EVALUATION OF HVOF COATINGS

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Resume

Attention in this paper is devoted to the evaluation of wear coatings deposited using HVOF technology (high velocity oxy-fuel). There were evaluated three types of coatings based on WC-Co (next only 1343), WC-Co-Cr (next only 1350) and Cr_3C_2-25NiCr (next only 1375). There was assessed adherence of coatings, micro hardness, porosity and the tribological properties of erosive, abrasive, adhesive and wear resistance of coatings in terms of cyclic thermal load. Thanks to wide variety of suitable materials and their combinations, the area of utilization thermally sprayed coatings is very broad. It is possible to deposit coatings of various materials from pure metals to special alloys. The best results in the evaluated properties were achieved at the coating with the label 1375.

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1. Introduction

Coatings applied by technology HVOF (High Velocity Oxygen Fuel) belong among the dynamically developing areas. In view of their excellent properties such as high resistance to heat, corrosion and wear are used in the basic industry as well as in renovation. During spraying the minimum thermal changes of the substrate occurs. The surface roughness of the base material with a surface treatment of these coatings is low [1]. Thermal sprayed coatings are widely used in applications on different surfaces to reduce the wear and increase their resistance to corrosion. Aviation, automotive, textile and mining industries are one of the many areas of the usage of thermally sprayed coatings, where are used for the different advantages that this group of coatings offer [2].

Progressive methods of thermal spraying include: thermal spraying by plasma, thermal spraying and explosion spraying high flame - HVOF (high velocity oxy-fuel). HVOF is a technological process of coating application, where the microparticles are of metal alloy or cermet, driven and heated in sonic or supersonic stream of gas and deposited on a substrate at high speed to form a thin layer of melted metal [3].

The process of coating application represents the most modern methods of thermally sprayed metal powders. It uses a combination of fuel-karosen that burn with plenty of oxygen and produce a flame, which combines a relatively low melting temperature of about 3000 ° C with extreme speed up-to 2000 m·s-1. It results in extremely dense, well bonded coatings with little or no oxidation during application [4, 5].

These technologies are the subject of studies dealing with the optimization of process parameters consistently bringing good bond strength with minimal residual stresses and low porosity. Today, these high-quality coatings commonly used [5].

Table 1

Chemical composition of the steel substrate (wt. %) [6].

C	Mn	Si	P	S
0.12 – 0.18	0.30 – 0.60	0.15 – 0.40	Max. 0.035	Max. 0.035

Table 2

Chemical composition of the powders (wt. %) [7].

Powder	C	Co	Fe	W	Cr	Ni
WC – 17 Co (1343)	5.5	16.2	0. 036	78.4		
WC-Co-Cr (1350)	5.5	9.9	0.02	80.58	3.9	
Cr_3C_2-25NiCr (1375)	10				68.5	21

2. Materials and experimental methods

The base material was used carbon steel C15E (STN 41 2020, 1.1141). Chemical composition of the steel is listed in Table 1 [6]. The substrates for test samples were of cylindrical shape Ø 50 mm, height of 15 mm. Test samples were pre-treated by air grit blasting: air pressure of 0.5 MPa, shot media - brown corundum, grain size 1.00 mm.

2.1 Technology of application coatings

Thermal spraying techniques are coating processes in which melted (or heated) materials are sprayed onto a surface. The "feedstock" (coating precursor) is heated by electrical (plasma or arc) or chemical means (combustion flame). The coatings were applied by HVOF technology. On the spray coating was used PRAXAIR Tafa JP 5000 device with the system HP / HVOF as powder feeder HVOF System Powder Feeder 1264.

2.2 Material of coatings

There were deposited three types of coatings by HVOF technology on pre-treated samples. On the first group of samples, coating of 1343 (C-17Co) was applied, on the second group of samples coating of 1350 (WC-Co-Cr) was deposited and on the third group of samples coating 1375 (Cr3C2-25NiCr) was deposited. Materials of coatings were supplied as a powder, agglomerated and sintered, produced by Praxair, Inc., USA. Table 2 shows chemical composition of the powders [7].

2.3 The test parameters

To determine the basic properties of coatings ”as-sprayed” and after thermal cycles were used these methods:

Assessment methodology microhardness of coatings: microhardness was measured according to STN ISO 4516 on Shimadzu HMV-2E test equipment, load 980.7 mN (10 g), dwell time 15 s [8].

Coating thickness: coating thickness measurements were carried out by means of QuaNix Keyless device. This device permits measuring the thickness of non-magnetic coatings on ferrous materials for example: lacquers, enamels, plastics, anodizing, and all the insulating layers, and the non-conductive non-magnetic coatings on metallic substrates such: aluminum, copper, brass, bronze, etc. [9].

Thermal loading: Samples were subjected to cyclic thermal load in an electric chamber furnace according to the following schedule [8]:

- heating to 900 °C,
- dwell in the furnace for 20 minutes,
- cooling of samples in still air to ambient temperature.

Samples were subjected to 10 thermal cycles, and after the 3rd, 5th, 8th and 10th thermal cycle.

Porosity of coatings was determined by mercury porosimetry using PoreMaster porosimeter [7].

The adhesion of the coating was evaluated by pull-off test according to STN EN 582 with help of tensile machine ZDM 10/91. After pull-off adhesion test, tensile stress necessary to rupture the weakest inter-phase (adhesive fracture) or the weaker component (cohesive fracture) of the test arrangement and also the nature of fraction were evaluated [8].

Erosive wear of the coatings: the coatings were subjected to erosion wear in abrasive impact angles 45° and 75°. To simulate the process of oxide impact a laboratory mechanical blasting device was used, which allows monitoring the circulation of abrasive. Abrasive used - brown corundum (Al_2O_3), grain size 1 mm. Intensity of coatings wear was evaluated using gravimeter (mass loss of the coating). Peripheral speed of blasting wheel was 51.0 $m.s^{-1}$ and output speed of abrasive was 70.98 $m.s^{-1}$. One erosive cycle means application of 500 g abrasive by abrasive grit blasting technology [8].

Adhesive wear: to simulate the working conditions, coatings were subjected to adhesive wear using pin-on-disc test (ISO 20808) at 21 °C and 900 °C. Testing conditions: relative humidity 21 %, atmosphere: air, test ball diameter Ø 6 mm, radius of ball track was 5.01 mm, linear velocity 10.00 $cm{\cdot}s^{-1}$, and normal load 5 N, stop condition 300 m [7].

Abrasive wear: abrasion resistance of coatings was evaluated on the device. The principle of the test is to be wading in bulk abrasives. Used abrasive was a brown aluminum oxide with grain size 1.2 mm, speed of the sample in abrasive was 1.74 $m.s^{-1}$, where *n* (turn) is 123 min^{-1}, dive into abrasive samples was 60 mm. Samples were subjected to impact abrasive at angles 45° and 75° [10].

3. Results and discussion

Thickness of the coatings as sprayed, were as follows: 1 343 – 234 µm, 1 350 – 356 µm and 1 375 – 393 µm. It was made 12 measurements and subsequently measured value calculated the average thickness of the coating. The measurements are shown in the Table 3, depicts the results.

Microhardness of the coatings: measured values are in Table 4 and shown in Fig. 1. The highest microhardness values was shown by coating 1 350 (1 447 HV 0.1) which was caused by a high content of tungsten and addition of cobalt compared to the coating 1 343, which also contains tungsten but at lower concentrations and had lower values of microhardness (1010 HV0.1). The lowest microhardness values were shown in coating 1375 with a high content of chromium, tungsten-free (975 HV 0.1) [11].

Porosity: the assessment of porosity showed that coating 1350 is more porous compared to the other two coatings which have almost the same porosity considering the structure of a coating and its chemical composition. Table 5 shows the recorded values of total porosity coatings, graphical representation of measured results shown in Fig. 2.

Table 3

Thickness of coatings (µm).

Coating	The average value
1343	334.02
1350	356.30
1375	393.30

Table 4

Micro-hardness coating (HV 0,1).

coating	1345	1350	1375
the average value	1009.66	1390	1154

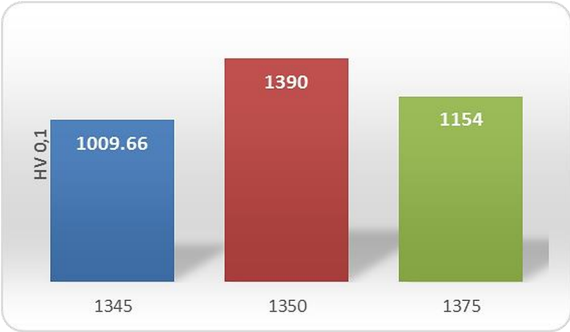

Fig. 1 Micro-hardness coating.
(full colour version available online)

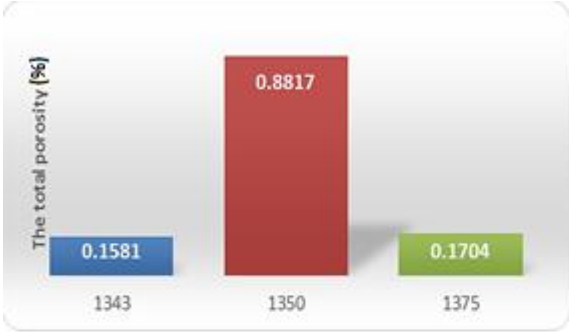

Fig. 2 Porosity coatings (%).
(full colour version available online)

Table 5

Porosity coatings (%).

Coating	„Total PS“ [%]
1343	0.1581
1350	0.8817
1375	0.1704

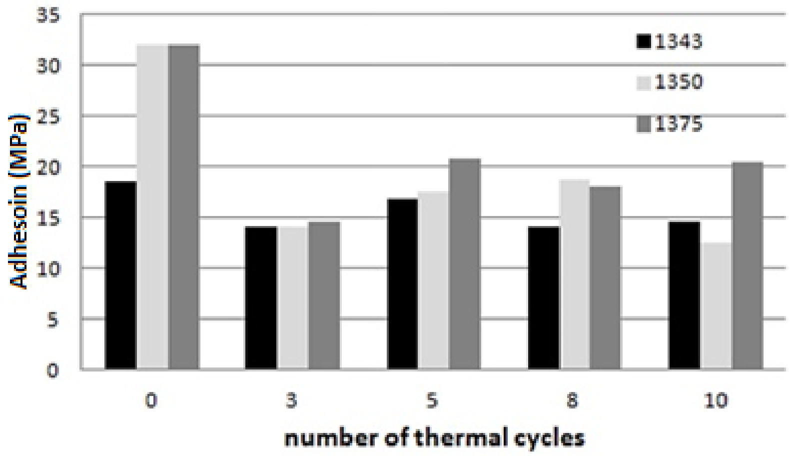

Fig. 3. Adhesive wear of coatings after thermal cycles.

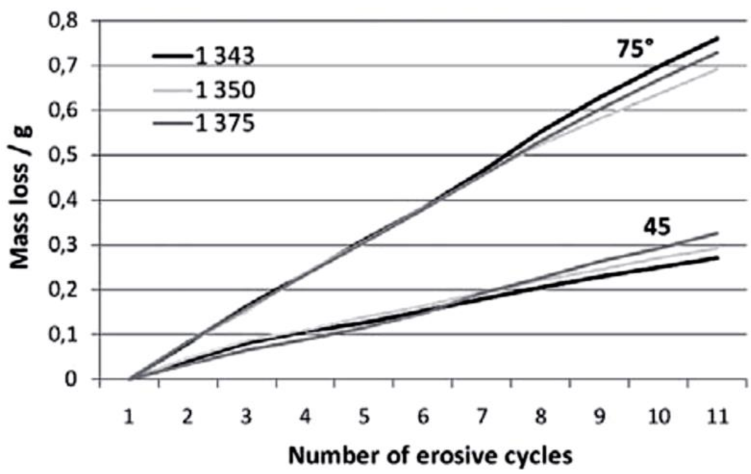

Fig. 4. Erosive wear of the coatings [4].

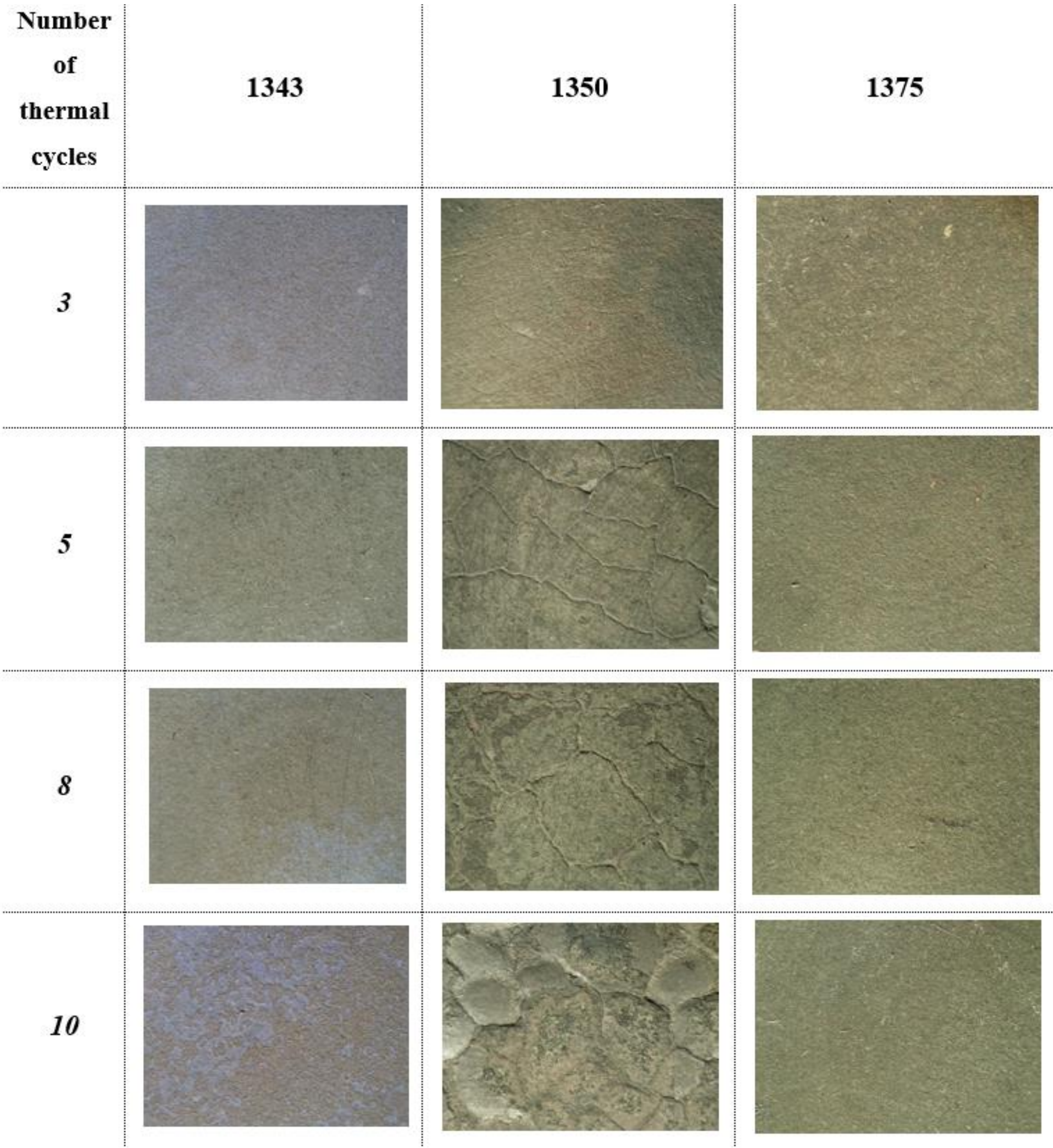

Fig. 5. Appearance of surfaces of investigated coatings after thermal cyclic loading [8].
(full colour version available online)

3.1 Evaluation of tribological tests

Adhesive wear: Results of coatings wear test at 900 °C showed that the wear rate of coatings 1343 and 1375 is extremely small, just a roughness change in wear track occurred. The coating 1350 showed small removal of material, Vdisc, 900°C = 0.056 mm^3, Wdisc, 900°C = $3.7.10^{-5}$ $mm^3 \cdot N^{-1} \cdot m^{-1}$. For other coatings was not observed measurable weight loss of coating material. Results of coatings adhesion are shown in Fig. 3. [7].

The measured values of the adhesion of coatings as-sprayed and the type of fracture showed that in neither case the damage of the coating occurred, therefore the observed initial adhesion values do not correspond to the actual adhesion of coatings, which is definitely higher [8].

Erosive wear: Fig. 4 depicts the dependence of erosive wear on the different impact angles of abrasive. For all types of coatings very similar dependences were achieved. Higher weight losses were recorded at an impact angle of 75° in all types of coatings. The references show that for the harder material, which also the evaluated coatings belong to, more intensive wear occurs at a larger impact angles, as confirmed by experiment [11].

Abrasive wear: Values of abrasion coatings were measured at angles of impact of bulk abrasive 45° and 75°. The highest value was recorded at both angles impact on coating 1343. At the same time, when compared angles of impact of this coating we conclude that greater weight wear was recorded at an angle of 45°. On 1350 and 1375 coatings were not measured weight losses [10].

Thermal loading: Despite its high hardness, the coating 1350 suffered thermal cracking after 3 thermal cycles, the surface of coating 1343 covered with a layer of blue oxides and showed strong chalking during the thermal cyclic loading. The coating 1375 retained its aesthetic and tactile qualities after thermal cycles. The appearance of surfaces of coatings during thermal cyclic loading is shown in Fig. 5 [8].

4. Conclusion

Experimental results point to the fact that, taking into account the results of measurements of resistance to cyclic heat such assessment shall be as follows: 1343 coating exhibits as said blue color with intense powdery, which was present throughout the course of cyclic thermal load. This activity can cause significant weight loss - coating thickness which may result in a lower life. Coating 1350 is also not suitable for real applications because of significant cracking, which leads to disruption of barrier protection effectiveness of the coating after a few cycles. This coating achieves high porosity value. In terms of follow-loading coatings primarily in corrosive conditions poses a risk just Sheetfed respectively. Open pores, which represents an input path for corrosive environments and for penetration into the coating degradation factors respectively. Thus delamination of the coating can occur, leading to the reduction and subsequent loss of adhesion of the coating. Penetrating corrosive atmosphere causes a reduction in the strength of cohesion coatings. Experimental studies confirmed low, almost zero porosity, in the 1375 coating when the HVOF technology was used for deposition. This claim was accepted on the basis of experimental evaluation, and despite the lower hardness, the coating has proven better in retaining the integrity, adherence, intractability or subject chalking throughout the thermal cyclic loading.

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