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DEPOSITION AND TESTING OF THERMAL BARRIER COATINGS ON GAS TURBINE VANES

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ABSTRACT

An innovative methodology to deposit, by plasma spraying, ceramic thermal barrier coatings on gas turbine blades and vanes was developed. Such a methodology produces a pattern of microcracks in the coating, thus improving its thermal shock resistance.

After a laboratory campaign of process optimization and coating characterization, real components were coated with a 150 µm thick layer of NiCoCrAlY as a bond coat and a 300 µm thick layer of ZrO_2, partially stabilised with 8%of Y_2O_3, as a top coat. In particular, four vanes, taken from the first stage of a land based gas turbine (V64.3, produced by Ansaldo), were coated on the whole airfoil.

The four vanes were submitted to a cyclic oxidation test in a burner rig simulating the operative conditions of a gas turbine. In particular, they were exposed to a gas flow with the same composition, temperature and speed of the inlet gas of a real gas turbine; moreover, they were cooled by an internal stream of compressed air for obtaining the same temperature profile of a vane in operation. The surface temperature of the vanes was monitored during the test by an optical pyrometer and the internal temperature by a thermocouple.

After 550 hours of test, corresponding to 550 cycles, the four vanes did not show any sign of damage.

1. INTRODUCTION

The deposition of a thermal barrier coating (TBC) on the first stage vanes of a gas turbine allows increased turbine inlet temperature (TIT), thus improving engine efficiency. However, a problem, often associated with the deposition process, is poor thermal shock resistance of the TBC. CSM has found a satisfactory solution to this problem by developing an innovative methodology, called ATCS (atmosphere and temperature controlled spraying).[1] Such a methodology allows deposition of ceramic coatings having a dense pattern of microcracks. Previous experimental work[1,2] had indicated that these microcracks are capable of improving the TBC thermal shock resistance. Therefore, it was decided to apply the ATCS methodology also during the coating of real components: a ZrO_2 based TBC was deposited on the whole airfoils of four vanes. These passed well a cyclic oxidation test in a burner rig simulating the operating conditions of the gas turbine.

2. EXPERIMENTAL

2.1. Coating deposition and characterization

The Controlled Atmosphere and Pressure plasma Spray (CAPS) equipment and the ATCS methodology were utilized for the TBC deposition. The CAPS, described in detail elsewhere [3], consists of a 80 kW plasma spray torch, installed in the deposition chamber, where the atmosphere composition (e.g. air, Ar, N_2 ...) can be controlled in the pressure range between 10 and 4000 mbar. A 5+1 axes robot allows the coating of components with complex geometry such as turbine blades and vanes. The temperature of the substrate, during deposition, is controlled by impinging on it a cloud of liquid Ar. The cooling creates a thermal shock on the external ceramic layers being deposited, so inducing an homogeneous growth of microcracks, without producing segmentation cracks and drastically decreasing residual stresses.

First, an experimental campaign was carried out to optimize the movement of the torch and minimize any temperature gradients along the substrate surface and within the coating. Some specimens, representative of the real components, and with the same composition (IN 738 superalloy), were made by injection molding and then coated,

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utilizing different robot programs. After deposition, their cross-sections were observed by optical microscopy and by SEM to verify the coating homogeneity and microstructure. Finally, four vanes, taken from the first stage of a land-based gas turbine (V64.3, produced by Ansaldo) were coated on their whole airfoil with a 150 μm thick layer of NiCoCrAlY bond coat, deposited by Vacuum Plasma Spray (VPS), and a 300 μm thick layer of ZrO_2, partially stabilized with 8% of Y_2O_3, as a top coat. The spraying parameters of this top layer are summarized in table I. The components were controlled with a Zeiss tri-dimensional tester, before and after the deposition, to verify the uniformity of the coating thickness.

Tab. I - TBC deposition parameters

Coating atmosphere			Ar
Deposition pressure		mbar	900
Deposition Temperature		°C	60
Distance between substrate and gun		mm	105
Plasma gases	Ar	liters per min.	40
	H_2	liters per min.	10
Power		kW	34

2.2. Thermal cyclic oxidation test

Considering the working conditions of the V64.3 turbine (vane surface temperature: 900 to 950°C, fuel: natural gas), the expected damage mechanism is the spalling of the TBC caused by thermal stresses in the ceramic coating and by the growth of an oxide layer at the interface with the bond coat. For this reason, the coated vanes were submitted to thermal cycling oxidation test.. Time and temperature were selected on the basis of the specification requirements for that particular gas turbine. Figure 1 shows the designed thermal cycle. The endurance test was planned to last 550 cycles, with visual inspections after 50, 150 and 300 cycles

The facility used for the test, named CYR (CYclic Rig) and shown in figure 2, is specially designed for cyclic oxidation testing. It consists of a combustion chamber, which produces a hot gas flow, a test section, where the test samples are in contact with the gas flow, and an exhaust system, where the hot gas is cooled down by cold air. In case of thermal cycling, the cooling of the heated samples is carried out by impinging on them a stream of cold air. Table II reports the main specifications of the CYR apparatus.

Table II. CYR combustion chamber specifications

Maximum power	500 Kw
Maximum gas flow (Wmax, Tsamples = 1000 °C, Mach=0.47)	900 Nm^3/h
Maximum temperature in the combustor	1400 °C
Maximum temperature in the test section	1300 °C
Minimum temperature in the test section	300 °C
Shortest cycle (Tmax - Tmin - Tmax)	10 min
Pressure	atmospheric
Fuel	natural gas
Combustive agent	air

The four vanes were tested together, and they were arranged in the same way as in the gas turbine first stage, i.e. three blade to blade passages and the two central components immersed in the gas flow like. Also, fixtures and cooling air distributors were made in such a way to simulate the actual set up of the turbine. Figure 3 shows the fixtures with the four vanes installed; figure 4 shows the same fixture installed in the CYR facility.

The surface temperature of one of the two central vanes was monitored during the test by utilizing an infrared pyrometer, aiming at a point near the leading edge at about 1/3 from the inner platform. The pyrometer had the following characteristics: measuring temperature range 600-1300°C, response time 5 ms to 98 %, detector Silicon cell, spectral response 0.7-1.0 μm; the emittance value has been set at 0.87. The base material temperature of the same vane was measured on the leading edge at about 2/3 form the inner platform by means of a thermocouple inserted in a purposely drilled hole. Such double temperature measurement on the same vane allowed determination of gradients produced within the ceramic coating. At the end of the test, the four vanes were inspected visually to detect any sign of damage in the coating.

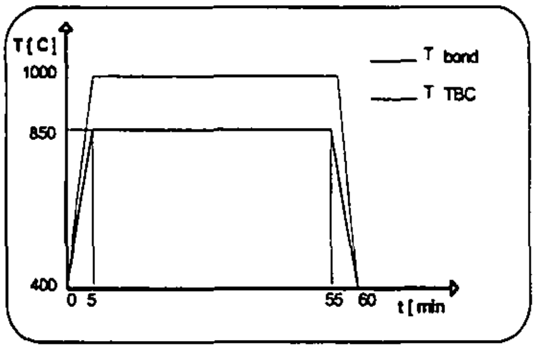

Fig.1. Designed thermal cycle for burner rig testing

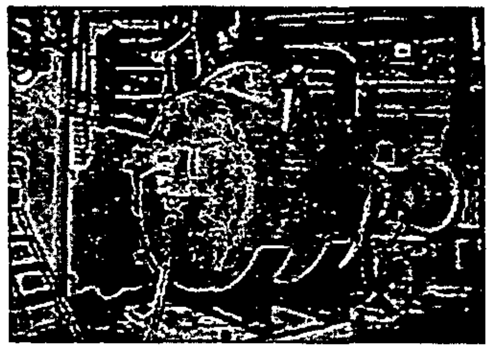

Fig. 2 - CYR facility

Fig. 3 Coated vanes installed in the fixture

Fig. 4 Fixture installed in CYR facility

3. RESULTS AND DISCUSSION

3.1. Coating deposition and characterization

Figure 5 is a SEM micrograph showing the microstructure of a TBC deposited on a representative specimen. It is evident a significant density of microcracks, which were enhanced by the relatively low deposition temperature (60°C) of the substrate. On this regard, past experience [1,2] indicates that lowering further the substrate temperature, during deposition, a higher density of the microcracks would be expected.

Figure 6 shows the four vanes after the TBC deposition. The dark color observed in the coated vanes is consistent with the ATCS process. In our case, it is due to a partial reduction of the zirconium oxide in the Ar spraying atmosphere. However, during the initial stage of turbine operation, the coating being exposed to heat and oxidizing conditions, regains its typical white coloration. Such a phenomenon has not been linked to any effect on the TBC performance. Dimensional measurements, performed both by optical microscopy analysis and by the tri-dimensional tester, showed the TBC thickness in the range between 300 and 350 μm.

Fig. 5 - Coating microstructure

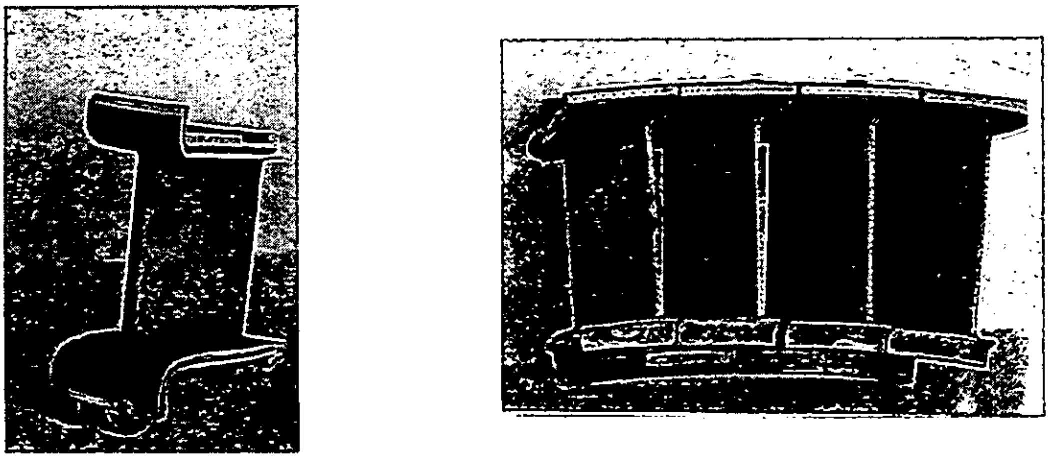

Fig. 6 - Coated vanes

3.2. Cyclic oxidation test

Figure 7 reports the temperature behavior of TBC and of the base material during one cycle. It can be noticed that a temperature gradient greater than 100°C is produced between the coating surface and the substrate.

Figure 8 shows the vanes after 550 thermal cycles. In this case, the color appearing dark in the figure is in reality red and it is due to the iron oxide present in the gas stream. No damage of the TBC was seen during visual inspections and, after the end of the test, no detachment of the ceramic coating was detected.

4. CONCLUSIONS

The microcracks density distribution of the TBC specimens and the good results of thermal oxidation cycling test on the four real components (although the experimental conditions were not too severe) support further the potential of ATCS methodology.

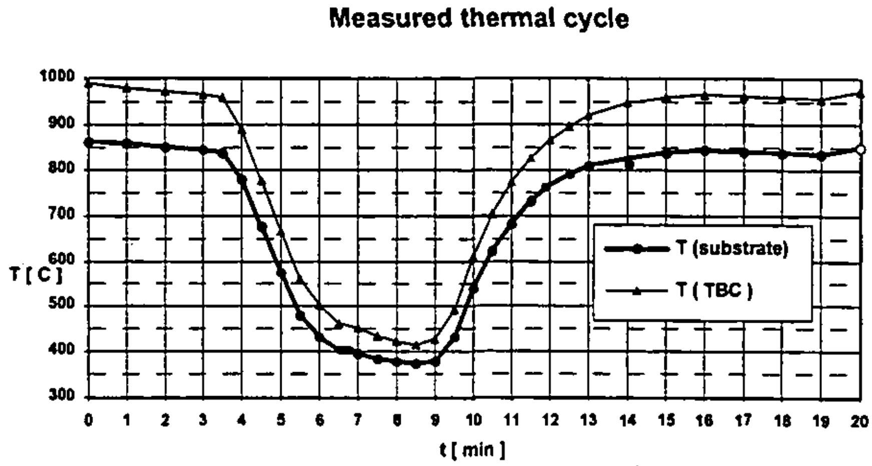

Fig. 7 - TBC and bond coat temperature during a thermal cycle

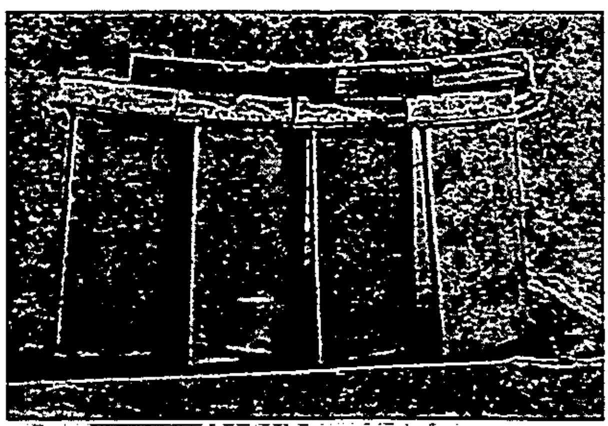

Fig. 8 - Vanes after 550 cycles

As a next step, it is foreseen the use of components such as vanes, coated by ATCS, in the first stage of a land-based gas turbine.

ACKNOWLEDGMENT

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