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Ni-based coatings for oil and gas industry fabricated by cold gas spraying

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Severstal

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- Introduction (Conditions and coatings in the Oil and gas industry)
- Objective
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- Conclusions

Introduction|Operating Conditions

Chemical Influences

- H_2S
- Cl^-
- CO_2
- $[H^+]$

Mechanical Influences

Hydroabrasive wear:
- sand
- friction
- flow

Mechanical loads:
- tensile
- torsion
- cyclic bending
- vibration

Climatic Influences

- temperature
- ultraviolet
- humidity

Physical Influences

- temperature
- pressure
- decompression

Introduction| Current Coatings In The Oil And Gas Industry

COATINGS

Polymer Coatings

- good adhesion
- abrasion resistance

- low strength under pressure changes,
- low temperature limit of use

Silicate Enamel coatings (Glass-Enamel coatings)

- resistance to abrasion and chemically aggressive substances, including H_2S;
- high adhesion;
- resistance to asphaltene deposits;
- wide temperature range of use

- fragility;
- low resistance to torsion, bending
- low resistance to thermal deformation.

Zinc Coatings

-high adhesion to the substrate
- low to asphaltene deposits

- the difficulty of obtaining a coating of the same thickness;
- low durability of the coating;
-low resistance to mechanical stress;
- roughness

Introduction| Properties And Characteristics Of Nickel Coatings

High corrosion resistance

- protect the base metal of the substrate mechanically, because in relation to steel, nickel coatings are cathodic E0 (Ni) = –0.25 V; E0 (Fe) = –0.44 V)

High wear resistance (microhardness from 250 to 650 kgf · mm $^{-2}$)

Electrical conductivity

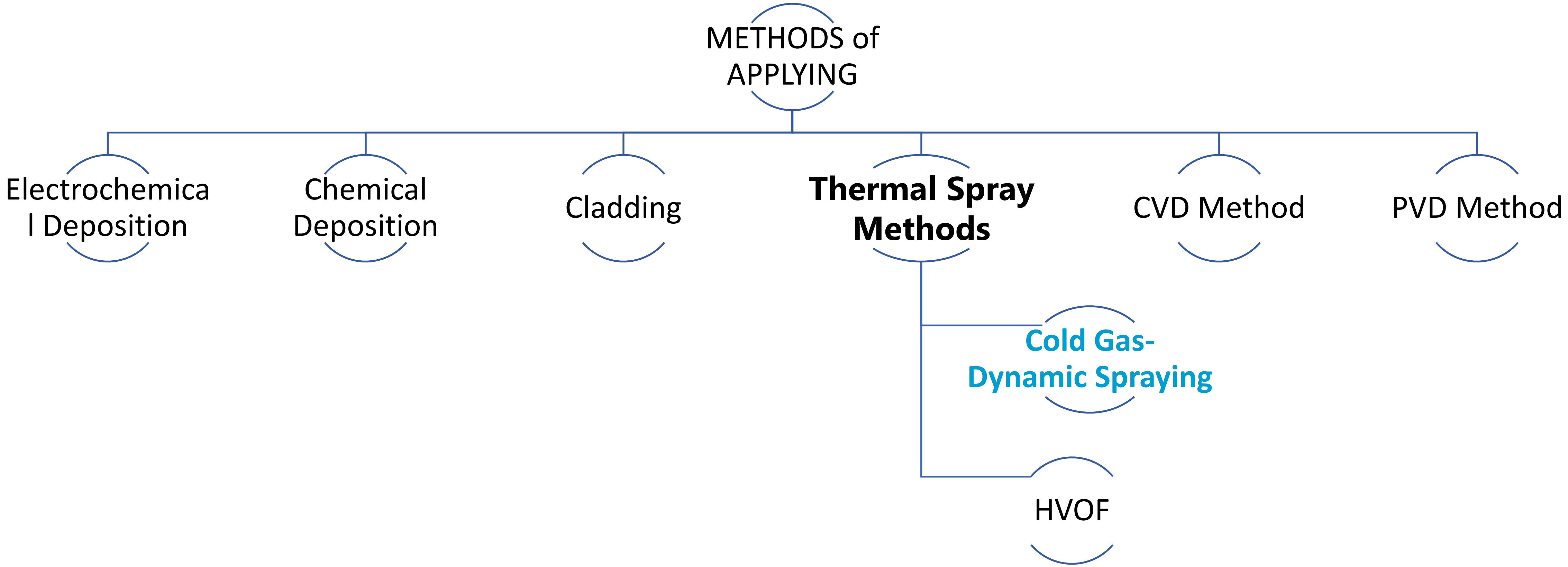
Heat resistance (permissible operating temperature up to 650 ° C)

The possibility of obtaining **COMPOSITE COATINGS** based on nickel:

- the introduction of solid particle additives into the metal matrix significantly increases the functional properties of the nickel plating, such as ***wear resistance***, ***corrosion resistance***, and exhibits excellent ***erosion resistance***.

Can be applied to non-metallic substrates

Introduction| Applied Methods Of Obtaining Coatings



Objective

- obtain nickel-based coatings by cold gas-dynamic spraying and evaluate their applicability for use in the oil and gas industry by **studying the effect of the chemical composition** (Ni, Ni-Cu, Ni-Zn, Ni-Al_2O_3, Ni-TiC) **on the corrosion and wear resistance** of nickel coatings

Experimental | Materials and Methods

Malvern Mastersizer 2000

- control of commercially produced gas-atomized powders for chemical and fractional composition

IVCh-3 type attritor installation

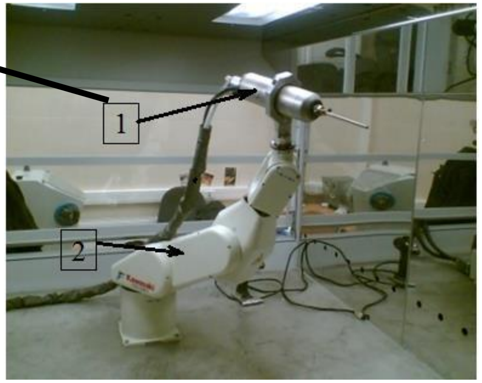
- preparation of two types of composite powders - mechanical mixture and mechanically alloyed powder

SNOL–30/1100 Muffle Furnace

- heat treatment of powder materials

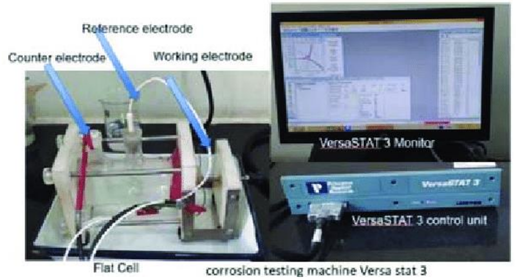
Dimet-403 installation

- sandblasting the surface of the substrate; applying a powder mixture to a substrate



Robotic complex for supersonic cold gas-dynamic spraying
1- spraying device of the Dimet-403 installation
2- robotic arm Kawasaki-FS 003

Corrosion tests



Potentiostat VERSA

Autoclave test

Hydroabrasive test

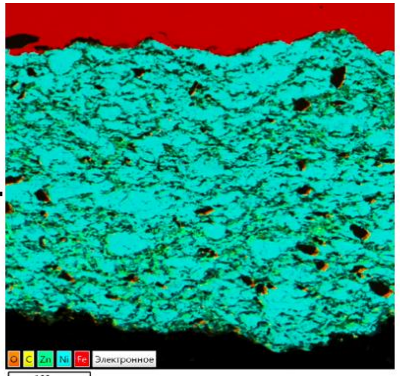
simulation oil and gas conditions

Microstructure and microhardness investigation

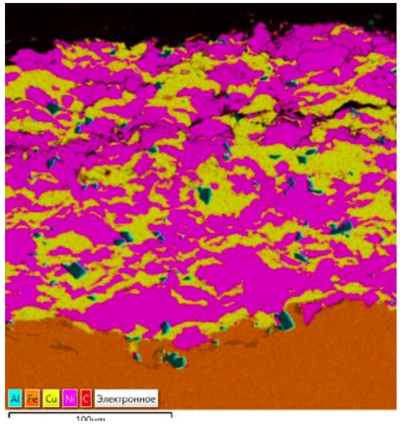
Electron Microscope Tescan VEGA 3 equipped with Inca X-Max EDS analyzer

Vickers microhardness tester Reichert-Jung Micro-Durmat 4000

Experimental| Composition and thickness

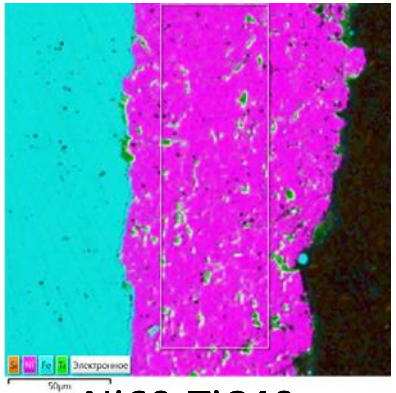


Ni-Zn coatings

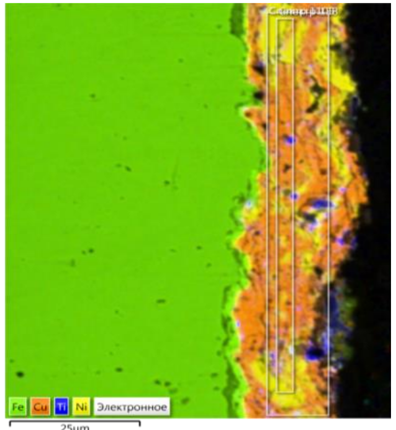


Ni-Cu coatings

Sample	Chemical composition, wt.%	Thickness, μm
Ni90-Cu10/150	Ni - 90%, Cu - 10%	150
Ni90-Cu10/40	Ni – 90%, Cu – 10%	40
Ni60-Cu40/120	Ni – 60%, Cu – 40%	120
Ni60-Cu40/50	Ni – 60%, Cu – 40%	50
Ni60-Zn40/100	Ni – 60%, Zn – 40 %	100
Ni60-Zn40/200	Ni – 60%, Zn – 40%	200
Ni90-Zn10/150	Ni – 90 %, Zn – 10 %	150
Ni90-Zn10/50	Ni – 90%, Zn – 10%	50
Ni60-$Al_2O_3$40/130	Ni –60%, Al_2O_3 – 40%	130
Ni60-$Al_2O_3$40/60	Ni – 60%, Al_2O_3 – 40%	60
Ni100/30	Ni – 100%	30
Ni90-TiC10	Ni – 90%, TiC – 10%	70
Ni60-TiC40	Ni – 60%, TiC – 40%	70
Ni50-Cu50-TiC40 (MA) Mechanically Alloyed	Ni – 50%, Cu – 50%	30



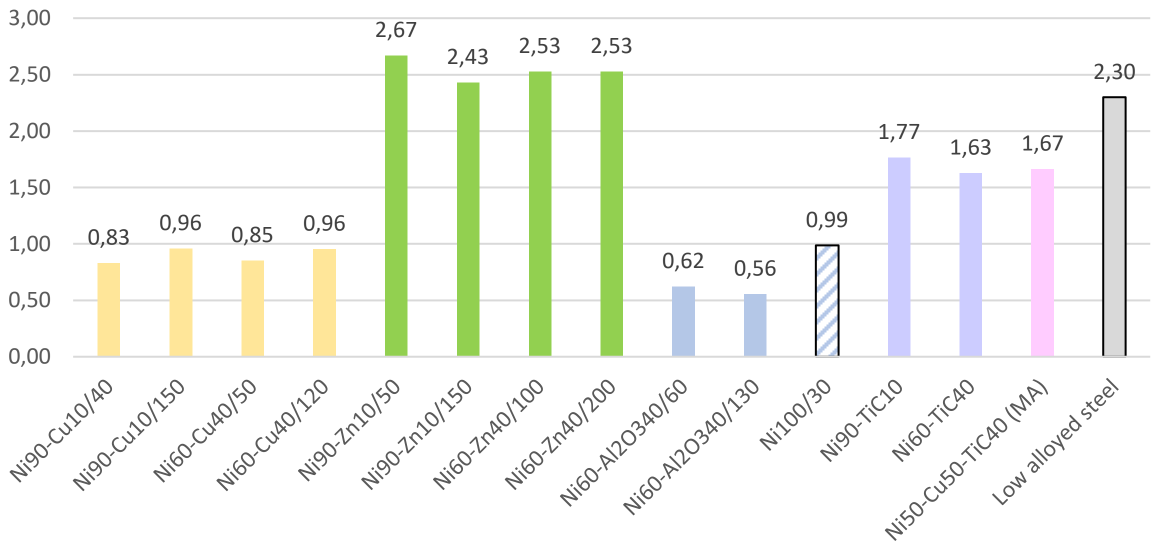
Ni60-TiC40



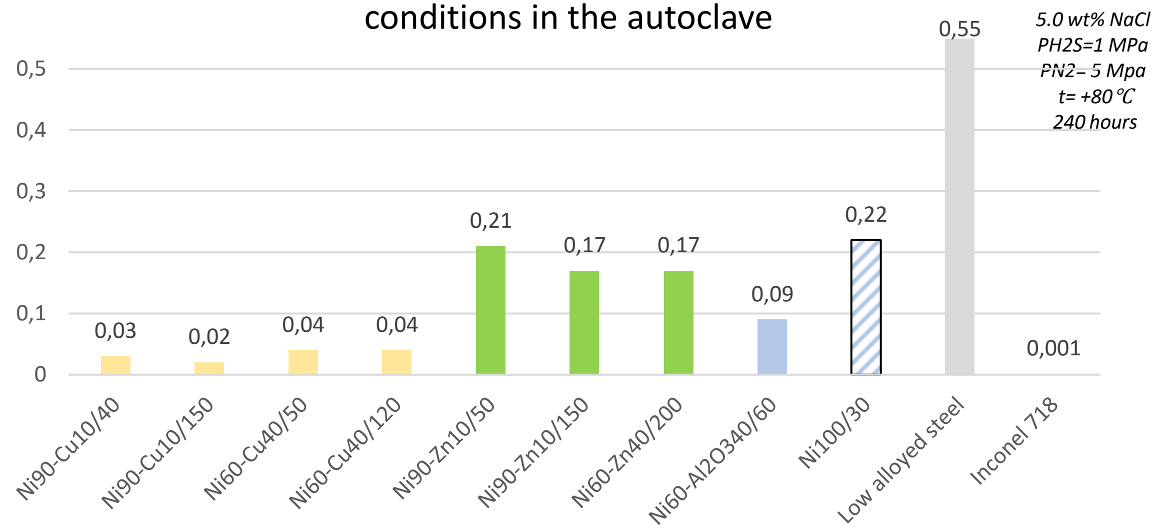
Ni50-Cu50-TiC40 (Mechanically Alloyed)

Results| Characterization of corrosion properties

Corrosion rate (in mm per year) of nickel coatings, calculated using electrochemical tests in a 3% NaCl solution with pH = 2.5



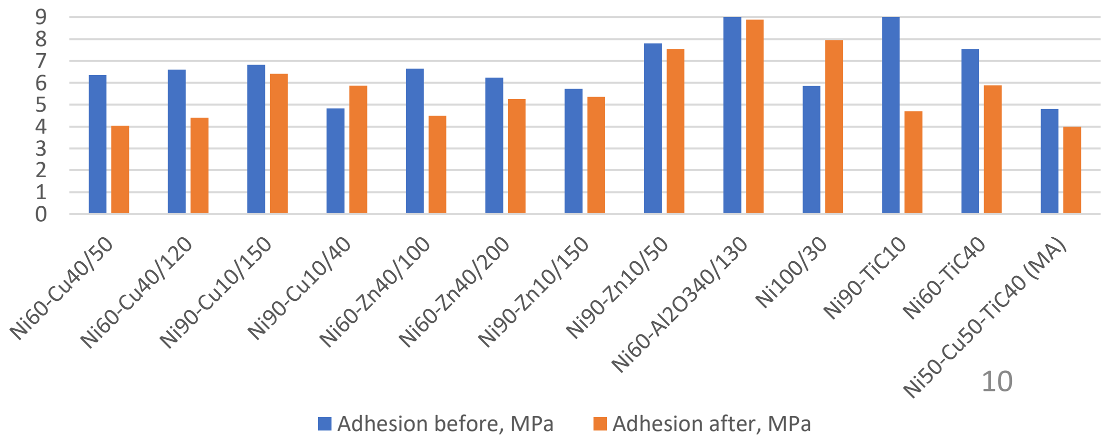
Corrosion rate (in mm per year) of nickel coatings in a simulated oil and gas conditions in the autoclave



The average values of porosity

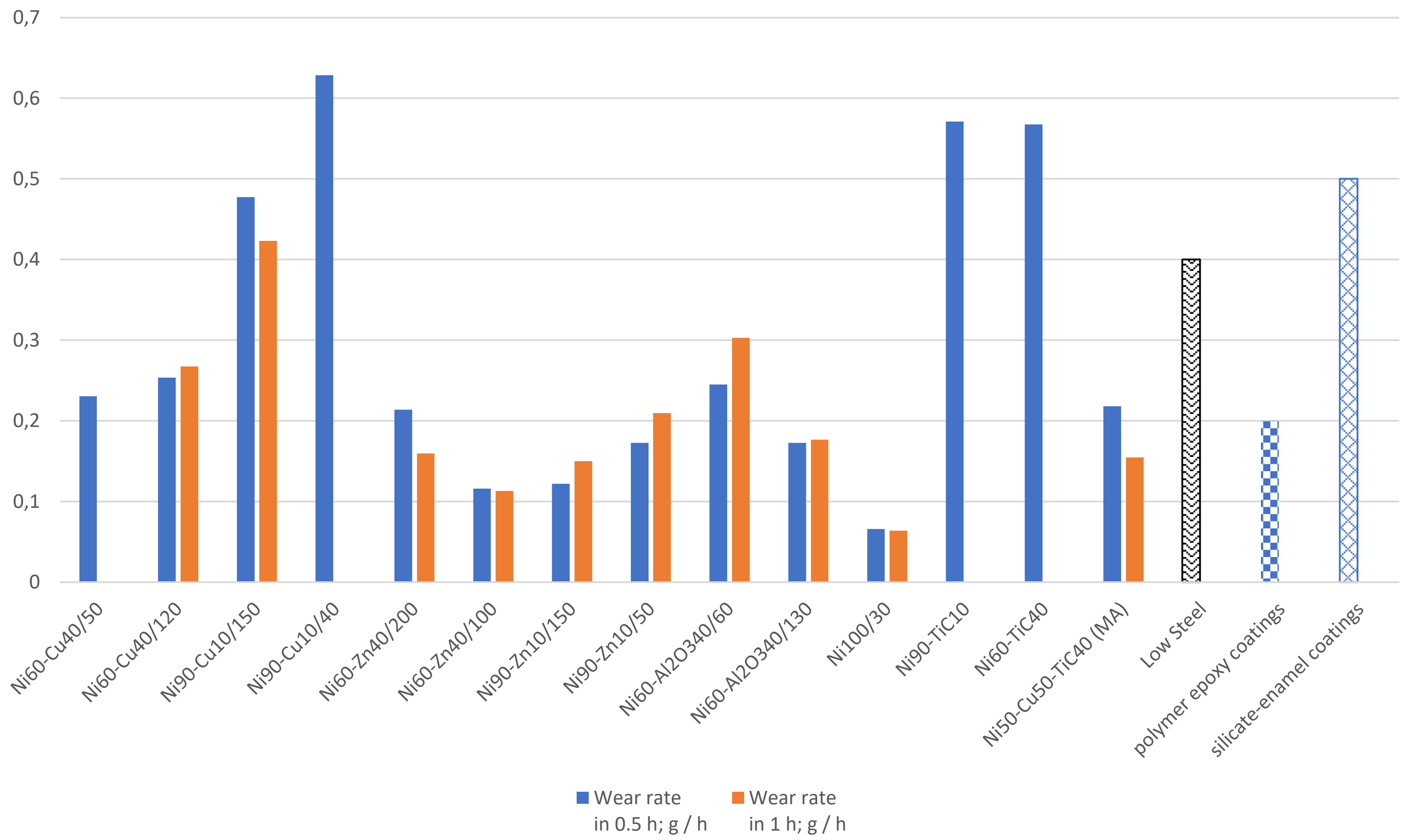
Type	Porosity, unit / cm2
Ni-Cu	0,6
Ni-Zn	2,1
Ni-Al_2O_3	0,5
Ni	1,1
Ni-TiC	1,1
Ni-Cu-TiC (MA)	1,2

Adhesion strength values before and after the autoclave test



Results| Characterization of wear properties

The rate of hydroabrasive wear of coatings for: 0.5 hour; 1 hour



The average values of microhardness of the studied coatings

Sample	Microhardness, HV
Ni-Cu	90
Ni-Zn	170
Ni-Al_2O_3	130
Ni	185
Ni-TiC	90
Ni-Cu-TiC (MA)	100

Conclusions

1. Nickel-based coatings are more resistance to hydroabrasive wear than industrially used non-metallic coatings.
2. The coatings based on Ni-Zn have the lowest corrosion characteristics (in conditions simulated oilfield conditions the corrosion rate is 0.17-0.2 mm / year), the highest wear resistance characteristics. However, the protective effect of zinc allows them to be used as corrosion-resistant, at the same time to be economically attractive.
3. The samples of Ni-Cu coatings have high corrosion resistance, but low wear resistance due to their low hardness. Applying coatings from mechanically alloyed powders of nickel-copper is practically not applied without TiC.
4. Al2O3/TiC additives give ambiguous results in the studied properties. Specimens with Al2O3 have a low hydroabrasive wear and high corrosion resistance; the introduction of particles TiC was not effective in improving these characteristics.
5. All the studied coating specimens have a sufficiently high adhesion.
6. Thickness of 40 – 60 microns provides sufficient performance of the studied coatings.