PRODUCTION OF COATINGS WITH USE OF GAS DETONATION ENGINE PARTS PRODUCTION AND REGENERATION APPLICATIONS

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Abstract

The first research studies on utilization of gas detonation in production of coatings on steel substrate were conducted in the fifties of the last century. In the first half of the 20th century the first constructions of the detonation guns were presented and patented and the first results of the production of coatings were published. Nowadays, the method is widely utilized in aircraft industry.

One of the main advantages of the detonation method is that it enables production of various kinds of coatings with use of a wide range of materials in form of fine particles: metals, alloys, carbides, oxides and others. The coatings obtained with usage of the detonation method have low porosity and high adhesion and cohesion. Potentially, the detonation method produces coatings with unique features, impossible to obtain by use of other methods. However, the quality of the coatings strongly depends on properties of the coatings material particles jet generated by the detonation gun and processes taking place inside the detonation gun barrel during acceleration of the particles by the flow behind the detonation wave.

The main aim of the paper is to present the general description and basic features of the detonation method of production of coatings and an original, Polish design of the detonation gun utilized in the process. The paper also presents results obtained with the use of the detonation gun and some examples of applications of the method.

Keywords: *detonation, surface engineering, coatings production*

1. Introduction

Technological process of material treatment with use of gas detonation energy has been being developed since the fifties of the last century. The principle of the process is quite simple and will be explained on the example of coating layer production. The specially constructed pipe (barrel), closed at one end, is filled with a combustible gas mixture generated in a mixing and detonation chamber. In most cases propane-butane or acetylene is mixed with oxygen. The mixture in the detonation chamber is then ignited. Initially, there is a deflagration and next there is deflagration to detonation transition and eventually the detonation wave propagates along the barrel. The velocity of the detonation products behind the detonation wave is of order of 1000÷1400 m/s and temperature is of order of 3500 K. In some distance from the outlet of the barrel there is an element on which the coating layer is produced. Into the barrel a coating material is injected in a form of fine particles. The particles of the coating material are accelerated and heated up by the detonation products and after flowing out from the barrel they hit surface of the element. The collisions of the particles generates pressure waves which propagates in the coating layer and in the element material causing some specific deformation and temperature rise as well as significant structural changes in the surface layer of the element material.

Up to now a mutual opinion that the plastic deformations of the surface layers of two colliding materials combined with formation of the cumulative jets are the main conditions of high adhesion and cohesion of the produced connection. If the hitting particle material has to high hardness or viscosity the connection will not be produced. Connection will also not be produced, if the temperature of the particles is too high, because in this case there will be no plastic deformations of the surface layers of the substrate.

To obtain a highly cohesive connection in production of coatings with the use of some materials, e.g. wolfram carbide WC, a mixtures of different material particles are used. In production of coatings of WC cobalt or nickel particles are used. The minimal mass fraction of cobalt or nickel particles in the mixture is in the order of 9%. In this case there are interactions between the particles of different materials i.e. WC and cobalt or nickel. The particles of WC, which have very high temperature of melting, collide with partially melted particles of cobalt or nickel. These collisions results in plating of the wolfram carbide by cobalt or nickel, what has a very positive impact on process of connection formation, when the WC particles hit the substrate and on the properties of the produced coating.

The detonation method can be applied in following technological processes:

- production of the coatings on the substrate of steel, titanium etc. using various materials of coatings,
- alloying of mechanical parts surface layers. Promising results were obtained with use of high energetic explosives, but there are problems with conservation of the element shape in this case,
- hardening of the surface layers by phase and structural changes.

So far, the detonation method has been used mainly in production of coatings with use of various materials of particles, difficult or even impossible to be applied using other methods. Characteristic features of the coatings produced with the detonation method are: high adhesion, high cohesion and low porosity, difficult to obtain with use of other methods. This makes the coating layer resistant to wear and to chemically aggressive agents. Regeneration of mechanical parts and production of parts working under high load or in aggressive agents are regarded as the main fields of application of the detonation method.

In Poland, the first research concerned with the detonation method of coatings production was conducted in the end of the last century. The new original detonation gun was constructed. Its main parameters are comparable and some are even higher then parameters of the constructions produced by the leading laboratories, what can be confirmed by a fact that it is utilized by the University of Dortmund.

2. Experimental facility and tests results

The scheme of the detonation gun is presented in Fig. 1. In most of constructions the detonation gun consist of two main parts: a detonation chamber and a barrel. It is also equipped with fuel and oxidizer supply systems, cooling system and coatings material supply system. Propane-butane or acetylene are used as fuel in most of applications. In the presented design propane-butane-oxygen mixture is utilized. Particles of coating material are of diameter equal to 26-45 μm. As it was mentioned above, in the detonation chamber following processes occur: mixing of fuel and oxidizer, spark ignition of the mixture and transition from deflagration to detonation.

The detonation wave generated in the detonation chamber propagates then in the barrel which is also filled with fuel-oxidizer mixture. Particles of coating material supplied to the barrel are accelerated and heated up in the flow behind the detonation wave. The end of the barrel is aimed to the surface of the substrate and the accelerated particles hit the surface and successive layers of the coating are produced. After outflow of the detonation products the detonation chamber and the barrel of the detonation gun are refilled with fresh fuel and oxygen and the processes is repeated. The frequency of the detonation gun work cycle is in order of 2-4 Hz and is controlled by the spark ignition system. In order to produce solid coatings with high mechanical properties it is important to obtain high repeatability of the processes taking place in the detonation gun, especially transition from deflagration to detonation process.

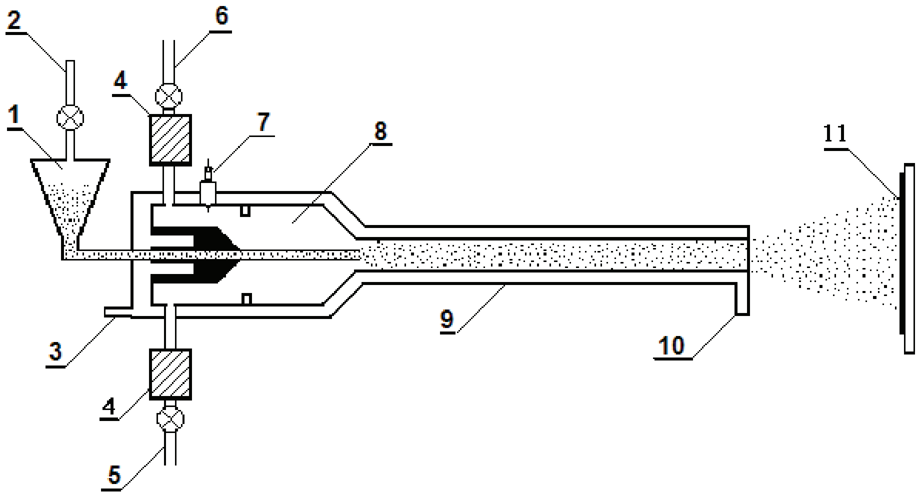


Fig. 1. Scheme of valve-less detonation gun: 1 – coatings particles container; 2 – nitrogen; 3,10 – cooling system; 4 – safety valves; 5 propane-butane; 6 – oxygen; 7 – ignition system; 8 – detonation chamber, 9 – barrel, 11 – substrate

In most of presently utilized constructions of the detonation gun the length of the barrel equals 1500-2000 mm and velocity of the coating material particles in the end of the barrel is of order of 1000-1100 m/s. In comparison with other designs the presented Polish construction is characterized by valve-less fuel and oxidizer supply systems, and length of the barrel equal to 710 mm. In the conducted research propane-butane was used as a fuel and the particles of various coating materials were tested:

- WC/Co 88 12 (wolfram carbide and cobalt)
- WC/Co 83 17,
- Ni,
- Al_2O_3/TiO_2,
- Ni+ (WC+12%Co),
- Ni+ (WC+12%Co) +(Cr_3C_2 + NiCr 80/20),
- Al_2O_3,
- Cr_3C_2/NiCr.

The main aim of the tests conducted in the initial stage of the research on the constructed detonation gun was to measure pressures inside the detonation gun and the gas velocities at the end of the barrel and to determine their dependence on the work cycle frequency. The initial tests were conducted without particles of the coating material. The results are presented in Fig. 2-4.

The graphs in Fig. 2. present pressure courses inside the barrel of the detonation gun measured by two pressure transducers, located 20 and 85 mm from the beginning of the gun. The measurements were conducted for two frequencies of the detonation gun work cycle: 2 and 4 Hz. As it can be seen on the presented graphs the increase of the frequency from 2 to 4 Hz resulted in significantly lower pressure and lower velocity of the detonation wave.

The next graphs, shown in Fig. 3 and 4, present results obtained with different set of the measurement gauges. Two pressure gauges were located 300 mm and 500 mm from the beginning of the barrel and 720 mm from the beginning of the barrel, behind its end, the velocity

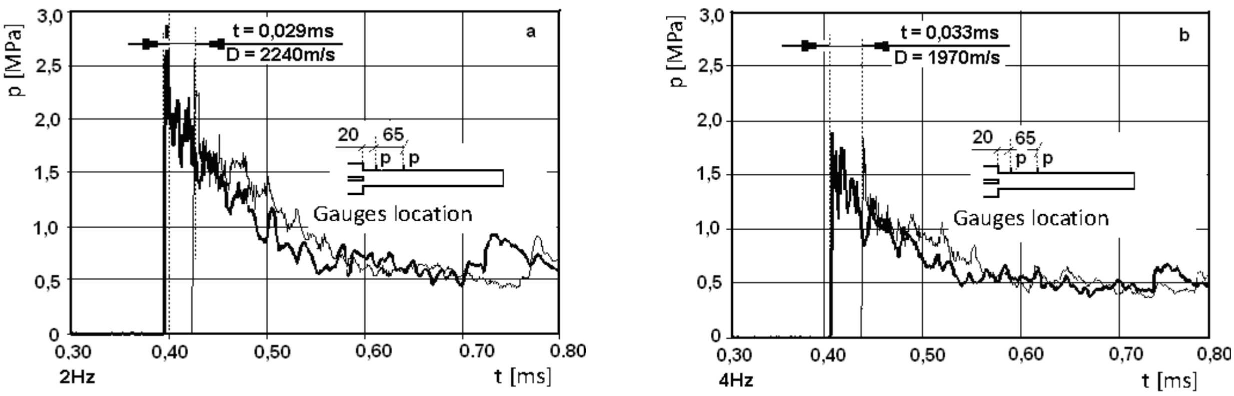


Fig. 2. Influence of the frequency on the pressure and detonation wave velocity, length of the barrel 710 mm: a – frequency 2 Hz; b – frequency 4 Hz

of out flowing gases was measured. Fig. 3 presents results obtained in test conducted with the frequency of the detonation gun work cycle equal to 4 Hz and Fig. 4 presents results obtained in the test with the frequency equal to 3 Hz. As it can be seen on the presented graphs, for the change of the frequency from 4 to 3 Hz there is a significant change of the detonation wave pressure and a small change of the maximal velocity of the gases flowing from the barrel. In both cases the velocity was in order of 500-600 m/s. For lower frequency the gases velocity is more stable and its oscillations are less intense, what has positive influence on the process of the coating production and on the properties of the produced coating.

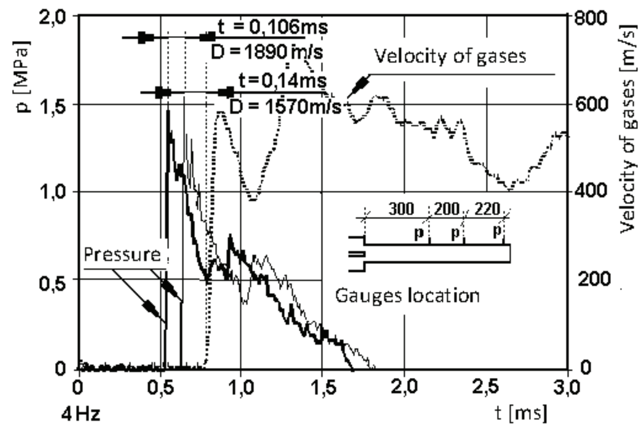


Fig. 3. Pressure and velocity of gas course for the test with frequency equal to 4 Hz

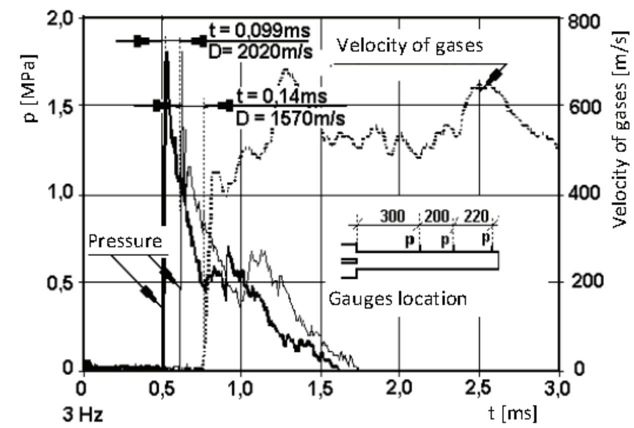
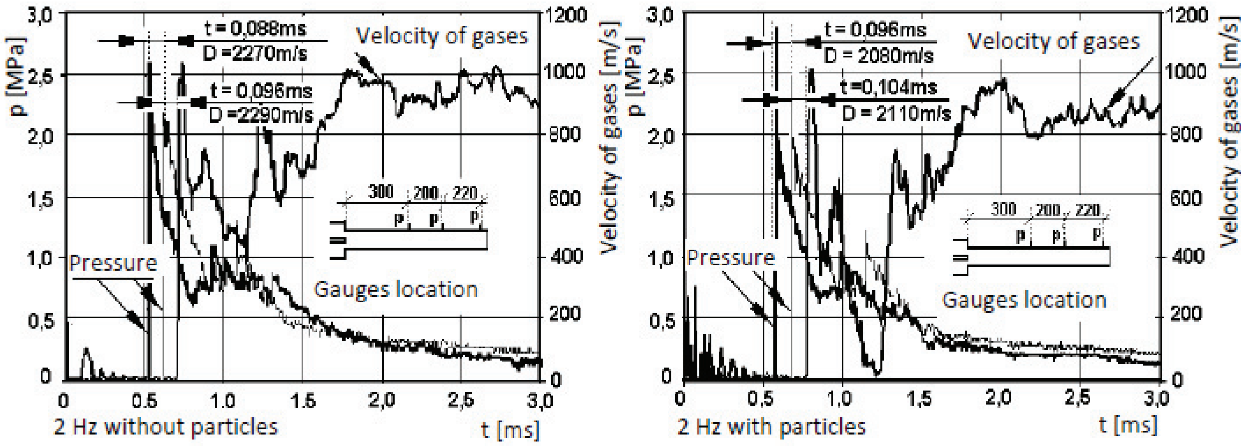


Fig. 4. Pressure and velocity of gas course for the test with frequency equal to 3 Hz

In Fig. 5. results obtained in the tests with the frequency equal to 2 Hz are presented. In the case of this frequency two kinds of tests were conducted: without the particles of coating material, like in the previously presented tests, and with particles of NiCrBSi. Diameter of the particles was in order of 26-45 µm.



a **b**

Fig. 5. Pressures and velocity of gases courses for frequency equal to 2 Hz: a – parameters of detonation products; b – parameters of two-phase flow of detonation products and NiCrBSi particles

In this case the maximal velocity of gases flowing from the barrel was much higher than for higher frequencies and it was in order of 900-1000 m/s. The maximal values of pressures measured by the gauges located inside the barrel and velocities of the detonation wave also were significantly higher than in previously presented cases. Injection of the particles has only minor influence on the parameters of flow at the end of the barrel and on the parameters inside the barrel, what a consequence is of relatively low mass flow rate of NiCrBSi particles.

On the basis of the conducted research it was stated that the frequency of the cycle equal to 2 Hz is optimal and further tests were conducted with this frequency.

Figure 6 and 7 present direct pictures of the particles jets for two kinds of particles mixtures: WC/Co 88/12 and Cr3C2+NiCr. Diameter of the particles in both tests was in range of 26-45 µm. The jets of particles flowing out from the barrel were registered with use of high speed digital camera Photron SA 1.1. As it can be seen in figures, the material of the particles has a significant influence on the particles jet formed inside the detonation barrel and the same influences quality of produced coating. In the case of Cr3C2+NiCr jet there is a clear flaming of the jet what indicates combustion of the particles. When the particles of Cr3C2+NiCr jet, accelerated and heated up by the flow of the detonation products, flow out from the barrel they start to mix and react with oxygen from ambient air. The test shows that for some types of particles materials the coatings should be produced in protective atmosphere.

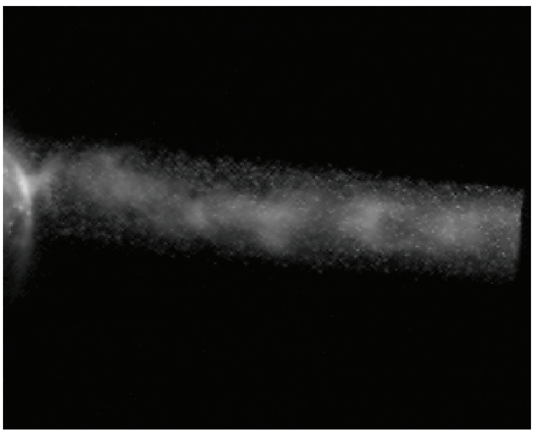


Fig. 6. WC/Co particles jet registered by fast camera. 40 000 f/s, shutter 1. 85 µs

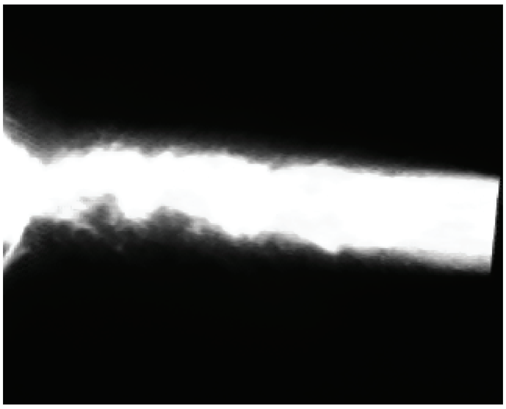


Fig. 7. Cr3C2+NiCr particles jet registered by fast camera. 40 000 f/s, shutter 1. 85 μs

In Fig. 8 and 9 the structures of coatings produced with use of the tested detonation gun are presented. The former picture shows structure of WC/Co 87/13 coating on steel St 45 and the latter one presents structure of WC/Co 87/13 on WT3 titanium substrate. As it can be seen on the pictures the contact zone is much swirled with intense granularity of the coating particles and of the substrate material grains in the layers close to the contact zone. The granularity of the coating particles and of the grains of the substrate material is favourable for production of highly adhesive and cohesive connection between materials of the coating and of the substrate.

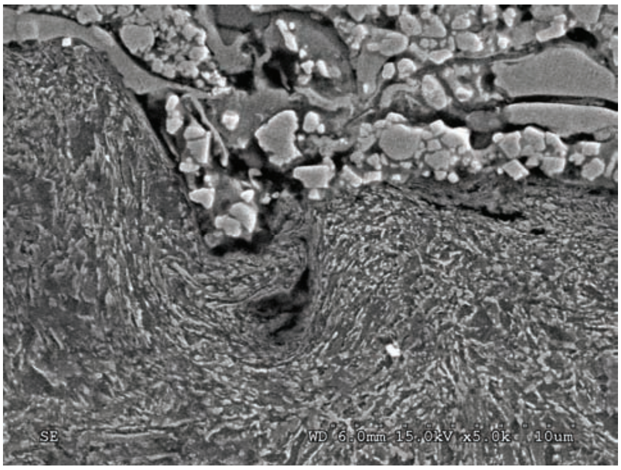


Fig. 8 Structure of WC/Co 83 17 coating on St45 steel substrate

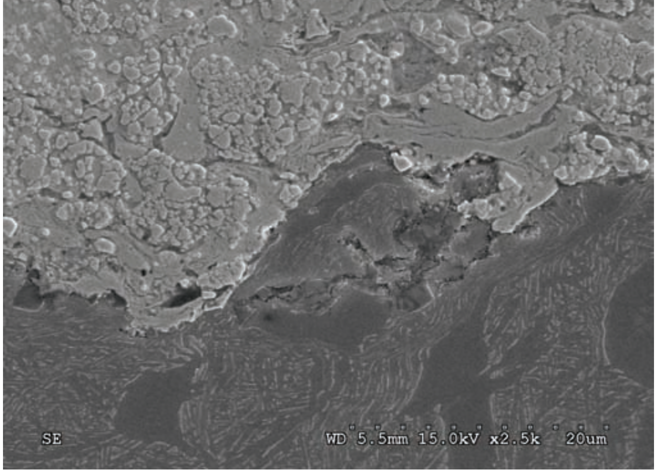


Fig. 9 Structure of WC/Co 83 17 coating on WT3 titanium substrate

3. Examples of applications

In the car industry the detonation production of coatings is used mainly in regeneration of the spark ignition and diesel engine parts e.g. regeneration of the crank shafts, when use of the bush of larger size is not possible. In the case of crankshaft, the coating can be deposited on both: main pivots and crank pivots (Fig. 10). The coating deposition process starts with grinding process which removes all marks of seizing, scratching and other damages. The jet-grinding treatment is the next step of the surface preparation. It has to be preceded with protection of all oil canals from insertion of the grinding and coating particles.

The coating deposition is conducted in this way to produce the coating on the whole area of the pivot. The thickness of the coating layer depends on the size of the bush. In general, the thickness should be large enough to obtain the diameter of the pivot about 0.4 mm larger than the nominal diameter, which is then acquired by grinding.

In the production of coatings on the pivots nickel or cobalt alloys particles are commonly utilized. The hardness of the particles material depends on the material of the bush co-operating with the pivot. The coating layers can be also produced on the crankshafts, on the surfaces under bearings, when the backlash is too large.

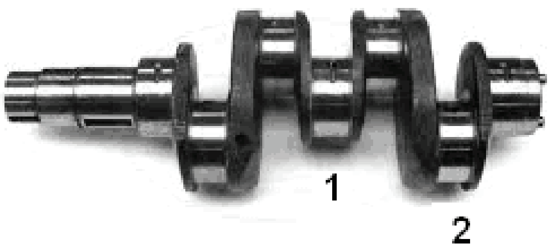


Fig. 10. View of crankshaft with coatings produced on two pivots: 1 – main pivot, 2 – crank pivot

In Fig. 11 the view of the engine head surface intended for regeneration is shown. The production of coatings on the surfaces of the engine heads is more complex. It is utilized for regeneration of the contact surface between the head and the head seal e.g. after the damage of the seal by the combustion products or erosion of the surface. The grinding process is conducted in the beginning and all marks of the damages are removed. Similarly to the production of the coatings on the pivots, all holes and canals need to be protected from insertion of the particles before the process. In the case of the head all holes, not only those in the treated surface, have to be secured. If the particles of the coating material are inserted inside the engine head, it will result with severe damage of the engine. After the coating production the surface is precisely polished. The sealing surface of the cap of the engine head can also be regenerated in this way. In the production of coatings on the engine head low hardness materials are used, e.g. alum or copper alloys.

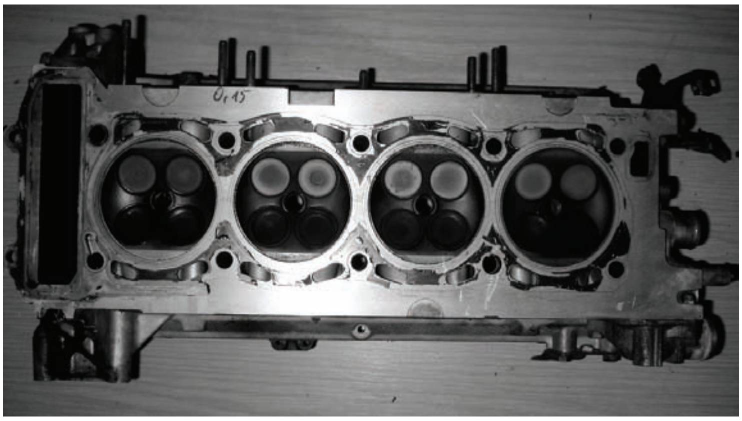


Fig. 11. Surface of engine head intended for regeneration

The next, commonly regenerated by the coating deposition parts are half-shafts (Fig. 11). The most common reason for regeneration of the part is rotation of the inert ring of the bearing on the shaft. It this case the coating layer is produced before new bearing is mounted. NiCrB or NiCrBSi particles are used in the coating production what enables to obtain hardness higher than 50HRC.

Fig. .11. View of car half-shaft after detonation coating production and grinding.

4. Conclusions

The conducted tests and the analysis of the coatings produced by the detonation gun shows that it is possible to produce high quality coatings with use of various coatings materials. The presented design of the detonation gun has unique features in comparison with other constructions: valve-less fuel and oxidizer supply systems, short barrel, high velocity of particles in the jet etc.

The practical examples of use of the detonation gun prove that it can be used in various applications. The detonation gun can be applied in production of the coatings on various mechanical elements of engines. It can be used e.g. as a technology of the mechanical part regeneration or improvement of the surface properties. The detonation method of coating production enables utilization of various materials of particles and production of coating layers on different substrates but still requires further research and tests.

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