Plasma sprayed coatings on crankshaft used steels

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Abstract. Plasma spray coatings may be an alternative to conventional heat treatment of main journals and crankpins of the crankshaft. The applications of plasma coatings are various and present multiple advantages compared to electric arc wire spraying or flame spraying. The study examines the layers sprayed with the following powders: Cr3C2- 25(Ni 20Cr), Al2O3-13TiO2, Cr2O3-SiO2- TiO2 on the surface of steels used in the construction of a crankshaft (C45). The plasma spray coatings were made with the Spray wizard 9MCE facility at atmospheric pressure. The samples were analyzed in terms of micro and morphological using optical microscopy, scanning electron microscopy and X-ray diffraction. Wear tests on samples that have undergone simulates extreme working conditions of the crankshafts. In order to emphasize adherence to the base material sprayed layer, were carried out tests of micro-scratches and micro-indentation. Results have showed a relatively compact morphological aspect given by the successive coatings with splat-like specific structures. Following the micro-scratch analysis it can be concluded that Al2O3-13TiO2 coating has a higher purpose in terms of hardness compared to Cr3C2-(Ni 20Cr) and Cr2O3-SiO2- TiO2 powders. Thermal coatings of the deposited powders have increased the mechanical properties of the material. The results stand to confirm that plasma sprayed Al2O3-13TiO2 powder is in fact a efficient solution for preventing mechanical wear, even with a faulty lubrication system.

1.Introduction

Steel C45 is used in many industrial sectors with scope plentiful due to very good combined properties. C45 steels are often used in the construction of crankshafts (1) In order to improve properties such as wear resistance and increased life expectancy, apply various thermal treatments such as APS (atmospheric plasma deposition), HVOF, PLD, carburizing, nitriding, chrome plating, carbonitriding and so on (2,3,4). Spraying the plasma jet is a practical and effective method by which is increasing the wear resistance of coatings, corrosion and high temperatures. (5) Plasma jet spraying has multiple applications in the aviation industry, auto oil extraction of gas.(6)Have been carried out multiple research with regard to the deposits in a jet of plasma on the surface of a steel C45, the most common method to deposit in a jet of plasma being nitriding according to T.Bell and H. Liu studies (7,8). Unlike the classical nitriding, plasma nitriding, the jet of material is subject to a flow of ions, and neutrons in the plasma discharge, thus yielding values even 1200 HV hardness of the layer (9).

Oxi-nitriding is a more efficient method, layers having regard enhanced properties from the method of nitriding in a jet of plasma, so the hardness of the deposited layer and the resistance to corrosion being improved in the Fe3O4 and Fe2O3 obtained as a result of the process of oxi-nitriding (10,11). Plasma nitriding requires a high consumption of energy and time, sometimes even a few hours in order to obtain the thickness of the layer and the desired properties unlike oxi-nitriding.(12) . Xuemei Ye and collaborators have conducted research with nitrocarburizing in plasma jet using the propane as a spray gas, so the rate of nitrocarburizing increased significantly, increasing the thickness and the hardness of the layer, but by subtracting subsequently once with the increase of the quantity of propane (13). Duplex treatment is another way to improve mechanical properties. (14)

A study reveals that the duplex treatment nitriding and aluminizing applied to a C45 steel, is very important the order of submission, so nitriding followed by aluminizing provide the steel very good properties in terms of microstructure and hardness, in reverse, the hardness values are lower . (15) F. Hakami et al conducted a study on the duplex treatment on a C45 steel chrome plating followed resulting from plasma nitriding, the study reveals that the deposited layer resistance was significantly increased compared with initial treatment chromium values reaching 1540 HV to 1270 HV using simple chrome plating . (16,17) In order to deposit a layer using plasma jet coating are very important the parameters to work with as in the case of a layer of Al2O3TiO2 analysis of nanostructures and testing reveals that there may be significant changes, so the values of the hardness of the layer can vary from 611 HV to 772 HV if a variation current from 550A to 650A. (18,19,20)

2. Experimental research

The alloy used in this study is a C45 with components in Table 1.

Table 1. Chemical composition of base material.

C45	**C**	**Si**	**Mn**	**S**	**P**
%	0.45	0.17	0.52	0.031	0.032

There were eight samples for processing, having dimensions of 30 X 10 X 2 mm. The samples were prepared for metallographic microstructure study using sandpaper of 200, 500, 800, 1200 that are introduced subsequently cleaned with alcohol and reagent NITAL 2% for chemical attack.

On the surface samples were performed a coating process using plasma spray powders: Metco 130: Al2O3-13TiO2, Metco 81NS: Cr3C2-25 (Ni20Cr) and Amdry 6462: Cr2O3-SiO2-TiO2.The deposits were made using SPRAYWIZARD 9MCE plasma equipment produced by Sulzer Metco. All deposits were made with the same spray parameters (Table 2).

Table 2. Technological parameters used for coating process.

	Powder		
Technological parameters	Al2O3-13TiO2	Cr3C2-25(Ni20Cr)	Cr2O3-SiO2-TiO2
Spray distance, (mm)	100	100	100
Injector	1.8	1.8	1.8
The intensity of plasma gas, (A)	600	600	600
The arc voltage (U)	75	75	75
Rotation speed (rot/min)	55	55	55
Argon flow rate (m3/h)	50	50	50
Hidrogen flow rate (m3/h)	14	14	14
Spray distance, (mm)	100	100	100
Injector	1.8	1.8	1.8
The intensity of plasma gas, (A)	600	600	600

Microstructure and morphology of specimens was highlighted using optical and electron microscopy. For optical microscopy was used DMI5000 microscope Leica M, with Leica HCS optical

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system and a magnification from 1.5X to 250X. For electron microscopy was used SEM electron microscope QUANTA 3D Dual Beam, manufactured by Dutch EIF. High Vacuum mode was used and LFG detector type (Large Field Detector). We have obtained magnification 500X, 1000X and 5000X with a working distance of about 15 mm. X-ray diffraction was performed using X-ray diffractometer, X 'Pert Pro MRD, endowed with an X-ray tube with Cu kα anode, λ = 1.54 Å, using a voltage of 45kV with an intensity of 40 mA, the angle of diffraction (2θ) ranging between 25 and 130º. Testing adhesion layers deposited on the surfaces was carried out by micro-scratch method and the indent method using tribometer CETR UMT-2, equipped with an indenter type DFH-20 Dual Friction / Load Sensor, which was mounted a blade whose top has radius 0.4 mm. The advance speed of the indenter was 10 mm / m.

3.Results and discussion

In Figure 1, we notice the SEM images of the powder obtained from the spraying SEM Metco 130. In the images of Figure 3 after the scratch test, small areas of delamination of the layer, can be seen highlighted by the appearance of the base material. Layer was not completely removed, which means a good grip and exfoliate areas were due to inhomogeneity and unmelted particles segregation. The layer thickness has approximative 40.8 μm.

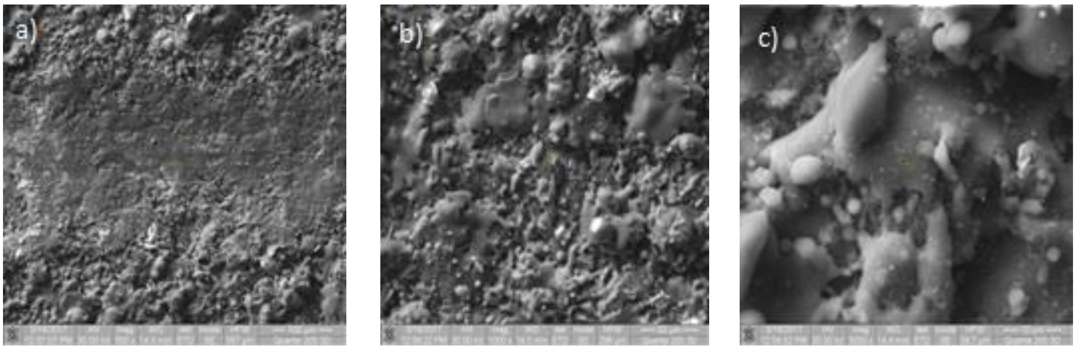

Figure 1. SEM images obtained after spraying with Metco 130; enlarged images at: a)500X, b) 1000X, c) 5000X.

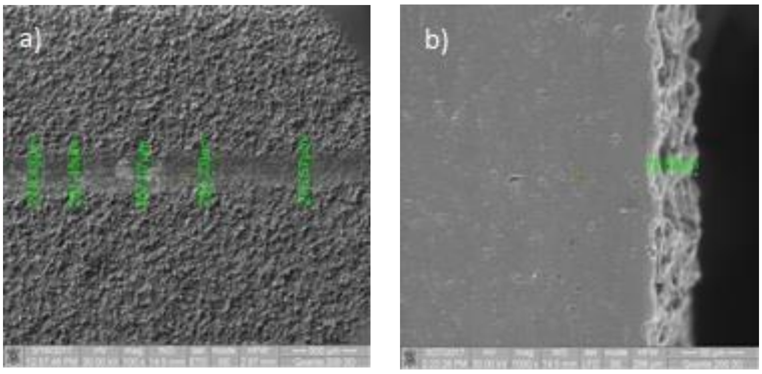

Figure. 2. SEM images obtained after spraying with Metco 130: a) microscratch b) layer thickness.

The morphology of the powder Metco 81NS shows a more compact structure (figure 3), with splats, no unmelted particles, and isolated areas of segregation with unmelted particles. Note few defects, such as pores and cracks. The layer is more adherent, such that after scratch test, the layer was not destroyed, falling short to the base material. The thickness of the deposited layer, reaching values of 92.38 micrometres, higher value compared to Metco 130 powder spraying (figure 4b).

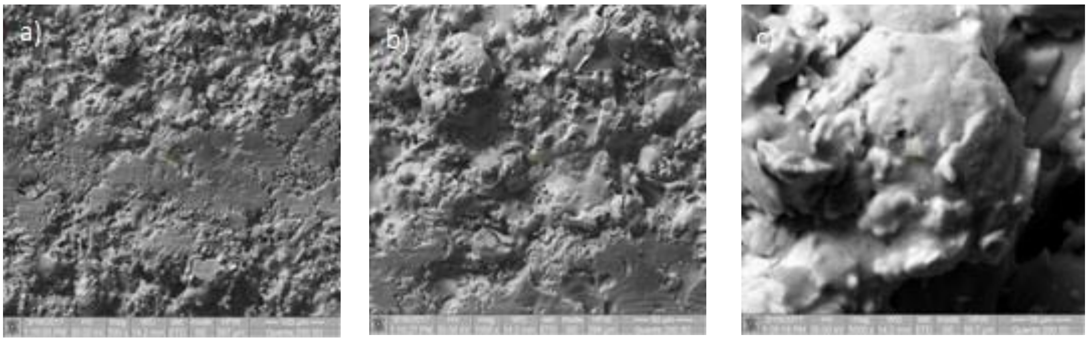

Figure 3. SEM images obtained after spraying with Metco 81NS; enlarged images at:
a) 500X, b)1000X, c) 5000X.

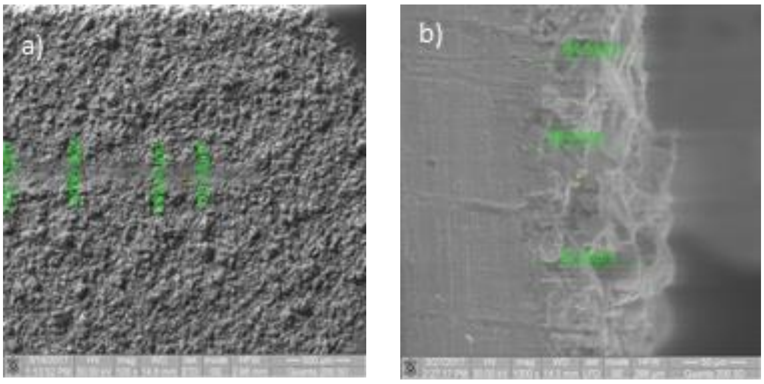

Figure 4. SEM images obtained after spraying with Metco 81NS:
a) scratch test, b) layer thickness.

The structure obtained after spraying with Amdry 6462, shows a non-uniform with low isolated splats and limited areas of segregation o funmelted particles , as can be seen in figure 6. Also a sharp porosity and micro cracks are isolated. Following the micro-scratch test (figure 5a) was found lower adherence than the other two coatings so that after the test were achieved highlighting large areas of the base material. The thickness reached the maximum values of 44.89 μm (figure 6b).

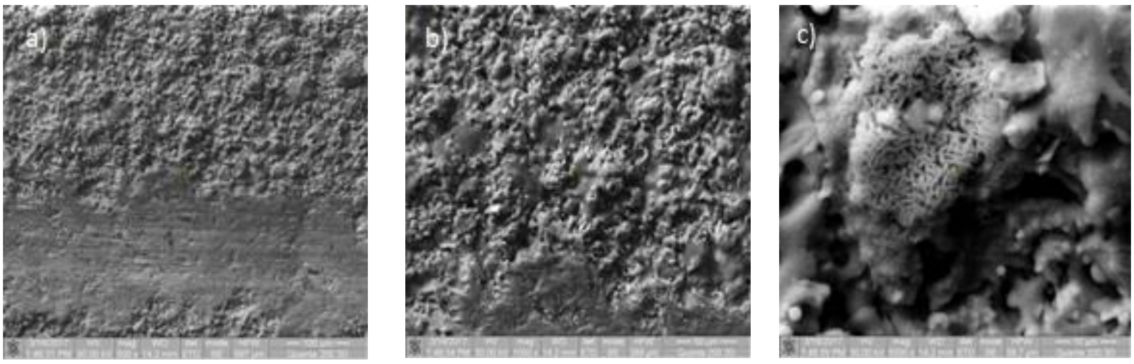

Figure 5. SEM images obtained after spraying with Amdry 6462; enlarged images at:
a) 500X, b) 1000X, c) 5000X.

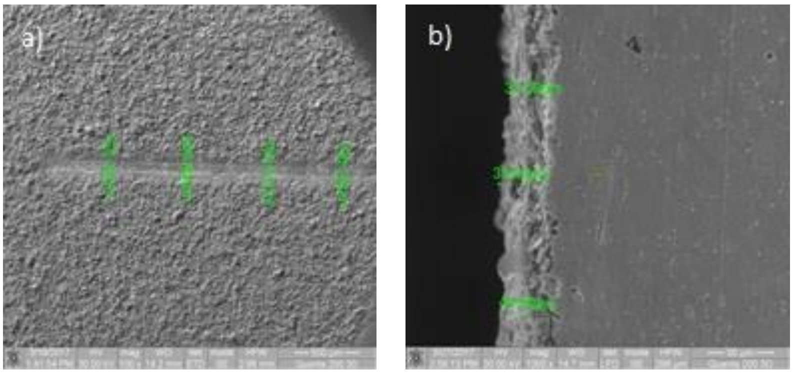

Figure 6. SEM images obtained after spraying with 6462 Amdry:
a) scratch test, b) layer thickness.

In figure 7, it can be observed the SEM images of base material, steel C45. It highlighted a ferritic-pearlitic structure having equiaxed grains, relatively even-grained. Note the inclusion of small, isolated, tendencies of segregation. Layers made of non-uniform structural porosity and cracks isolated. Splats are seen surrounded by unmelted particles.

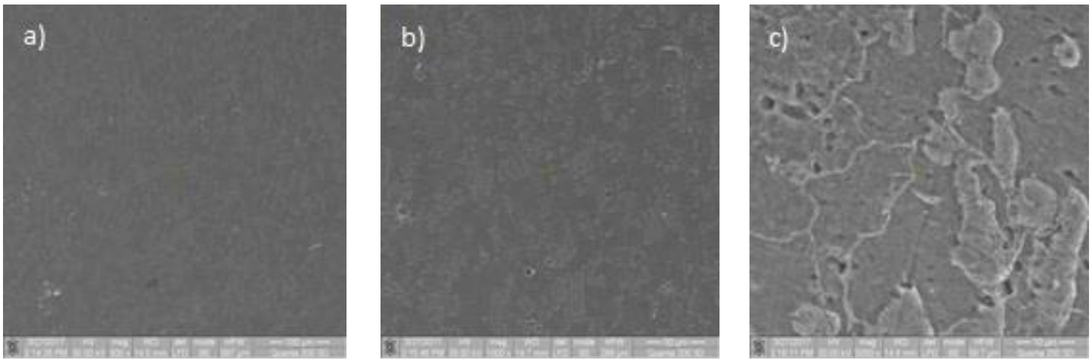

Figure 7. SEM images of the base material, C45 steel; enlarged images at:
a) 500X, b) 1000X, c) 5000X.

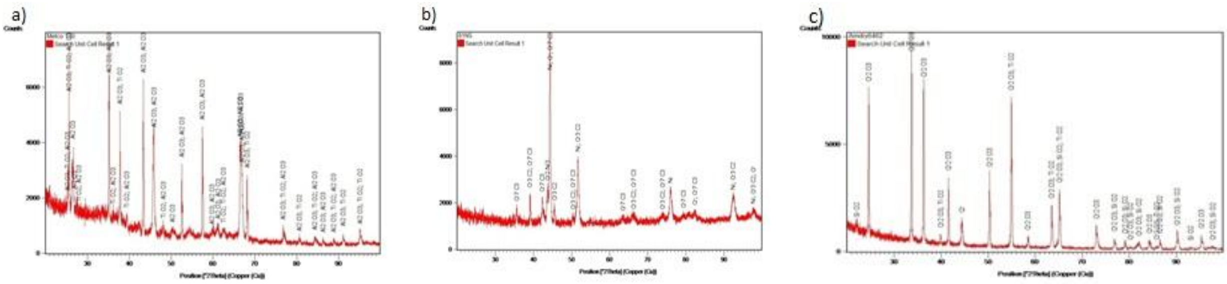

Figure 8. X-ray diffraction patterns for powders : a) Metco 130, b) 81NS Metco,
c) Amdry 646.

The XRD patterns of the 3 powders used: Metco 130, Metco 81NS and Amdry 6462 can be observed in figure 8.The predominant phases identified in figure 8, of Al_2O_3 has characteristic peaks at 34,47°,36,47 °, 45,49° and 67,11°. Al_2O_3 is identified by a tetragonal crystalline structure. TiO_2 is revealed through 2 anatase and rutile form with characteristic peaks at 25,27°, 27,47°, 36,08°, 48,03° and 54,37°. Rutile and anatase have a tetragonal structure. Cr can be observed in figure 8b, showing a crystalline cubic structure, with characteristic peaks at 44,58°, 64,65°and 82,31°. Cr_2Ni_3 with a cubic type structure has the characteristic peaks at 43,75°, 50,97°, 74,96° and 91,05°. Cr_3C_2

compound shows characteristic peaks at 39,04°, 40,23°, 46,59° and 48,69°. Cr3C2 has a orthorhombic type structure. Predominant phases of Cr7C3 have characteristic peaks at 39,21°, 39,35°, 42,58° and 44,20°. The same as Cr3C, Cr7C3 has a orthorhombic type structure. Ni has characteristic peaks at 44,26°, 51,57°, 75,93° and 92,33 with a cubic type crystalline structure.

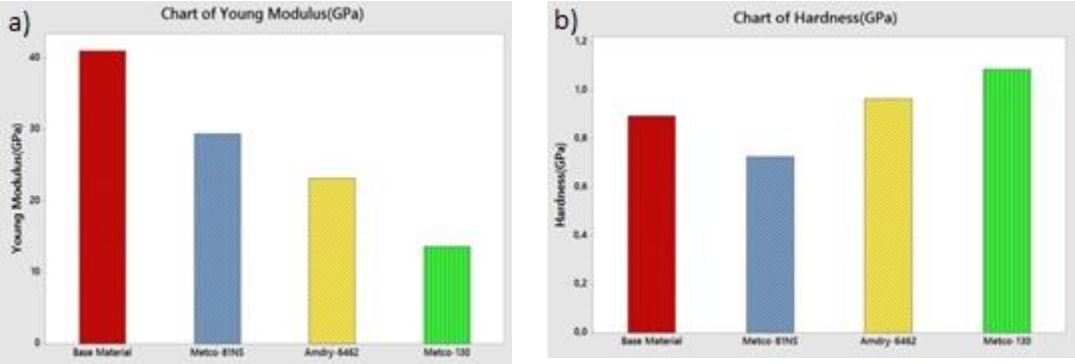

Figure 9. Compared graphics: a) Young's modulus (GPa), b) Hardness (GPa).

The Amdry 6462 powders XRD can be seen in fig 8c, has Cr in component, with a cubic type structure and characteristic peaks at 44,3° and 81,68°. Cr2O3 shows peaks at ,62°, 36,23° and 54, 89°. If the Cr2O3 has a rhomboid like structure, the SiO2 and TiO2's crystalline structure is tetragonal.
The friction coefficient has similar values for all 3 powders, considerably less than the base material. The average coverage is approximately equal to the base material. Unlike the Metco 81 NS powder plasma deposition, Metco 130 and Amdry 6462 have superior hardness values compared to the base material which leads to an increased wear resistance.

The values for the modulus of elasticity of the base material are superior to the 3 depositions, Metco 81NS being the weakest. This shows increased rigidity of the layers deposited compared with the base material surface.

Table 3. Mechanical properties of coatings.

Powder	Young'smodulus(Gpa)	Hardness(Gpa)	Stiffness (N/µm)	COF
Metco 81 NS	13.63	0.726	2.185	0.6101
Metco 6462	23.12	0.966	3.193	0.662
Metco 130	29.36	1.087	3.795	0.655
Base material	40.98	0.896	5.773	1.158

4. Conclusions

Although the powders were deposited in the same processing parameters were recorded different values of the thickness of the layers of 40.8µm maximum values for the Metco 130, respectively 92.38µm 44.89µm for the Metco 6462 Amdry 81NS.
Microscopic analysis shows that the deposited layers using plasma jet deposition method is an effective method, deposited layers having a low porosity, is tough and has no major defects, just cracks and cracks isolated.
XRD analysis reveals that the layers deposited have a complex microstructural feature and requires no initial deposit layers across work what involved increased costs and more time spent filing.

The coefficient of friction for the three powders have similar values like the base material. The values of the modulus of elasticity for the particulate deposited base material are inferior, but the hardness of the coating layers is superior to the base material, except for the Metco 81NS.

5. References

[1] Han L, Jingcai L, Yating C, Wei W , Jing H 2015 A novel plasma oxynitriding by using plain air for AISI 1045 steel, *Vacuum* **121** pp 18-21
[2] Hermann H, Sampath S, McCune R, 2000 Thermal Spray: Current status and future trends *Volume* **25** pp 17-25
[3] Mareci D, Cimpoesu N, Popa, M 2012 Electrochemical and SEM characterization of NiTi alloy coated with chitosan by PLD technique, *Materials and Corrosion* **63** pp 985-991
[4] Paulin C, Chicet D L, Istrate B, Panţuru M, Munteanu C 2016 Corrosion behavior aspects of Ni-base self-fluxing coatings, *IOP Conference Series: Materials Science and Engineering* **147** Article number 012034
[5] Davis J R (Ed.) 2002 Surface Hardening of Steels: Understanding the Basics, ASM International, Materials Park, OH pp 1-16
[6] Reeve C 2001 Thermal Spray – Coating: Better performance for less, *Machine Design*, pp 73-76.
[7] Bell T, Y. Sun Y, Suhadi A 2000 *Vacuum* **59** pp 14-23.
[8] Liu H, Li J C, Sun F, J. Hu, 2014, *Vacuum* **109** pp 170-174.
[9] Çetin A, Tekb Z, Öztarhan A, Artunç N 2007 A comparative study of single and duplex treatment of martensitic AISI 420 stainless steel using plasma nitriding and plasma nitriding-plus-nitrogen ion implantation techniques, *Surface & Coatings Technology* **201** pp 8127–8130
[10] Liu H , Li J , Chai Y, Wei W , Hu J 2015 A novel plasma oxynitriding by using plain air for AISI 1045 steel, *Vacuum* **121** pp 18-21
[11] Kou L, Hyun, Ki Suk N, Pyung Woo S 2003 Mater Letters **57** pp 2060-2065
[12] Li J C, Yang X M, Wang S K, Wei K X, Hu J 2014 Material Letters **116** pp 199-202
[13] Ye X, Wu J, Zhu Y, Hu J 2014 A study of the effect of propane addition on plasma nitrocarburizing for AISI 1045 steel, *Vacuum* **110** pp 74-77
[14] Meletis E I,Erdemir A, Fenske G R 1995 Surface and Coatings Technology, *Volume* **73** pp 39-45
[15] Haftlang F , Habibolahzadeh A, Sohi M H 2014 Duplex treatment of AISI 1045 steel by plasma nitriding and Aluminizing, *Vacuum* **107** pp 155-158
[16] Hakami F, M. Sohi M H , Ghani J R 2011 Duplex surface treatment of AISI 1045 steel via plasma nitriding of chromized layer, *Thin Solid Films* **519** pp 6792–6796
[17] Ahangarani Sh, Mahboubi F, Sabour A R 2006 *Vacuum* **80** pp 1032-1034
[18] Rahim A, Sahaba M, Saadb N H, Kasolangb S, and Saedonb J 2012 Impact of Plasma Spray Variables Parameters on Mechanical and Wear Behaviour of Plasma Sprayed Al2O3 3%wt TiO2 Coating in Abrasion and Erosion Application, *Procedia Engineering* **41** pp 1689 – 1695
[19] Żórawski W, Góral A, Bokuvka O, Berent K 2013 Microstructure and mechanical properties of plasma sprayed nanostructured and conventional Al2O3–13TiO2 coatings, *Proceedings of the International Thermal Spray (ITSC) Conference*. Busan, Republic of Korea
[20] Kim G E,Thermal Sprayed 2011 NanostructuredCoatings: Applications and Developments, *Perpetual Technologies, Inc., Ile des Soeurs*, Quebec, Canada pp 91-92