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Performance of Selected Thermally Sprayed Coatings in Comparison with a Competitive Surface Treatment

HOUDKOVÁ Š.[1,a], ČESÁNEK Z.[1,b], POLACH P.[1,c]

[1]Research and Testing Institute Plzeň, Tylova 1581/46, 301 00 Plzeň, Czech Republic

[a]houdkova@vzuplzen.cz, [b]cesanek@vzuplzen.cz, [c]polach@vzuplzen.cz

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Abstract. The selected High Pressure/High Velocity Oxygen Fuel (HP/HVOF) sprayed coatings were tested in terms of mechanical, tribological and corrosion behavior and their performance was compared to the performance of competitive types of surface treatment, relevant to the aimed applications. The main purpose of the intended surface treatments is the protection of components in the power industry. The HP/HVOF sprayed coatings were chosen on the basis of their potential to resist wear, high temperature oxidation and corrosion in an aggressive environment. The completive types of surface treatment were chosen according to their relevance to a specific type of loading.

Introduction

In power industry, the surfaces suffer from various kinds of degradation caused by external loading as well as by the influence of increased temperature and corrosion aggressive environment. To protect the critical components surface from such a degradation, surface treatments are applied. With respect to the type of the component, its shape complexity and requirements given by the type of the loading, different types of surface treatment are chosen: surface hardening and nitriding for increased hardness in the case of low-temperature sliding wear, suitable for small complex-shaped components, hard surfacing for protection from oxidation, corrosion or wear, applicable on large components, where the temperature influence of a substrate material is not limitation, Physical Vapour Deposition (PVD) layers protecting the surface from wear, etc.

One of the applicable surface treatment technologies is a thermal spraying. This technology enables to create coatings from a wide range of materials including ceramics, metals and their alloys or hardmetals. Based on the used coating materials, different functionalities of the surface can be addressed. Thickness of the thermally sprayed coatings usually reached 0.2–0.3 mm, which is comparable to hard surfacing. The advantage of thermal spraying lies in the absence of the thermally affected zone in the underlying substrate. On the other hand, the mechanical locking of the coating on the surface asperities does not provide the adhesive strength comparable to e.g. the laser or the electron beam cladding [1].

In the group of thermally sprayed technologies, High Velocity Oxygen Fuel (HVOF) offers the possibility to deposit coatings of metal alloys and hardmetals in a superior quality [1]. The kinetic energy of the coating materials' particles impacting against the substrate is responsible for creating the coating of a low porosity and a high cohesive strength. On the other hand, the relative low flame temperature (in comparison with e.g. atmospheric plasma spraying) keeps the undesirable phase changes in the coating material at a low level [2].

The hardmetal coatings are characterized by the combination of hard carbide particles with a tough metal matrix. While the carbides ensure the wear resistance, the matrix is mainly responsible for the corrosion and the oxidation resistance. Two types of hardmetal systems are widely spread: WC-based hardmetals, suitable for low temperature applications up to 350 °C and Cr_3C_2-based hardmetal for the application up to 900 °C [3]. As the intended coatings application requires the oxidation resistance of the coating material in the hot steam environment (up to 610°C), attention is paid to the $C_{r3}C_2$-based hardmetals with 3 different types of matrix: NiCr; NiCrMoNb and CoNiCrAlY. From this group, the Cr3C2-25%NiCr composition is the most investigated one, both the HVOF and the Atmospheric Plasma Sprayed (APS) [4–7]. Up to now, less attention was paid to the coating of a variable matrix composition. The effect of thermal treatment on the tribological properties of Cr_3C_2-50%CoNiCrAlY was evaluated in [8]. Recently, the HVOF and the High Velocity Air Fuel (HVAF) sprayed Cr_3C_2-50%NiCrMoNb was analyzed in detail in [9].

For high temperature applications, the superalloys based on Co and Ni are used. A typical representative is a Co-based alloy known as Stellite©, the Hastelloy© Ni-based alloy or the NiCrBSi alloy. These materials often serve as coatings deposited using a laser cladding technology [10, 11]. Alternatively, they can also be thermally sprayed, with the benefit of maintaining the original chemical composition without diluted zones, typical for cladding.

The aim of the paper is to test the response of the above-mentioned coatings to the relevant loading conditions and to compare it to the alternative surface treatments to select the best surface treatments for specific applications. The coating materials were chosen on the basis of their potential to resist wear at a high temperature and a corrosive environment [12,13]. The completive types of surface treatment were chosen according to their relevance to the specific type of loading [14].

Experiments

The study involved the materials based on chromium carbide hardmetals and on Co and Ni-based alloys. The types of competitive surface treatment were laser cladding of Co-based alloy (Stellite 6), PVD thin film TiAlN and gas nitrided X22CrMoV12-1 steel. Laser clad Stellite 6 coating was chosen for the comparison of microhardness HV 0.3, abrasive and sliding wear resistance and corrosion resistance in the aggressive 18%$Na_2SO_4$82%$Fe_2(SO_4)_3$ environment. The PVD layer was tested and compared with the HP/HVOF sprayed coatings for hard particle erosion resistance and water droplet erosion resistance.

The microstructures were evaluated on the coatings' cross sections prepared by the standard metallographic procedure. Both the optical (OM) and the scanning electron (SEM) microscopy were used for the microstructure evaluation. The microhardness was measured on the coatings' polished cross-sections using the HV0.3 method. For each coating, at least 7 indents were done and the average value is reported.

Wear resistance to three-body abrasion and solid particle erosion was measured using the Dry Sand/Rubber Wheel test in accordance to ASTM G65 and the centrifugal erosion test [15]. The impact angle of erosive media (Al_2O_3; F70) varied from 15° to 90°. The coatings volume loss was determined from the mass loss using the values of density, previously determined using the Archimedes method. For each coating at least 3 independent measurements were done and the average value is reported. The worn surfaces were subsequently observed by SEM.

The sliding wear resistance was evaluated using the Ball-on-Flat test, according to ASTM G133. The test parameters were as follows: 25 N load; AISI 440C steel; 6 mm diameter ball counterpart; 5 Hz oscillating frequency; 10 mm stroke length; 1000 s testing time. Three different measurements were performed for each coating. The wear tracks' profiles were measured by the KLA-Tencor P-6 Profiler profilometer, at three different places, and the wear volume was calculated. Prior to sliding-wear tests, the coating surface was ground and polished to the 0.04 ± 0.02 µm Ra value.

The water droplet erosion test was performed in Doosan Škoda Power Ltd. Company in accordance with the company internal test prescription. The testing apparatus consists of a cylindrical vessel, in which a fixed strength disk is rotating, with the test pieces attached to the periphery. The nozzle creates a stream of droplets, through which the samples pass, causing the droplets to strike the samples at a prescribed velocity. Standard testing parameters are as follows: absolute pressure in the chamber: 3 kPa; shaft speed: 12000 RPM; impact velocity: 524 m/s; droplet size: 0.41 mm; total test duration: 3 hours 30 minutes. The samples were weighted in the defined period. The tested samples surface was smoothed using a metallographic procedure prior to the testing. Four samples of each type of coating were tested and the average value is reported.

The protective properties of the coatings in the high temperature aggressive environment of 18% Na_2SO_4 82% $Fe_2(SO_4)_3$ was tested. The thermal cycling from the room temperature up to 600 °C was repeated 50 times, the weight gain was recorded and evaluated. The high temperature test is described in detail in [12].

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The coatings' cross section microstructures can be seen in Fig. 1. No macro-defects, such as cracks or delamination, are visible in the observed coatings. The porosity is also negligible, except the Hastelloy C-276 coating (Fig. 1f), where pores are recognizable between the individual splats. The laser clad Stellite coating (Fig. 1f) has a dendritic structure consisting of the Co-based solid solution. Solitary small pores are concentrated in the interdimeric areas. As they do not connect each other, they do not represent a thread regarding the protection of the substrate from the corrosive environment.

The cross section microhardness is presented in the graph in Fig. 2. While the Cr_3C_2-based hardmetal coatings and the NiCrBSi coating, whose microstructure is strengthened by fine hard boride and carbide particles, are comparable, the alloy HVOF sprayed Stellite and Hastelloy coatings are softer. The laser clad Stellite coating showed a lower hardness then the HVOF sprayed coating of a similar composition.

Generally, the coatings microhardness determines the resistance of the coatings to the abrasive wear (Fig. 3) and the sliding wear (Fig. 4). The carbide-based hardmetal HP/HVOF sprayed coatings were the hardest and also the most abrasive and sliding wear resistant. On the contrary, the HVOF alloy coatings, namely Ni-based Hastelloy, were less wear resistant. Comparing the HVOF sprayed and the laser clad Stellite coatings, the HVOF sprayed coating is harder, and more wear resistant under both type of loading – abrasive and sliding. The mechanism of wear is clearly different (Fig. 5). While in the case of the HVOF coating the delamination of whole splats appeared, a significant adhesive wear can be observed in laser welding.

On the other hand, the solid particle erosion test (Fig. 5) showed the poorer erosion resistance of brittle hardmetal coatings while ductile alloy coatings suffered from lower erosion. Although the erosion tests of the laser clad Stellite coating were not provided, based on the previous experience, a high erosion resistance could be expected.

Comparing to the base material and the PVD TiAlN layer, the HVOF sprayed coatings are less erosion resistant. It is caused probably by a lower cohesive strength of the coating, where delamination of individual splats can appear as a result of repeated impacting of hard erosive particles. Similarly, the water droplet erosion revealed poorer resistance of the HVOF sprayed coating compared to the basic material or the PVD layer under such a type of loading (Fig. 6).

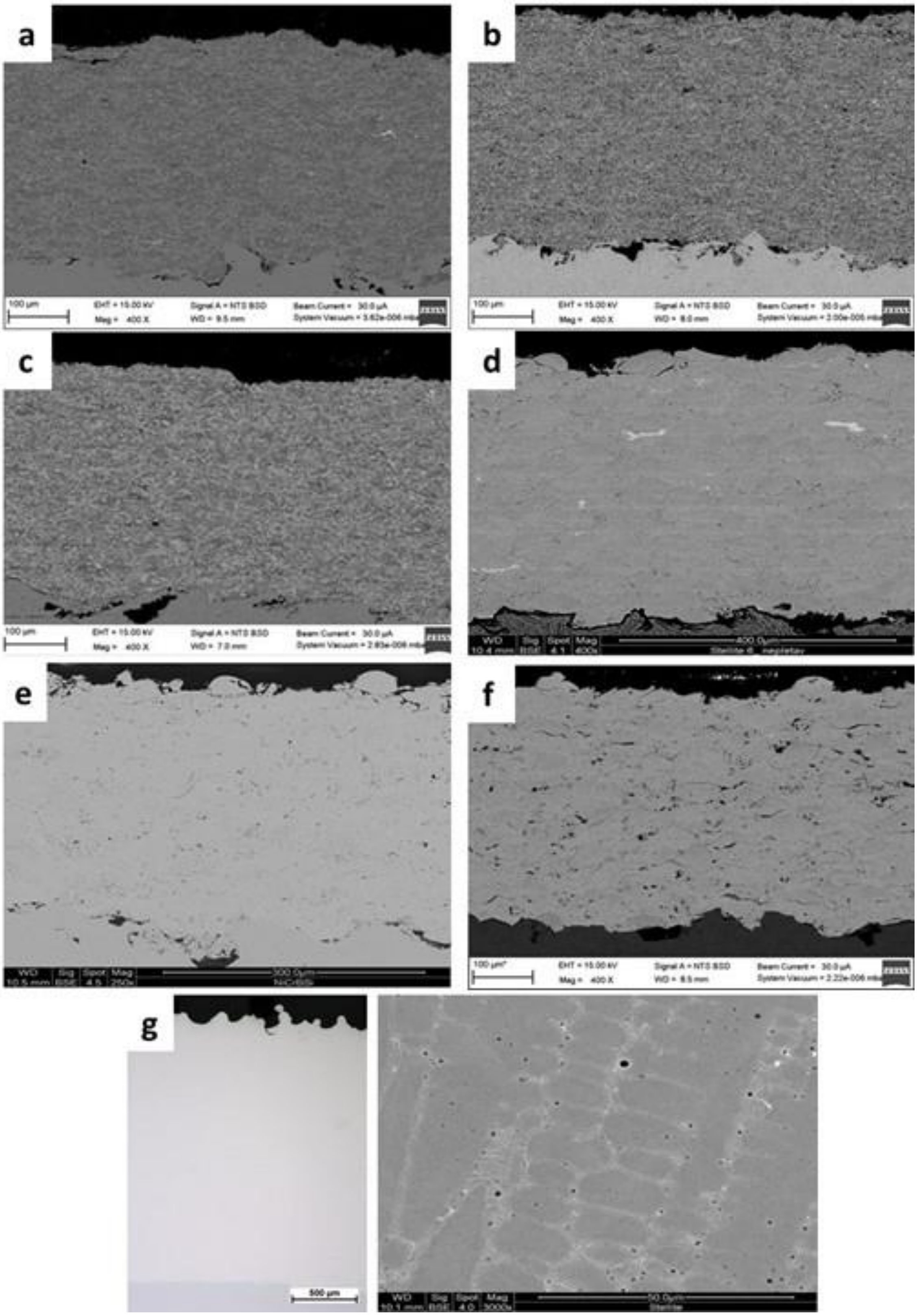

Fig. 1: Microstructure of coatings' cross sections: (a) Cr_3C_2-25%NiCr; (b) Cr_3C_2-5%CoNiCrAlY; (c) Cr_3C_2-50%NoCrMoNb; (d) Stellite HVOF sprayed coating; (e) NiCrBSi HVOF sprayed coating; (f) Hasteloy C-276 HVOF sprayed coating; (g) Stellite laser clad coating

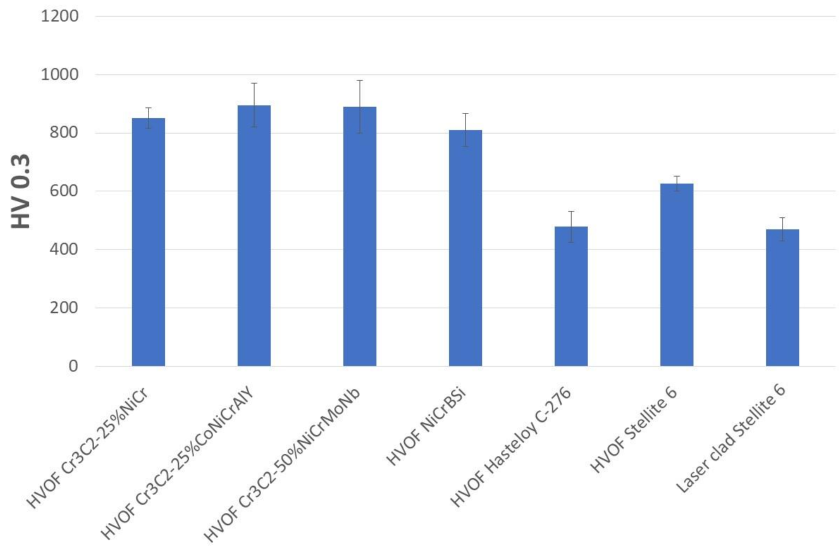

Fig. 2: Microhardness of selected HVOF sprayed coatings and the laser clad Stellite 6 coating

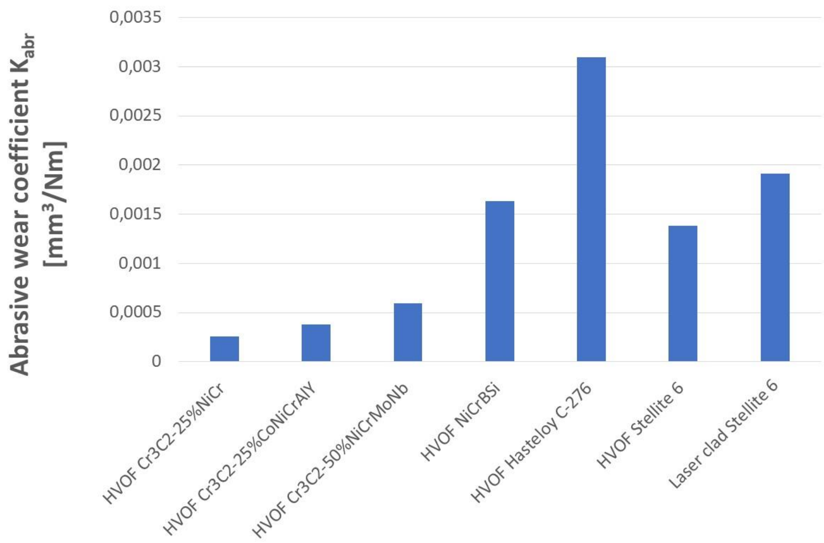

Fig. 3: Abrasive wear of selected HVOF sprayed coatings and the laser clad Stellite 6 coating

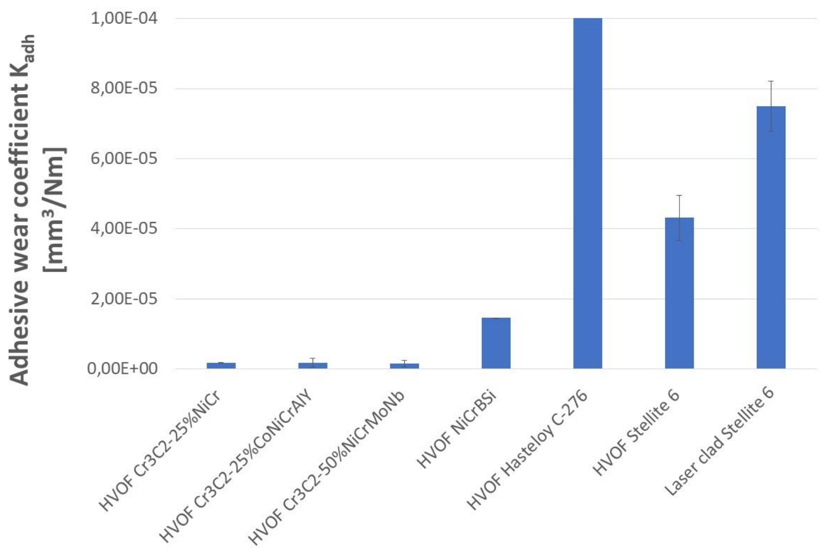

Fig. 4: Sliding wear of selected HVOF sprayed coatings and the laser clad Stellite 6 coating

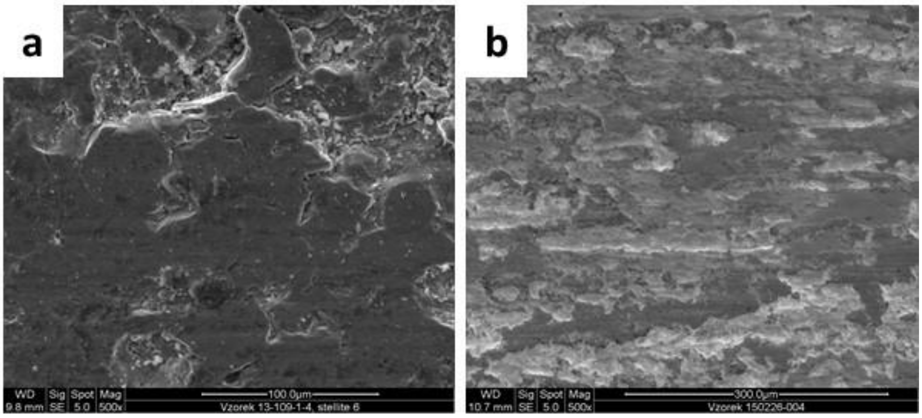

Fig. 5: SEM of wear scar after the sliding wear ASTM G-133 test of (a) the HVOF sprayed Stellite coating; (b) the laser clad Stellite coating

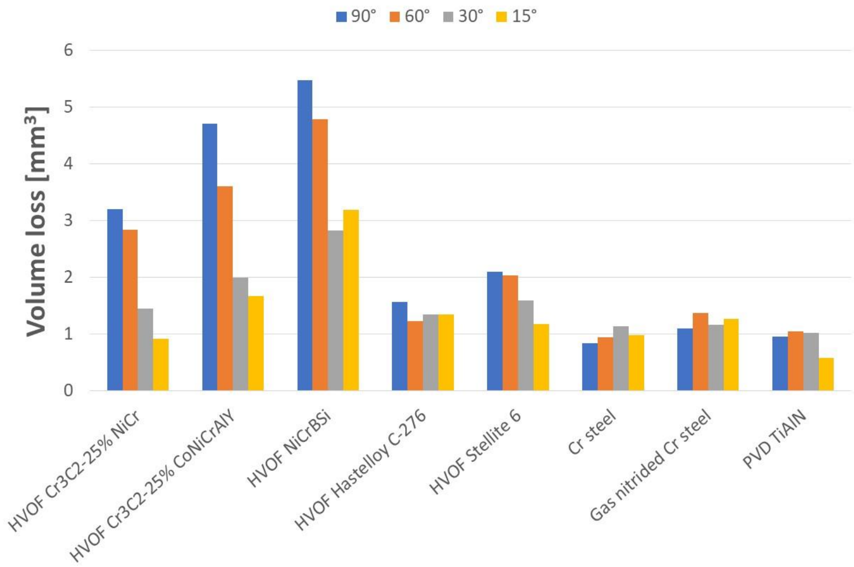

Fig. 6: Solid particle selected HP/HVOF sprayed coatings, erosion of the base material, the gas nitrided surface and the PVD TiAlN layer

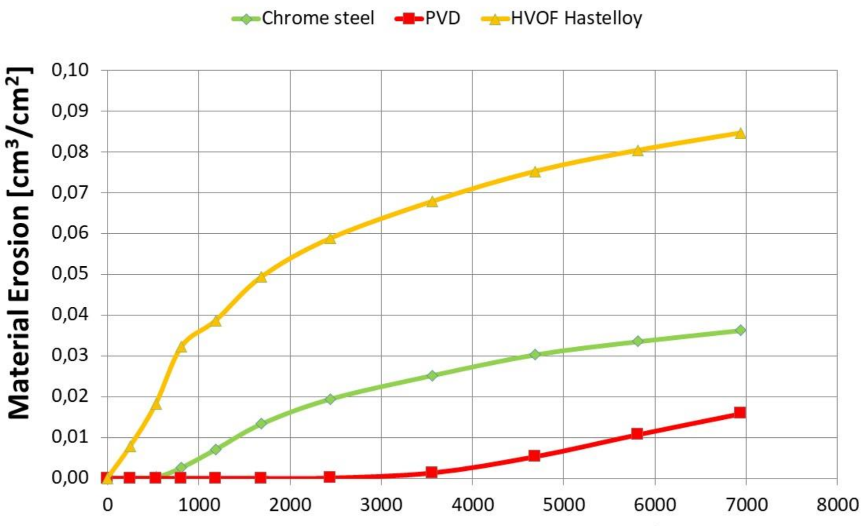

Fig. 7: Water droplet erosion of the base material, the HP/HVOF sprayed Hastelloy coatings and the PVD TiAlN layer

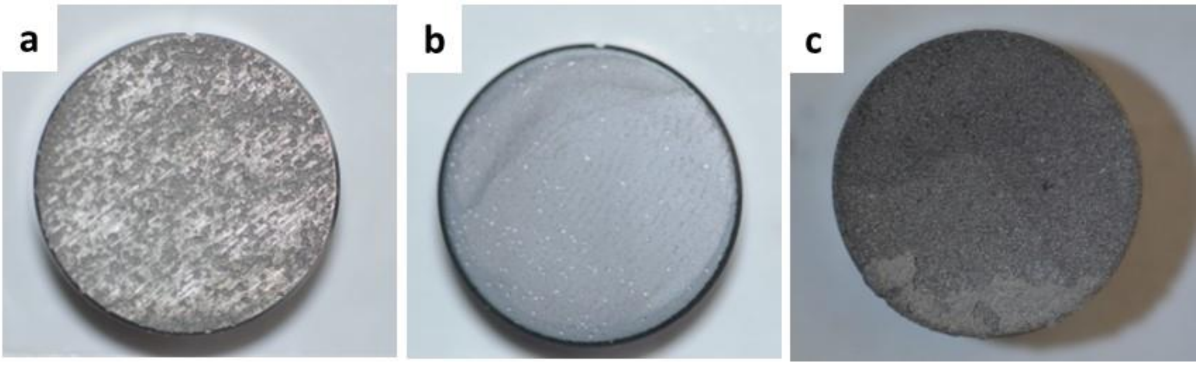

Fig. 8: The surface of eroded surfaces after 130 min of the Water droplet erosion testing: (a) base material; (b) PVD TiAlN layer; (c) HVOF sprayed Hastelloy C-276 coating

Results of the high temperature corrosion testing in the aggressive environment of 18% Na_2SO_4 82% $Fe_2(SO_4)_3$ are shown in Fig. 9. All the tested HVOF sprayed coatings proved their ability to protect the underlying substrate and improve their lifetime. Their protective ability was comparable to that of the laser clad Stellite 6 coating.

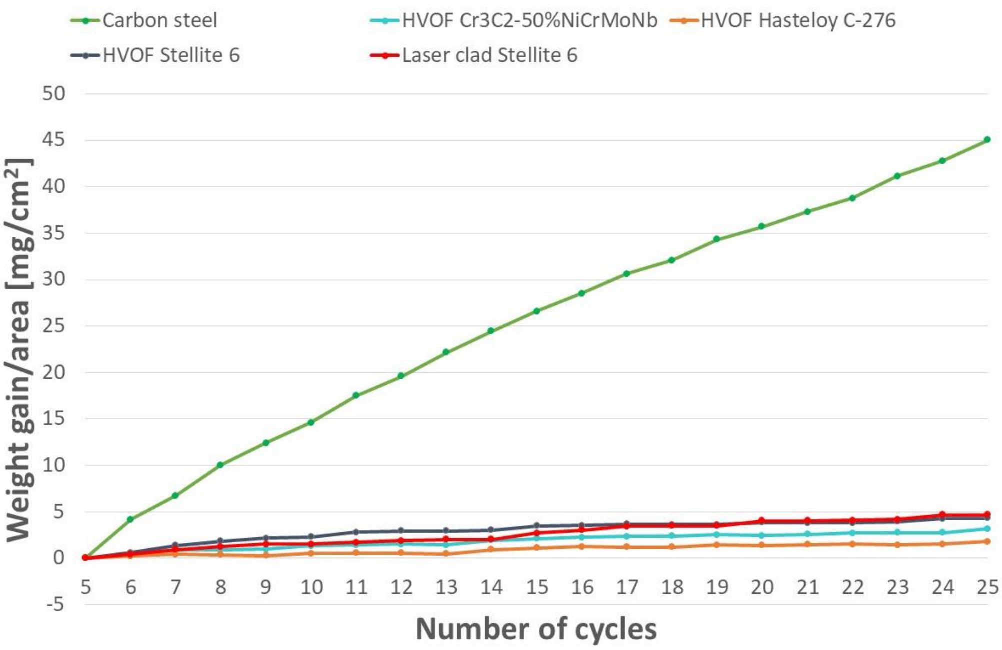

Fig. 9: Cumulative mass gain in dependence on the number of cycles at the high temperature corrosive aggressive environment

Conclusions

Based on the above reported results, the superior behaviour of the HVOF sprayed coatings, namely the Cr_3C_2-based hardmetals, was proved under the abrasive and the sliding wear loadings. On the other hand, the lamellar structure of the thermally sprayed coatings, consisting of individual splats, weakens the resistance of the HVOF coating under repeated loading, such as the solid hard particle erosion or the water droplet erosion. In this type of loading, the alloy coatings provide better results than the hardmetal coatings, but lower that alternative PVD layer. Regarding the protection of the substrate from the corrosive environment, they are comparable to the laser clad Stellite coatings. Based on these findings, the application on the components suffering from oxidation and corrosion can be recommended if the part is loaded mostly with sliding or abrasive wear.

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