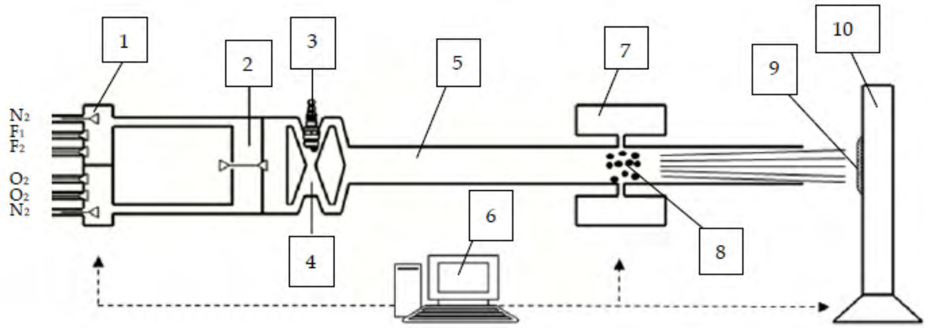
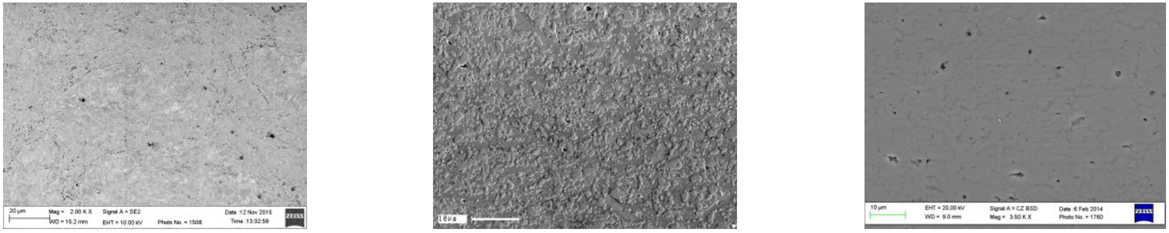


Figure 2. Functional diagram of the detonation complex CCDS*2000*: 1- gas supply unit; 2- pressure stabilizer; 3 – ignition plug; 4 – mixing and ignition chamber; 5- barrel; 6- control computer; 7- powder feeder; 8- powder in the barrel; 9- processed part; 10- manipulator

CCDS*2000* can work on different gas fuels (hydrogen, acetylene, propane-butane, MAPP, etc.) High-energy acetylene is used in deposition of high-temperature ceramic and cermet coatings. It provides the detonation velocity $D = 2934$ m/s, temperature behind the detonation front $T = 4516$ K, and mass velocity of detonation products $u = 1311$ m/s in the equimolar mixture with oxygen. For spraying of metals, especially easily-melted ones, it is advisable to use the gas mixtures with lower temperature behind the detonation wave front, such as the mixture based on propane $C_3H_8 + 3O_2$ ($D = 2580$ m/s, $T = 3769$ K, $u = 1179$ m/s). Recent studies show that gas MAPP (a stabilized mixture of methylacetylene (propyne) and propadiene) is also the promising fuel for the DS [9, 10]. The gas mixture MAPP + $3O_2$ has the following detonation parameters: $D = 2539$ m/s, $T = 4097$ K, $u = 1153$ m/s.

2. Properties and application of detonation coatings

Comparing to the other thermal spray technologies, DS produces most strong and dense coatings. The microsctructure of some coatings is shown in Figure 3. Porosity, adhesion, and hardness are normally the main characteristics of a metal or hard-alloy coating. Wear resistance under abrasive action is also an important index for wearing surfaces, thus certain coatings are tested in accordance with the ASTM G65 standard in the special test rig. The wear is characterized by the coating volume loss resulting from the friction against a rotating rubber-coated disc accompanied with supply of grained abrasive material onto the contact surface [11].



A b c

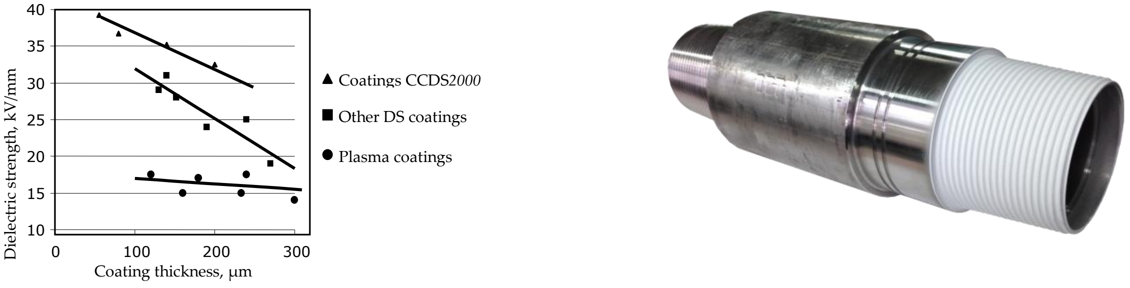
Figure 3. Coating micrregister: a) nichrome, b) cemented carbide WC/Co, c) aluminum oxide

Table 2 presents the properties of the cemented carbide and some metal coatings. Ceramic coatings are also of interest, as they are wear-resistant on the one hand, and electrically insulating on the other hand. Aluminum oxide is the mostly used material, and the CCDS technology provides the highest dielectric strength of the coating (Fig. 4a), caused by its low porosity and absence of micro cracks [12].

Table 2. Properties of coatings from different alloys [10]

Coating	Density, g/cm^3	Abrasive wear, mm^3/1000 rev.	Adhesion, MPa	Hardness		porosity, %
				HRa	HV$_{300}$	
Ni-chrome Ni80Cr20	8.4	35.7	105	68	300	≈ 1
Self-fluxing alloy NiCr17Si4B4	6.9	55.1	97	80	700	≈ 1
Stanless steel FeC0.2Ni2.2Cr13Mn0.8	7.7	17.5	99	75	500	≈ 1
Cast iron FeC2.6Ni15Cu7Cr2.2 Si2.2 Mn1	7.3	55.5	95	74	500	1-2
Bronze CuAl8.5Fe4Ni5Mn1.5	7.5	108.7	93	65	300	< 0.5
Cermet WC/Co (75/25)	13.2	4.9	210	83	900	< 0.5

Detonation coatings find an application in different areas of engineering and scientific experiment. For example, the DS method is used in the technology of electrical insulating of the drill string element threaded joint (Figure 4b).



a b

Figure 4. Ceramic coatings: a) dielectric strength of alumina coatings produced by different technologies [12], b) drill string nipple coated with Al_2O_3

The DS is especially effective in deposition of hard-alloy coatings, thus only this technology is used in all aviation engine plants for the processing of edges of gas turbine blade anti-vibration wings in order to increase their wear resistance (Figure 5a). The CCDS technology enables to coat the complex surfaces of different geometry, such as said edges of blade anti-vibration wings (Figure 5a) and parts of borehole remote meters (Fig. 5b, c).

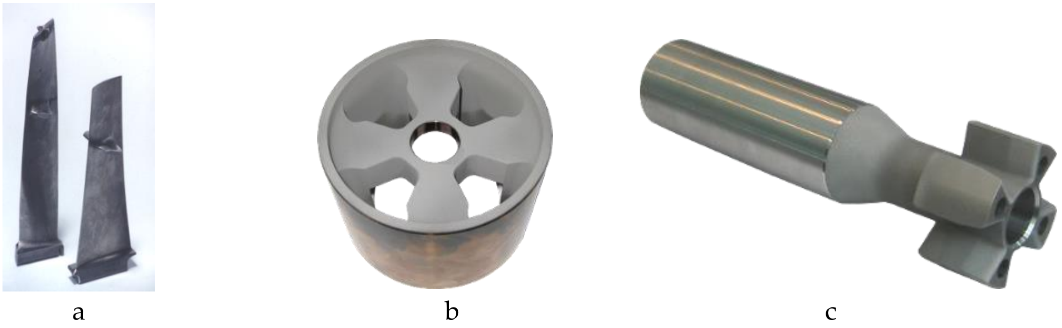

a b c

Figure 5. Gas turbine blades (a) and parts of borehole remote meters (b, c) with cemented carbide coatings

The detonation coatings work successfully in the parts of electro-physical devices used in nuclear research and in the equipment for reprocessing of waste nuclear fuel (Figure 6).


a b

Figure 6. DS in atomic equipment: a) support pads with ceramic isolation and anti-friction bronze layer (ITER project),
b) rings with hard-alloy coating used in the equipment for cutting of waste nuclear fuel

Above mentioned alumina coatings have the adhesion and cohesion on the steel substrate up to 70 MPa, hardness 1200HV (loading 200 g), porosity 0.6%, their dielectric strength exceeds 25 kV/mm when the layer thickness is below 300 μm. High melting point (2044^0 C) together with above mentioned strength characteristics and low porosity permits making heat- and fire-resistant alumina coatings on different metals, as well as on carbon-filled plastic and glass-reinforced plastic.

Conclusion

The CCDS technology realized in the detonation complex CCDS*2000* enables deposition of strong and dense functional coatings of a wide range of materials on different substrates.

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ОПРЕДЕЛЕНИЕ ТЕМПЕРАТУРЫ В КОНТАКТНОЙ ЗОНЕ ПРИ СВАРКЕ ВЗРЫВОМ С ПОМОЩЬЮ АНАЛИЗА ОБРАЗУЮЩИХСЯ ИНТЕРМЕТАЛЛИДОВ

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Введение

Для решения ряда научных и технологических задач требуется применение двухслойных цилиндрических конструкций (биметаллических труб). Известно, что прочное соединение двух металлов по всей площади контакта возможно при использовании технологии сварки взрывом [1]. Для отработки режимов сварки были проведены опыты, как в цилиндрической геометрии, так и в плоской. В качестве соединяемых материалов брались медь М1, титановый сплав ПТ3В, технически чистый титан ВТ1-0 и алюминиевый сплав АМг6.

Существует два способа сварки взрывом труб: внешнее и внутреннее плакирование [2]. Первоначально трубы располагаются коаксиально вдоль общей оси и разделяются технологическим зазором.

- Внешнее плакирование. Заряд ВВ размещается на поверхности внешней цилиндрической заготовки. При детонации ВВ заготовка метается, соударяется с внутренней трубой и приваривается к ее поверхности. Для исключения необратимых деформаций деталей в полость внутренней трубы устанавливается твердый металлический стержень, который исключает сжатие и деформирование труб при ударноволновом нагружении.