DEGRADATION MECHANISM STUDY OF SELECTED THERMALLY SPRAYED COATINGS IN THE ENVIRONMENT OF STEAM TURBINE

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Abstract

In the paper, the influence of high temperature and hot pressure steam on the microstructure and phase composition of HVOF sprayed wear resistant Cr_3C_2-NiCr coating and flame sprayed NiCrAl-Bentonite abradable coating is studied. Both the results of laboratory oxidation tests and the long-term exposition tests in the steam turbine are presented. The mechanism of selective carbide oxidation was observed in both laboratory test and long-term oxidation test in the case of HVOF Cr_3C_2-NiCr coating. The oxidation of NiCrAl matrix of flame spray abradable coating is described. Both coatings suffered from oxidation, but their integrality was not disrupted even after 5.5 years of exposition in steam turbine environment.

Keywords: Steam turbine, degradation, thermal spray, abradable, Cr_3C_2-NiCr, NiCrAl-Bentonite

1. INTRODUCTION

The requirements imposed on the materials of in steam turbine components differ according to components purpose and location. Nevertheless, all used materials have to resist degradation of their properties due to the influence of environment. The increased temperature, reaching up to 600 °C, can cause the devastating loss of mechanical properties or oxidation level leading to fatal failure (**Figure 1**). That is why the attention has been paid to the study of bulk materials degradation already several decades. The same attention has to be paid to the evaluation of degradation mechanisms which take place in coatings, applied on the surface of steam turbine components to increase their functional properties, such as wear or oxidation resistance or for other purposes, such as thermal barrier coatings or abradable coatings.

HVOF sprayed Cr_3C_2-NiCr coatings are widely applied on the surface of components, working in high temperature environment up to 870 °C. Its main purpose is to increase the components wear and oxidation resistance. The microstructure and properties of HVOF sprayed Cr_3C_2-NiCr was studied many times, as well as the influence of the high temperature [1,2]. Based on these studies, the stability of the HVOF sprayed Cr_3C_2-NiCr coating at high temperature was proved. On the other hand, only minor attention was paid to the evaluation of the influence of steam turbine environment, where the combination of corrosive-aggressive steam and increased pressure appears. In the study of Matthews [3], the mechanism of selective oxidation of carbides was suggested, possible responsible for above mentioned coating degradation.

The abradable coatings, such as flame sprayed NiCrAl-21%bentonite coating, are used to increase the efficiency of aircraft or industrial gas turbines through decrease the necessary clearance between the rotating blade tips and the casing. The main abradable coating requirements are the easy abradability, oxidation and erosion resistance, and low thermal conductivity together with thermal shock resistance. To fulfill the expectation, the porous microstructure, consisting of metal-alloy matrix (usually Ni or Al based) and solid lubricant, such as graphite or bentonite [4-6]. Besides the above-mentioned characteristics, the stability of microstructure and mechanical properties in high temperature environment as also the crucial [7].

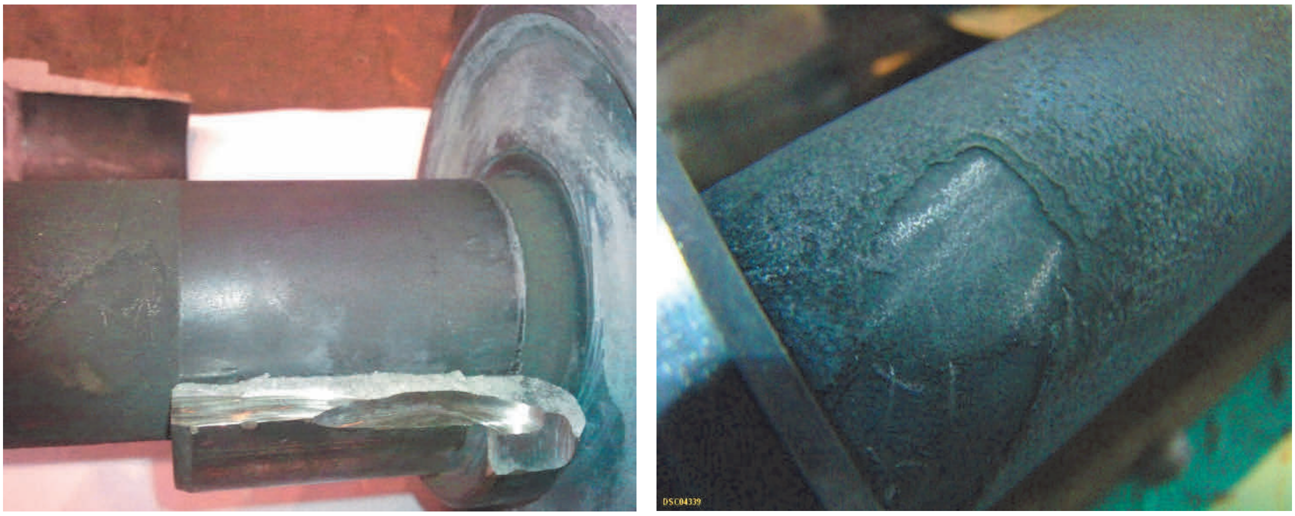


Figure 1 Failure of Cr_3C_2-25% NiCr HVOF sprayed coating of a steam distribution component TG 23 ETU (2012) [8]

In the literature, the results of laboratory tests are usually presented, performed in conditions, that are supposed to simulate the real working conditions or that are even severe. The drawback of these experiments is their shortness, compare to expected lifetime of coated parts. In this work, the results of long-term exposition in real steam turbine working condition are presented, and compare to the short-term laboratory tests.

2. EXPERIMENTAL

2.1. Coatings deposition

The commercially available Amperit 588.074 powder was used to deposit the hard, wear resistant Cr_3C_2-25%NiCr coating, using the HP/HVOF TAFA JP5000 spraying device. The previously optimized process parameters were used [9] to produce the coating with high hardness and low porosity. The commercially available abradable material Durabrade 2313 from Oerlicon Metco was used to deposit a NiCrAl-21% Bentonite coating using the 6P-II flame spraying gun. Both coatings were sprayed onto grit blasted (Al_2O_3; F22) surface of X22 steel bar, 25 mm diameter. The surface of Cr_3C_2-NiCr coating were consequently grinded, while the abradable Durabrade 2313 coating was left in the as-spread state, similarly to the application condition.

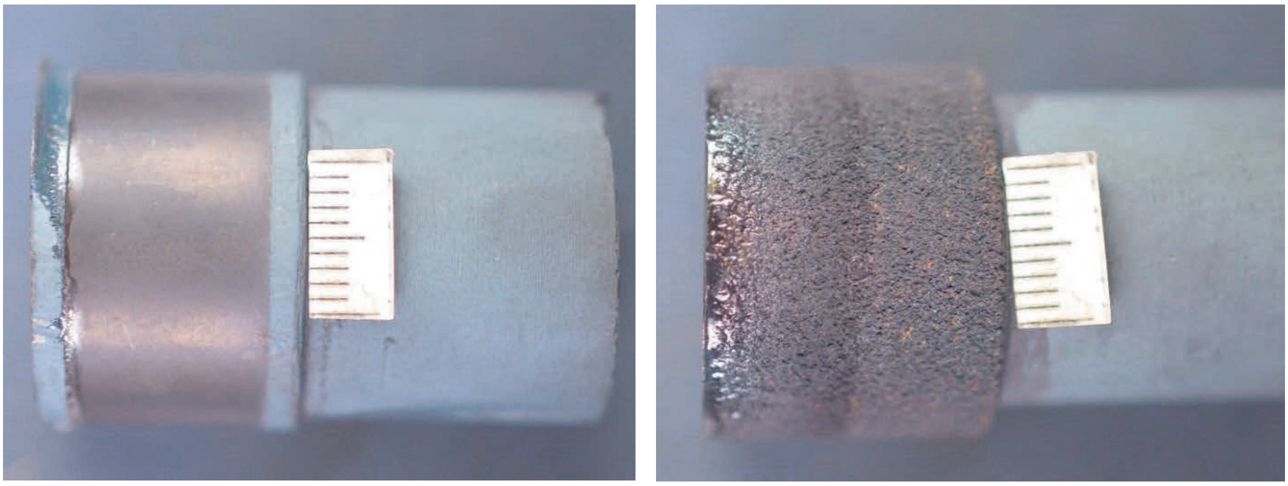
2.2. Characterization

The sample bars were placed into the exposure channel ETU21 of power plant Tušimice, together with s of other samples of tested steels and surface treatments [10]. The temperature in exposure channel reached 540 °C and the pressure of the steam 17 MPa. After certain time periods, the samples were checked and analyzed. The samples, reported in this study, was exposed for 5.5 years (**Figure 2**).

The microstructure of the coatings was analyzed on the coating's cross sections (grinded and polished by an automatic Leco grinding and polishing equipment) by optical microscope Nikon Epiphot 200 and Scanning electron microscope EVO MA25, Zeiss, (with LaB6 thermal filament), equipped by EDX detector SDD X-Max 20, Oxford Instruments.

The coatings' phase composition was evaluated by means of powder X-ray diffraction (PXRD), using the D8 Discover powder diffractometer in Bragg-Brentano geometry with 1D detector and CuKα radiation.

The microhardness of the Cr_3C_2-NiCr coating was measured on the ground cross-sections of as-sprayed and exposed coatings using the HV0.3 method. For each coating, at least 10 indents were done, and the average value is reported.



a) b)

Figure 2 Samples after 6 years of exposition: a) HVOF Cr_3C_2-25%NiCr; b) flame sprayed NiCrAl-Bentonite

3. RESULTS AND DISCUSSION

3.1. Cr_3C_2-25%NiCr coating

After 5.5 years of exposition, the HVOF sprayed Cr_3C_2-NiCr coating surface was covered by a thin, well adhered layer Cr-based oxides. No massive oxidation or delamination was observed on the surface (**Figure 2a**) or cross section (**Figure 3**) of the analyzed sample.

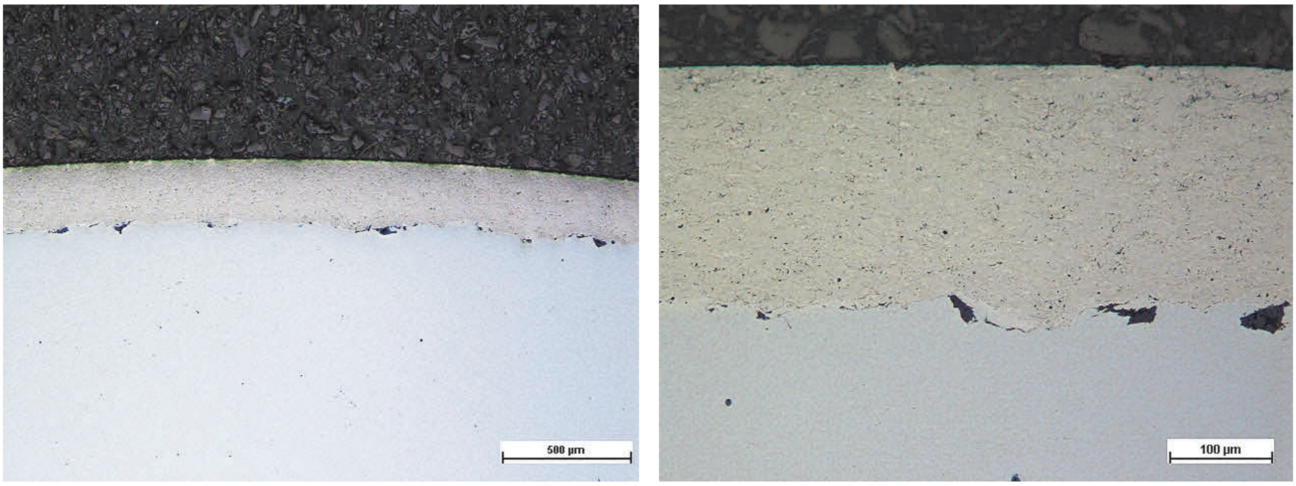


Figure 3 Optical micrograph of Cr3C2-NiCr coating after exposition

The SEM analyses revealed the microstructural changes, caused by heat exposition. The precipitation of secondary carbides from supersaturated NiCr matrix can be observed. This phenomenon was previously described for samples, exposed in laboratory to the temperatures above 650 °C [2], but not for samples exposed under 400 °C [1]. The long-term heat treatment at 540 °C have also led to secondary carbide precipitation, which is supposed to restore the toughness of the matrix. Near the surface of the coating

(**Figure 4**), the oxidation of carbide particles was recorded by SEM at several locations. It was not developed enough to disrupt integrity of the surface, but was significantly more developed that the same effect observed for similar coating (**Figure 5**), tested in the laboratory conditions [11] (steam; 609 °C; 24 MPa; 116 h). In both cases, the EDX analyses proved the presence of oxygen, carbide and chromium in the dark phase, while only chromium and carbon are presented in the middle of carbide particles.

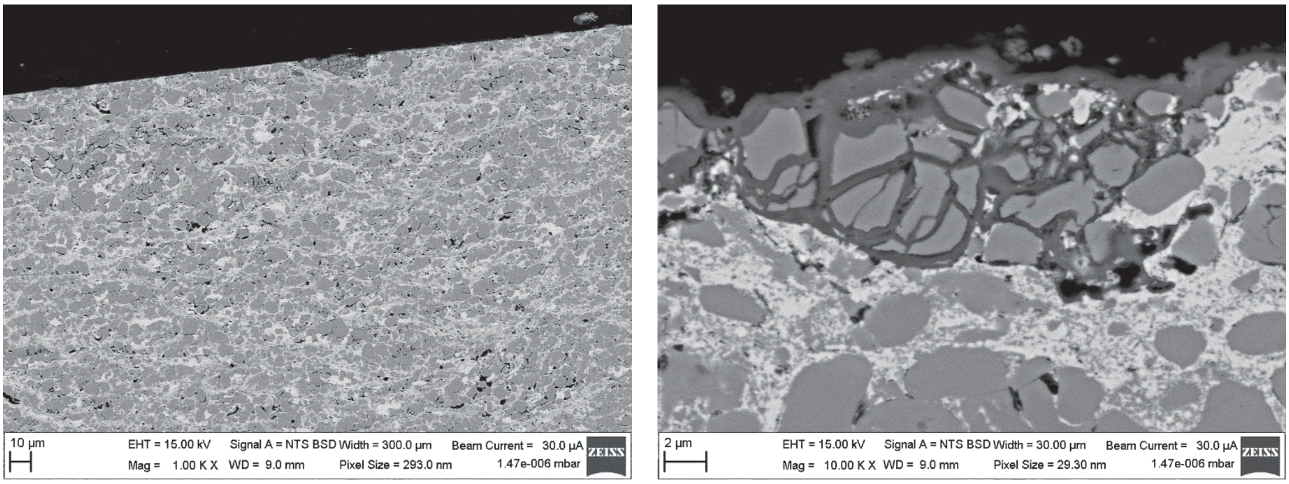


Figure 4 SEM micrograph of Cr_3C_2-NiCr coating after exposition in exposure channel ETU21

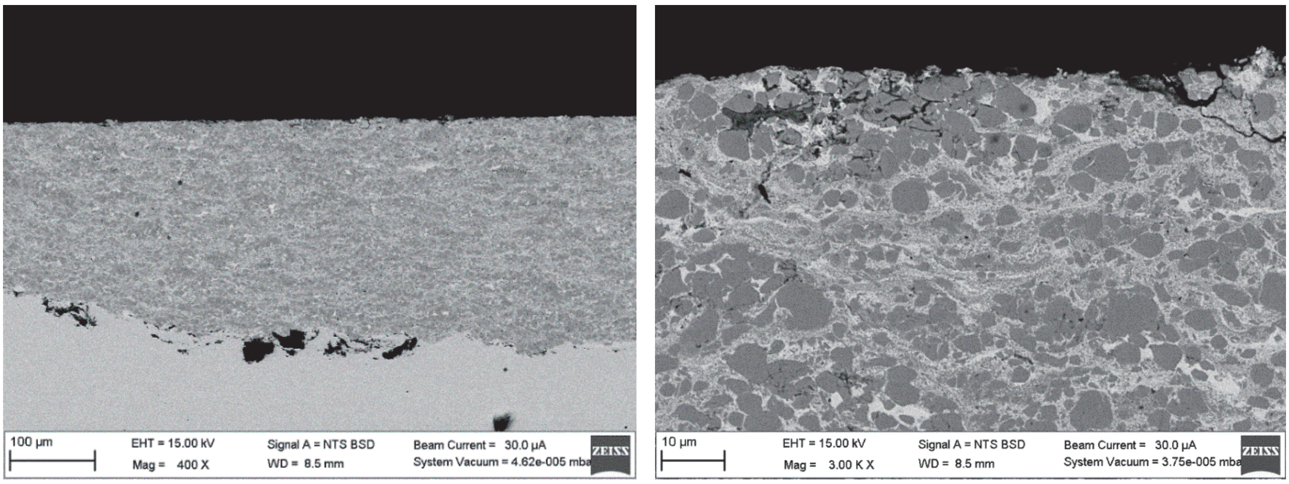


Figure 5 SEM micrograph of Cr_3C_2-NiCr coating after exposition in hot steam/high pressure autoclave VŠCHT

The XRD analyses confirm the SEM observation (**Figure 6**). The surface of the exposed coating is covered by Cr_2O_3 oxide, the expected Cr_3C_2 carbide and Ni-based matrix phase was detected. In the **Figure 6**, the comparison with the results obtained from our previous experiments is presented [11]. It can be seen, that the long-term exposition led to disappearance of non-stable lower carbides Cr_7C_3, that appeared after in the as-sprayed coating due to dissolution of carbides into matrix.

The microhradness measurement shows the evolution of related mechanical properties. While there are only small differences in microhardness of as-sprayed (920±46 HV0.3) coating and coatings after hot-air annealing (985±42 HV0.3) and steam annealing after short-term laboratory test (1004±89 HV0-3), the drop of microhardness was observed after 5,5 years of exposition at 450 °C (773±46).

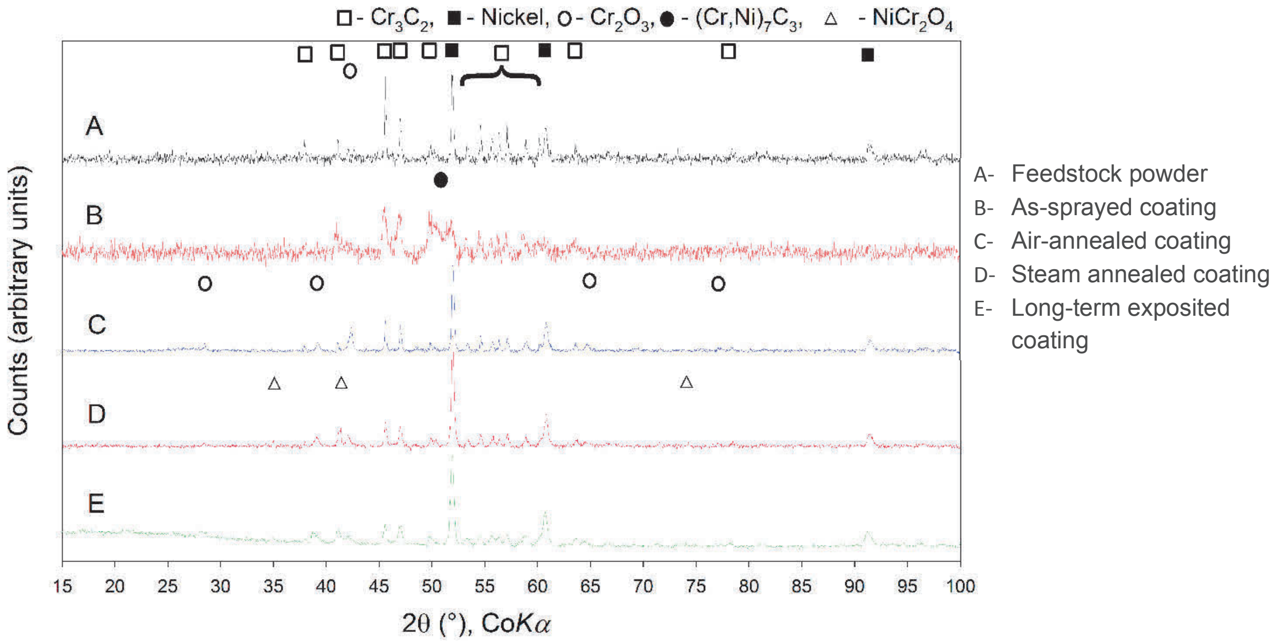


Figure 6 XRD phase analyses of Cr_3C_2-NiCr powder and coatings in after exposition in different environments

3.2. NiCrAl-Bentonite coatings

The cross section of flame sprayed NiCrAl-Bentonite coating didn't show a major degradation, no cracks, delamination or spallation appears after 5.5 year of 540 °C exposition in ETU21 exposure channel (**Figure 3b**). The SEM and EDX analyses showed the changes in the composition of NiCrAl matrix (**Figure 7**). It can be seen, that the oxidational s well as phase transformation took place (**Figure 8**). On the surface of the exposed coating, only the Ni-based oxide was recorded by XRD analyses.

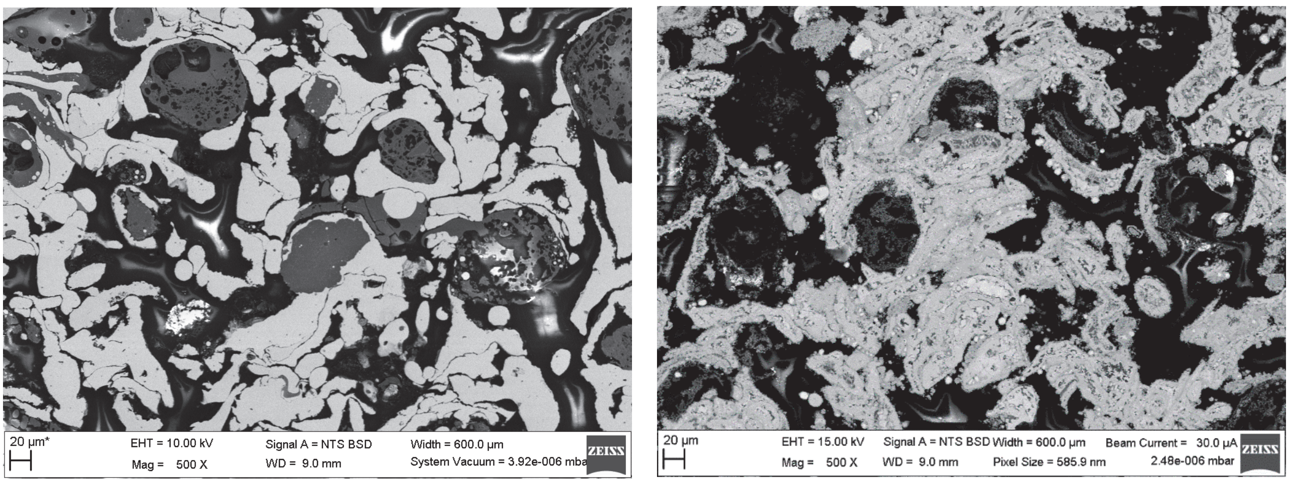


Figure 7 SEM micrograph of NiCrAl-Bentonite coating: a) as sprayed; b) after exposition in exposure channel ETU21

The mechanical properties of the exposed coating cannot be measured cross section of flame sprayed NiCrAl-Bentonite coating does not showed a major degradation, no cracks, delamination or spallation appears after 5,5 year of 540 °C exposition in ETU21 exposure channel (**Figure 3b**). The SEM and EDX analyses showed the changes in the composition of NiCrAl matrix (**Figure 7**). It can be seen, that the oxidation as well as phase transformation took place (**Figure 8**).

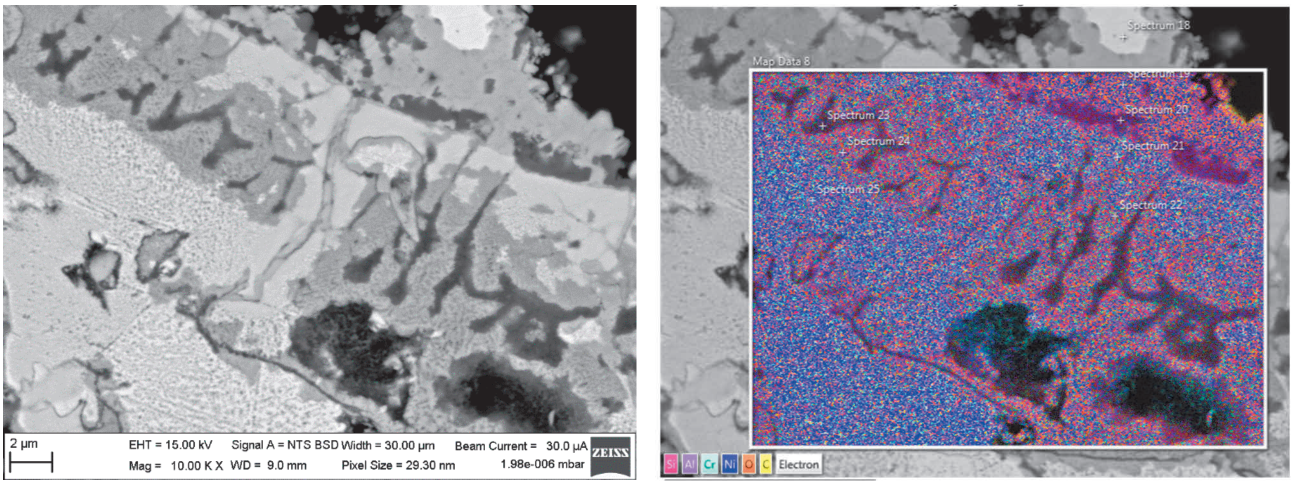


Figure 8 SEM micrograph of NiCrAl-Bentonite coating: a) as sprayed; b) after exposition in exposure channel ETU21

4. CONCLUSION

The results of 5.5 year long exposition in exposure channel ETU 21 confirmed the satisfactory lifetime of two types of thermally sprayed coatings in given environment. The detailed SEM and EDX analyses revealed oxidation of both coating materials, but not in a level leading to coatings destruction. Being applied on functionality parts, the combination of environment with mechanical loading can be expected. In this case, the negative effect of observed oxidation on the coating functionality cannot be excluded.

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