CHARACTERIZATION OF FLAME SPRAYED ABRADABLE SEAL NiCrAl-BENTONITE COATINGS

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Abstract

The NiCrAl-21% Bentonite abradable coating, deposited by flame spraying, was exposed to 720°C / 1 hour air-annealing to evaluate its resistance against heat-induced changes. The SEM and XRD microstructure evaluation was done. After the air-annealing, the increase of HR15Y surface hardness was recorded and accompanied with decrease of abradability evaluated by Progressive Readability Hardness (PAH) test, although no demonstrable microstructural changes was recorded by SEM. XRD analyses evidenced the formation of nickel oxides and ordered Ni_3Al phase during the air-annealing. Besides the abradable coating evaluation, this work brings the verification of the potential of PAH for scratch hardness testing. The measurement provides the results with low scatter, compared to usual surface hardness testing, and enables to distinguish between the depth of indentation in loaded and unloaded state, pointing out to the elastic/plastic deformation ratio.

Keywords: NiCrAl-Bentonite, abradable seal, flame spray, abradability

1. INTRODUCTION

Abradable seal coatings 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. To fulfill the expectations, the coatings have to provide specific properties: high abradability combined with erosion and oxidation resistance [1,2]. In order to achieve the combination of such contradictory material properties, a specific microstructure was developed, consisting of usually metal matrix (Ni- or Al-based), responsible for erosion and oxidation resistance and solid lubricant phase, responsible for abradability [3]. To deposit such coatings, the atmospheric plasma spraying (APS) technology is the most frequently used [4,5,6], although by easy-to-operate flame spraying (FS) technology. It can also provide the abradable seal coatings in good quality [6,7]. Besides the mechanical properties in as-sprayed state, the oxidation resistance or thermal shock resistance are also a matter of interest. Working in high temperature conditions, the abradable coatings have to provide the stability of mechanical properties during long-term heat exposition [8].

Although the abradable coatings are used extensively in aircraft engines and turbomachinery, the methods of their laboratory testing are still rather limited.

As the most often used, the simplest method of Rockwell superficial hardness measurement can predict the sufficient mechanical properties. Generally, it is used to test the coatings with thickness too low to be measured with the standard range. The diamond cone indenters are used for hard coating materials, while for the soft materials, such as the abradables, the ½” steel ball, loaded by 15 kgf (HR15Y) is the suitable indenter [9].

For soft coatings, the Hoffman scratch hardness [10] can be used to evaluate the hardness hardness/abradability. In this test the width of the scratch, created on the coating surface by sharp indenter constantly loaded of 19.6 N. The wider the scratch, the lower the hardness is.

The more sophisticated test of abradability is the abradable rig test. The principle of the test simulated the real contact between the blade tip and the abradable coating. During the test, the cutting force is recorded, and the wear of both abradable coating as well as blade tip is evaluated [11]. Being a single-purpose device, the abradable rig testers are not widely available across the surface engineering laboratories. The replication of the engine environments is expensive and time-consuming [3]. Moreover, the different methodologies and definitions of the abradability makes the simple comparison between the published results uneasy.

In the work of Ma and Matthews [3,12], the simple-to-realize test of abradability was suggested, using the well know method of scratch test. Progressively increasing load of Rockwell diamond indenter is used to create a scratch, which depth is recorded by the scratch tester. Based on the obtained data (actual normal and tangential forces, and the corresponding depth of indenter displacement), the “progressive abradability hardness (PAH)” number was calculated. The PAH value includes both the energy necessary to create the scratch, as well as the volume loss of abraded material (Eqv.1.)

$$PAH = \frac{W}{V} = \frac{W_P + W_I}{V} = \frac{\sum_{i=1} F_{Ti}.D_{Pi} + \sum_{i=1} F_{Ni}.(D_{i+1} - D_i)}{\sum_{i=1} A_i\,(D).D_{Pi}} \qquad (1)$$

where:

W_I - the work of indentation (Nmm)

W_P - the work of ploughing (Nmm)

V - volume of abraded material (mm^3)

A - groove cross section area (mm^2)

F_T - tangential force (N)

F_N - normal force (N)

D_P - ploughing displacement (mm)

D_I - indentation displacement (mm)

In this work, the available laboratory tests methods are exploited to evaluate the mechanical properties of flame sprayed NiCrAl-21%Bentonite abradable coating in the as-sprayed and heat-treated state. The possibility of application of the NiCrAl-21%Bentonite coating on the parts with service temperature up to 700°C was verified. The annealing temperature was chosen with respect to the intended coating applications on aircraft engines components, where the routine working temperature does not reach 600°C,but can exceed the 650°C during short-term periods of overloading. Simultaneously, the potential of easy laboratory scratch test for testing of coatings abradability was also investigated.

2. EXPERIMENTAL

2.1. Coating material

The commercially available abradable material Durabrade 2313 from Oerlicon Metco is a nickel-based, mechanically clad powder. The Ni-based (Ni4Cr4Al) alloy is combined with 21 wt% of Bentonite. The powder with particle distribution within 74 - 177 μm is suitable for flame spray deposition. The SEM of coating particles and their cross sections can be seen in the **Figure 1**.

The powder cross section shows the Ni-based rim, encapsulated Bentonite core of the particles. According to manufacturer [13], the powder is developed to ensure both clearance control and thermal barrier insulation up to 650°C.

2.2. Coating deposition and treatment

The powder was deposited onto the grit blasted (Al_2O_3; F22) surface using the 6P-II flame spraying gun. The hot air annealing was realized in a muffle furnace (LM 212), at 720°C for 1 hour and cooled in air. To protect the non-coated parts of steel samples against oxidation during annealing, they were covered by oxidation protective paint CONDURSAL Z 1100.

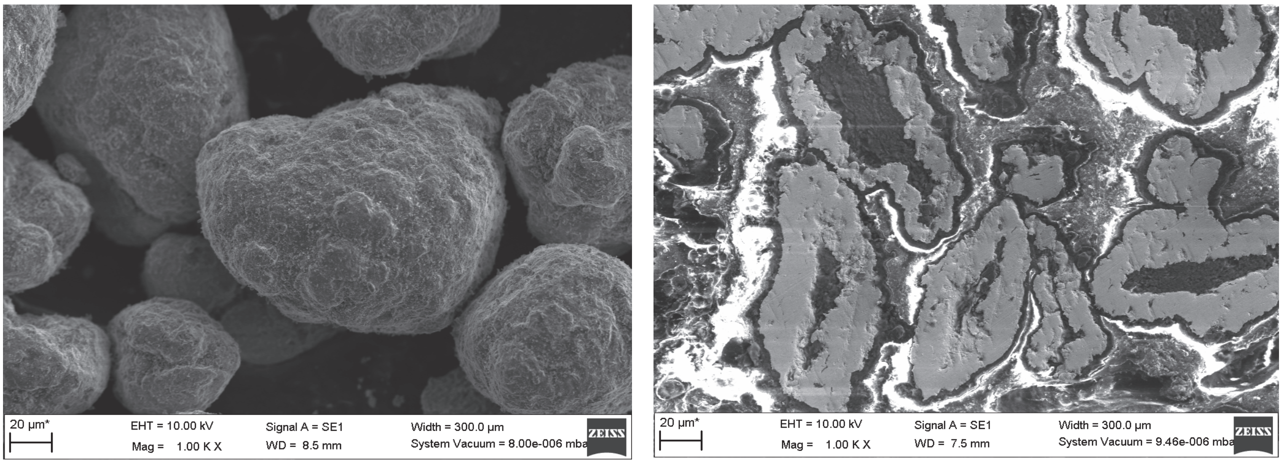

Figure 1 Durabrade 2313 abradable powder surface (left) and cross section (right)

2.3. Testing procedures

The microstructure of the coatings was evaluated on the coatings 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.

Surface hardness HR15Y was measured on the lightly ground surfaces of as-sprayed coatings. At least 7 measurements were done for each coating, the average value and its standard deviation was evaluated.

Scratch test of abaradability was realized on the coating as-received surface of the coating in as-sprayed and air-annealed state. The CETR UMT2 tribometer equipped with Rockwell C 120°diamond cone with 200 μm tip radius was used to apply the progressively increasing load to the samples surface. The loading rate of 100 N/min was used for each set of tests. Five scratch grooves were made for each final length: 0.9 mm; 2.9 mm; 4.9 mm and 9.9 mm, resulting in the end loads of 10 N, 30 N, 50 N and 100 N. At the beginning of the scratch, initial load of 1 N was applied at each test, in accordance to methodology developed by Ma and Matthews [3,12].

3. RESULTS AND DISCUSSION

3.1. Microstructure

The microstructure of abradable coating can be seen in the in the **Figure 2.** After spraying (**Figure 2, left**), the Ni-based alloy (light) deforms slightly and creates the porous structure of the coating, responsible for expected low cohesive strength. The bentonite rounded particles (dark gray) remains, compared to the original powder, unaltered. Between the particles, a high number of irregular pores with size comparable with size of the particles can be observed (dark). After the 720°C / 1 hour air annealing (**Figure 2, right**), no significant difference were observed in comparison with the as-sprayed state. The XRD phase analysis of the feedstock DU2313 powder (**Figure 3**) reveals presence of Ni-based solid solution (gamma phase), ordered Al_3Ni phase and aluminosilicates originated from Bentonite clay. The as-sprayed coating exhibits only gamma phase matrix with small amount of silicon oxides and aluminum oxide formed by transformation of phases present in Bentonite. The air-annealing have led to nickel oxide formation and caused also the formation of ordered Ni_3Al phase, which is evidenced by superreflexion peaks in low angle range.

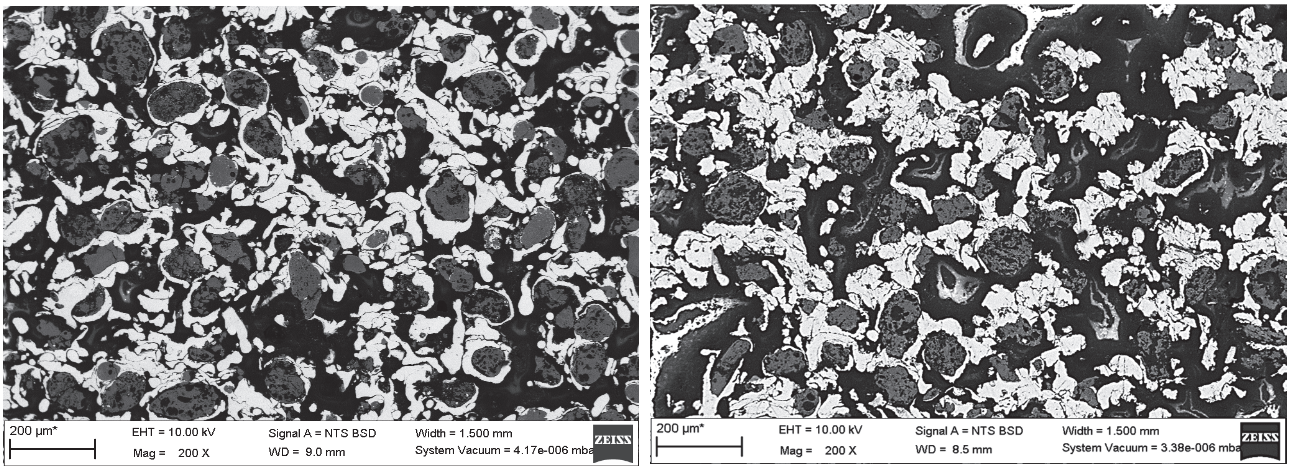

Figure 2 Durabrade 2313 abradable coating in as-sprayed (left) and air-annealed (right) state

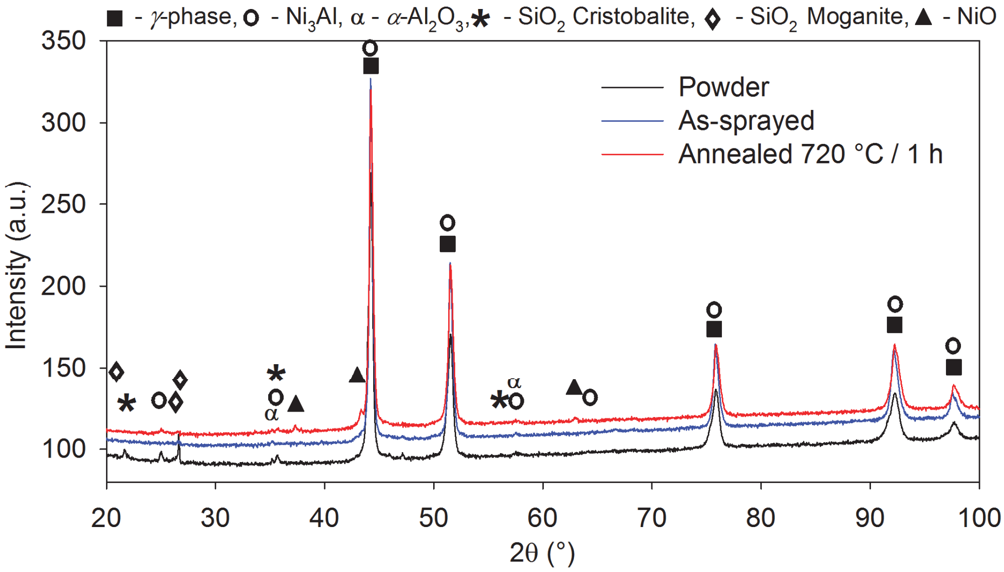

Figure 3 XRD phase analyses of Durabrade 2313 abradable powder, as-sprayed and air-annealed coating

3.2. Surface hardness HR15Y

The hardness values, measured on the surface of as-sprayed coating reached 46.0 ± 3.2 HR15Y. After 720°C / 1 hour air-annealing, the surface hardness increased slightly to 49.2 ± 3.5 HR15Y. With respect to the scatter, the change of the hardness is not absolutely conclusive. Nevertheless, it pointed out to heat-induced changes in the DU2313 coating.

3.3. Progressive abradability hardness PAH

The CETR UMT2 tribometer enables to measure the profile of the surface before, during and post scratch testing (**Figure 4**). The actual depth of indentation during loading and after the test in unloaded state can be compared, pointing out the ratio between elastic and plastic deformation. The procedure of calculation of the ratio between plastic and elastic part of deformation energy will be done in future work.

The data obtained from the tribometer sensors (actual normal and tangential forces F_N and F_T resp.) can be correlated with corresponding indentation and ploughing displacement D_I and D_P, resp. Using the equation (1), the calculation of the Progressive Abradability Hardness (PAH) value in dependence on the end loads was made. The results PAH is shown in the **Figure 5**. It can be seen, that its value is higher for 0.9 mm long scratch groove (10 N end load), but for 2.9 mm, 4.9 mm and 9.9 mm (30 N, 50 N and 100 N end loads) it is length-independent. PAH varied between 300-450 MPa in steady state. In the work of Ma and Matthews [3,12], lower PAH values (200-300 MPa) were measured for abaradable coatings based on Ni-graphite, Ni-Si-graphite or Al-Si-polyester.

The difference between the as-sprayed and air-annealed coatings in PAH is significant, more pronounced that in the case of surface hardness HR15Y measurement. Moreover, the difference between the values calculated in loaded and unloaded state can be observed, more pronounced in the case of air-annealed coating.

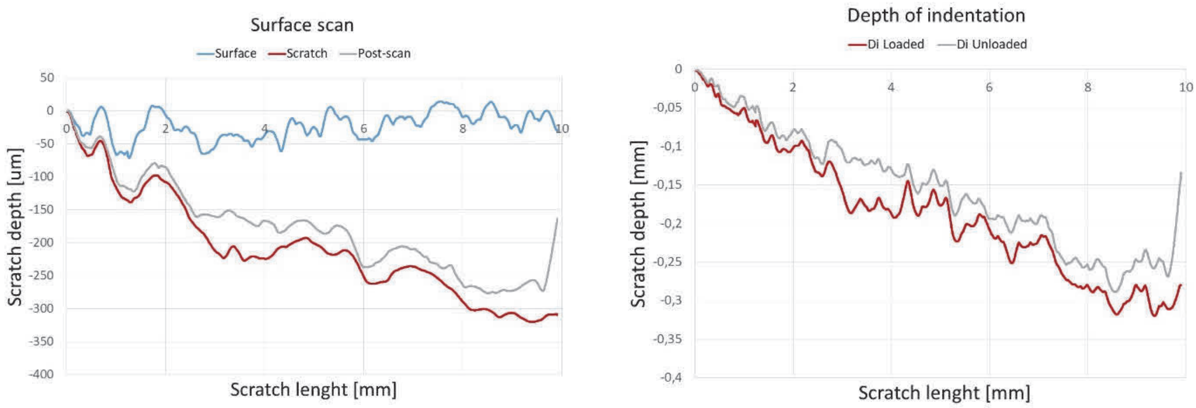

Figure 4 The surface scan (left) and depths of indentation (right)

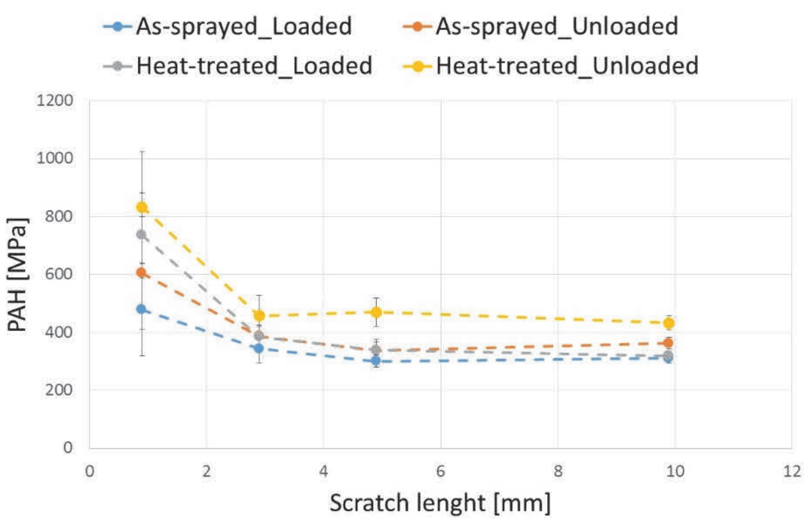

Figure 5 The results of PAH evaluation

4. CONCLUSIONS

The NiCrAl-21%Bentonite (Durabrade 2313, Oerlicon Metco) flame sprayed coating increase its hardness after it is exposed to 720°C temperature for 1 hour in air. The difference was observed in both tests - static HR15Y superficial hardness measurement, as well as by scratch hardness, involving both indentation and ploughing work, however no microstructural changes of NiCrAl alloy was recorded by SEM. The XRD analyses gives the evidence of changes in the metal component of the coating in the vicinity of surface after air-annealing, and formation of Al_2O_3 and SiO_2 in bentonite phase. The potential of instrumented scratch testing to evaluate the abradability of the coating was proved. The PAH results involved both the indentation and ploughing part of energy necessary to create a scratch. The results were found to be not load dependent, apart from the lowest load, where the roughness of original surface plays a significant role.

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