ADMIRAL MAKAROV NATIONAL UNIVERSITY OF SHIPBUILDING
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Department of Materials Science and Technology of Metals

Improving Physical and Mechanical Properties of Thermal Sprayed Coatings by Electropulse Action and Formation of Composite Coatings

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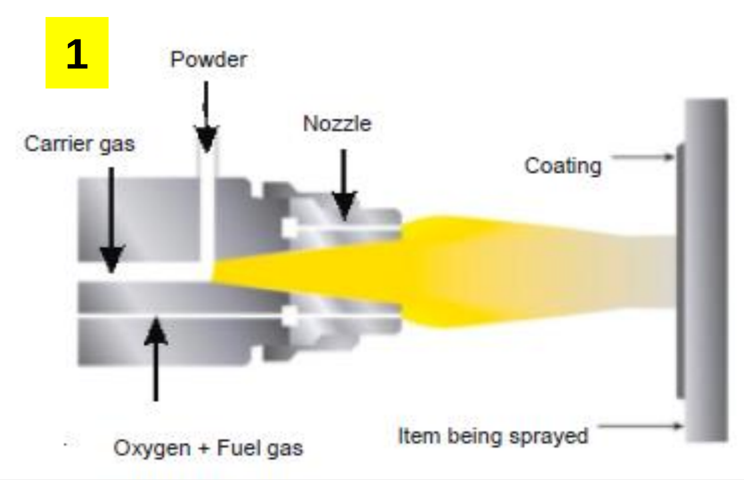
Introduction in Thermal Spray Technology

Thermal Spraying Methods

1. Flame Spraying | **2. Electric arc** | **3. Plasma spraying** | **4. Detonation spraying**

Schemes of processes

1



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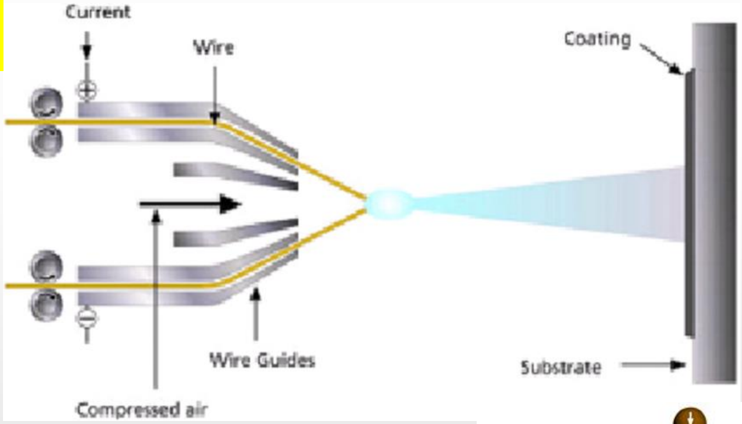

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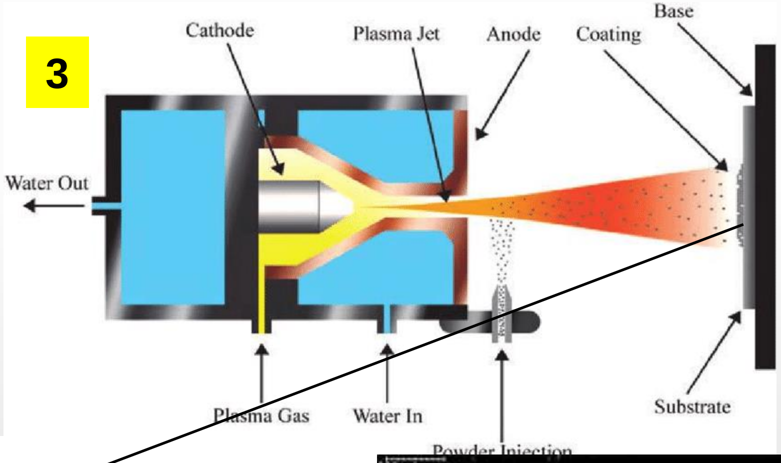

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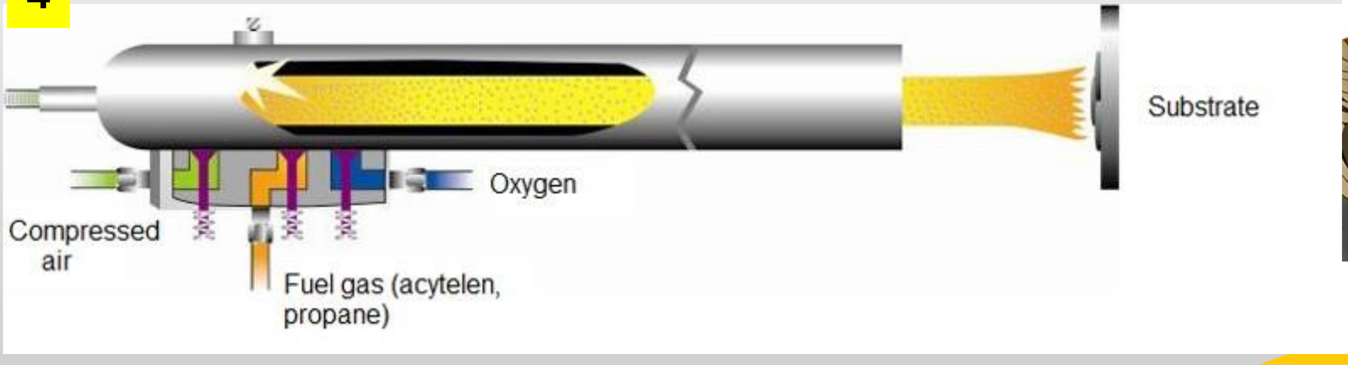
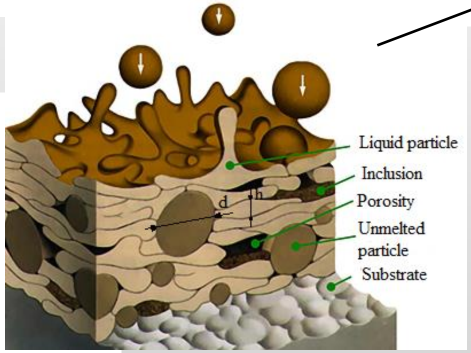




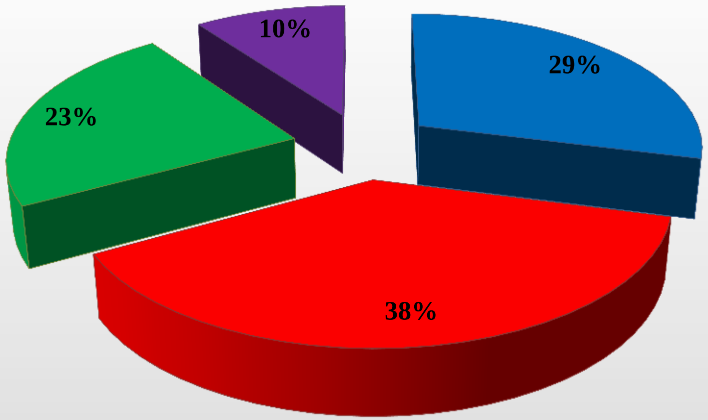
Typical coating microstructure

Advantages and Disadvantages of Methods

Method	Advantages:
1. Flame Spraying	▪ Simple equipment ▪ Mobility ▪ Low noise level
2. Electric arc	▪ Low equipment and materials cost ▪ High productivity ▪ High material utilization factor
3. Plasma spraying	▪ Using different materials for coating spraying ▪ Many types of substrate material can be coated
4. Detonation spraying	▪ High coating density and bond strength ▪ Using different materials for coating spraying

Disadvantages:

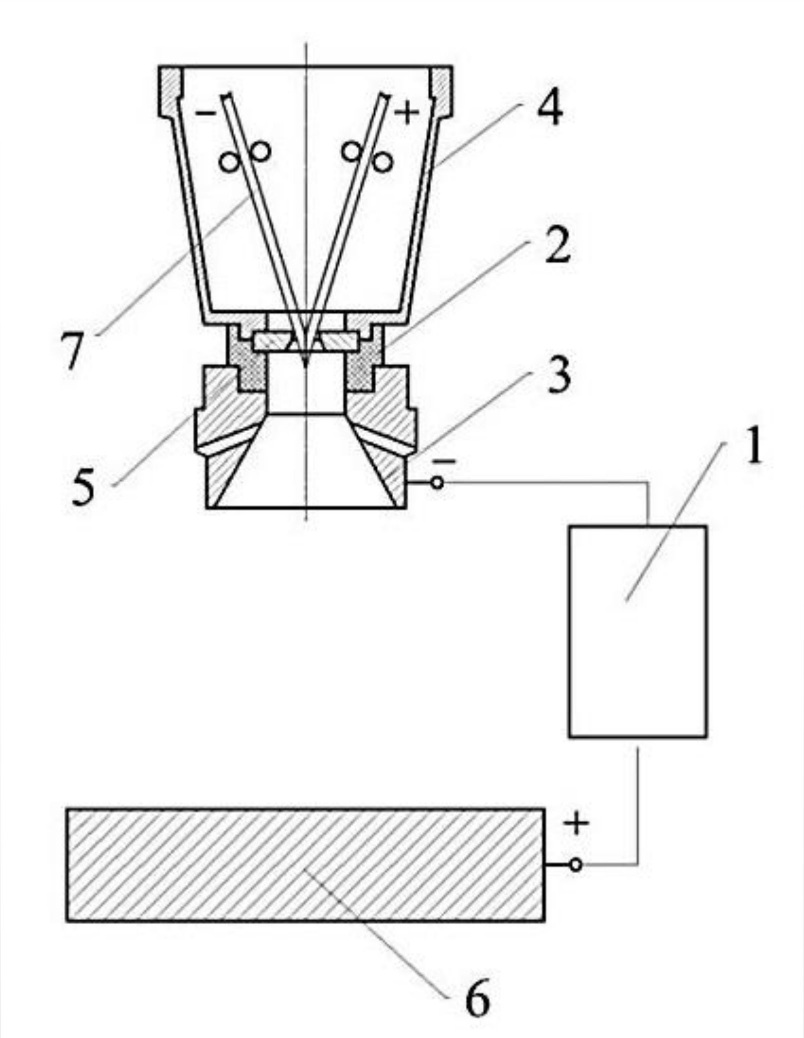
- **Low bond strength (up to 20…30 MPa for electric arc and flame, up to 50 MPa for plasma) and high porosity (up to 15%)**



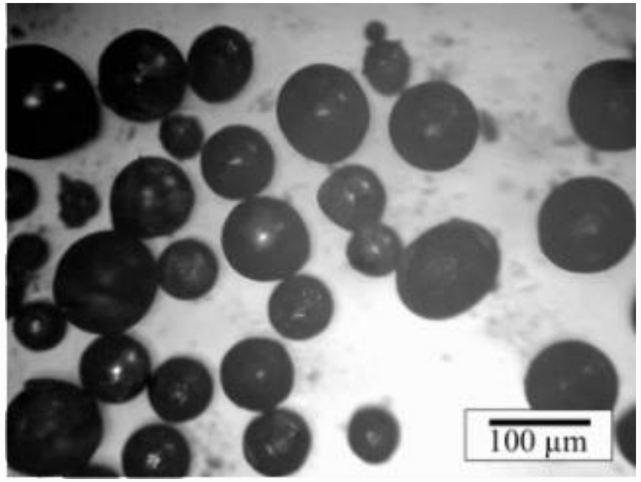
■ - flame; ■ - electric arc; ■ - plasma; ■ - detonation

Using of different thermal spraying methods in manufacturing and repairing

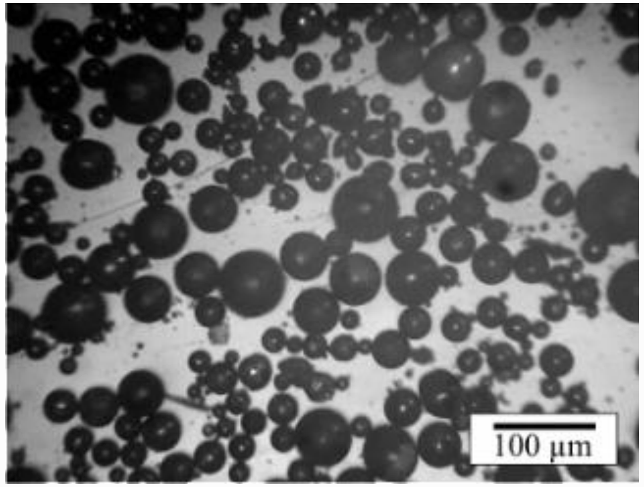
Electropulse action. Electric arc spraying



Scheme of electric arc spraying with electropulse action :1 - source of high-voltage electrical pulses; 2 - insulator; 3 - protective screen; 4 - metallizer cap; 5 - nozzle; 6 - substrate; 7 - electrodes

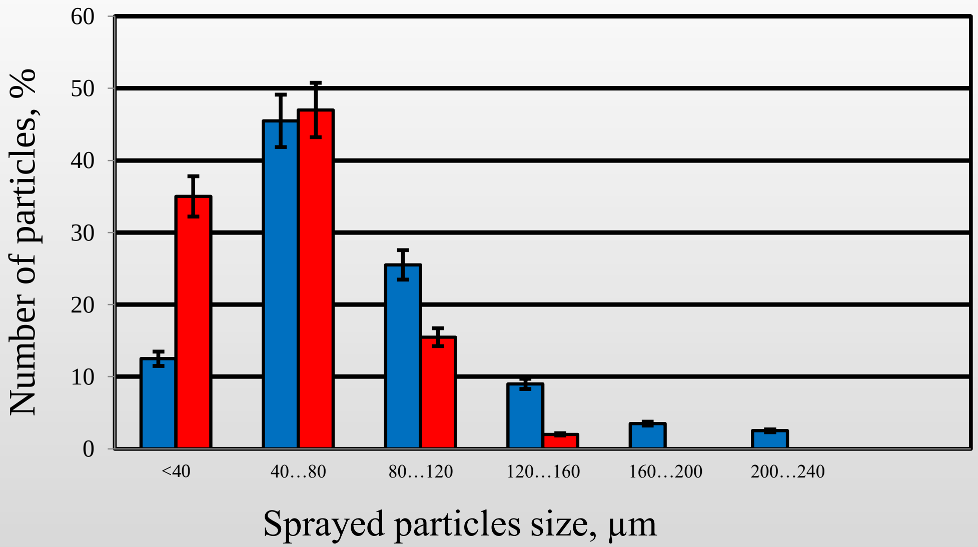


a



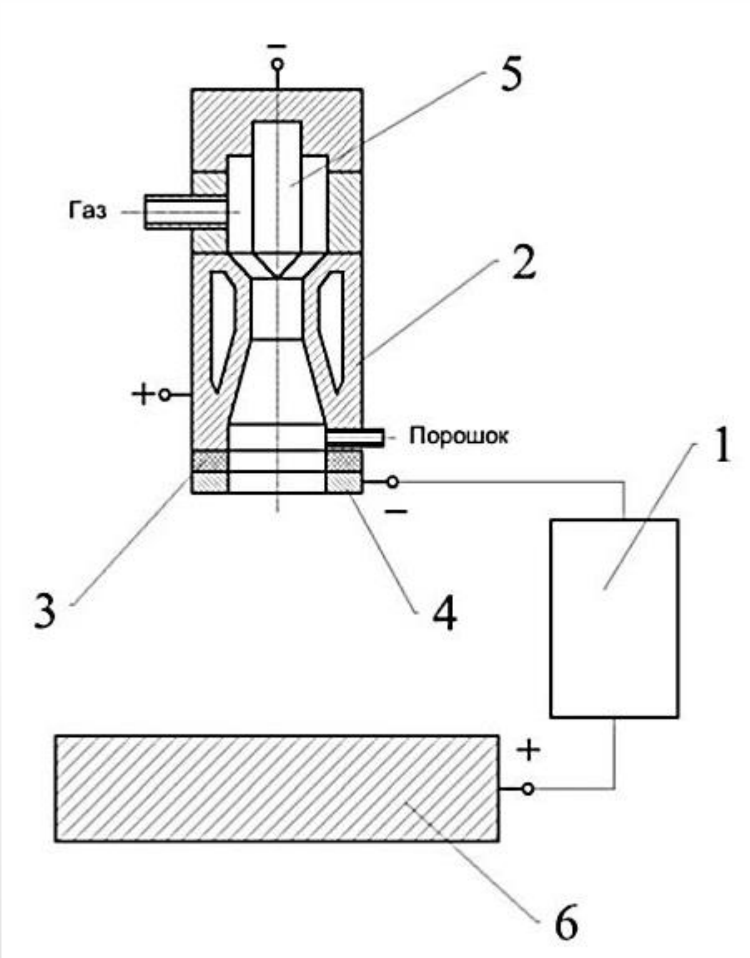
b

Sprayed particles in water (steel wire): a – convention technology; b – electropulse action

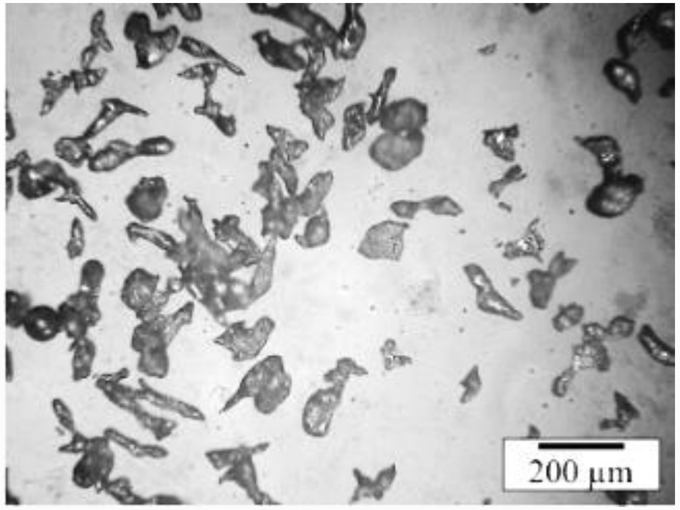


Grading of sprayed particles (steel wire):
■ - convention technology
■ - electropulse action

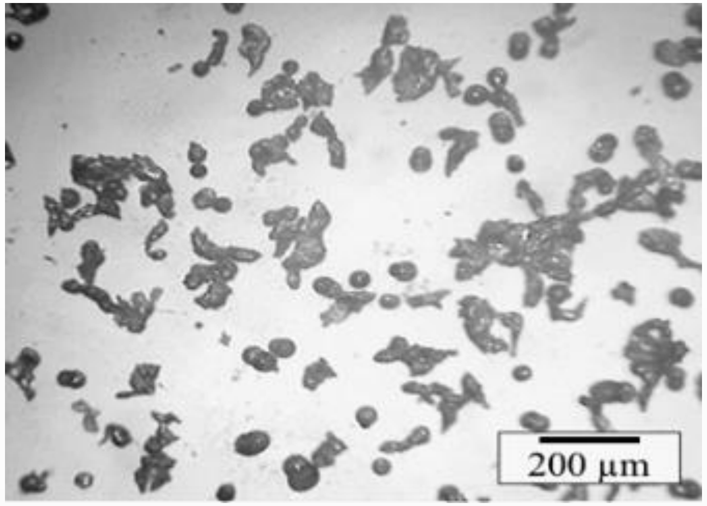
Electropulse action. Plasma spraying



Scheme of plasma spraying with electropulse action
1 - source; 2 - anode; 3 - insulator; 4 - ring;
5 - cathode; 6 - substrate.

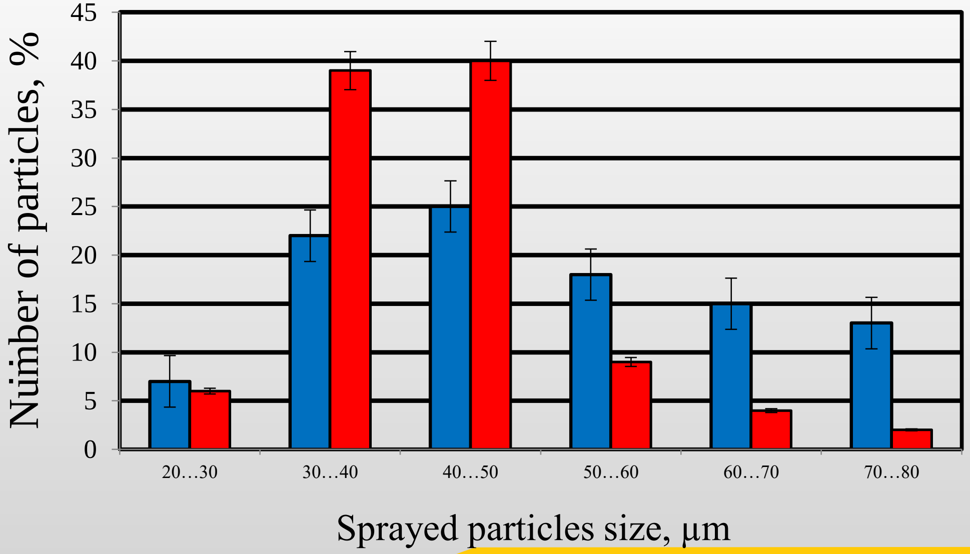


a



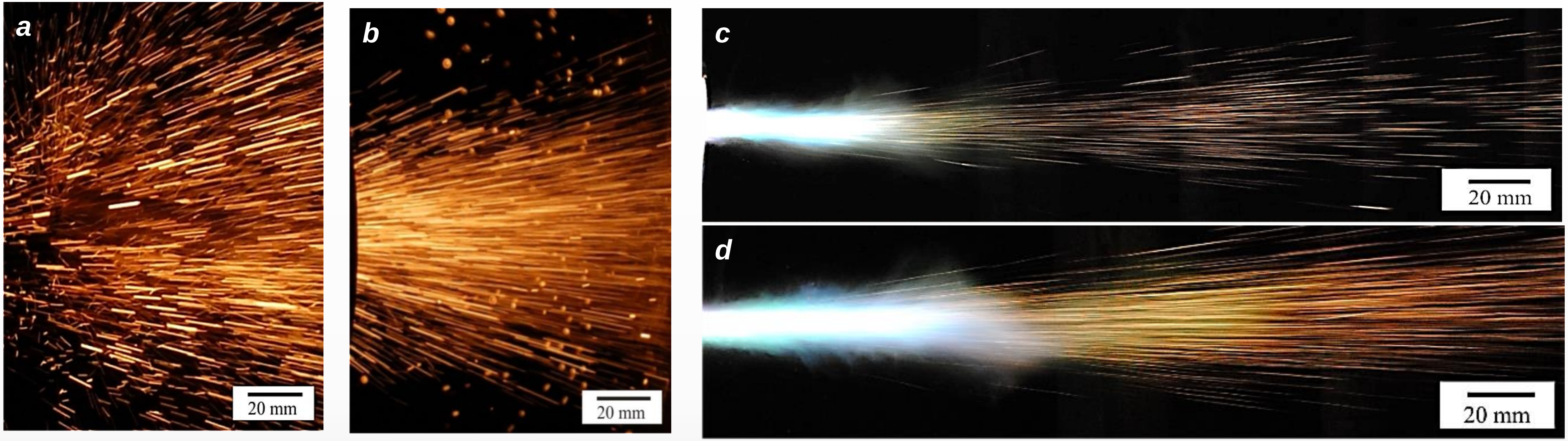
b

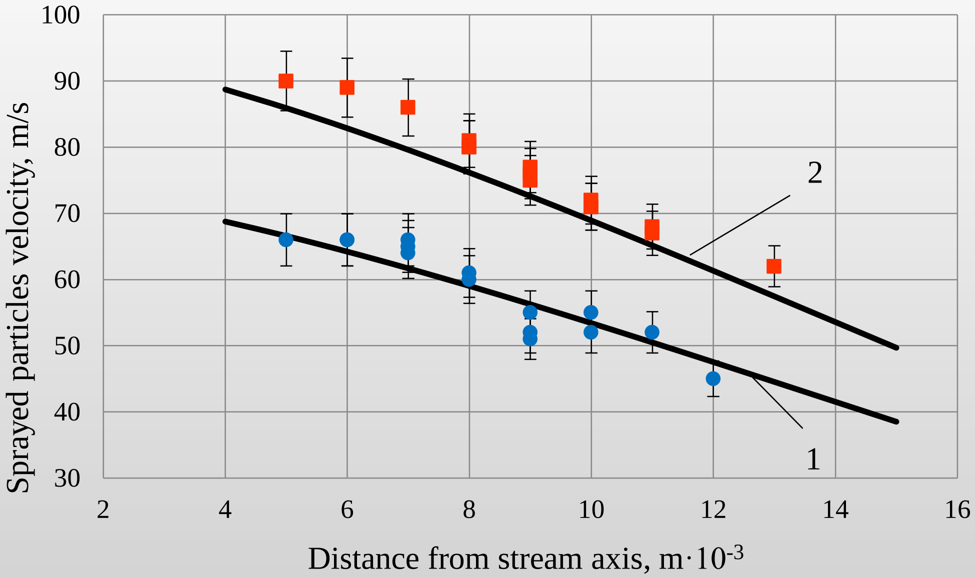
Plasma sprayed particles in water (bronze powder): a – convention technology; b – electropulse action



Grading of sprayed particles (steel wire):
- ■ - convention technology
- ■ - electropulse action

Effect of electropulse action on particles velocity

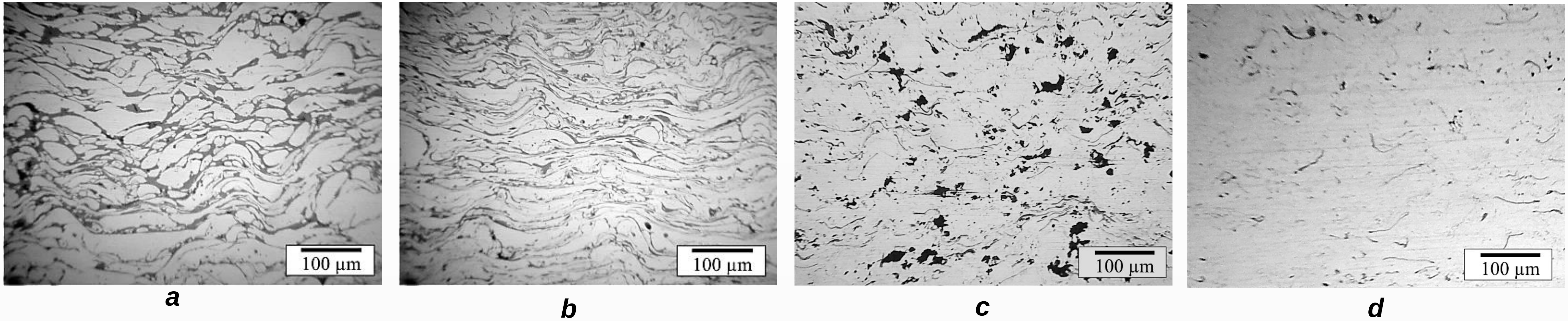




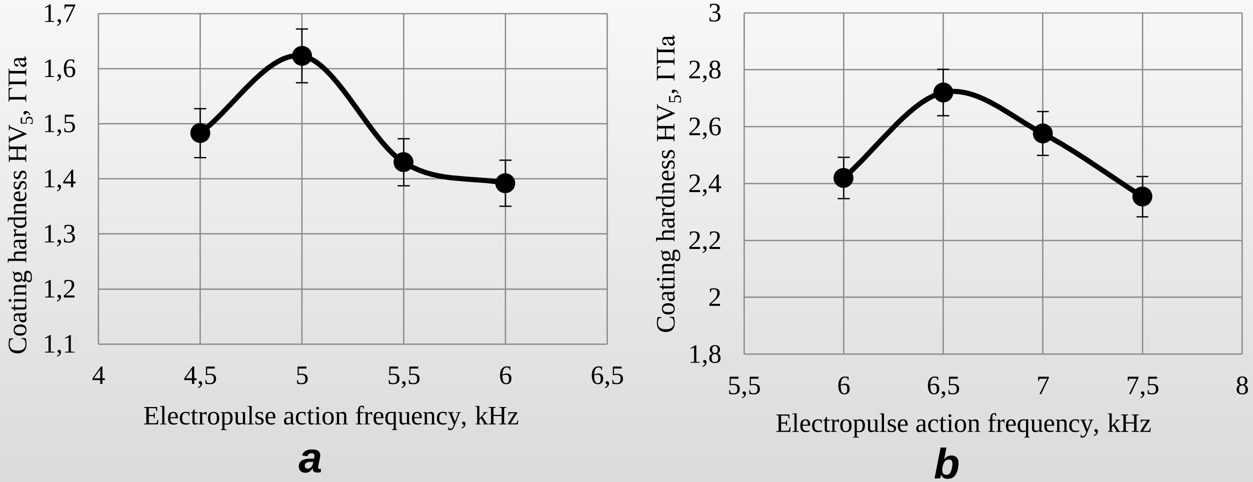
Jet tracks during electric arc spraying of steel wire (exposure 0.25 · 10^{-3}s) (a, b) and plasma spraying of bronze powder (exposure 0.5 · 10_{-3} s) (c, d): and, in - on traditional technology; b, d - using electropulse action

Dependence of particle velocity on the distance from the stream axis at a spray distance of 100 mm: 1 - calculation for a particle diameter of 84 μm; 2 - calculation for a particle diameter of 54 μm; ● - experimental data in determining the velocity of particles in electric arc spraying by traditional technology; ■ - experimental data in determining the velocity of particles in electric arc spraying using electropulse action.

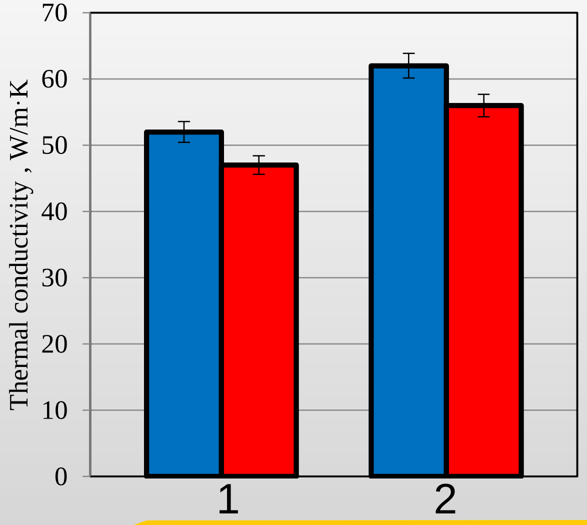
Effect of electropulse action on hardness, porosity and thermal conductivity of sprayed coatings



Microstructure of electric-arc (a,b) and plasma (c, d) sprayed coatings: a,c - convention technology; b, d – electropulse action

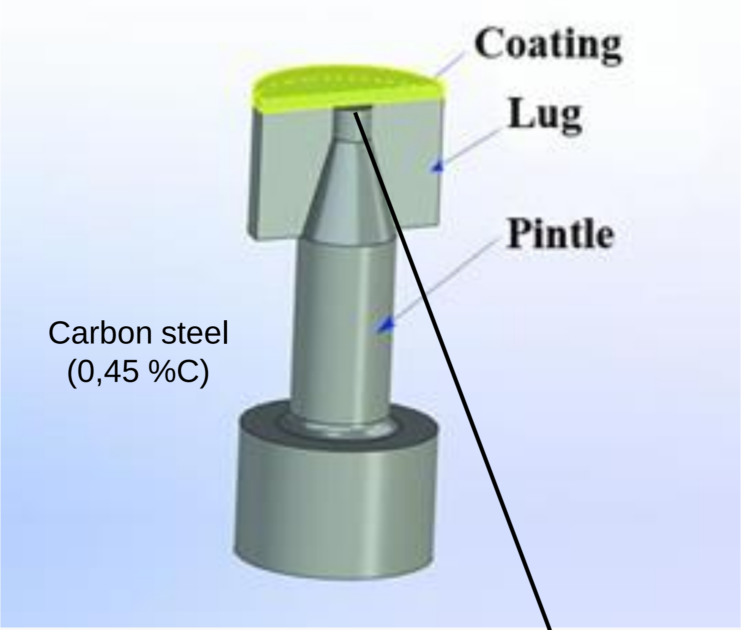


Effect of electropulse action frequency on coatings hardness:
a – electric arc , b – plasma sprayed coatings

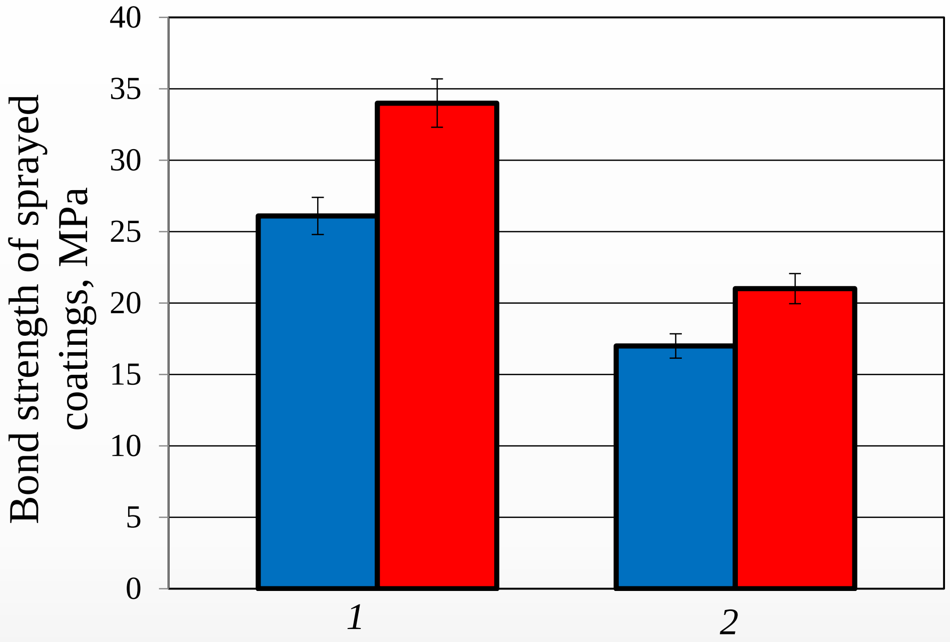


Thermal conductivity testing results:
1 – electric arc; 2 – plasma sprayed coatings;
■ - convention technology;
■ - electropulse action

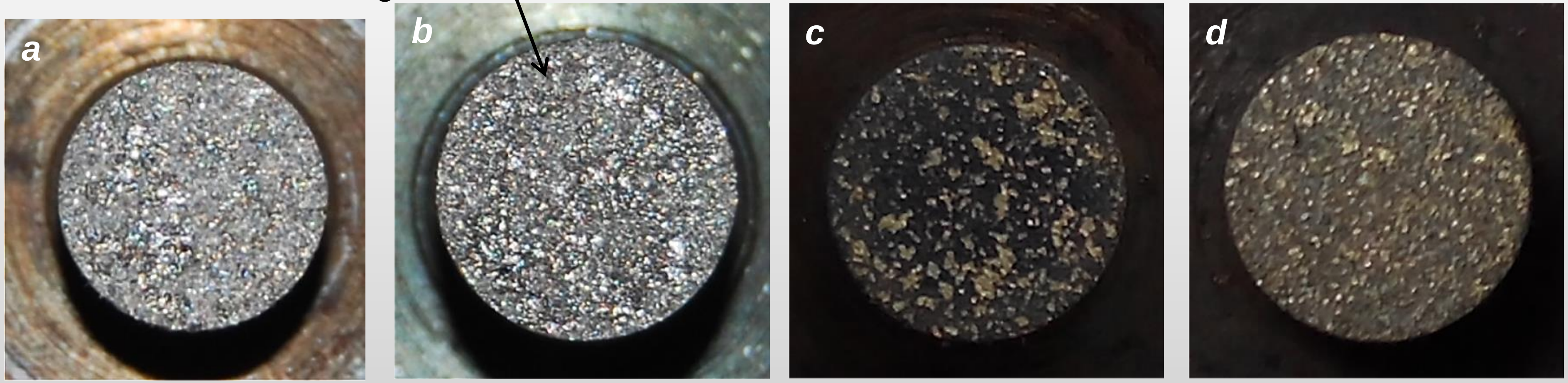
Effect of electropulse action on bond strength of sprayed coatings



Specimen for bond strength testing

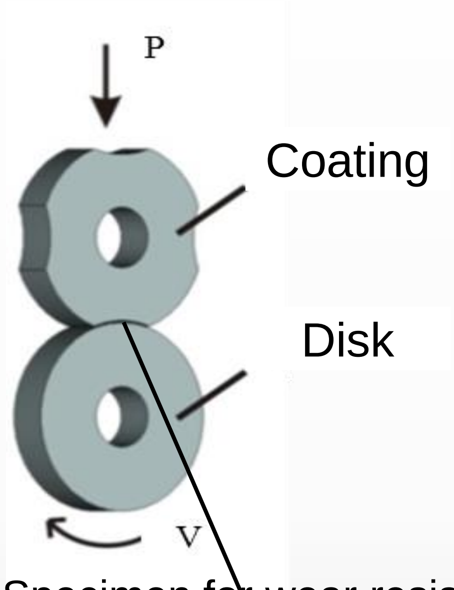


Bond strength measuring results: 1 – electric arc sprayed steel coatings; 2 – plasma sprayed bronze coatings; ■ - convention technology; ■ - electropulse action

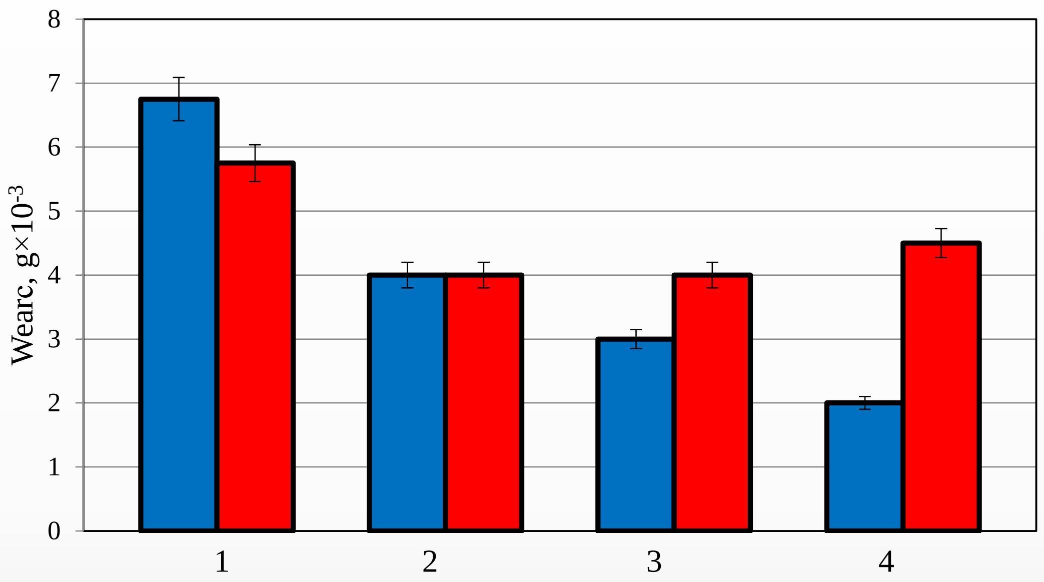


Specimens after bond strength testing of electric arc steel (a, b) and plasma sprayed bronze (c, d) coatings: a, c - convention technology; b, d - electropulse action

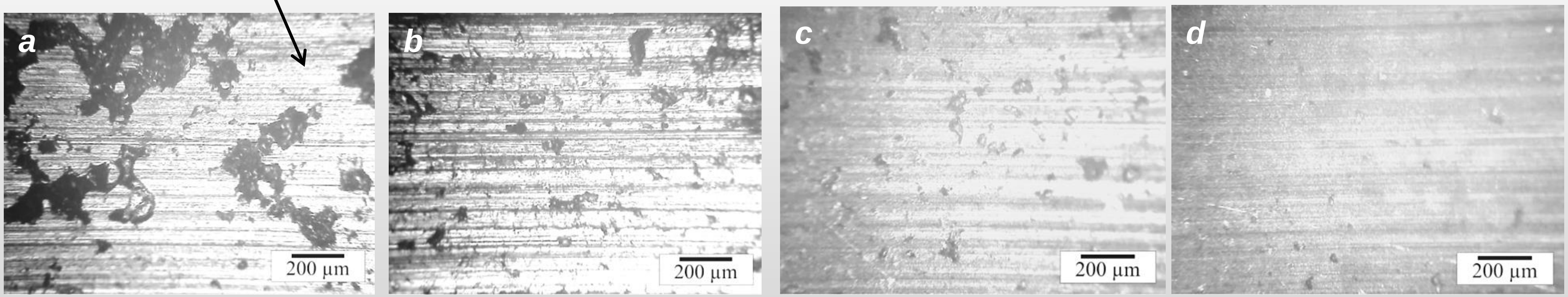
Effect of electropulse action on wear resistance of sprayed coatings



Specimen for wear resistance testing

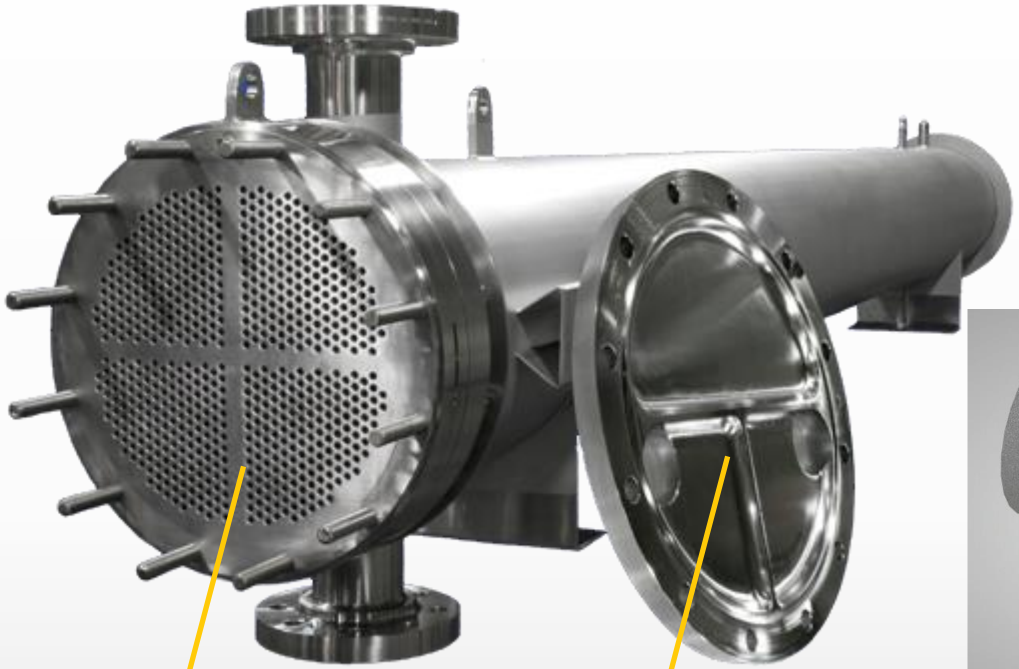


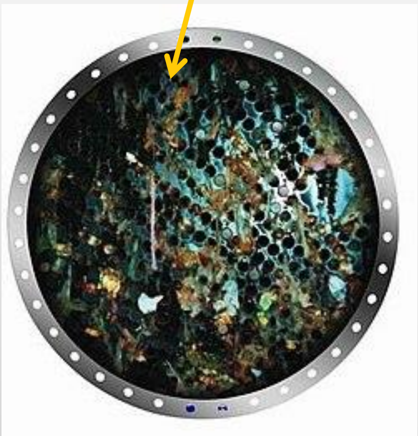
Wear resistance testing results: 1 ,2 – electric arc sprayed steel coatings; 3, 4 – plasma sprayed bronze coatings; ■ - convention technology; ■ - electropulse action



Specimens surface after wear resistance testing of electric arc steel (a, b) and plasma sprayed bronze (c, d) coatings: a, c - convention technology; b, d - electropulse action

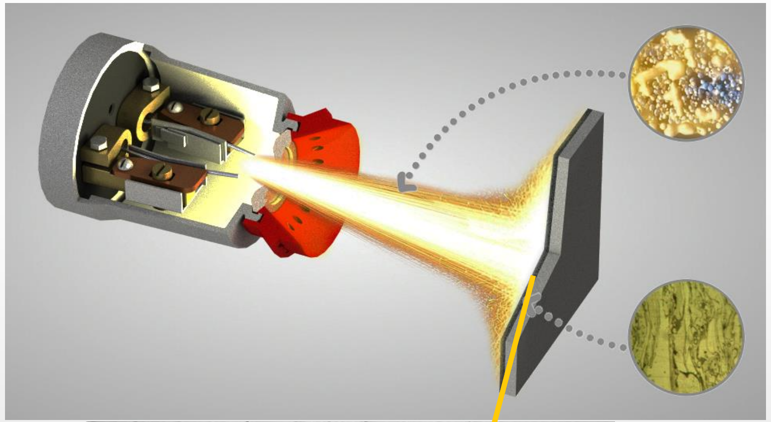
Industrial application. Repairing and corrosion protection covers of a heat exchangers

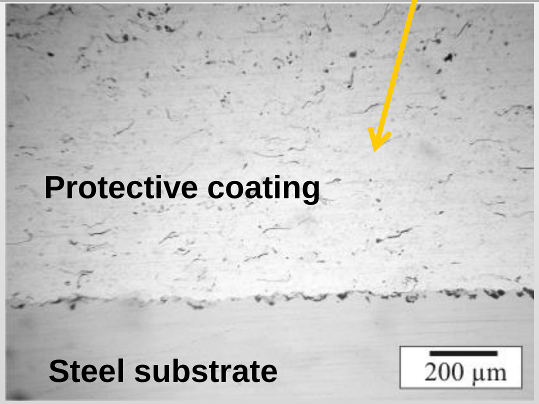




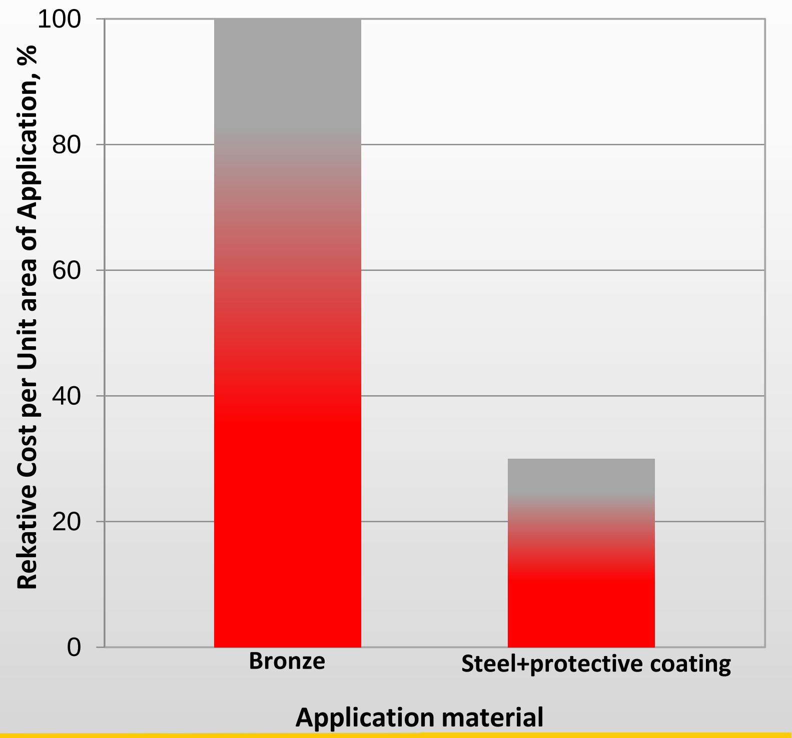
<u>Traditional materials</u>: bronze, Cu-Ni alloys.

<u>Proposal materials</u>: cheap carbon steel with protecting thermal sprayed coating (thickness 1…3 mm).

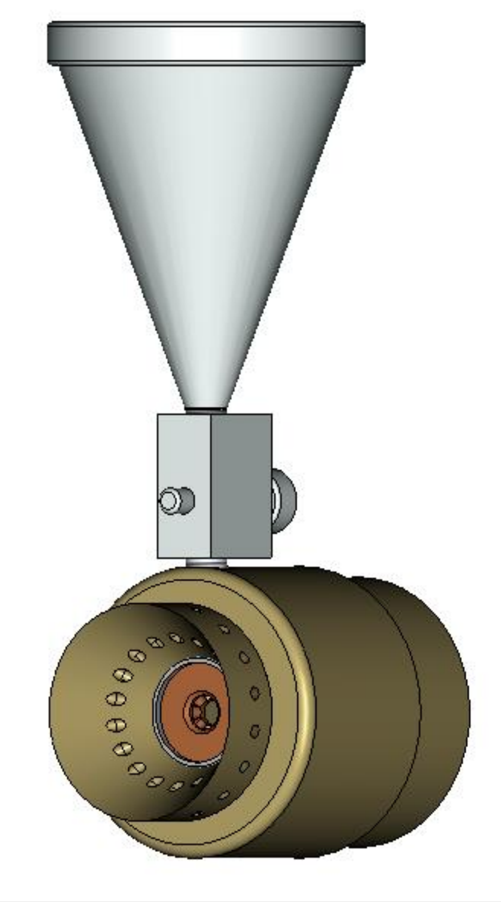




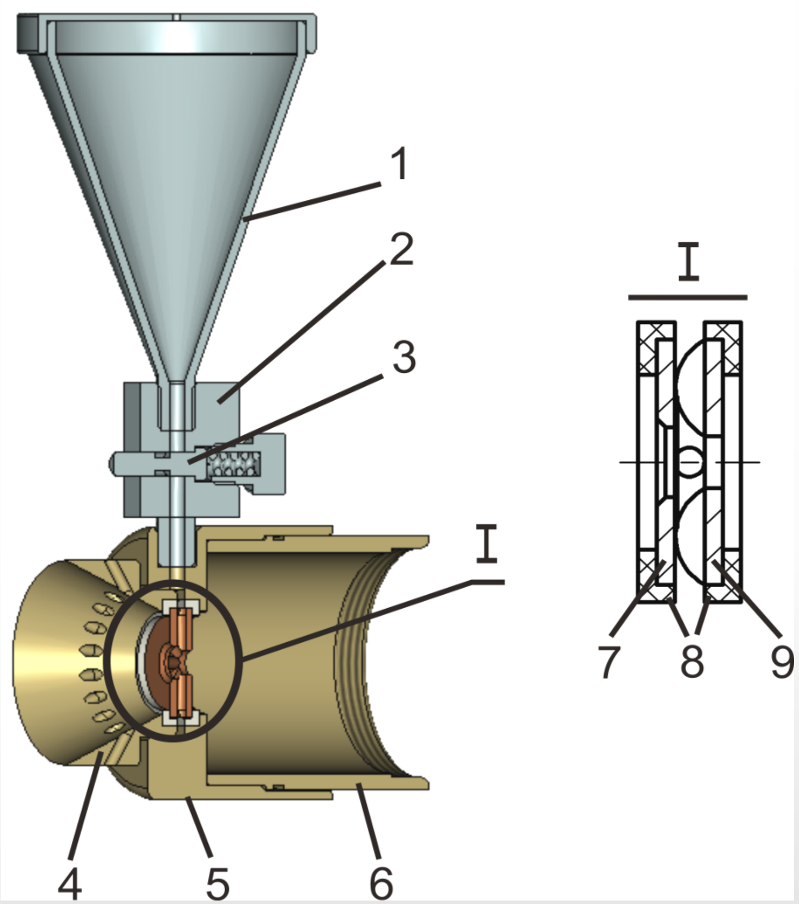
<u>Cost comparison</u>



Chapter 2. Electric arc composite coatings deposition. Modernized spraying gun



General view

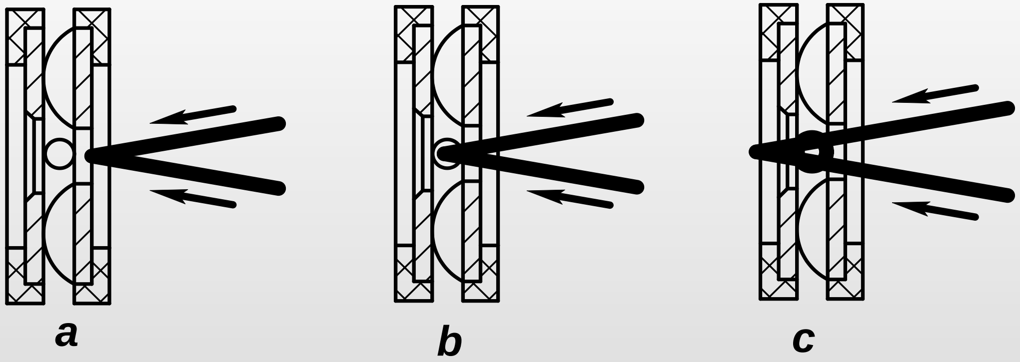


Cross section

1 - powder feeder; 2 - dosing device; 3 - control lever of the dosing device; 4 - protective screen; 5 - cap of the spray head; 6 - adapter; 7 - additional nozzle; 8 - insulating inserts; 9 - main nozzle.

Before modernization

After modernization

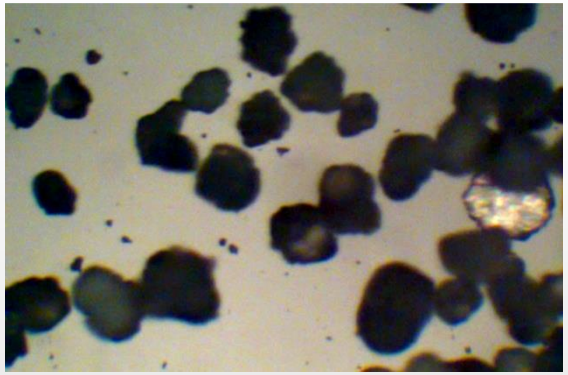


Powder injection zones: a – before electric arc; b – in arc; c – after arc

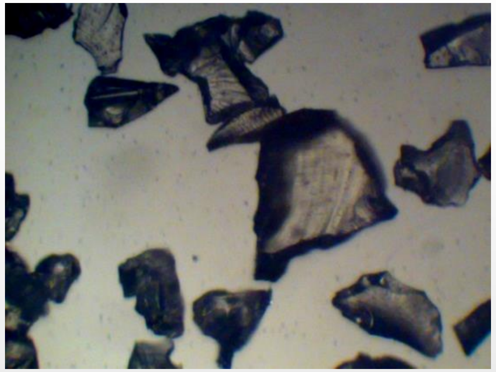
Feedstock powder and wire analysis for composite coatings

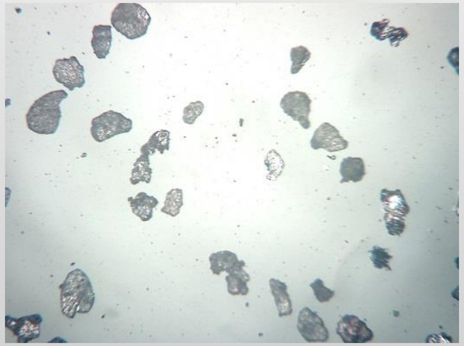
Wire diameter 1,2 mm:	*Powders 40…80 µm:*
1. Low carbon steel wire ER70S-6; 2. Aluminium base alloy wire AlMg5 (ER5356). 3. High carbon steel wire 65G (0,65% C)	1.P-EP-219 (polymer) 2. Al_2O_3 3. ZrO_2 stabilized by 7 % Y_2O_3 (7YSZ) 4. Group A glass breakage 5. TiC powder 6. Cr_2C_3 powder

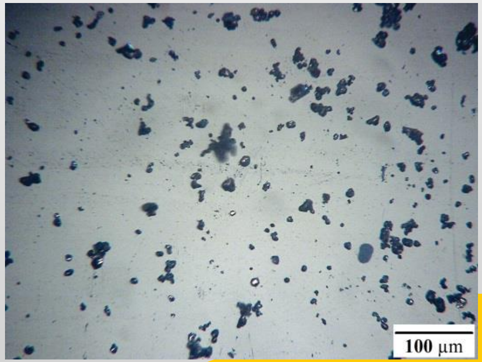

P-EP-219 powder ×150


Al_2O_3 powder ×150


7YSZ powder ×150

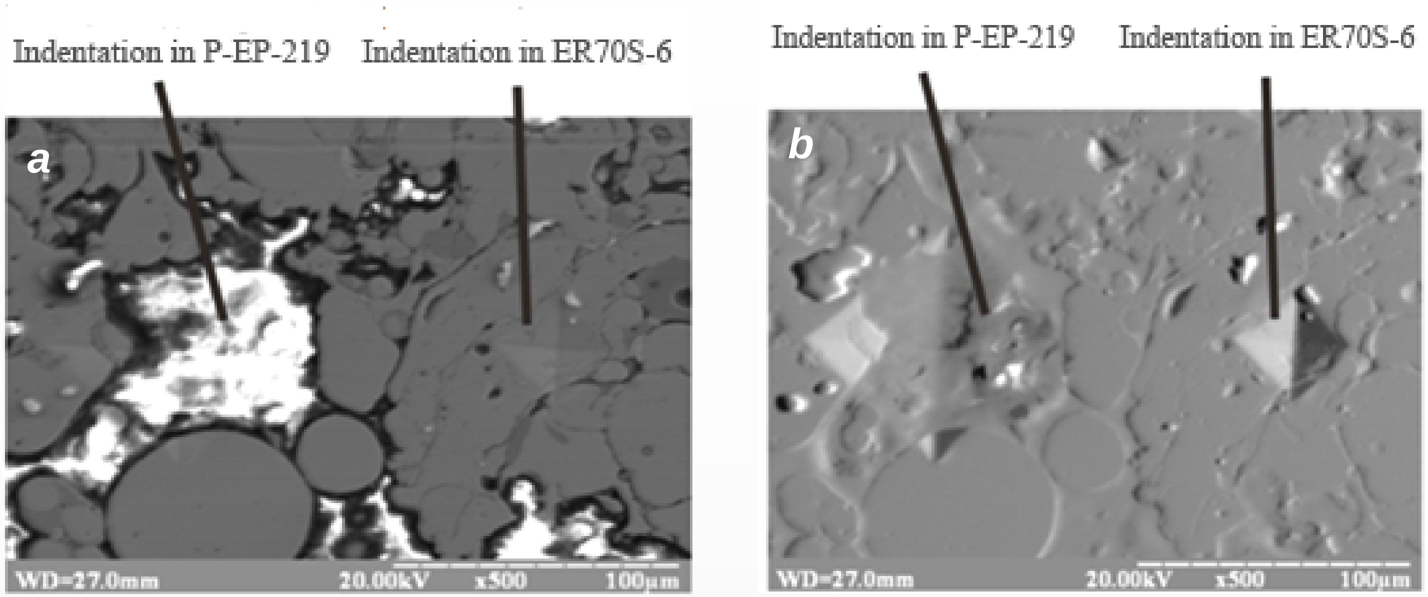

Glass powder ×150


TiC powder ×300

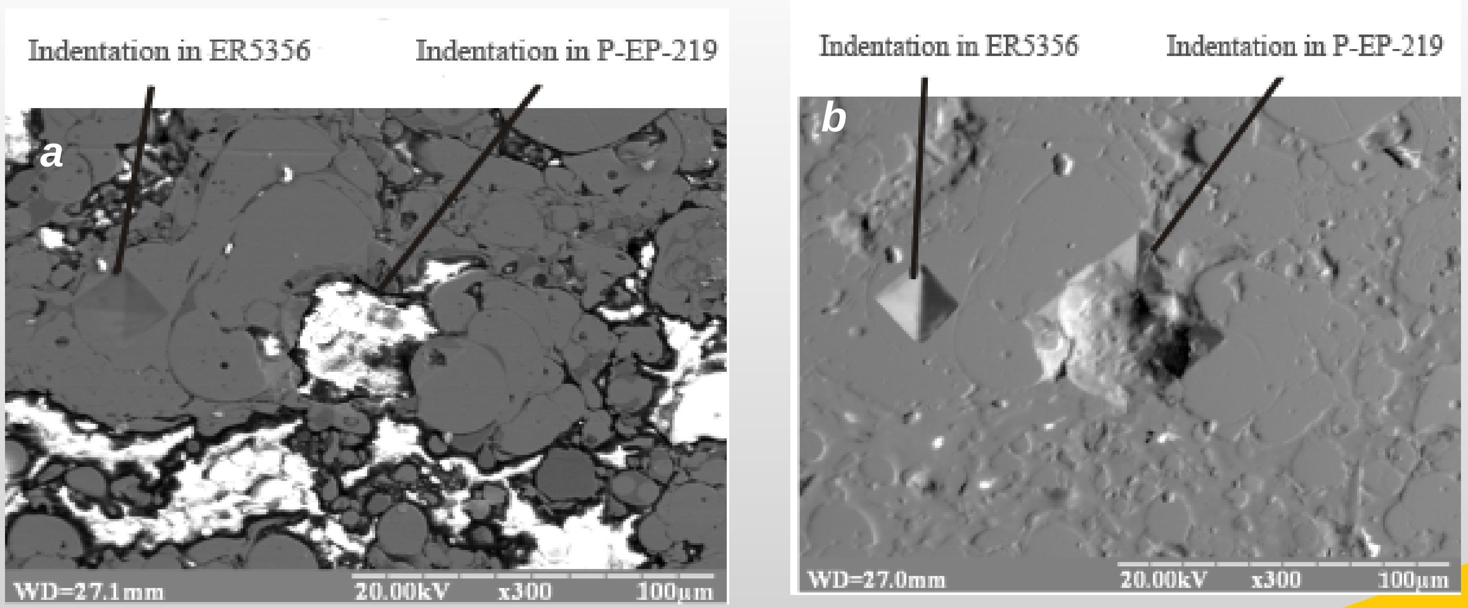


Cr_2C_3 powder

Electric-arc sprayed metal-polymer composite coatings phases identification

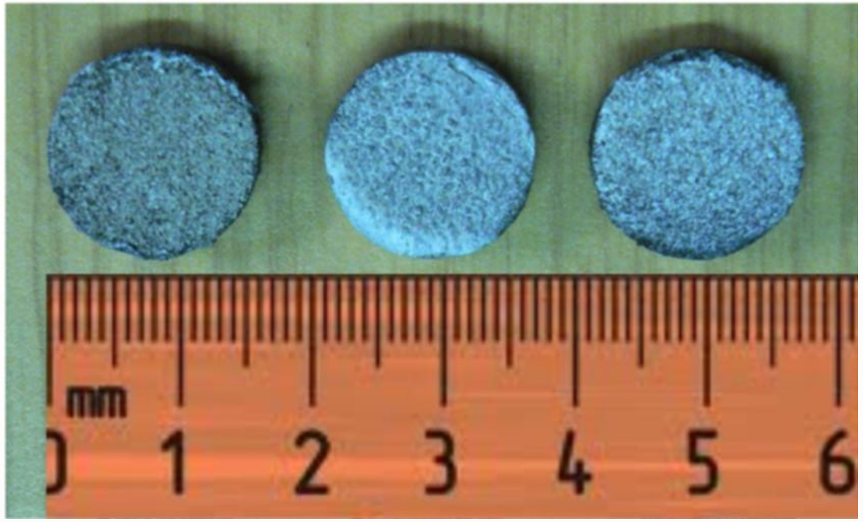


Microhardness measurement results of different phases in composite coating composition ER70S-6 – P-EP-219:
a – backscattered SEM image; b - surface topography

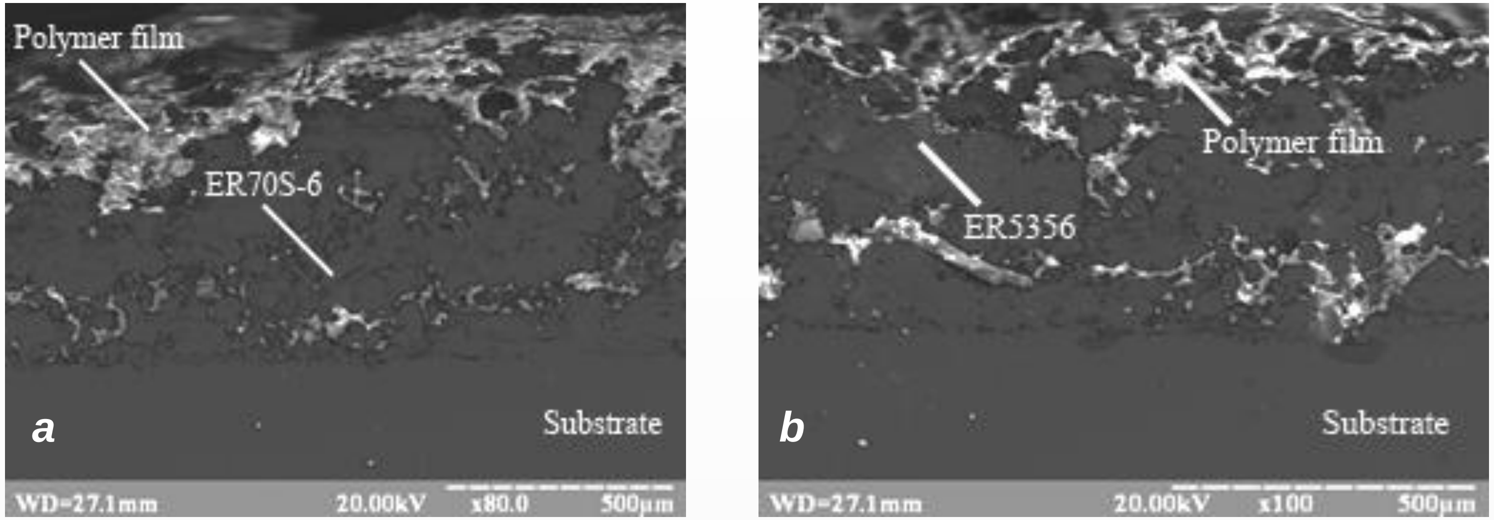


Microhardness measurement results of different phases in composite coating composition ER5356 – P-EP-219:
a - backscattered SEM image; b - surface topography

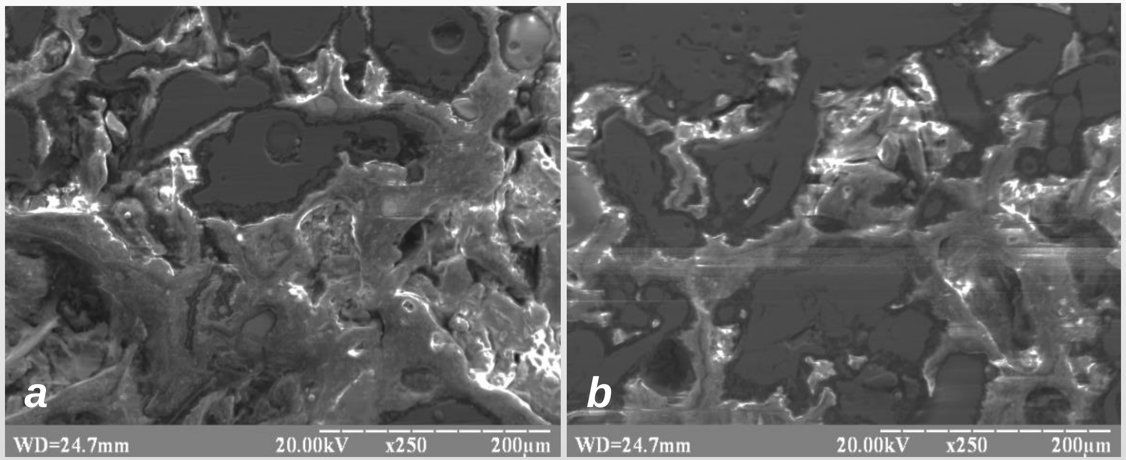
Coatings microstructure analysis and effect of polymer phase on thermal conductivity



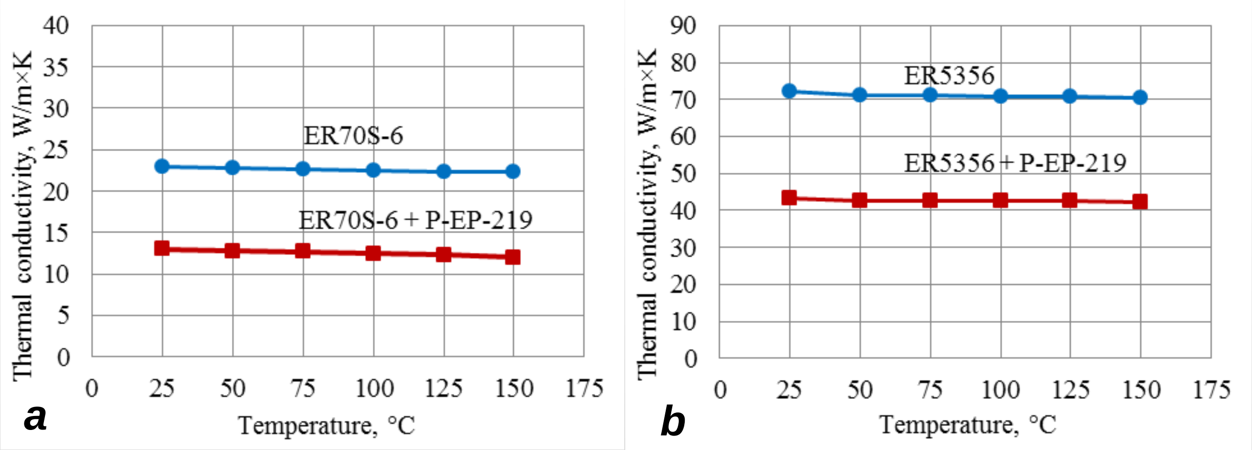
Metal-polymer coated specimens



Cross section SEM micrographs of electric arc composite coatings with surface thin polymer film: a - ER70S-6 - P-EP-219; b - ER5356 – P-EP-219

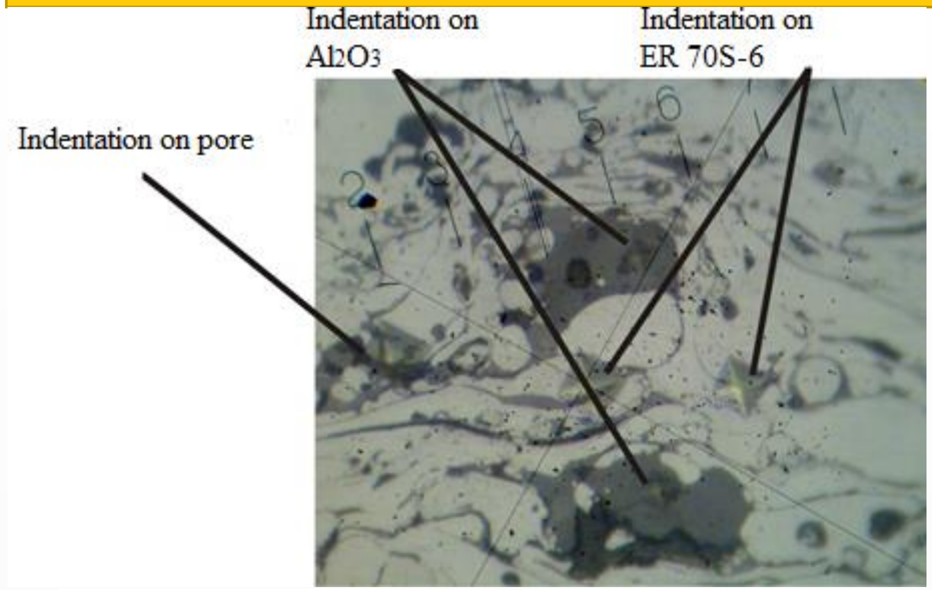


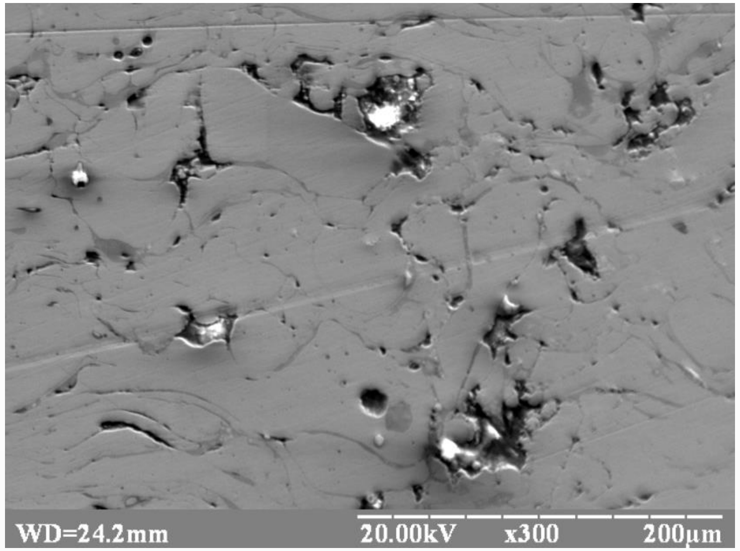
Cross section SEM micrographs of electric arc composite coatings with maximum polymer content: a - ER70S-6 - P-EP-219 (40% vol.); b - ER5356 – P-EP-219 (30% vol.)



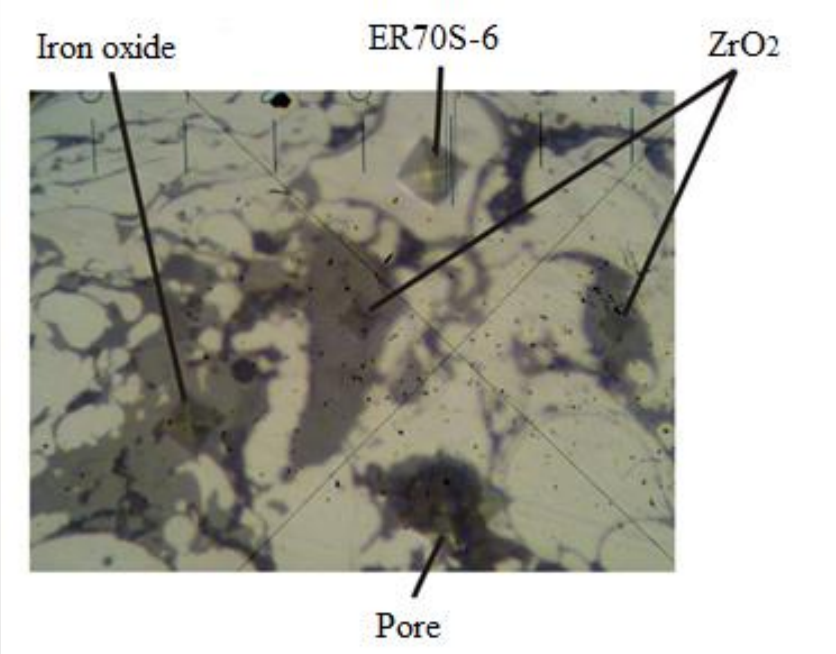
Thermal conductivity comparison between conventional ER70S-6 and composite coatings ER70S-6 – P-EP-219 (a); conventional ER5356 and ER5356 – P-EP-219 coating (b)

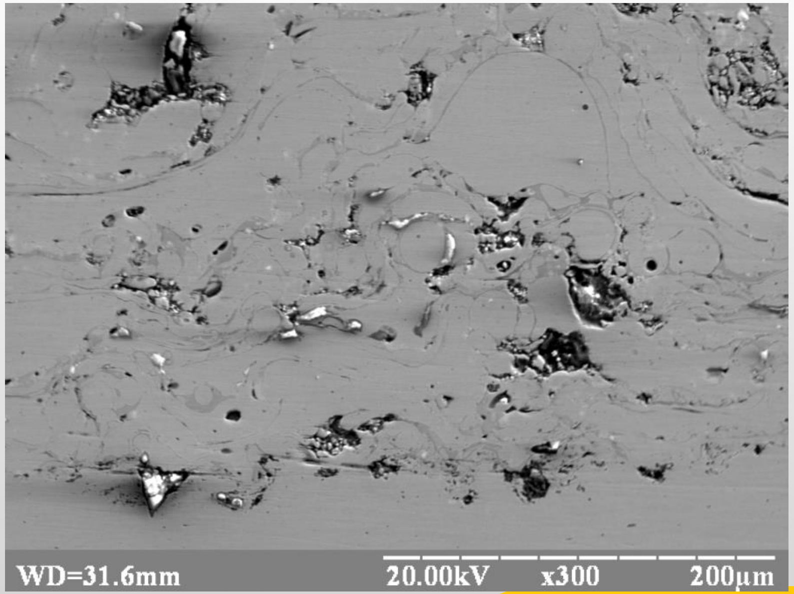
Electric-arc sprayed metal-ceramic composite coatings phases identification





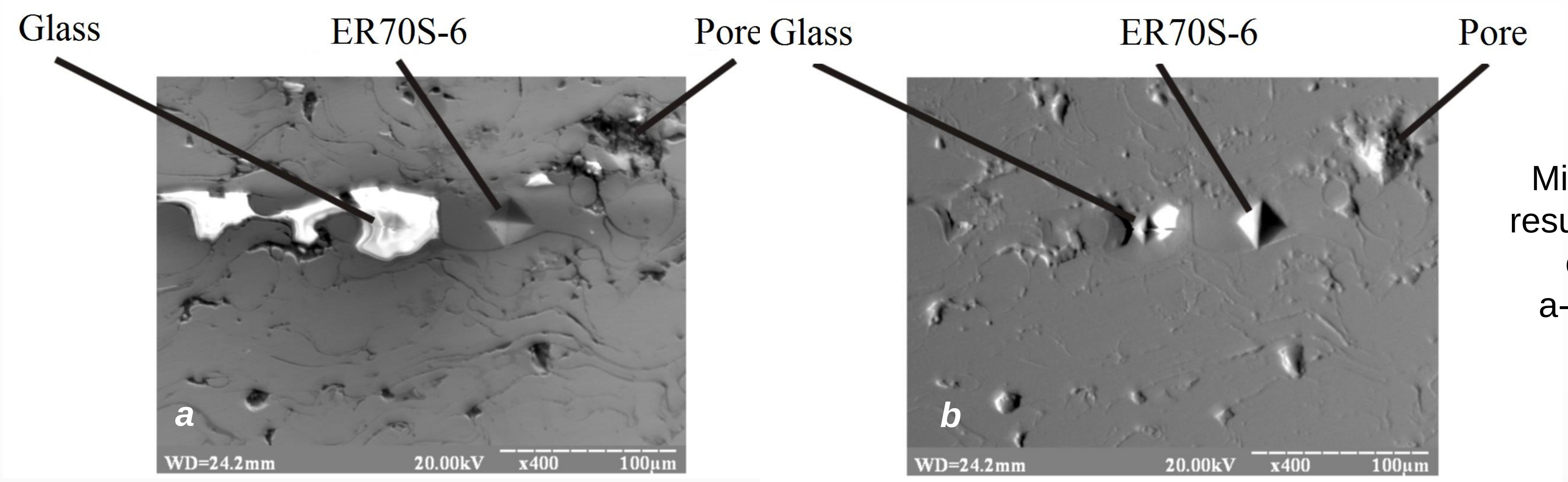
Microhardness measurement results of different phases in the coating ER70S-6 - Al_2O_3 and its typical microstructure
Maximal Al_2O_3 content 11,5% vol.



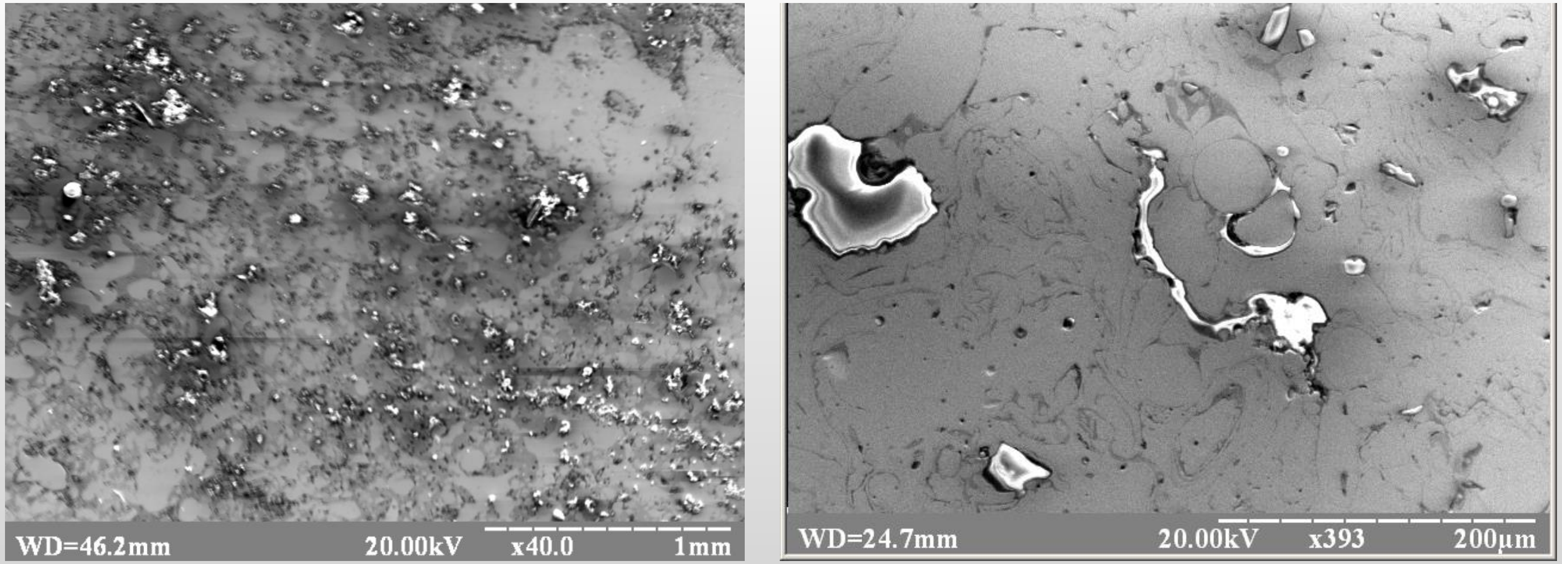


Microhardness measurement results of different phases in the coating ER70S-6 - ZrO_2 and its typical microstructure
Maximal ZrO_2 content 14% vol.

Electric-arc sprayed metal-glass composite coatings phases identification



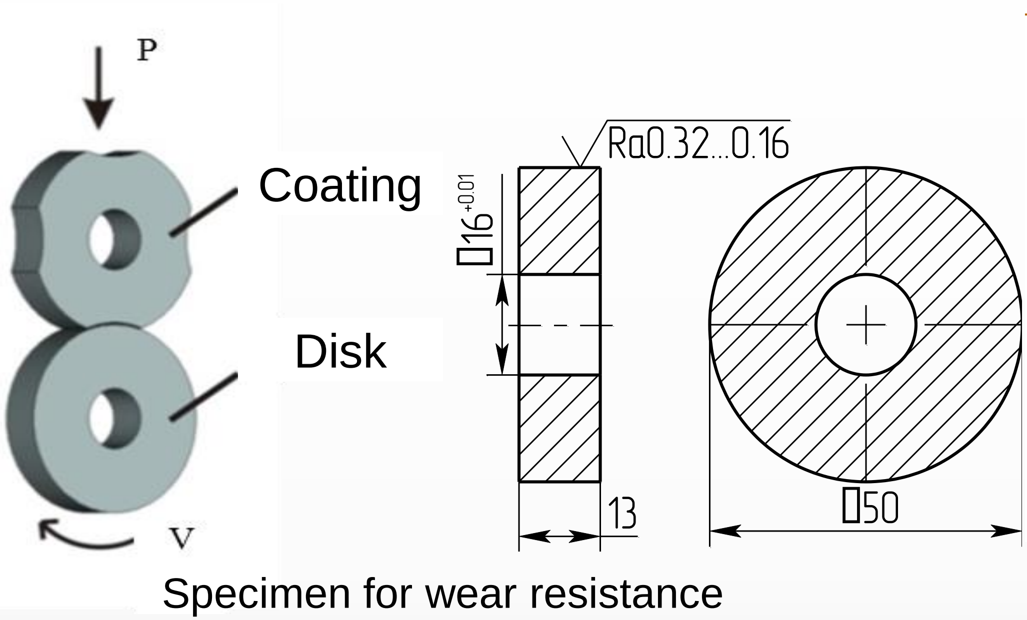
Microhardness measurement results of different phases in the coating ER70S-6 - Glass
a-microstructure; b - surface topography



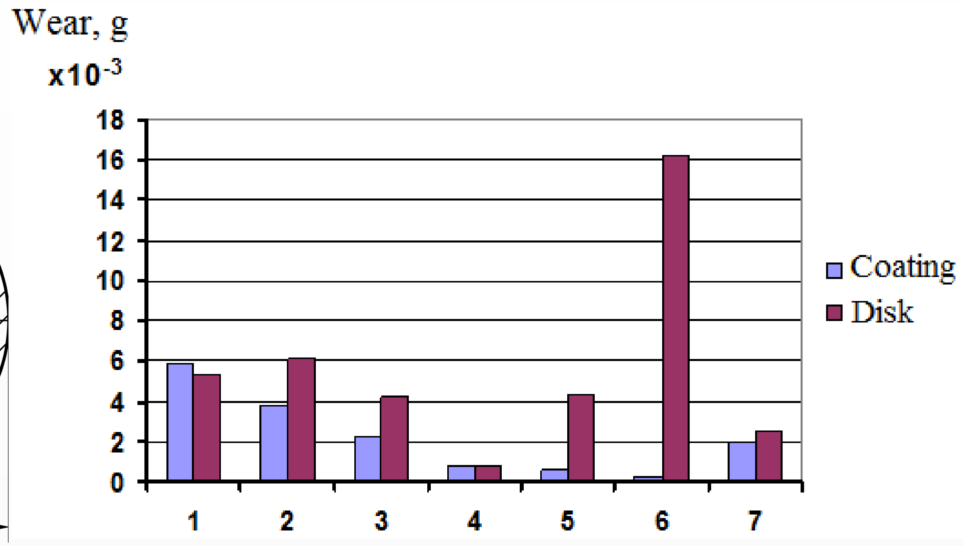
Typical microstructures

Microhardness $H\mu_{50}$ of metal matrix ER0S-6 – 1990 MPa;
Microhardness $H\mu_{50}$ glass particles– 6860 MPa;
Coating porosity 8…10 %.
Maximal glass content 19,5% vol.

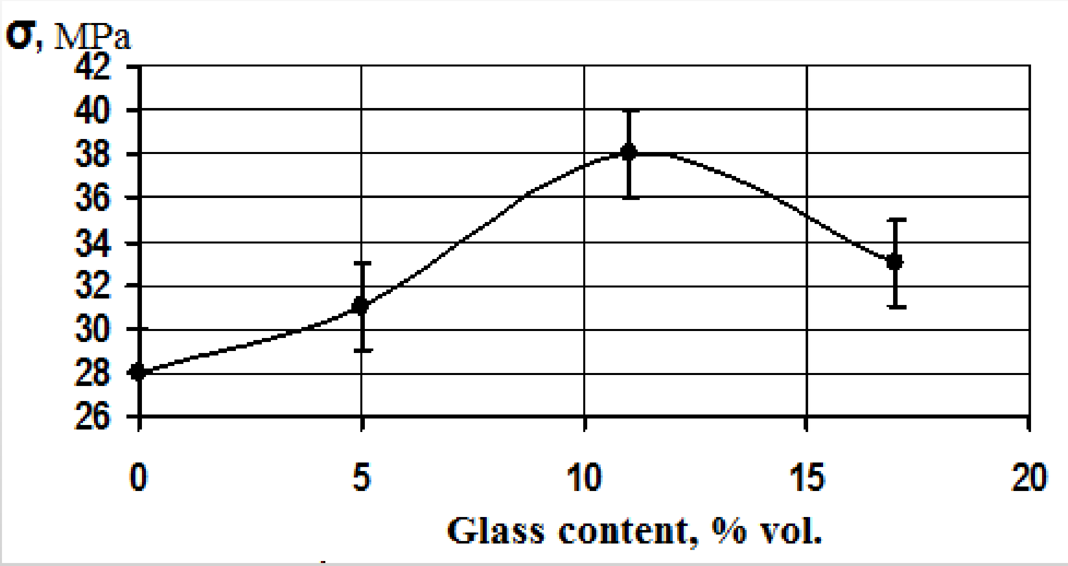
Bond strength and wear-resistance of metal-glass composite coatings



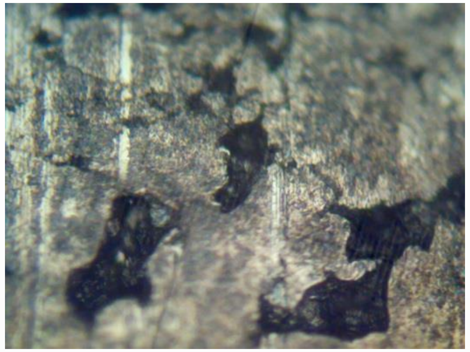
Specimen for wear resistance testing



Wear resistance testing results of coatings with different glass content %, vol: 1 – 0%; 2 – 5%; 3 – 8%; 4 – 11%; 5 – 14%; 6 – 17%; 7 – Aluminium bronze



Bond strength vs. glass content in electric-arc sprayed composite metal-glass coatings

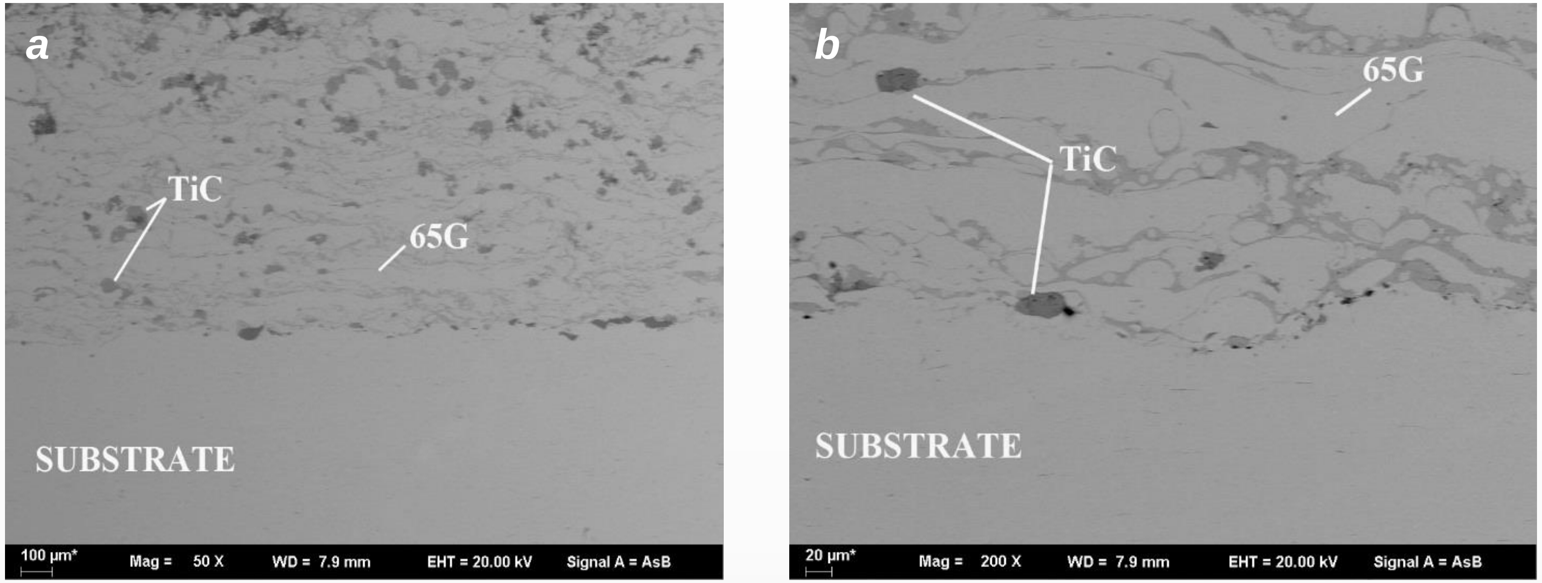


a

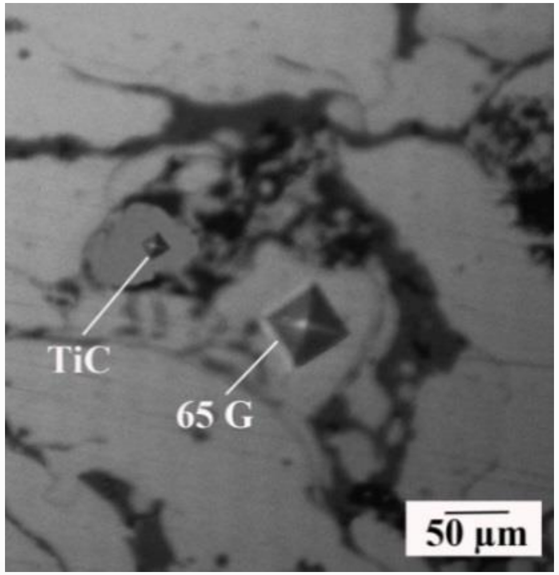
b

Specimens surface after wear resistance testing:
a –coating
b - disk

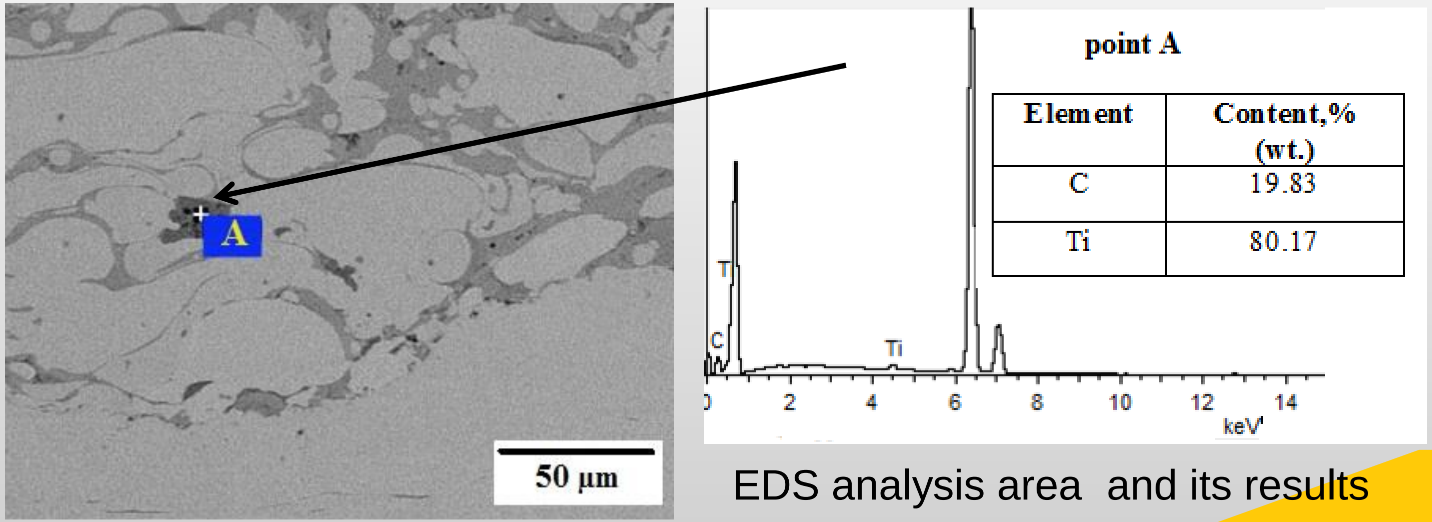
Electric-arc sprayed metal-carbide (TiC) composite coatings phases identification and microstructure analyses



Cross section SEM micrographs of electric arc cermet coatings at different magnifications: a × 50; b × 200



Microhardness measurement results of different phases in the coating

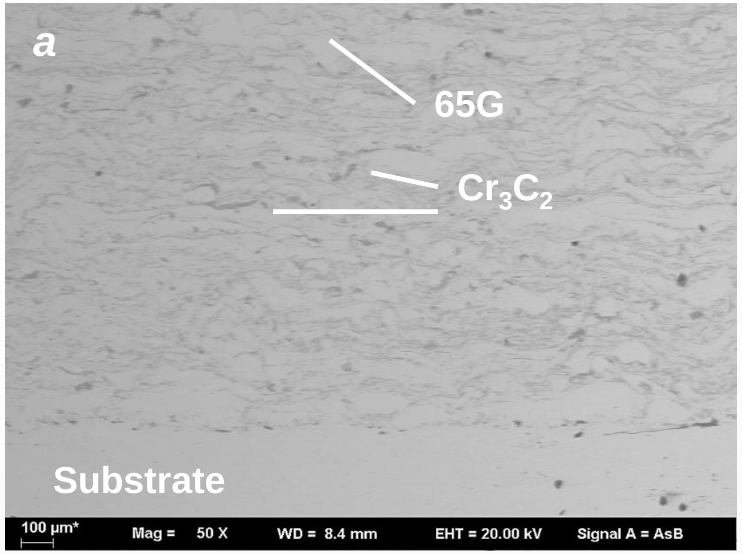


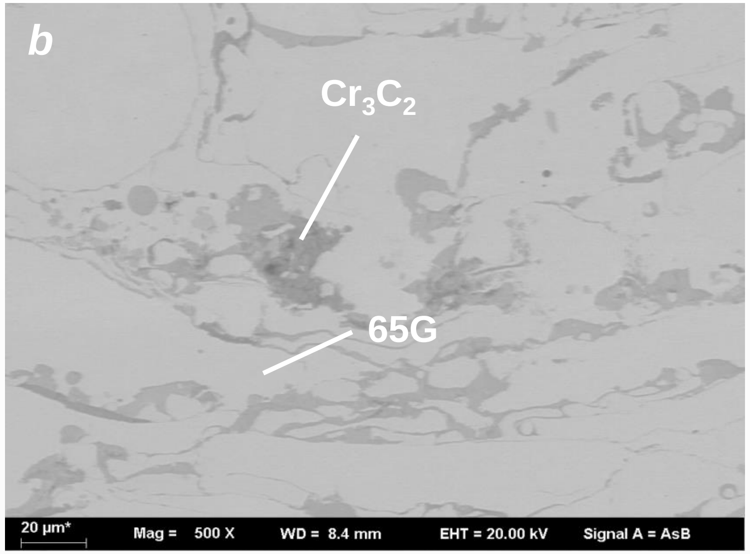
Element	Content,% (wt.)
C	19.83
Ti	80.17

EDS analysis area and its results

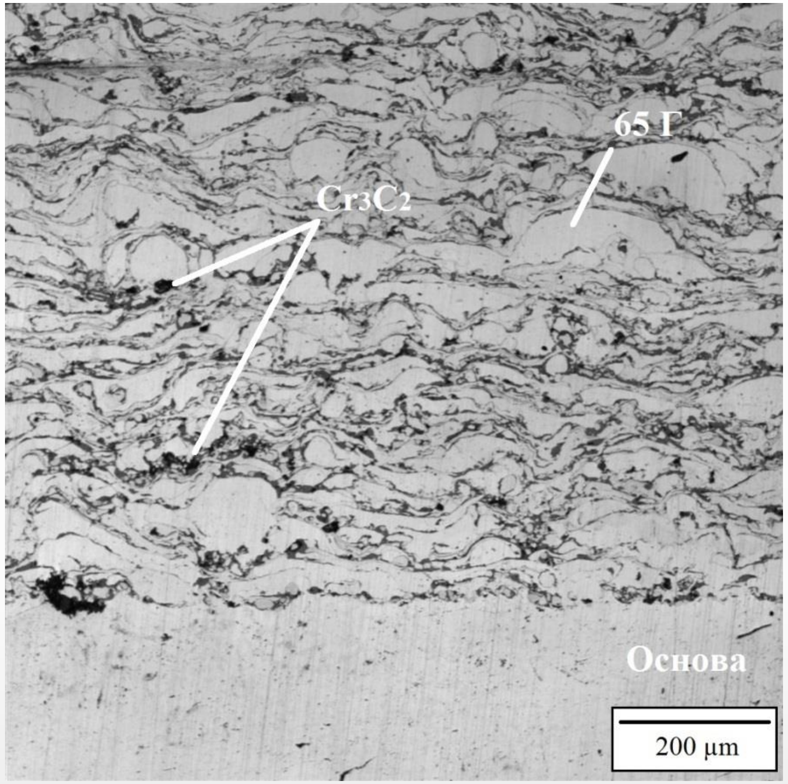
The microhardness of the light phase (steel 65G) was about 3.2 GPa; dark - 31 GPa (TiC), which corresponds to the microhardness of titanium carbide.

Electric-arc sprayed metal-carbide (Cr_3C_2) composite coatings phases identification and microstructure analyses

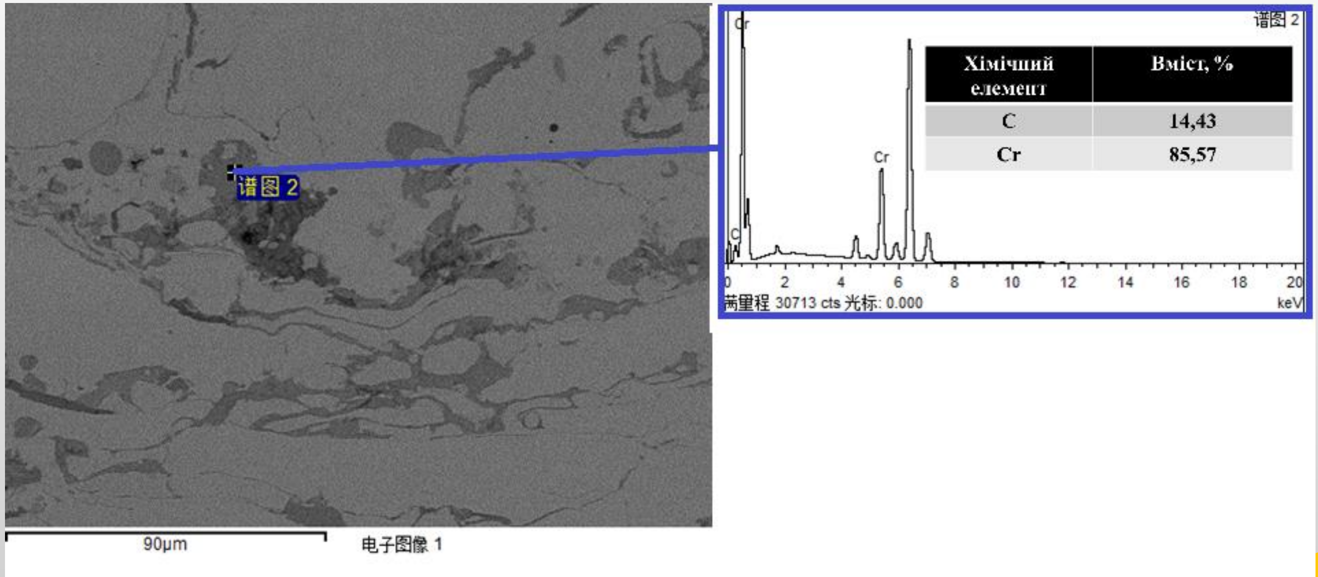




Cross section SEM micrographs of electric arc cermet coatings at different magnifications: a × 50; b × 500



Cross section optical micrographs of electric arc cermet coatings

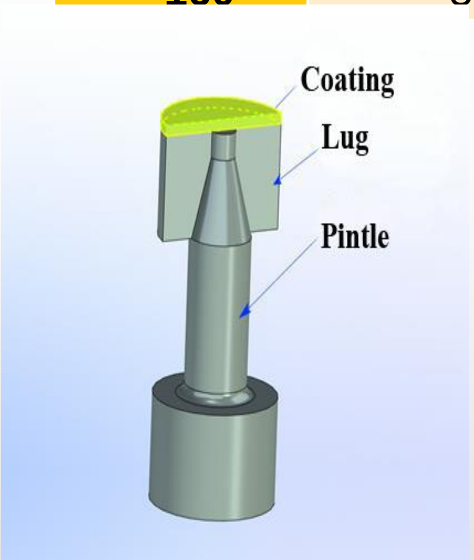


Хімічний елемент	Вміст, %
C	14,43
Cr	85,57

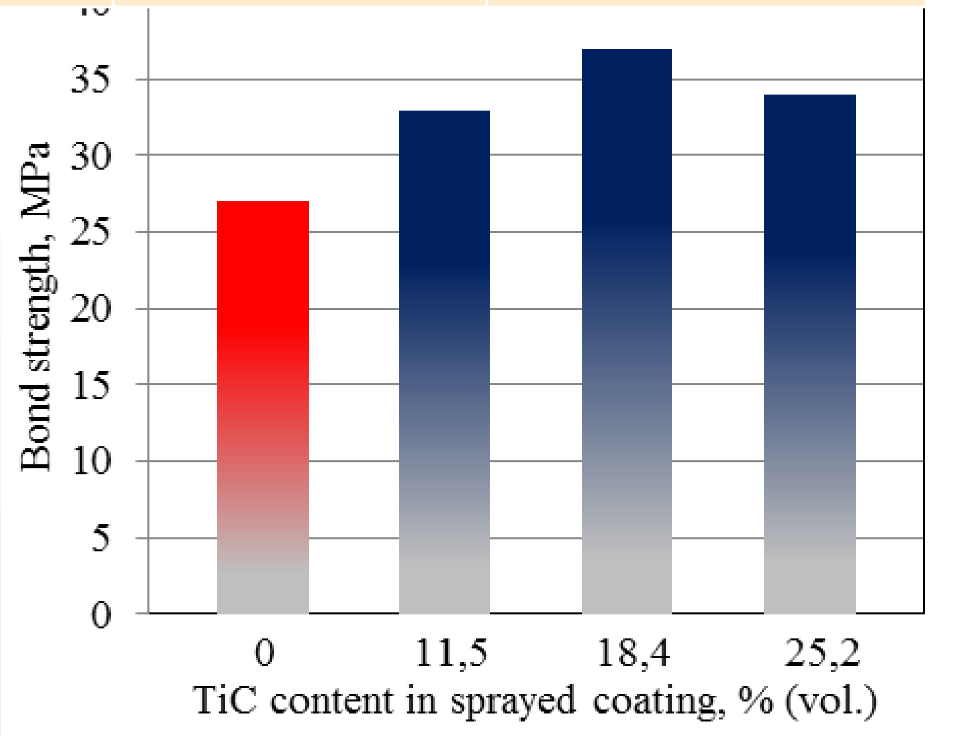
EDS analysis area and its results

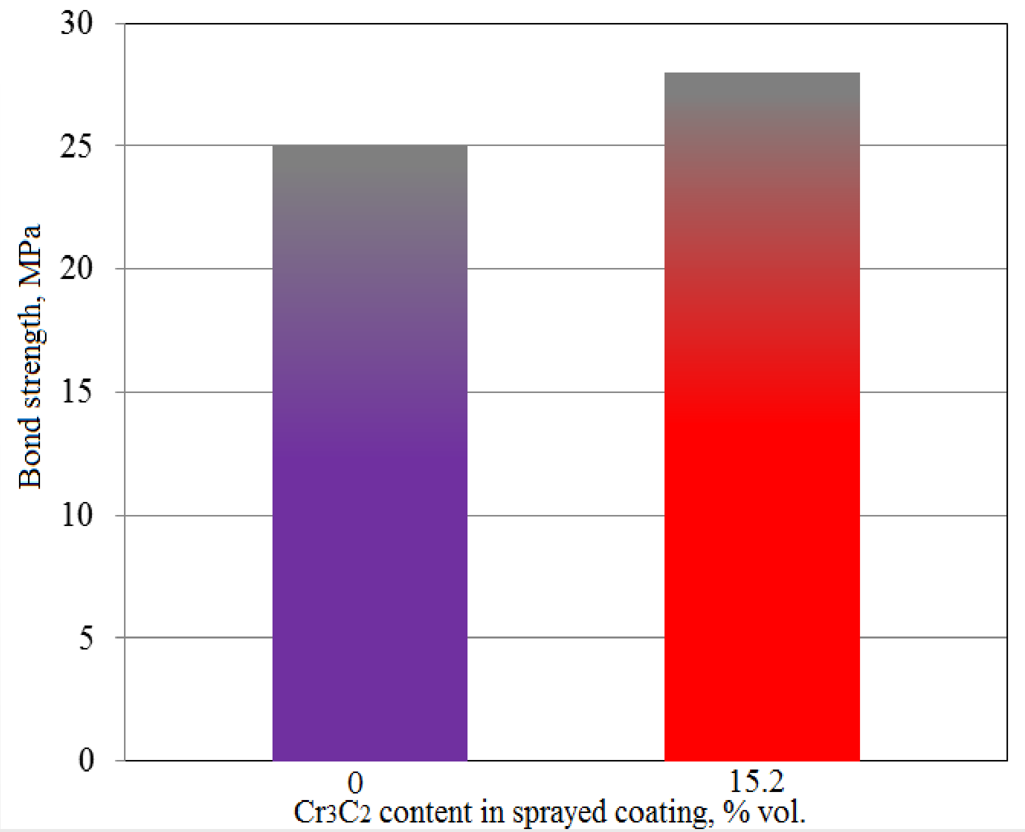
Bond strength testing of electric-arc sprayed metal-carbide composite coatings

Current, A	Voltage, V	Powder consumption, g/min	The content of the carbide phase (TiC) in the coating, % (vol.)
80	25	25	11,5
120	30	30	18,4
160	35	35	25,2



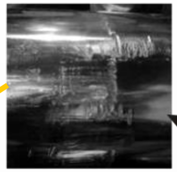
Specimen for bond strength testing





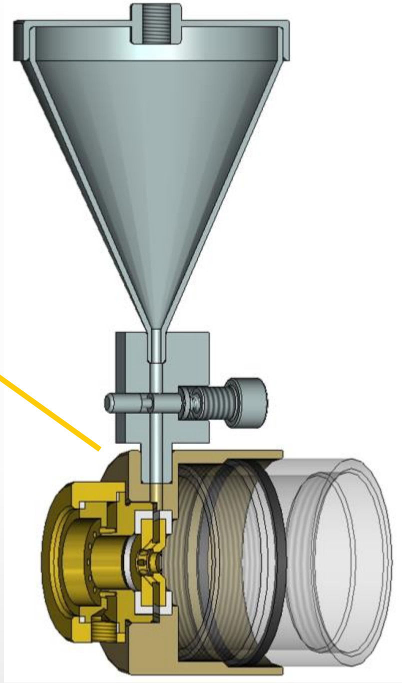
Results of bond strength testing

Industrial application of composite coatings



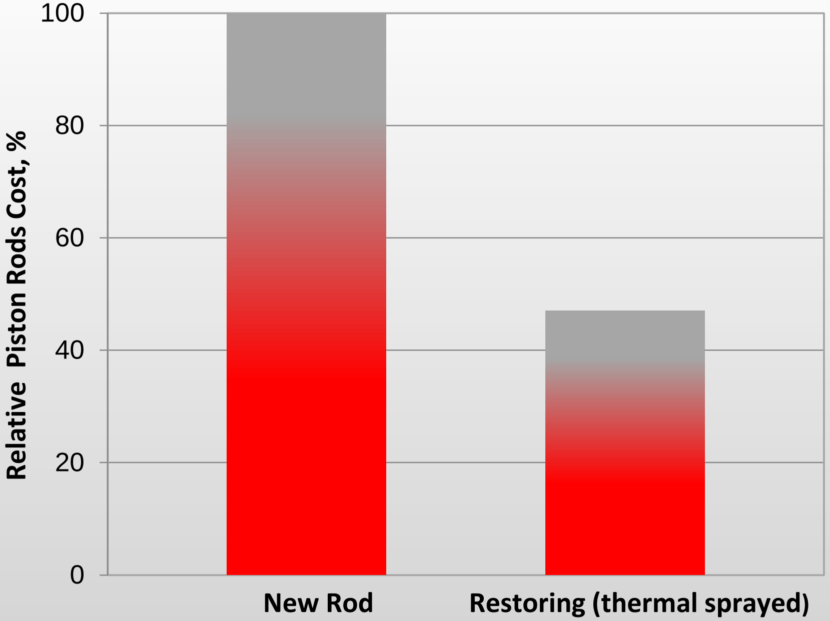
Surface defects

HYDRAULIC PISTON RODS RESTORING

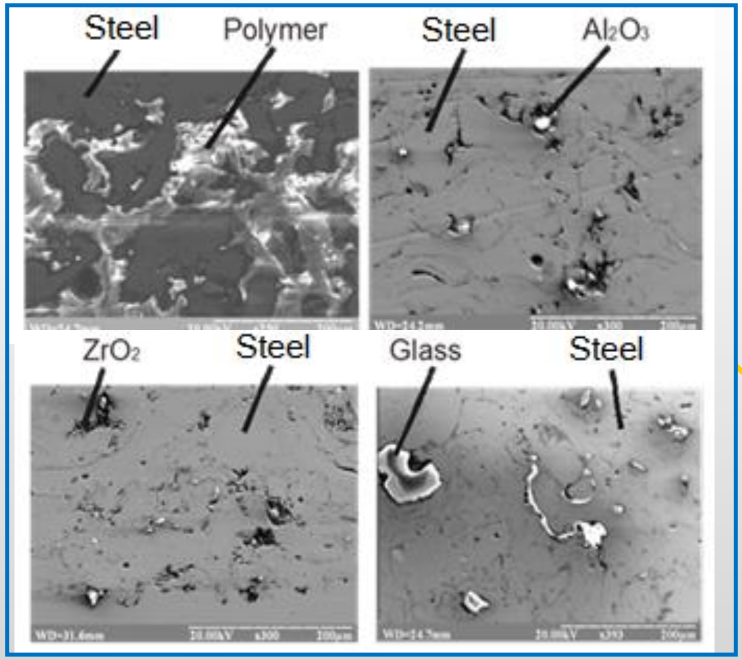


Modernized gun

Cost comparison



Coatings microstructures



Conclusions

1. The optimum amplitude and frequency parameters of the EPA of the electric arc spraying of steel wire (pulse frequency – 6.5 kHz, amplitude – 5 kV) and a plasma bronze powder (frequency – 5 kHz, the amplitude – 5 kV) were determined, which provide increase in hardness by 35 and 24 %, the bond strength by 30 and 18 %, the wear resistance 1.7 and 1.5 fold as well as decrease in porosity from 6 to 3 % and from 8 to 5 %, respectively.

2. An electric arc spraying method has been developed by expanding the possibilities of creating composite coatings by forming a three-phase jet by supplying powder to the high-temperature zone of the sprayer using an improved design of the spray head and developing the technological foundations for their application.

3. Coatings were obtained from the following compositions: ER70S-6 - P-EP-219; ER5356 - P-EP-219; ER70S-6 - Al_2O_3; ER70S-6 – ZrO_2; ER70S-6-O - A-glass. The maximum content of strengthening phase in composite coatings for the improved sprayed gun EM-14M was established: for the metal-polymer coating from the composition ER70S - P-EP-219, the content of P-EP-219 is 40% (vol.), for the composition from ER5356 - P-EP-219 - 35% (vol.); for the ceramic-metal coating from the composition ER70S-6 - Al_2O_3, the content of Al_2O_3 is 11.5% (vol.), for the composition from ER70S-6 - ZrO_2, the content of ZrO_2 is 14% (vol.); for the glass-to-metal coating from the composition ER70S-6 - A-glass, the content of the glass phase is 19.5% (vol.).

4. A decrease in porosity in metal-polymer coatings was established: in the composition ER70S-6 - P-EP-219 from 13 to 7%, in the composition ER5356 - P-EP-219 from 10 to 4%, while the thermal conductivity of the composition ER70S-6 - P-EP-219 is reduced by 46%, compared with the coating of ER70S-6.

5. The influence of the technological parameters of spraying on the amount of the hardening phase (TiC) in the structure of the coating and its content on their bond strength to the substrate has been determined. The maximum value of the bond strength to the substrate (37 MPa) was obtained at a carbide phase content of 18.4% (vol.).


Thank you for your attention!