THE TECHNOLOGY AND PROPERTIES OF COMBINED SPRAYED BARRIER COATINGS

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Annotation

The aim of this paper is to investigate the combination of different coating technologies for renovating mechanical defects, improving properties of surface with gas flame and gas dynamic and solvent based coatings.

Key words: *coatings, gas dynamic spraying, bond strength, structure.*

Introduction

Thermal spraying is used for applying coatings on components of industrial structures in order to protect them against corrosive attack or wear. The coating results from the impact of accelerated particles (jet) on a substrate surface. The acceleration of the particles is achieved with a gun or torch device. During thermal coating the particles are usually molten or at least softened; if they are not, the process is called „cold gas spraying“.

Cold spraying was piloted and developed in the Soviet Union in the mid 1980's in the Institute of Theoretical and Applied Mechanics by prof A. N. Papyrin and his team. In the process solid powders (1 to 50 μm in diameter) are accelerated in supersonic gas jets up to 500–1000 m/s. During the impact with the substrate, particles undergo plastic deformation and adhere to the surface. To achieve a uniform thickness the spraying nozzle is scanned along the substrate.(Schneider; Belashenko; Dratwinski; Siegmann; Zagorski 2006).

In the cold spraying process the kinetic energy of the particles supplied by the expansion of the gas is converted to plastic deformation energy during bonding. Its significance is that the powders are not being melted during the spraying process. (Alkhimov; Kosarev;. Nesterovich; Papyrin 1990).

Metals, polymers and composite materials can be deposited by using cold spraying. The coating method is widely used for renovating damages of various machine parts. (Ashby 2003). In Fig 1.a is shown an image of a damage and in Fig 1.b the same damage coated by cold spraying. The materials for gas dynamic spraying are mostly soft and subsequent to that it is relevant to increase the wear resistance by hard base coat. In this paper the cold sprayed coatings are used as a bond coat for aluminium and steel.

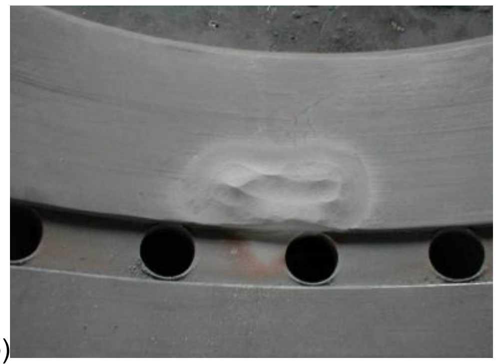
a)  b) 

Fig 1. Damaged machine part. a) Before renovating, b) After spraying with Ni

Experimental Procedure

Coating Materials and Coating Technology

In the research specimens of aluminium alloy (2024 – AlCu4Mg1, EN 573) and steel (S235, EN 10025) with dimensions 30X30X4 mm were blasted with Al_2O_3 abrasive and coated with NiAl up to thickness of 150 μm and yttria stabilized zirconia up to 300 μm by flame spraying for wear resistant and barrier coating. Specimens with the same dimensions were subsequently polished to the surface roughness of 0,8 μm for electrochemical coating (electroplating). For spraying ceramic materials was used flame spray gun CDS 8000 and spraying distance was 100...200 mm. The solvent based commercial ceramic coatings from NIC Industries Inc were sprayed with HVLP spray gun. The parameters used for blasting and flame spraying are reported in Table 1 and Table 2. The used ceramic spray materials are given in Table 3.

Table 1

Blasting parameters (NIC Industries 2008)

Machine used	ILB 120
Grit used Al_2O_3	100…150 μm
Air pressure	0.6 MPa
Distance	40…50 mm

Table 2

Flame spraying parameters

Gun	CDS 8000
Spray distance	100…250 mm
Acethylene pressure	0.07 MPa
Oxygen pressure	0.4 MPa
Compressed air	0.3…0.4 MPa

Table 3

The used spray powders

Type of powders	Chemical composition	Particle size [μm]
Castoline 51000 [1)]	NiAl15Ti5Si1,5	+6 -120
Castoline 28085 [1)]	ZrO2/30CaO	+11 -53
ZrO2/Y2O3 [2)]	92ZrO2/8Y2O3	+45 -75

[1)] Castolin

[2)] Sulzer Metco

For comparing the properties and technology were used solvent based ceramic coatings from NIC Industries Inc. The used coating materials were C-104, V-136 and W-207; working temperatures as follows: C-104 500 K, V-136 890 K and W-207 1000 K. For spraying these materials was also used HVLP (gravity feed) spray gun. The compositions of the sprayed solvent based materials are given in Table 4. In this investigation the most studied material was W-209. After spraying the solvent based ceramic coating needs additionally to be heated up to 300^{o}C.

Table 4

Compositions of solvent based ceramic materials

Coating material	Composition	Content [%]
C 122	Tert-butyl acetate Benzene Proprietary siloxane	35 ...45 25…30 20…40
V 136	Benzene , 1-chloro-4-trifluormethyl $Mg_3H_2(SiO_3)_4$ Proprietary Formulation	50…60 2,7…7 20…30
W 209	Al powder Phosphor acid Quartz MgO Chromiumtri(VI)oxide SiO_2 Al_2O_3 Chromium (III) oxide	30…50 10…35 8…10 < 5 <3 1…2 2…3 < 1

Chemical Composition of Solvent Based Ceramic Coatings

For studying chemical composition in the research was used microscope INCA 350 EDX. Most ceramic materials are good insulators. Investigated solvent base composite material C-122 has a good wear resistance and a good thermal conductivity. The sample analysis were taken from 8 different places and results are given in Fig. 2. The chemical composition of composite coating are given in Table 5.

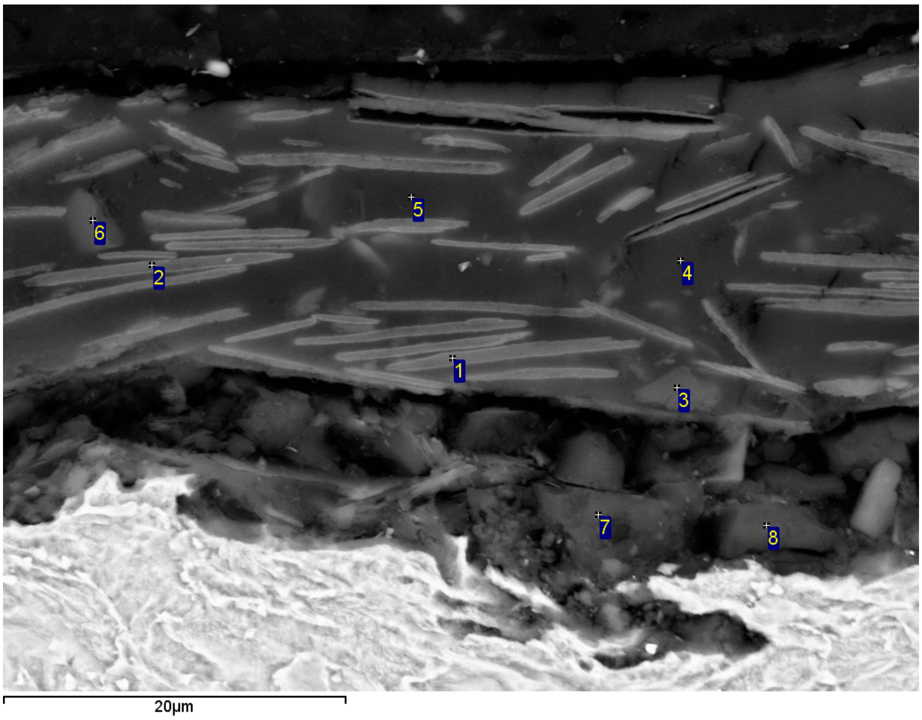


Fig. 2. The microstructure of solvent base coating W 209 with areas for chemical composition.

Table 5

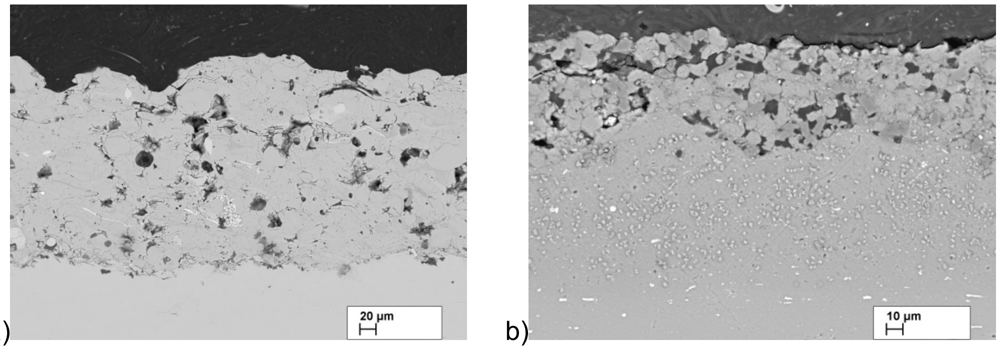
The chemical composition of solvent based coating C 122

Nr of area	O	Na	Mg	Al	Si	Cl	K	Ti	Fe
1	47,39	0,42	0,24	8,07	21,45	0,01	3,31	14,74	4,37
2	45,29	0,26	1	5,38	27,03	0,06	2,35	15,65	2,97
3	45,76	0,12	0,17	22,57	24,89	0,15	1,44	1,61	3,29
4	41,62	0,21	0,05	5,05	45,83	0,26	0,92	4,74	1,32
5	50,97	0,11	0,22	6,17	26,26	0,07	2,65	10,92	2,64
6	43,37	0,15	0,36	3,57	33,75	0,15	1,45	11,46	5,74
7	44,92	0,15	0,21	2,1	44,7	0,33	0,05	0,7	6,83
8	25,61	0,01	0,01	2,17	30,22	0,17	0,05	0,61	41,14

Structure of Coatings

The powder sprayed ceramic coatings had thickness of at least 0,2 – 0,3 mm and solvent based ceramic coatings of 0,05 to 0,1 mm. The thickness of cold sprayed coatings depends on the purpose and is from some microns to 0,2...0,3 mm. The structure of flame sprayed coatings on aluminium are given in Fig.3a, the ceramic solvent based coating in Fig. 3b.

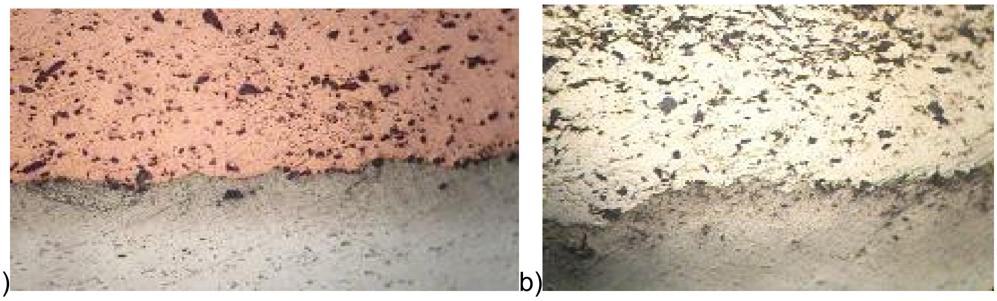
In the current research were used two different technologies for making the bond coat. Firstly was made base coat with cold spraying equipment Dymet 413 and after that bond coat was on based by thermal spraying. For sprayed bond coat was used special powder on base of copper (commercial type C-01-01, Cu and Al_2O_3) (Pihl; Mikli 2002). The bond strength of the sprayed layer was from 40 MPa to 50 MPa.



a) b)

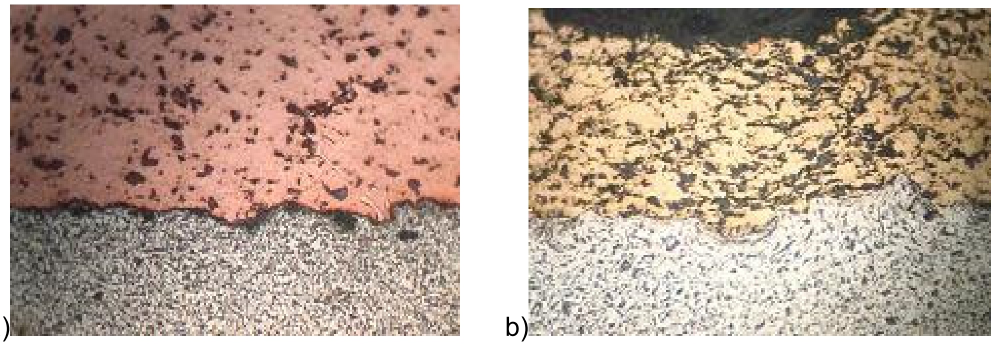
Fig.3. Microstructure of coated specimens: 3a - Flame sprayed powder coating ZrO_2/30CaO, 3b – The solvent based ceramic coating V 136.

The cold sprayed coatings on aluminium and on steel are given in Fig 4 and Fig 5. Powder and solvent coated structure variations are shown on figure 6, 7 and 8.



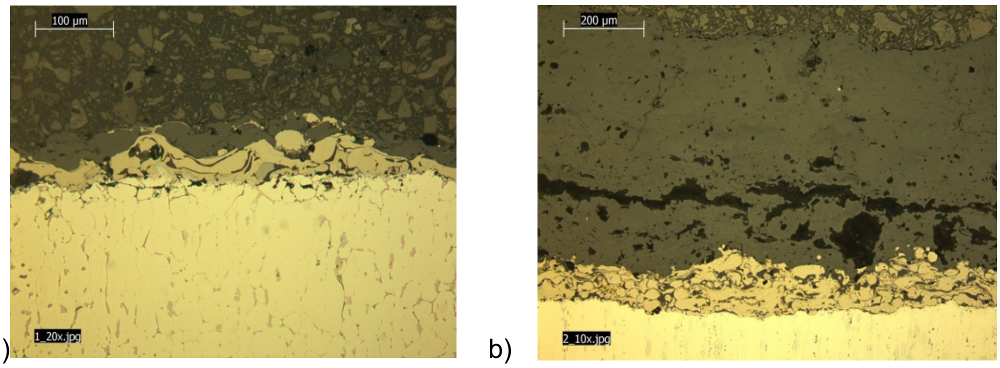
a) b)

Fig 4. The sprayed bond coats: a- Cu on aluminum; b- Ni on aluminum



a) b)

Fig 5. The sprayed bond coats on steel: a- Cu on steel; b – Ni on steel



a) b)

Fig.6. Microstructures of powder coated specimens (6.a ZrO_2/30CaO , 6.b ZrO_2/Y_2O_3)

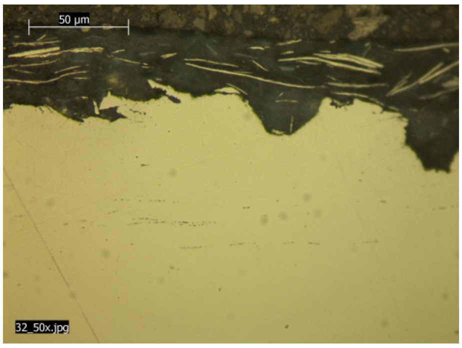
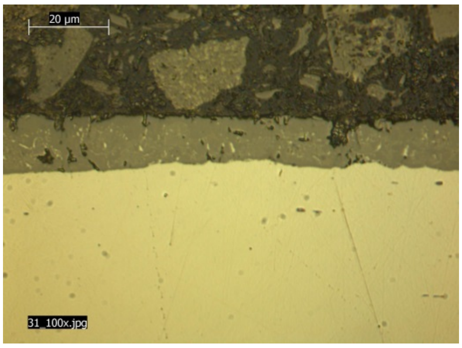
a)  b) 

Fig.7. Microstructure of solvent based ceramic coating V-104 (7.a- front elevation, 7.b- side elevation)

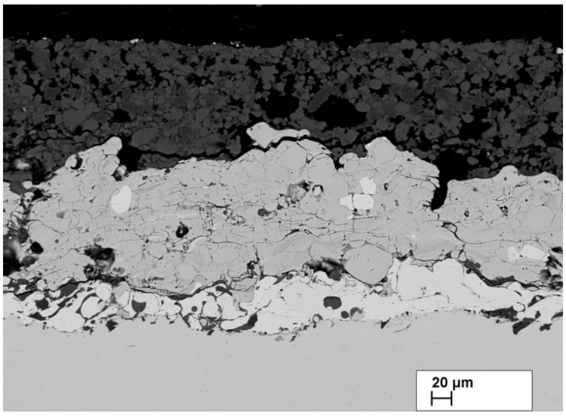


Fig 8. Combined NiAl15Ti5Si1 + ZrO_2/30CaO and W209 coatings on steel

Bond strength and Hardness of Coatings

The bond strength of coatings is the most important property which determines the field of use of coatings especially for ceramic coatings. For measuring the bond strength of coatings were used special samples from steel and aluminium alloys (Fig 9). The diameter of centre pin of specimens was 4 mm (Pihl; Vainola 2009). For testing the bond strength was used hydraulic tensile-compression testing machine GUNT WP 300.20. The bond strength of sprayed ceramic coatings are given in Table 6.

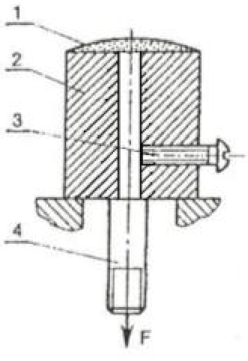


Fig. 9 Specimen samples

Table 6

The bond strength and hardness of sprayed coatings.

Specimen material	Material of coating	Hardness [HV]	Bond strength [MPa]
Aluminium	ZrO_2/ 30CaO	700	9,9
Steel	ZrO_2/ 30CaO		15,4
	ZrO_2/ 30CaO + W209		37,2

Also the resistance loads were considered in the following combinations:
Aluminium + ZrO_2/ 30 CaO coating
Steel + ZrO_2/ 30CaO
Steel + ZrO_2/ 30CaO + W209
Test results are given in Fig 10, Fig 11 and Fig 12 and collected in Table 7.

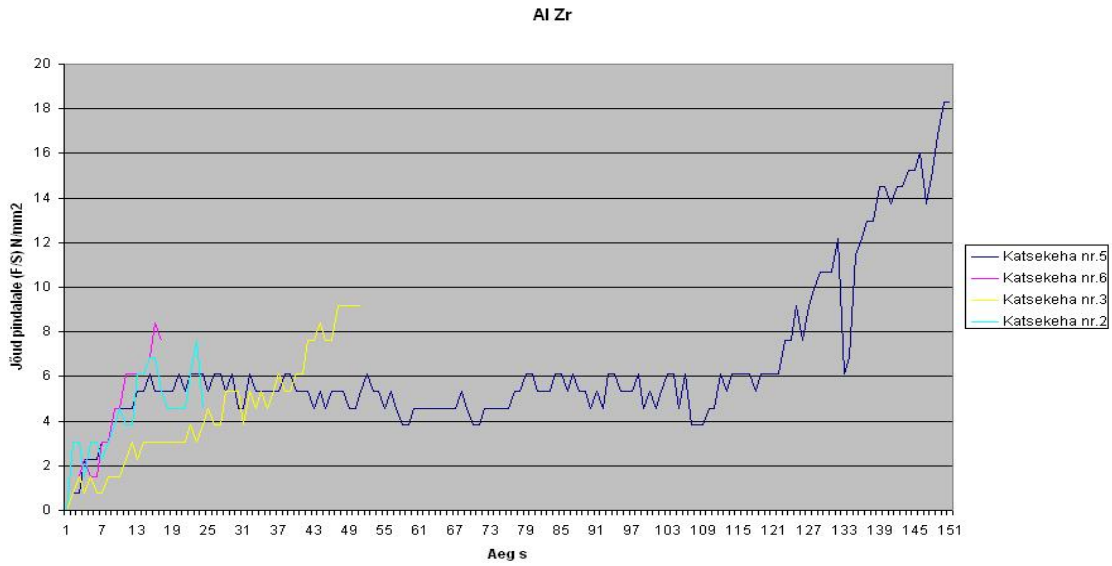


Fig. 10. The bond strength of coating ZrO_2/ 30CaO on aluminium

Fig. 11. The bond strength of coating ZrO_2/ 30CaO on steel

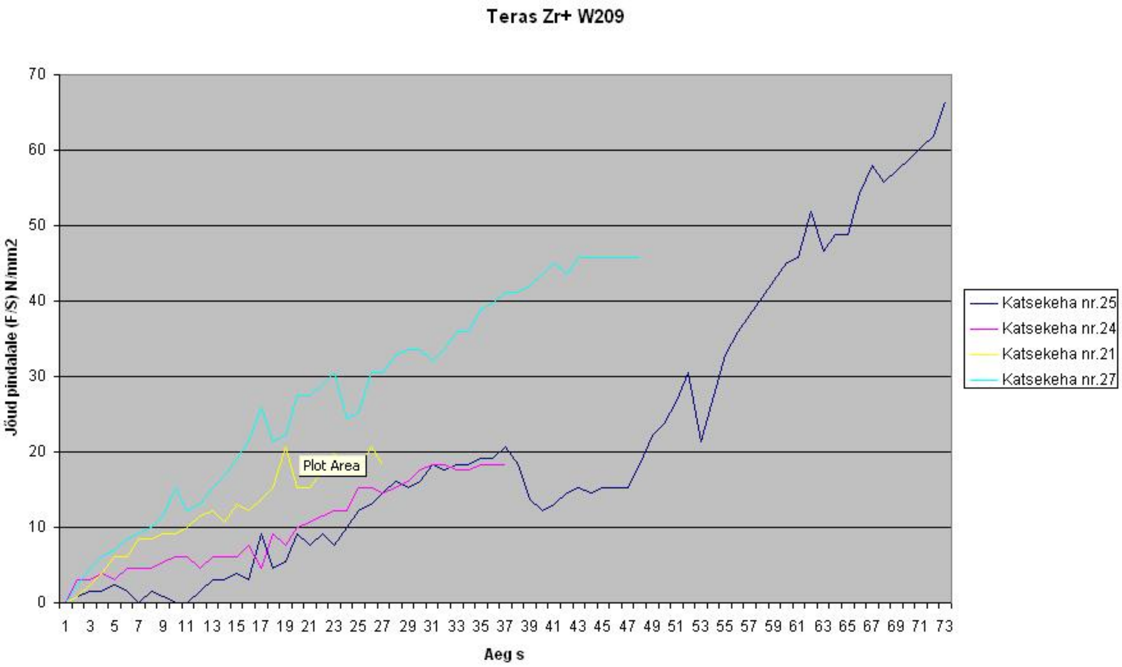


Fig. 12. The bond strength of combined coating ZrO_2/ 30CaO + W209

Table 7

The results of bond strength

The specimen material	Coating material	Test 1 (N/mm^2)	Test 2 (N/mm^2)	Test 3 (N/mm^2)	Test 4 (N/mm^2)	Average (N/mm^2)
Aluminium	ZrO_2/ 30CaO	18,3	7,6	9,2	4,6	9,9
Steel	ZrO_2/ 30CaO	20,6	18,3	11,4	11,4	15,4
	ZrO_2/ 30CaO + W209	66,4	18,3	18,3	45,8	37,2

The research resulted on the beneficial use of the coatings and methods. Due to that the ceramic coatings with different compositions are used in several places of the similar damage cases. In Fig 13 is shown an example of uncoated and with thermo-barrier coating coated exhaust tubes which gained excellent results directly connected to this research in application areas. The example is a good and clear evidence of the need for continuous research on such application areas and remarkable benefits for rising life expectancy for machine elements by using coatings.

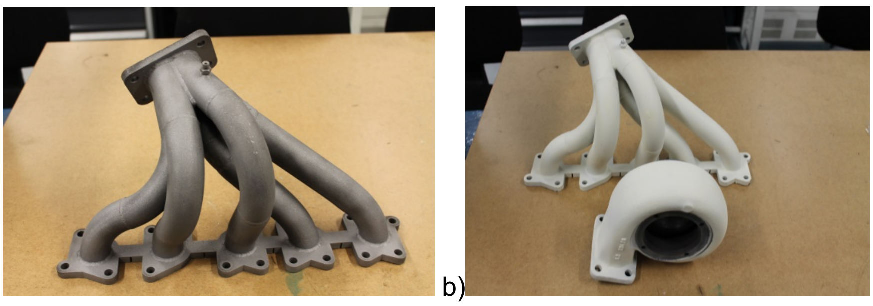
a)  b)

Fig 13. The exhaust system tubes a) without coating, b) with flame sprayed barrier coating

Conclusions

The following conclusions have been drawn for flame sprayed powder and solvent based ceramic coatings. The bond strength was investigated for flame sprayed coatings and it is an important property when using with thermal barrier coatings. The best results occurred when using the coatings by applying with plasma spraying. Based on the results it can be concluded that using thermal barrier coatings with engine elements it is possible to rise highly the efficiency of the engine work and subsequently lower the usage costs. The research also resulted that combination with cold spraying technology does not improve the bond strength of barrier coatings.

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