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TRIBOLOGICAL AND QUICK THERMAL EVALUATION OF PROTECTIVE COATINGS FOR AEROSPACE AND METALLURGY

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Abstract: *Hot parts of turbo engines as well as those working in extreme conditions in the metallurgical industry are subject to complex loads, leading to wear factors that sometimes work together: temperature, thermal shock, erosion, corrosion, sliding friction, etc.*

The paper presents the types of protective structures developed, techniques used, methods of testing, investigation and results.

Protective materials used are from the class of ceramics such as M/MeCrAlY/ $ZrO_2 \cdot Y_2O_3$ *(CaO, MgO, CeO), Me/NiCrAlY/*Y_2O_3-Yb_2O_3-GdO_3-Nd_2O_3-ZrO_2/ZrB_2 *and other variants, as well as the type of complex alloys associated with Cu support. The techniques used for creating protection layers are EB-PVD coating or WIG welding.*

By tribological or extreme thermal testing on a facility design and made within INCAS, it was verified experimentally the basic properties of the protected structures.

Stand tests made on real components, successfully validate the materials and technology solutions we designed.

Keywords: *Tribology, coating, EB-PVD, high temperature, multiplex structure*

1. INTRODUCTION

The protection systems imposed as a solution to increase the life of some components from aircraft due to the limitation imposed by the thermo-mechanical properties of the materials but as well as a necessity in the other related fields. The effects which appear further to the degradations as corrosion at high temperatures, oxidation, erosion with pyrolyzed particles, wear, thermal degradation by overheating, and thermal fatigue, which are known further to the functional conditions can be minimize by protection coatings. The protection ceramic layers, thermal barrier coatings (TBC) are used both in aero spatial industry and in the machine building industry, metallurgy, power systems and electronics.

For aerospace industry two types of protection systems are used: TBC and FGM (functionally graded materials). Thermal

barrier coatings are thin layers of ceramic composites based on Zr, Al, Ti, B, Gd, etc. deposited on a metallic support [1].
So, a system of thermal barrier layers is formed from a high alloy metallic support resistant at temperature, a bonding layer an oxide layer - TGO (thermally grown oxide) and an external thermal resistant layer. Together the TBC and metallic support form a complex system of materials [3].

For metallurgical industry a protection system associated to some extreme stressed parts as tuyere from steel plants is formed from a metallic support, usually electrolytic cooper and a complex alloy based on Ni and Co which are deposited by an electric welding technology in protective atmosphere, argon inert gas – WIG (wolfram inert gas) [4].

The paper also shows, the conceive method and the installation made by authors to evidence the behaviour of the multiplex protective structures against the most perturbing wear factor – thermal shock.

The wear factors associated to the tuyere are: temperatures > 1000° C, quick thermal shock, erosion, hot corrosion, and metal liquid contact.

2. MATERIALS AND OBTAINING METHOD

2.1 Materials

The materials used for hot parts of aero engines are:

1. Duplex layers - MeCrAlY/$ZrO_2$20%Y_2O_3
2. Triplex FGM type
3. Triplex layers type: MeCrAlY/MeCrAlY90% + Al_2O_3 10%/ $ZrO_2Y_2O_3$
4. NiCoCrAlY/ Al_2O_3 /$ZrO_2Y_2O_3$
5. NiCoCrAlY/ Al_2O_3 +$ZrO_2Y_2O_3$/ $ZrO_2Y_2O_3$
6. NiCoCrAlY/$ZrO_2Y_2O_3$ Nano
7. Duplex NiCoCrAlY/$ZrO_2Y_2O_3$ CeO_2, NiCoCrAlY/ $ZrO_2Y_2O_3$ TiO_2
8. Me/NiCrAlY/Y_2O_3-Yb_2O_3-GdO_3-Nd_2O_3-ZrO_2/ZrB_2 [5,6]

The materials used for the experimental program of the protective coatings are complex alloys:

- Ni, Cr, Si, B, Fe
- Ni, Cr, Si, B, Mo [7]

2.2 Obtaining method

The methods used in the case of the thermal barrier layers resistant at wear for the hot parts of aircraft are:

- Air plasma spray (APS)
- Non-conventional methods: PVD – Physical Vapor Deposition; cathodic deposited pulverization (sputtering)
- Wolfram inert gas equipment - WIG

3. SPECIMEN

In figures 1, 2 and 3 are presented, for aircraft industry the specimen support (fig. 1), the specimen no.9 - NiCrAlY/Al_2O_3 + $ZrO_2Y_2O_3$ before being tested (fig. 2) and the same specimen after being tested at 800° C (fig. 3). [5,6,7,8].

Figure 1. Specimen support for aircraft industry

Figure 2. Specimen for aircraft industry before being tested – C9 - NiCrAlY/Al_2O_3 + $ZrO_2Y_2O_3$

Figure 3. Specimen C9 - $NiCrAlY/Al_2O_3+ZrO_2Y_2O_3$ for aircraft industry after being tested at 800°C

In figures 4, 5 and 6 are presented, the specimen support (fig. 4) for the metallurgical industry, the specimen Cu/Casto TIG (cooper and silver alloy) before being tested (fig. 5) and the same specimen after being tested at T=1000° C (fig. 6) [4,6].

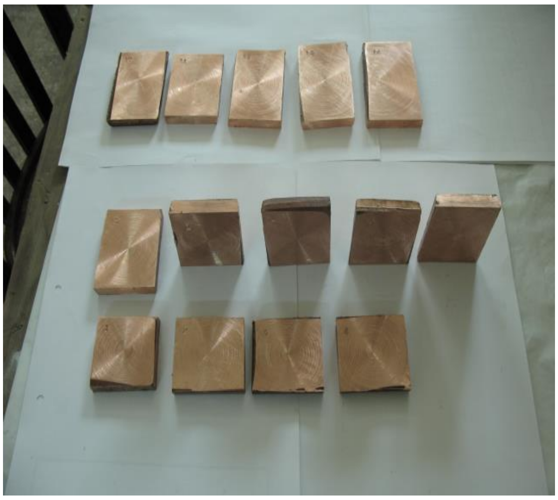

Figure 4. Specimen support for metallurgical industry

Figure 5. Specimen for metallurgical industry before being tested - Cu/Casto TIG (cooper and silver alloy x3)

4. TESTS

4.1. Thermal shock test

For aircraft industry the main tests are the quick thermal shock tests [2].

The main parameters of the QTS-2 installation, conceived, designed and manufactured by INCAS are:

- heating temperature 1300°C
- heat up thermal shock 10 s
- dwell time – about 300 s
- cooling time – 60 s
- max cooling air pressure 9 bar
- cycle duration – 6 minutes

Figure 6 shows the QTS-2 – quick thermal shock installation and figure 7 shows a graphic of a test at 1200° C [3,8].

Figure 6. Quick thermal shock installation – Patent number 127339

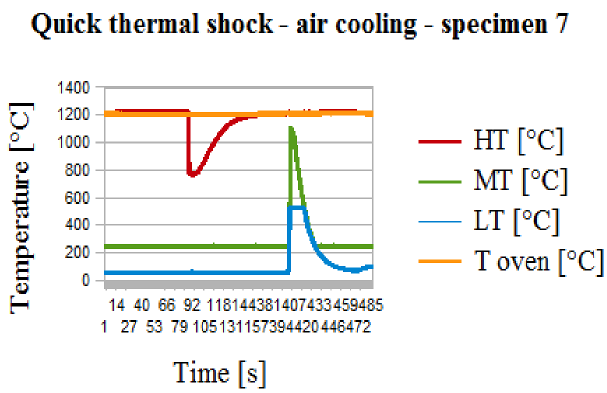

Figure 7. Quick thermal shock test graphics – heating at 1200° C, air cooling

4.2. Tribological tests

Tribological tests were performed under dry conditions using block on ring installation. For the ring we used the bearing sleeve of the Timken A4138 series. The steel block is provided with a nimonic support coated with a bonding layer (NiCrAlY) a ceramic oxide layer (Y_2O_3-Yb_2O_3-GbO_3-Nd_2O_3-ZrO_2) and an external ZrB2 layer. The tests were performed with universal tribometer CETR UMT-3 Bruker.

In Figure 8 is presented the Universal tribometer CETR-UMT-3 Bruker bloc on ring module.

Figure 8. Universal tribometer CETR-UMT-3 Bruker bloc on ring module

The testing method as per ASTM G77-98 standard allows the determination of the sliding wear for different materials with block on ring module. The test result is measured in volume diminution in mm³ both for block and ring. The collecting data are: F_x – friction force; F_z – normal force; T – testing time; Z_1 – the vertical position to determine the depth of wear, COF – friction coefficient.

The study was performed on a ceramic powder based on zirconia, used as TBC and sprayed on nimonic metallic support.

In Table 1 are presented the parameters used in the tests.

Table 1. Testing parameters used

Loading force, F [N]	Sliding length, L [m]	Sliding speed [m/s]	Speed [rot/min]	Testing time [s]
10	1000	0.25	136.42	3999.96
		0.50	272.84	2000.04
		0.75	409.26	1333.32

In Figure 9 is presented the COF variation of three speeds.

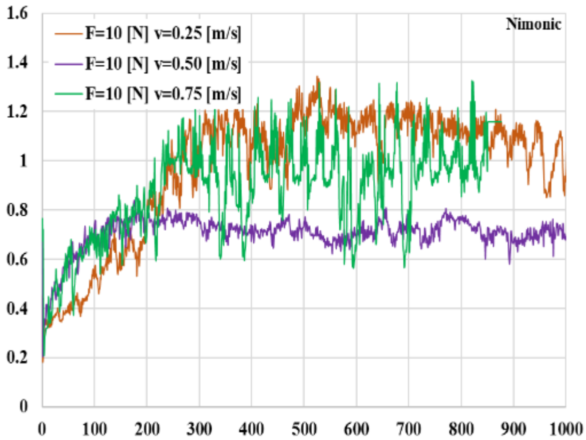

Figure 9. COF variation of three speeds

For the three speeds tested the graphic of the friction coefficient presents a slight decrease in the incipient stage, about 1% of the sliding length, after that an increase of the friction coefficient and then the stabilization of the value at the end of the test.

In figure 10 is presented COF variation of the specimen coated with NiCrAlY/Y_2O_3-Yb_2O_3-GbO_3-Nd_2O_3-ZrO_2/ ZrB_2.

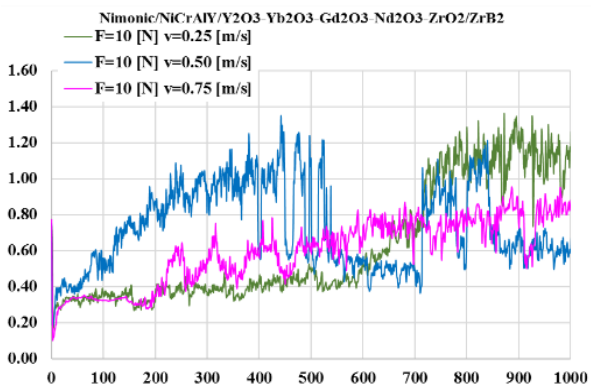

Figure 10. Friction coefficient variation for the tested specimens - Nimonic coated with NiCrAlY/ Y_2O_3-Yb_2O_3-GbO_3-Nd_2O_3-ZrO_2/ ZrB_2

At the minimum testing speed, the graphic of the friction coefficient shows a stable wear at the beginning, from 0 to 600 m and an increase for the rest of the test up to 1.3.

Taking into account the parameters of this study (sliding length and loading force) and the recent studies of the wear parameters, the following mathematical expression for wear rate is:

$$\mathrm{Wm} = \frac{\Delta \mathrm{m(mg)}}{\quad} \qquad (1)$$

Where:

- Δm [mg] loss of mass after testing,
- F [N] loading force,
- L [m] sliding length.

Table 2. Mass loss of the specimen with and without coatings

Materials	Sliding speed [m/s]	Initial mass [g]	Final mass [g]	Mass loss, Δm [mg]
NIMONIC (without coating)	0.25	9.1652	9.1644	0.8
	0.50	10.2081	10.2071	1.0
	0.75	10.0719	10.0712	0.7
NIMONIC + NiCrAlY/ Y_2O_3-Yb_2O_3-GbO_3-Nd_2O_3-ZrO_2/ ZrB_2	0.25	9.0401	9.0390	1.1
	0.50	9.0179	9.0176	0.3
	0.75	9.0876	9.0868	0.8

5. REAL PARTS

In figures 11 and 14 are presented a burning chamber for an aircraft engine before and after coating with duplex ceramic layers.

Figure 11. Part for aircraft industry - burning chamber before coating

Figure 12. Burning chamber after coating

In figures 13 and 14 are presented a tuyere for metallurgical industry before and after coating with special alloy based on Ni and Cr.

Figure 13. Part for metallurgical industry – tuyere before coating

Figure 14. Tuyere after coating

6. CONCLUSIONS

- ➢ Some aimed parts from aeronautics (hot parts of turbo engines) and metallurgy (tuyere, lance tip) presents similitudes of the wear factors - high temperatures, thermal shock, erosion, corrosion, etc.
- ➢ The support materials of the aimed parts are different (super alloys for turbo engines and electrolytic copper for tuyere) and as consequence specific solutions for the protective layers are imposed -

ceramic multilayer for turbo engines and complex alloys from compositional point of view for the tuyeres.

- The quick thermal shock test is fundamental to establish the ranking of the protective elaborated solutions.
- Quick thermal shock installation (and the associated method), conceived and achieved by INCAS is reliable, versatile, function in semiautomatic regime and can display all the parameters of the test in real time - oven temperature, temperature of the specimen surface inside and outside of the oven, air cooling pressure, heating time, cooling time, etc.
- The tuyeres with selecting protection present a superior endurance in function with 10-15% in relation to those without protection.

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