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A STUDY ON FLUE GAS CORROSION AND WATER VAPORS SORPTION ON A $ZrO_2/20\%Y_2O_3$ PLASMA SPRAYED COATING FOR TURBINE BLADES APPLICATION

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Abstract: *This paper presents a concept of thermal barrier coating which consists of a $ZrO_2/20\%Y_2O_3$ ceramic top layer and a NiCrAlY bond layer, both deposited by atmospheric plasma spraying (APS) on a Ni based super alloy. Atmospheric plasma spraying (APS) is a widely used deposition method for obtaining variable thickness coatings on surfaces with different degrees of complexity. The analyzed samples were obtained by thermal deposition with the METCO 7 MB plasma jet installations. The corrosion test followed the chemical influence of the flue gas on the deposited coating. This test is important because the turbine blades are corroded by the flue gas during operation, so the chemical behavior of the ceramic coating is an important aspect for a safe service. Due to the significant amount of water vapors in the flue gases the sorption capacity of the coating is assessed. The highlighting and interpretation of the structural and chemical changes caused by the high temperature flue gas were made by using modern methods of structural analysis.*

Keywords: *$ZrO_2/20\%Y_2O_3$, flue gas, corrosion*

1. INTRODUCTION

This paper analyzes coatings deposited by atmospheric plasma spraying on a Ni based super alloy material used in the manufacturing of turbine blades. Thermal barrier coatings used in the manufacturing of turbine blades are meant to isolate the components of a gas turbine aircraft engines which are exposed to severe regimes of temperature, thereby ensuring a good and safe functioning. [1] That would otherwise not be possible due to excessive heating of the material from which they are made. [1] TBC layers permit lowering the temperature of the "hot parts" targeted in the energy industry and aeronautics with 100-200°C. [2] The high temperature flue gas also causes corrosion to the base material of the blades. For this reason the deposited ceramic coating also has the role to protect de base material from corrosion. [3]

The obtained quality for thermal spray coatings can be assessed by: roughness, thickness, strength and porosity. [4] These aspects can be influenced by the technological parameters used for the adopted spraying methods. Another parameter is the chemical stability of the ceramic material so it can withstand high working temperature without the appearance of oxidation and corrosion. [4]

Because there is a significant amount of water in the flue gases (water vapors from intake air and water vapors resulted from the combustion process) it is important to assess

the sorption capacity of the deposited ceramic coating. [5]

2. MATERIALS, METHODS AND INSTRUMENTATION

The protection layers were obtained by successive deposition of the bonding and ceramic top layer by air plasma jet method on a 7MB METCO type installation. The parameters used for the plasma spraying deposition are presented in Table 1.

Table 1: Parameters of deposition

Technological parameters	NiCrAlY	ZrO_2/ 20%Y_2O_3
Spray distance, (mm)	120	120
Injector	1,8	1,8
Plasma gas intensity, (A)	600	600
Arc voltage (U)	62	65
Speed of rotation (rot/min)	55	55
Argon flow (m^3/h)	50	40

The samples used for the test were made from a Ni base super alloy of rectangular cross section with the dimensions 30x8x2 mm. The ceramic coating deposited on the samples has different thicknesses. The coating thickness for the three samples is: 100µm, 200µm şi 400µm. The samples were placed in the exhaust pipe of a boiler. The AV00 boiler uses diesel fuel and the gas circulation is forced (the flue gases are discharged by a fan) (Fig.1). The excess air coefficient has the value of 1,5.

Fig.1. The placing of the samples in the exhaust pipe of the AV00 boiler

The Quanta 200 3D electron microscope was used to perform secondary electron images and EDAX analysis, working in the Low Vacuum module at pressures ranging from 50 to 60 Pa and using the LFD (Large Field Detector) detector. The voltage used to accelerate the electron beam had the value of 30kV and a working distance varied from 12 to 15 mm, Fig.2.

Fig.2: Quanta 200 3D electron microscope

The water vapors sorption capacity of the analyzed samples was measured at 25°C in the relative humidity domain of RH=0-90%. The test was done using the IGAsorp equipment. This equipment is fitted with a ultrasensitive microbalance which measures the mass changes of the studied material along with the change of humidity in the sample chamber. The temperature in the chamber is kept constant with the help of a thermostat.

3. STRUCTURAL ANALYSES OF THE LAYERS SUBJECTED TO CORROSION IN FLUE GASES

The samples were placed in the exhaust pipe of the boiler. The clamping of the samples in the exhaust pipe is presented in Fig.1.

The corrosion test followed the chemical influence of the high temperatures flue gases on the ceramic layer deposited on the samples. The coating was subjected to gravimetric analyze and elementary chemical analyze (EDAX).

Following the gravimetric analyses for the three samples subjected to corrosion a loss of mass was measured. For the samples with the layer thickness of 100 µm the loss of mass is greater than in the case of the other two samples. This happens due to the exfoliation of the layer. The 100 µm coating has a weaker adherence to the base material then the other two coatings. On the other two samples no exfoliations marks are present and the lost of

mass is due only to the evaporation of volatile matter.

In Table. 2. are presented the results of the gravimetric analyses.

Table 2. The results of the gravimetric analyses

The layer thickness	The mass of the sample before the test [g]	The mass of the sample after the test [g]	The mass los [g]	The mass los from the initial mass [g]
100 µm	3,49	3,48	0,01	0,28
200 µm	3,143	5,14	0,003	0,06
400 µm	5,108	5,10	0,008	0,16

After the corrosion test the sample with the layer thickness of 100 µm shows macroscopic marks of exfoliation. This fact is presented in Fig.3.

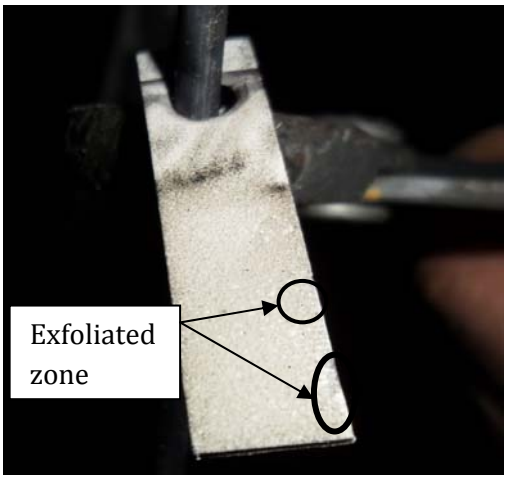

Fig.3. The sample with the coating thickness of 100 µm after the corrosion test.

In the SEM imagine from Fig. 4-a it can be observed that the layer structure is made of elongated grains, separation surfaces and pores of different dimensions. In Fig. 4-b a crack in the coating is visible. The crack is produced by the exfoliated tendency of the layer due to the velocity the flue gas and the high working temperature. The elongated grains preserve their shape and no corrosion is present.

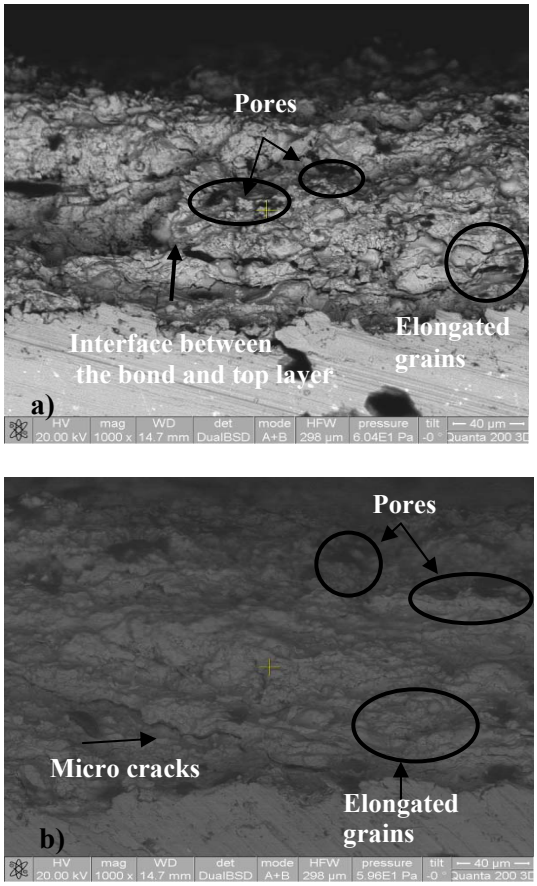

Fig. 4. Cross section SEM images of the $ZrO_2/20\%Y_2O_3$ coating with the thickness of 100 µm: a) before the corrosion test and b) after the corrosion test.

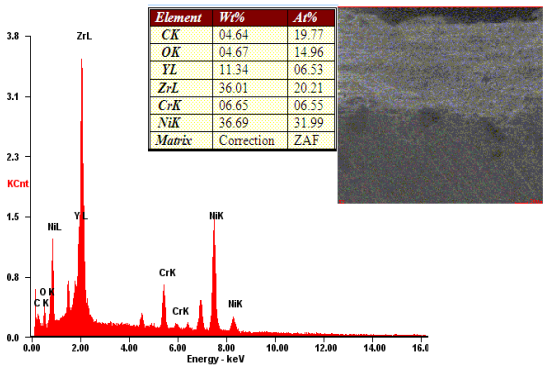

Fig. 5. EDAX of the $ZrO_2/20\%Y_2O_3$ ceramic layer after the corrosion test

From the elementary chemical analyses results that some chemical changes occurred due to the fact that traces of carbon are present

on the coating. The carbon comes from the chemical composition of the flue gases (Fig.5).

In Fig. 6 are presented cross section SEM imagines of the sample with the layer thickness of 200 µm, before and after the corrosion test. The bond layer shows a structure composed of elongated grains. [7] These grains are elongated due to the high kinetic energy of the sprayed plasma which converts to energy of variation of the shape. In the coating pores of different dimensions are also present (fig. 6-a). After the corrosion test it can be observed in Fig. 6-b that no significant changes appear in the coating. The grains have the same elongated shape, the pores tend to combine (coagulation) to the surface areas of the layer. Also some micro cracks are present in the layer.

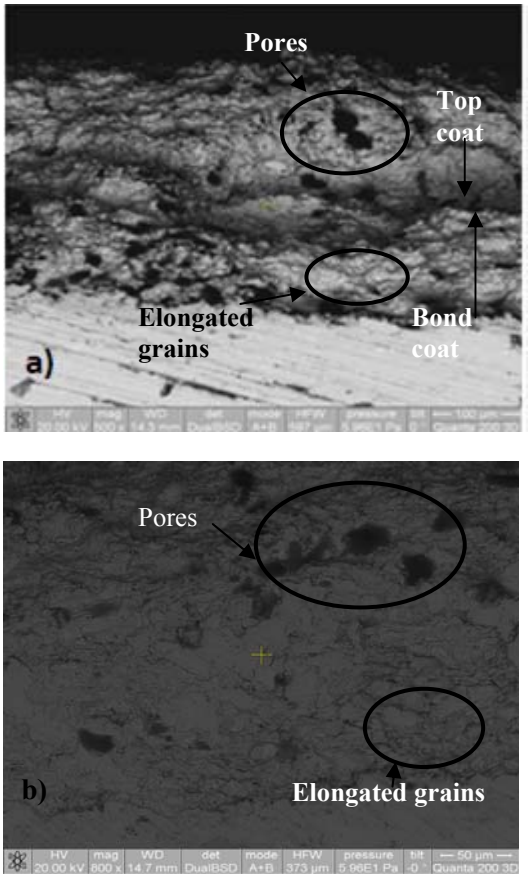

Fig. 6. Cross section of the ZrO_2/20%Y_2O_3 layer with the thickness of 200 µm: a) before corrosion test and b) after corrosion test

From the EDAX analyses carbon traces are present on the sample surface from the composition of the flue gas (fig. 7). [8]

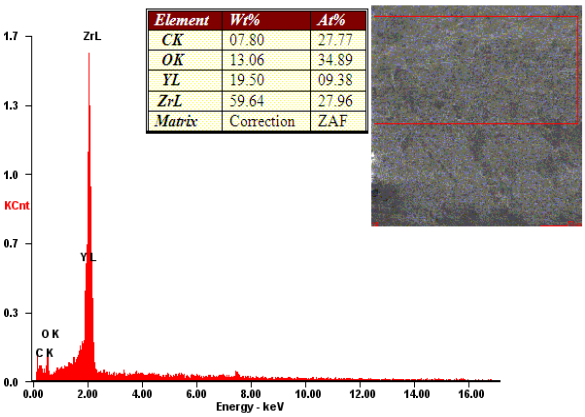

Fig. 7. EDAX chemical analyses of the 200 µm ZrO_2/20%Y_2O_3 ceramic layer

In Fig. 8 are presented SEM cross section images, before and after the corrosion test, of the sample with the layer thickness of 400 µm. The ceramic layer before corrosion test is presented in Fig. 8-a. The structure of the layer is uniform with pores of different dimensions with different orientations. After the corrosion test different dimension pores are also present, the bond layer is made of elongated grains and no corrosion zones are present at the interface between layers (fig. 8-b). [7]

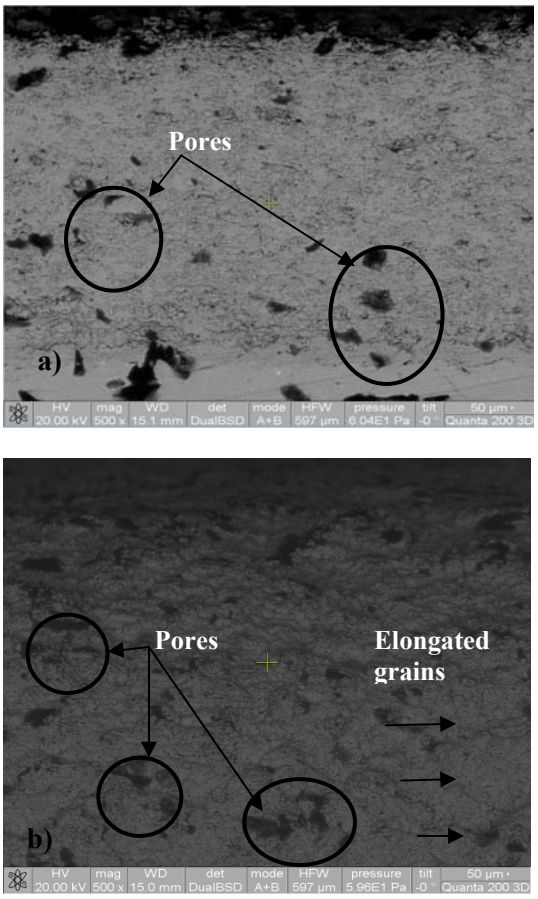

Fig. 8. SEM imagines of the 400 µm layer in cross section: a) before corrosion test and b) after corrosion test

Also in this case the EDAX analyses shows traces of carbon on the coating due to the flue gas composition (fig. 9).

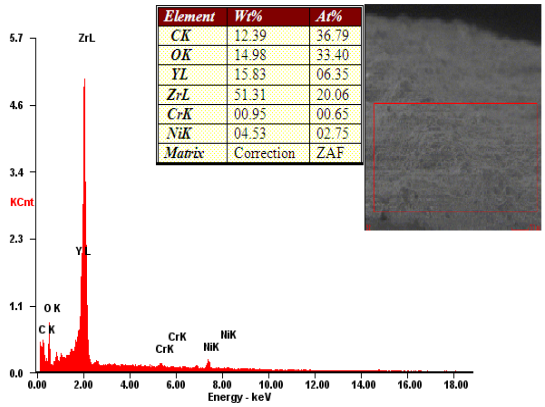

Fig. 9. EDAX chemical analyses of the ceramic layer with the thickness of 400 µm after the corrosion test

4. THE DINAMIC SORPTION CAPACITY OF WATER VAPORES

The vapore pressure in the sample chamber was made in steps of 10% humidity, each step having an equilibrium setting of 20-30 minutes. At each step the absorbed or lossed mass is recorded when equilibrium is reached.

Before the sorption - desorption isotherm mesurament, the drying of the samples is done using nitrogen flow (250 mL/min) at a temperature of 25°C untile the sample mass reaches a constant value at a relative humidity smaller then 1%. In Table 2 is presented the sorption capacity of the three samples.

Table 2. The sorption capacity of the samples depending on the coating thickness

Sample (µm)	Sorption capacity (%)
100	0.2996
200	0.1252
400	0.3398

The thin coating (100 µm) has a sorption capacity of around 0,3% and to drops in the case of the sample with the coating of 200 µm to the value of 0,125%, which implies a greater compactness of the layer. The layer with 400 µm thickness, due to a successive disposition of the splats with micro cracks between them, shows a greater sorption capacity of around 0,34%. The sorption/desorption isotherms recorded in this conditions are shown in Fig. 10, Fig. 11 and Fig. 12.

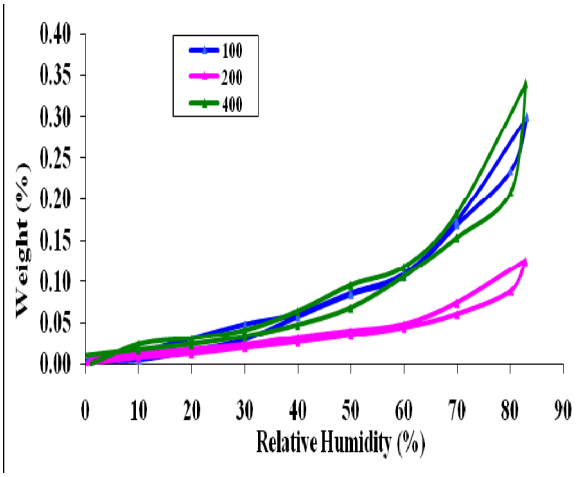

Fig. 10. Comparative representations of the sorption/ desorption isotherms

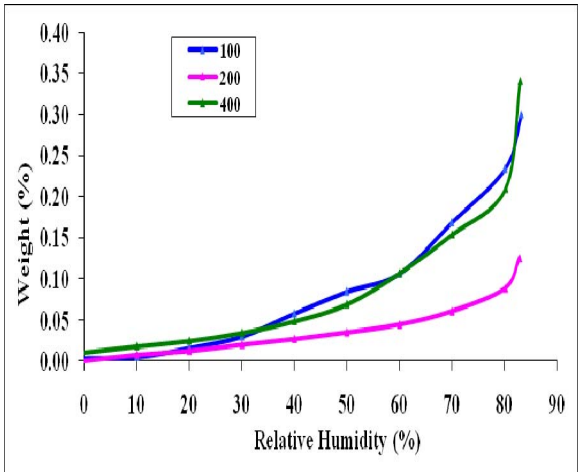

Fig. 11. Comparative representation of the sorption isotherms

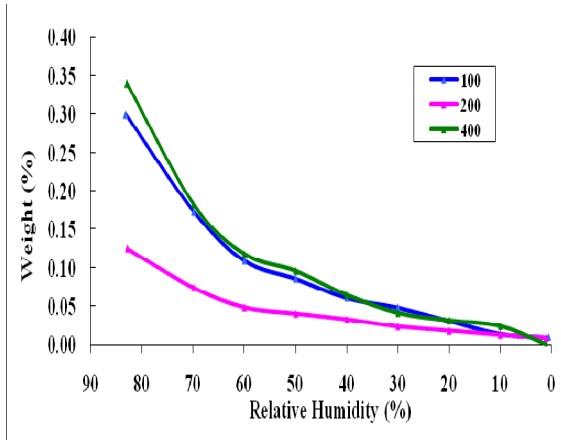

Fig. 12. Comparative representation of the desorption isotherms

5. CONCLUSIONS & ACKNOWLEDGMENT

The corrosion test is relevant because the turbine blades are corroded by the flue gases and the chemical behavior of the deposited ceramic coating is very important. The samples with the ceramic layer thickness of 200 µm and 400 µm behaved very well to the corrosion test and are recommended for deposition on turbine blades. The coating with the thickness of 100 µm was strongly influenced by the flue gases and presents exfoliation marks.

The low values of the water vapors sorption capacity for the studied samples prove their hydrophobic nature. The shape of the sorption/desorption isotherms for all samples can be correlated with type V according to the IUPAC classification. The hysteresis happens due to the different speeds for which the two physical processes take place. Also it can be concluded that the desorption speed is lower than the sorption one.

The sample with the layer thickness of 200 µm behaved better than the other two from the point of view of water vapors sorption. This is due to the greater compactness of the layer. It can be concluded that the layer with the thickness of 200 µm is recommended for turbine blade deposition from the point of view of water vapors sorption.

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