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WEAR FACTORS ACTING ON AVIATION TURBO ENGINES

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***Abstract**: "Hot parts" of turbo engines, co generative systems, etc. during operation are driven by factors wear complex, tough acting simultaneously at high values.*
From the types of wear identified - corrosive, erosive, adhesive, by thermal fatigue - industrial applications targeted group the thermal fatigue wear heat shock assign most disruptive acts on multilayer structures such as TBC- thermal barrier coating. TBC is widely accepted as technological solution for protection of turbo engines.
In this paper we chose to specifically analyze the relationship between the parameters that define the thermal shock and structural changes induced in the TBC type layers of protection.
To conduct the testing phase coatings, the authors have designed and developed a quick thermal test shock installation to evaluate the materials under extreme conditions of the basic parameters of the process.
This paper aims to contribute at expanding the information structural changes, of the delaminating mechanism and finally on the damages of coatings induced by extreme heat factor.

***Key words**: turbo engines, wear factors, quick thermal shock, thermal fatigue, TBC*

1. Introduction

Gas turbine generators are characterized by operational conditions far worse than those usually encountered in engineering. Thus, the turbo engines work at mechanical and thermal superior limits, plus the corrosive effects of chemical fuels. The temperature in commercial aircraft turbines can reach 1500°C [1].

For extreme operational conditions occurring in aircraft flight, engine stop in flight, missing landing, etc., for other equipment, machine power and metallurgical industry is very important to know the behavior of materials at high speed heating and cooling.

"Hot parts" of turbo- engine fire walls, blades, adjustable nozzles, tube, etc. - during operation are subject to wear complexity factors that can act simultaneously.

From all wear the factors that work simultaneously on the "hot parts" of the turbo engines – temperatures above 1500ºC,quick thermal shock, pyrolyzed particle erosion to speeds above Mach 3, corrosion, adhesion, etc.-the thermal factor acts most disturbing.[2]

Thermal fatigue is defined as a phenomenon of gradual destruction of the material due to repeated heating and cooling which induces thermal cycle's efforts. Each cycle is a complex combination of effort to change with the temperature and material properties vary.

In the case of "hot parts" of turbo engines, temperatures vary depending on flight operation rules on taking off, landing, intermediate cruising, engine stop in flight, missing landing, etc.

Temperature distribution produces stretching and contracting thermal efforts and implicitly thermal stresses inside.

These increases in thermal efforts though short duration, especially at start up and shut down, can have considerable value and lead to plastic deformation of the material.

Repeating these cycles can lead either to damage or decrease the resistance to oxidation and corrosion of components.

Transitional arrangements worst in terms of thermal shock applications are starting and stopping the engine and the post-combustion functioning.

Successive passages through other operating modes (maximum take-off, intermediate cruising, landing and idling), lead to changes in thermal parameters with values between 5-20%.

In the case of combustion chamber and turbine jet engines, the use of protective systems is absolutely necessary in view of the operating system very hard.

Compressors and valves for storage, which directs the hot gas to the turbine wall, are usually cooled with air at temperatures below 1100°C.

Those components are clearly degraded by oxidation, hot corrosion and thermal fatigue.

Mechanical stresses when the combustion chambers are generally minor.

To the wear by thermal fatigue, we associate thermal shock stresses which act the most disturbing on the turbo engines TBC coatings.

We present some situations that thermal shock still operates predominantly in the functioning of turbo engines:

- Start engine leads to a thermal shock from ambient temperature of engine to operating temperature within tens of seconds. Conditions imposed restrict military aircraft under one minute interval for interceptor aircraft engines in conditions of emergency take off.
- Another example of thermal shock is the stop of the turbo engine at cruising altitude around 11.000m, where the cold air temperature is about -50°C
- Failure landing requiring maximum engine operation in intervals of tens of seconds to restore the aircraft in flight cruising speed

2. Experiments

In the conditions mentioned above, which associate turbo engine extreme operational conditions with values very much on short-term for thermal shock appeared to be necessary to study material behavior at high speeds of heating-cooling, at quick thermal shock test.

2.1. Materials

For experiments were used multilayer samples:

1. Refractory super alloy Nimonic 90 support
2. Bonding layer MeCrAlY layer (AMDRY 997) having as composition Ni, Co, Cr, Al, Ta, Y chemical elements -shaped spherical particles with sizes 37 μm
3. Outer layer of 0.1; 0.2 and 0.3 mm thickness of AZY25 nanometric powder achieved by INCDMNR - Institutul National de Cercetare Dezvoltare pentru Metale Neferoase si Rare.

The specimens have rectangular shape with dimensions 2.6 x 30 x 50 mm.

2.2. Methods and instrumentation

To assess structural changes due to thermal fatigue, thermal barrier coatings were tested at thermal shock and then were investigated by electron microscopy.

Layers of protection were obtained by depositing successive the bonding layer and ceramic layer with air plasma jet method on a type METCO installation.

The thermal shock is the heating of samples from tens of degrees temperatures at hundreds of degrees temperatures i

n a short time (approx. 1 min) and vice versa the cooling of the samples from high temperatures (hundreds of degrees) at low temperatures (tens of degrees).

It should be noted that there is no standardized method and an installation for thermal shock tests for materials covered with layers of protection.

Generally the manufacturers as well as the materials users have both created their own equipment.

It is also important to note that the known installations have generally lower heating and cooling rates of the order of several tens of ºC / min, for both heating and cooling.

These installations are useful for parts that are subjected to mild thermal shock, installations which may not give results in the case of parts from the aerospace industry, space shuttles, hot parts of the turbo engines, parts of metallurgical industry, turbine blades from power industry, etc..

These parts are subjected to heating-cooling cycles hard within a few tens of seconds, the temperature at which they undergo can increase from the ambient temperature above 1000ºC and in as many seconds to reach from 1000ºC to ambient temperature.

Below is presented QTS2 installation, designed and built by the authors for testing materials under conditions of mild heat shock but also for extreme conditions of heating-cooling rates. (Fig.1)

Fig.1. QTS2-Installation for material testing in extreme thermal conditions

Functional parameters of QTS2 installation are: testing materials up to 1500°C, variable heating speed and quick cooling speed of the specimen up to 70^{o}C/s, operating in automatic cycle, monitoring functional parameters, continuous measurement of temperature specimen at heating and cooling, Lab View data acquisition system, view oven heating curve, heating curve cooling curve of specimen.[7]

2.3 Thermal shock resistance test

Thermal shock resistance test aims to reveal micro structural changes of samples tested. Thermal shock test is completed when the macroscopic appear-exfoliation damage, cracks, porosity, more than 25% of the TBC surface tested.

The thermal cycling has been performed at 900ºC, 1000ºC and 1100ºC temperatures.

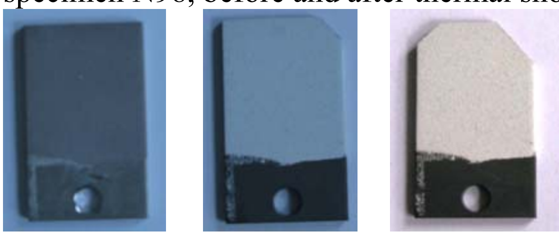
There were 25 tests for each temperature cycling. There were tested 6 specimens, numbered N94, N96, N97, N98, N99 and N100

The oven is heated at the test cycling temperature. The sample is moved from the environment temperature into the oven. The heating speed of the specimen is variable depending on the specimen size, type of material, single layer or multilayered.

The specimen is moved from inside the oven to the cooling area where is cooled till about 40°C.

The quick thermal test shock were carried out with the following parameters: speciemn heating speed 12.98°C/s;specimen cooling speed 12°C/s; cooling time – 60 s; maintaing time in oven-5 min;test duration- 6 min; cooling air maximum pressure- 8,7 bar; cooling air minimum pressure- 7.13 bar.

In Fig. 2 are presented images of the specimen N98, before and after thermal shock.



2.a 2.b. 2.c.

Fig.2 Specimen N98 before thermal shock test and after test shock at 900ºC and 1000°C.
2a- before starting the test
2b- after test at 900°C
2c- after test at 1000°C

In Fig.3 and 4 are graphs of thermal shock test at temperatures of 900ºC and 1100ºC. The data were obtained with Lab View software and processed with the Origin 6 program.

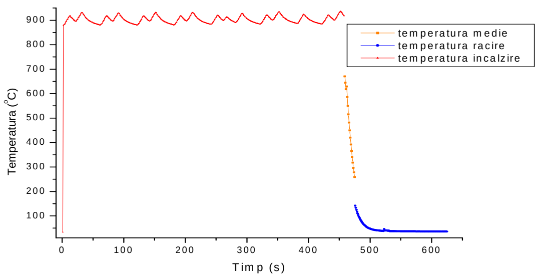


Fig.3 Graphic thermal shock test N98 specimen at 900ºC

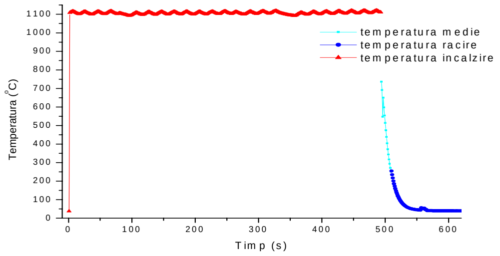


Fig.4. Graphic thermal shock test N98 specimen at 1100ºC

3. Microscopic investigations

Micro structural investigations were made by scanning electronic microscope SEM. It was made a comparative study of the layers deposited both before and after successive testing of specimens at thermal shock.

Fig. 5 and 6 show the composition image of protection coating layer NiCrAlY/ $ZrO_2Y_2O_3$ Al_2O_3 (ASZ25) nano before thermal shock testing. It shows a uniform thickness. It also noted a relatively low porosity. The ceramic layer thickness is between 46.5 -55 µm. The thickness of the bonding layer is 17 - 21.6 µm. At the interface bonding layer / metal support but also the bonding layer / ceramic layer can notice the existence of horizontal cracks.

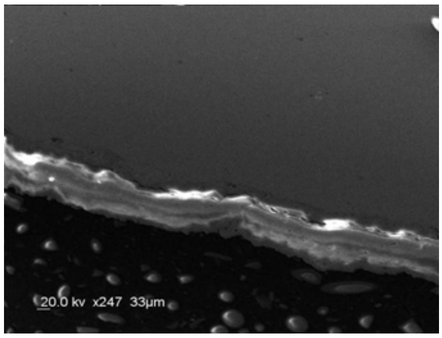


Fig. 5 Image composition NiCrAlY/$ZrO_2Y_2O_3$ Al_2O_3 (ASZ25) protection coating layers before thermal shock test (x247)

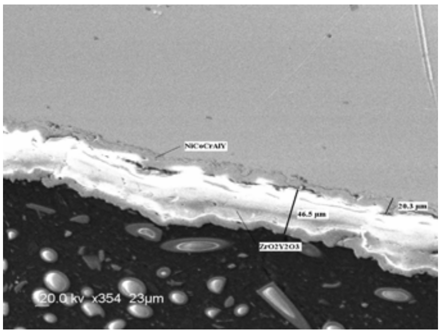


Fig.6. Image composition NiCrAlY/$ZrO_2Y_2O_3$ Al_2O_3 (ASZ25) protection coating layer before thermal shock test (x354)

Fig. 7 and 8 show the composition image of protection coating layer NiCrAlY/$ZrO_2Y_2O_3$ Al_2O_3 (ASZ25) protection coating layers after thermal shock test at 900°C. Note maintaining thickness uniformity. It also noted a relatively low porosity. The ceramic layer thickness is between 47 -64 µm. The thickness of the bonding layer is 17.65 - 24.58 µm. At the interface bonding layer / base metal is observed the existence of horizontal cracks. At the interface bonding layer / ceramic layer is formed a transitional oxide layer, TGO - thermal oxide grown with a variable thickness ranging between 15.69 - 16.35 µm. This oxide layer was formed due to oxidation of bonding layer after migration from coating of the reactive elements (eg Al).

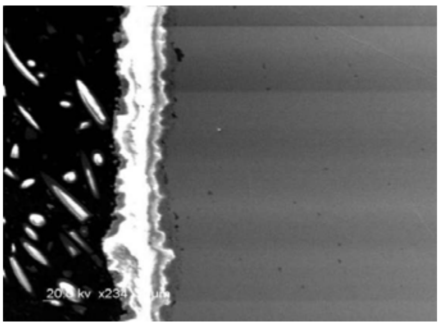


Fig. 7 Image composition NiCrAlY/ $ZrO_2Y_2O_3$ Al_2O_3 (ASZ25) protection coating layers after thermal shock at 900 ° C (x234)

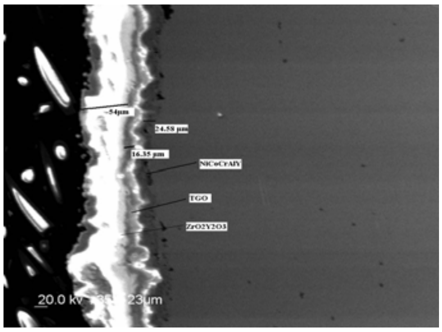


Fig. 8 Image composition NiCrAlY/ $ZrO_2Y_2O_3$ Al_2O_3 (ASZ25) protection coating layers after thermal shock at 900 ° C (x354)

Fig. 9 and 10 shows the composition image NiCrAlY/$ZrO_2Y_2O_3Al_2O_3$ protection system, after thermal shock test at 1000ºC. Note maintaining thickness uniformity. Porosity is low. The ceramic layer medium thickness is 68.28 µm. The thickness of the bonding layer is about 23 µm. At the interface bonding layer / base metal is observed the existence of horizontal cracks. It reveals the existence of chaotic oriented cracks on a small area in the bonding layer.

At the interface bonding layer / ceramic layer are witnessing TGO layer - thermal oxide grown with a variable thickness between 5.69 - 16.40 µm.

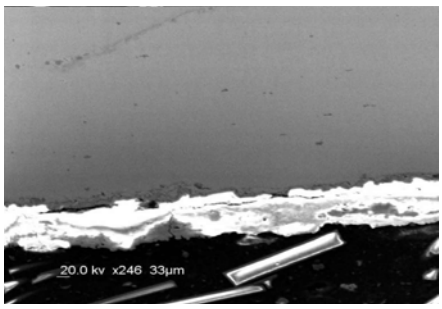


Fig.9 Image composition NiCrAlY/ $ZrO_2Y_2O_3$ Al_2O_3 (ASZ25) protection coating layers after thermal shock at 1000 ° C (x246)

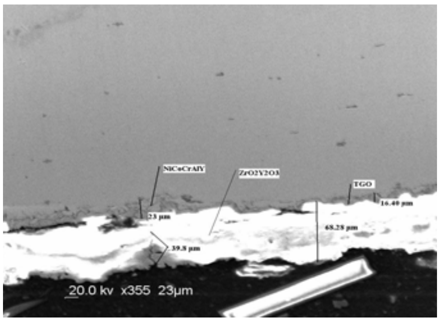


Fig.10 Image composition NiCrAlY/ $ZrO_2Y_2O_3$ Al_2O_3 (ASZ25) protection coating layers after thermal shock at 1000 ° C (x355)

4. Conclusions

1. The "hot parts" of the turbo engines but also those of the co generative systems from power industry are subject to factors of wear-corrosive, erosive, adhesive, by thermal fatigue, which act simultaneously at high values
2. Wear by thermal fatigue which we associate the thermal shock act most disturbing on the endurance of TBC-Thermal Barrier Coating- type protecting coatings of turbo engines
3. Thermal shock tests of the elaborated materials, in order to evaluate the behavior of materials under extreme conditions of the turbo engines were made with an original installation conceived and achieved by the authors of this paper. The QTS 2, quick test installation is a necessary tool, versatile, for evaluating the behavior of materials under high thermal regimes, operating in automatic cycle, monitoring functional parameters, continuous measurements of temperatures between 20 ÷ 1500° C, heating rate specimen up to 100°C / s and cooling rate specimen up to 70°C / s.
4. Quick thermal shock testing on QTS2 installation, allowed the hierarchy of the elaborated materials in relation with a fundamental functional parameter of turbo engine
5. Quick thermal test shock parameters increase, induces macro and micro structural modification of the TBC layers-porosity, developing networks of reticular cracks, oriented mainly horizontally
6. Electron microscopy study reveals the formation of an oxide layer, complex, nano or micron thick at the interface bonding layer/ceramic layer, TGO-Thermal Oxide Growth - due to migration of reactive elements from the bonding layer and their subsequent oxidation
7. TGO layer grows, due to increasing thermal shock parameters amounts, (temperature, and heating-cooling velocity) and may represent fundamental cause which initiates the delaminating of the ceramic coating of the turbo engine and finally its deterioration.

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