THE ADHERENCE OF A $ZrO_2/20\%Y_2O_3$ CERAMIC COATING ON A Ni BASE SUPER ALLOY FOR TURBINE BLADES APPLICATION

Crîșmaru Ionuț Vasile[1], Pintilei Geanina Laura[1], Marian Vasile Lozneanu[1], Paulin Constantin[1], Papatoiu Biniuc Carmen[1] and Munteanu Corneliu[1]

[1] *"Gheorghe Asachi" Technical University of Iasi, Faculty of Mechanical Engineering, 61-63 Prof. dr. doc. D. Mangeron Blvd, 700050, Iasi, Romania, crismaru.ionut@yahoo.com.*

Abstract: *Atmospheric plasma spraying (APS) is a widely used deposition method for obtaining variable thickness coatings on surfaces with different degrees of complexity. This paper presents a concept of thermal barrier coating which consists of a $ZrO_2/20\%Y_2O_3$ ceramic top layer and a Ni-22wt%Cr-10wt%Al-1wt%Y bond layer, both deposited by atmospheric plasma spraying (APS) on a Ni based super alloy. The analyzed samples were obtained by thermal deposition with the METCO 7 MB plasma jet installations. The paper analyzes the adhesion of the deposited coating on the base material. The adherence test was performed using the "scratch" method with UMTR 2M-CTR type tribometer. To assess the surface roughness measurements were conducted using Form Talysurf Intra system, manufactured by Taylor Hobson LEICESTER, ENGLAND. Highlighting and interpretation of the results were performed using scanning electron microscopy with Quanta 200 3D DUAL BEAM electron microscope.*

Keywords: *$ZrO_2/20\%Y_2O_3$, scratch, adhesion*

1. Introduction

The deposition of a ceramic layer on a Ni base super alloy aims to achieve a thermal barrier for the base material which has a great importance for the manufacturing of turbine blades used in aircraft turbine engine.[1,3]

The obtained quality for thermal spray coatings can be assessed by: adhesion, roughness, thickness, strength, porosity.[2,5] These aspects can be influenced by the technological parameters used for the adopted spraying methods.

Another important aspect which gives different layer properties is the material used to obtain de deposited layer.[4,5] This paper analyses the way how a $ZrO_2/20\%Y_2O_3$ layer, deposited by plasma jet method, behaves in terms of adherence on a Ni based super alloy.

Adhesion is a molecular or atomic interaction phenomenon acting on the contact area between two solid state material surfaces.[7,10]

This process is obvious when one of the two solid layers in contact is thin or has a small size. When the contact area of the surfaces is large, the real contact points will represent only a small part of the total area, therefore the specific adhesion of these points will be weak, related to the entire surface of the bodies. [9]

The materials plasticity has an important influence on adherence for materials in contact. With the increase of plasticity, the adhesion between the layers will be stronger.[11] The thermal state of the contact materials is another crucial factor to obtain a strong adhesion between layers. [12]

2. Materials, methods and instrumentation

The samples used for the scratch test were composed of a Ni super alloy base material on which a successive deposition was made using atmosphere plasma jet with a 7MB METCO type installation. The materials used for the deposition were a NiCrAlY bond material and $ZrO_2/20\%Y_2O_3$ as the top coat.

The coating material is produced by SULTZER METCO in the form of a powder. Because of the small adhesion strength between the deposited ceramic layer and the base material it is recommended to use an intermediate layer. Therefore we used Amdry 962 (NiCrAlY) powder as intermediate layer. The powder has excellent resistance to oxidation and corrosion at temperatures above 1050ºC (1323 K).

The commercial denomination of the ceramic powder used for plasma spraying is Metco 202NS (ZrO_2/20% Y_2O_3). This type of powder is widely appreciated because of the good behavior as insulator and very good resistance to thermal wear at temperatures above 980°C (1253 K). In Table 1 are presented the parameters used for the plasma jet deposition.

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 Quanta 200 3D electron microscope was used to perform secondary electron images and EDS analysis, working in the Low Vacuum module at pressures ranging from 50 to 60 Pa and using the LFD (Large Field Detector) detector (Fig.1).

Figure 1: *Quanta 200 3D electron microscope*

The scratch test conducted on the UMTR 2M-CTR type tribometer uses three methods to detect the coatings failure. Firstly, a load cell is used to measure the change of the friction force value, secondly the acoustic emission made by the cracks are detected and thirdly, after the test is complete, the scratch channel can be viewed using an optical or an electron microscope, to see how the crack has propagated.

The intensity of the acoustic emissions is dependent on the type of failure suffered by the coating during the adhesion test: cracking, chipping or delaminating.

For this reason is important to view how the coating had failed after the adhesion test and to confirm the critical load by analyzing the failure with a microscope.

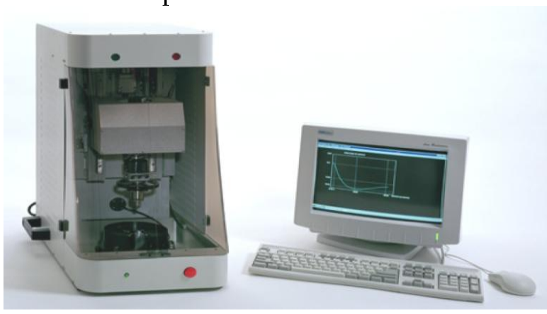

Figure 2: *CETR UMT-2 tribometer*

The method used to assess the analyzed layer in this paper is the progressive loading method (PLST - Progressive Load Scratch Test) and consists of applying a force gradually (from 0 - 19N) over the indentation for a defined period of one minute. The speed of the indentation is 10 mm/min. The indenter used is a DFH-20 Dual Friction/Load Sensor, which has been mounted with a micro blade with a peak radius of 0.4 mm.

By varying the spraying parameters different thicknesses of the TBC deposition coating are achieved. The thicknesses are 100 µm, 200 µm and 400 µm.

3. The scratch method used to determine the adhesion of the layer

There are three characteristic zones of the scratch indentation: the initiation zone (corresponding to the application of force from 0 N to 7 N), an intermediate zone (7-13 N) and the final (13 to 19 N). These zones were used to observe the behavior of the coating at progressive loading. After the scratch testing on the first samples it can be observed that the destruction of the layer starts from the final zone (corresponding to approximately 13 N of force after approximately 38 sec.). This can be seen in Fig. 3 on the SEM images and especially using the energy - dispersive X-ray spectroscopy performed on the final scratch, as can be observed in Fig. 4.

The third analysis performed is drawing the profilometry of the final segment of the scratch (Fig. 5). It can be seen that the destruction of the layer has a width of 1.2 mm and a depth of 185 µm.

By using the data from the chart presented in Fig. 6, calculations were carried out from which resulted that the exfoliation begun in the 38 second which corresponds to a force of 13 N.

On the same chart high variation of the friction coefficient are observed. The maximum value of the friction coefficient is 0,179. The variation of the friction coefficient is due to the porosity of the layer and the columnar stratified structure of the material. The friction coefficient drops to the value of 0,04 when the indenter reaches the base material.

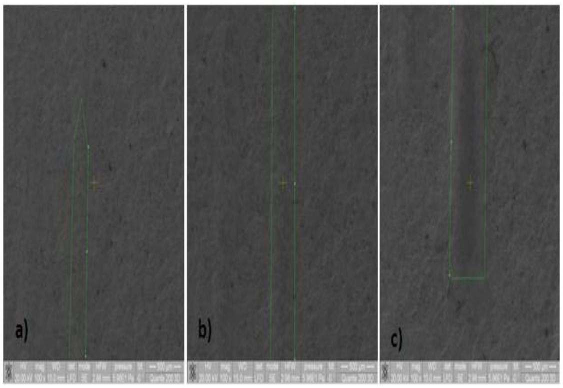

Figure 3: *SEM imagines of the scratch marks on the sample with the layer thickness of 100µm: a) initial zone (0 – 7 N), b) intermediate zone (7 – 13 N) and c) final zone (13 – 19 N)*

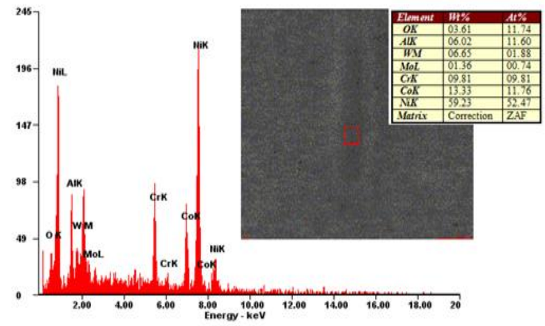

Figure 4: *Spectral analyses of the final mark of the scratch on the sample with the layer thickness of 100µm*

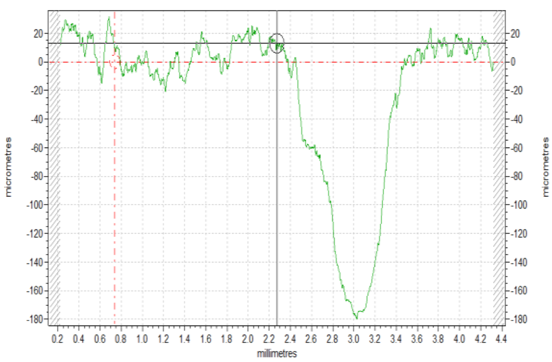

Figure 5: *The profile of the scratch for the 100µm layer sample*

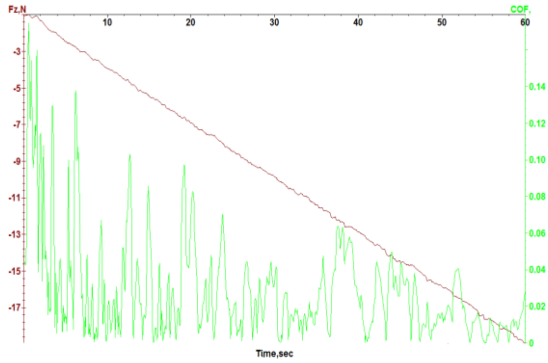

Figure 6: *The variation of the friction coefficient due to the progressive applied force*

For the sample with the layer thickness of 200 µm in Fig. 7 is observed that the coating was not affected visibly after the scratch test. The present three zones are: the initiation zone (corresponding to the application of force from 0 N to 4,5 N), an intermediate zone (4,5-14 N) and the final zone (14 to 19 N). The fact that no visible damage to the layer is produced is proved also by the spectral analyses from Fig. 8 on which only chemical elements specific to the layer are present: Zr, Y.

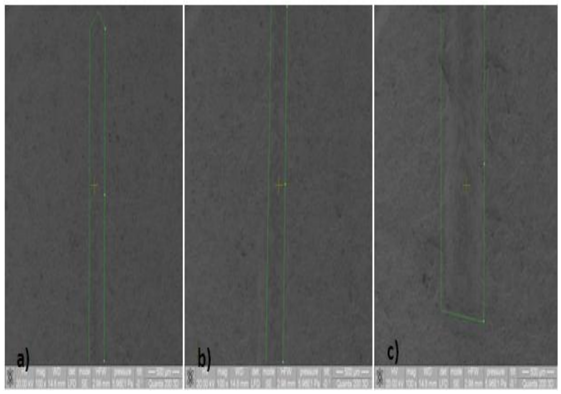

Figure 7: *SEM imagines of the scratch marks on the sample with the layer thickness of 200µm: a) initial zone (0 – 4,5 N), b) intermediate zone* (4,5 – 14 N) *and c) final zone* (14 – 19 N)

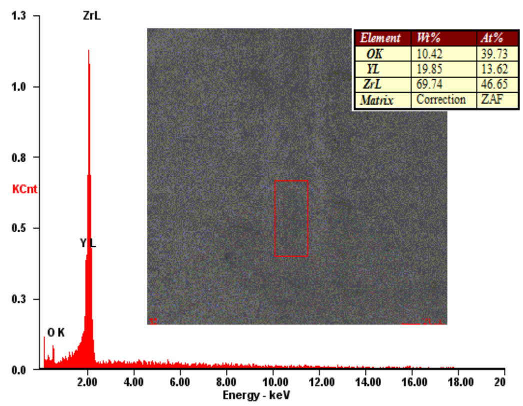

Figure 8: *Spectral analyses of the final mark of the scratch on the sample with the layer thickness of 200µm*

However, on the scratch profile presented in Fig. 9 a mark can be seen with a width of 0,8 mm and depth of 100 µm.

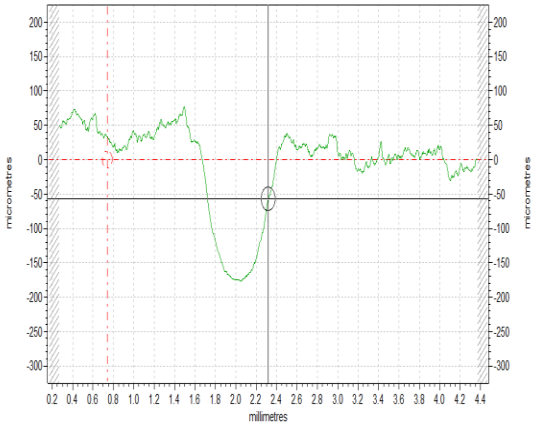

Figure 9: *The profile of the scratch for the 200µm layer sample*

On the chart resulted from the scratch test (Fig. 10) can be observed that in the first 15 sec the friction coefficient is high due to the pronounced porosity and after that it's decreases. This happens due to the smoothing of the coating. After the smoothing of the layer the friction coefficient value is around 0,03.

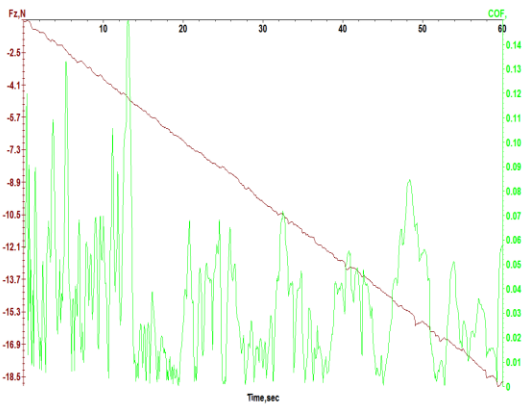

Figure 10: *The variation of the friction coefficient due to the progressive applied force for the sample with coating thickness of 200 µm*

For the sample with the coating thickness of 400 µm the behavior is similar to that of the coating with the coating thickness of 200 µm. In Fig. 11, which presents the SEM image of the coating, no notable marks can be seen (in all of the three zones of the test).

The integrity of the layer is also highlighted by the elementary chemical analysis which presents only the chemical elements specific to the layer.

On the scratch profile the indenter mark has the following dimensions: a width of 0,8 mm and a depth of 200 µm (Fig. 13).

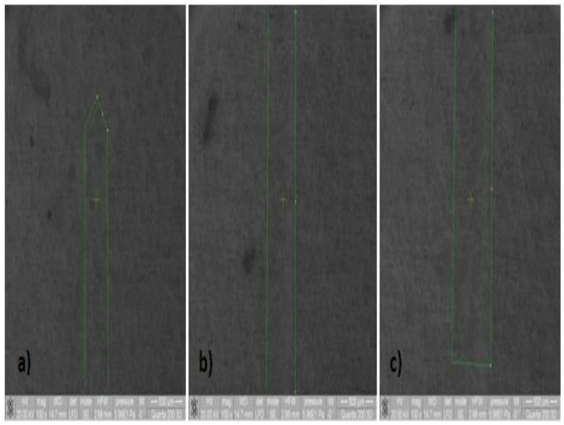

Figure 11: *SEM imagines of the scratch marks on the sample with the layer thickness of 400µm: a) initial zone (0 – 5 N), b) intermediate zone (5 – 13 N) and c) final zone (13 – 19 N)*

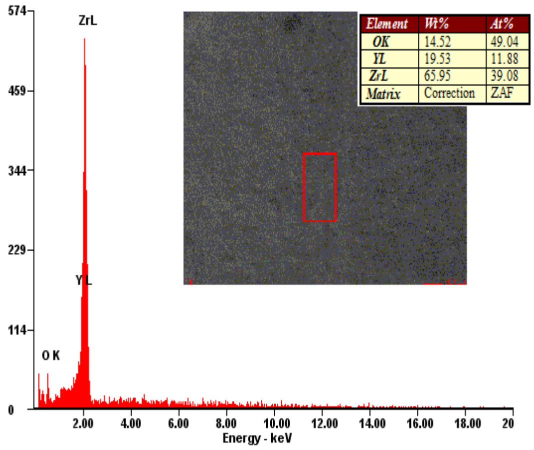

Figure 12: *Spectral analyses of the final mark of the scratch on the sample with the layer thickness of 400µm*

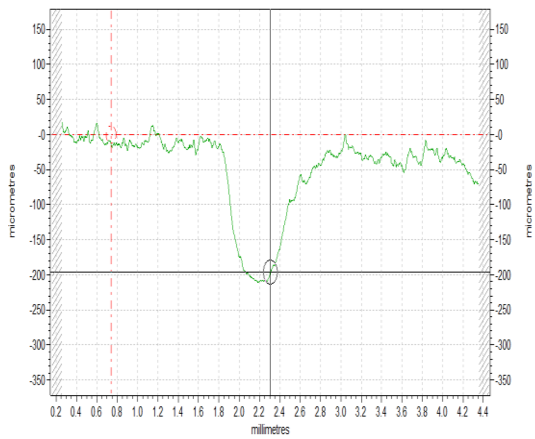

Figure 13: *The profile of the scratch for the 400µm layer sample*

In the first 12 sec of the scratch test, for the third sample, the friction coefficient is also high due to the porosity of the coating (Fig. 14.). With the increase of the applied force a smoothing of the layer happens so the friction coefficient decreases at a average value of 0,04.

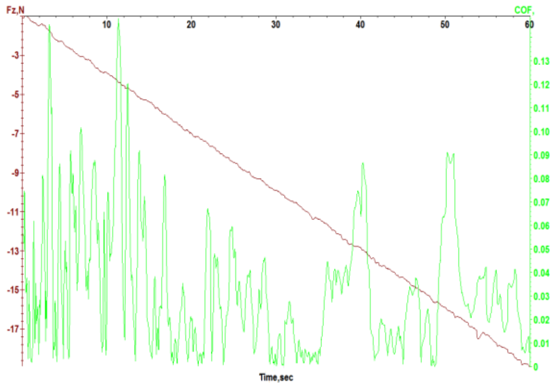

Figure 14: *The variation of the friction coefficient due to the progressive applied force for the sample with coating thickness of 400 μm*

Conclusions

The paper followed the influence of the deposited ceramic layer thickness concerning its properties and characteristics. To obtain different coating thicknesses, the number of passes of the spraying gun on the working surface was varied.

The coating adhesion testing was performed with the scratch method. The obtained results were conclusive regarding the adhesion of the layer and its minimal thickness. The samples with the layer thickness of 200 and 400μm had the best adherence to the base material, while the sample with the coating thickness of 100μm exfoliated in the final zone of the test. Given the harsh thermal and stress conditions in which turbine blades operate it is very important for the protecting ceramic coating of the layer to have a good adherence to the base material. In this respect the deposited coatings with thicknesses of 200 and 400μm are recommended for use on turbine blades.

References

[1] F. Petit, C. Ott and F. Cambier, *Multiple scratch tests and surface-related fatigue properties of monolithic ceramics and soda lime glass*, Journal of the European Ceramic Society, Volume 29, Issue 8, May 2009, Pages 1299-1307

[2] Per-Lennart Larsson, *On representative stress correlation of global scratch quantities at scratch testing of elastoplastic materials*, Materials & Design, In Press, Accepted Manuscript, Available online 13 February 2013

[3] Dipankar Ghosh, Ghatu Subhash, Ramachandran Radhakrishnan, *Tirumalai S. Sudarshan, Scratch-induced microplasticity and microcracking in zirconium diboride–silicon carbide composite,* Acta Materialia, Volume 56, Issue 13, August 2008, Pages 3011-3022

[4] N. Schwarzer, Q.-H. Duong, N. Bierwisch, G. Favaro, M. Fuchs, P. Kempe, B. Widrig and J. Ramm, *Optimization of the Scratch Test for specific coating designs*, Surface and Coatings Technology, Volume 206, Issue 6, 15 December 2011, Pages 1327-1335

[5] Aleksandar Vencl, Saioa Arostegui, Gregory Favaro, Fatima Zivic, Mihailo Mrdak, Slobodan Mitrović and Vladimir Popovic, *Evaluation of adhesion/cohesion bond strength of the thick plasma spray coatings by scratch testing on coatings cross-sections,* Tribology International, Volume 44, Issue 11, October 2011, Pages 1281-1288

[6] Y Xie and H.M Hawthorne, *A controlled scratch test for measuring the elastic property, yield stress and contact stress–strain relationship of a surface*, Surface and Coatings Technology, Volume 127, Issues 2–3, 22 May 2000, Pages 130-137

[7] Y Xie and H.M Hawthorne, *On the possibility of evaluating the resistance of materials to wear by ploughing using a scratch method*, Wear, Volume 240, Issues 1–2, May 2000, Pages 65-71

[8] V. Bellido-González, N. Stefanopoulos and F. Deguilhen, *Friction monitored scratch adhesion testing*, Surface and Coatings Technology, Volumes 74–75, Part 2, October 1995, Pages 884-889

[9] V. Cannillo, L. Esposito, E. Rambaldi, A. Sola and A. Tucci, *Microstructural and mechanical changes by chemical ageing of glazed ceramic surfaces*, Journal of the European Ceramic Society, Volume 29, Issue 9, June 2009, Pages 1561-1569

[10] F. Petit, V. Vandeneede and F. Cambier, *Ceramic toughness assessment through edge chipping measurements—Influence of interfacial friction*, Journal of the European Ceramic Society, Volume 29, Issue 11, August 2009, Pages 2135-2141

[11] T. Sander, S. Tremmel and S. Wartzack, *A modified scratch test for the mechanical characterization of scratch resistance and adhesion of thin hard coatings on soft substrates*, Surface and Coatings Technology, Volume 206, Issue 7, 25 December 2011, Pages 1873-1878

[12] Y Xie and H.M Hawthorne, *A model for compressive coating stresses in the scratch adhesion test*, Surface and Coatings Technology, Volume 141, Issue 1, 4 June 2001, Pages 15-25

[13] Mustafa Özgür Bora, Onur Coban, Tamer Sinmazcelik, Volkan Günay and Muzaffer Zeren, *Instrumented indentation and scratch testing evaluation of tribological properties of tin-based bearing materials*, Materials & Design, Volume 31, Issue 6, June 2010, Pages 2707-2715

Acknowledgements

We thank to SC Plasma Jet SA for the support in the plasma jet deposition of the analyzed layer from this paper.

I give thanks to the Faculty of Mechanics for the support and for making available the science of materials and Materials Science laboratories for performing the necessary tests for the paper.

I give thanks to the Faculty of Mechanics for the support and for making available the science of materials and tribology laboratories for performing the necessary tests for the paper.