CMMT(MN)029

Measurement of Thermal Mechanical Fatigue (TMF) Resistance of Coatings Used In Gas Turbines

Summary

A test method based on use of the NPL electro-thermal mechanical test (ETMT) system has been developed. Essentially a small testpiece is heated resistively and strain applied using a servo-motor. The existing rig proved to be incapable of generating heating rates that adequately simulated those experienced by the hot-section turbine blades. The problem arose because it was necessary to use larger cross-section testpieces to overcome edge effects on the coated testpieces. The larger testpieces also required stronger motors which could be mounted in-line with the stress axis to apply the necessary loads to correctly simulate the operating cycles. Furthermore, strain measurement, which was originally carried out by capacitance transducers remote from the testpieces, was unsatisfactory and two other methods of strain measurement have been investigated: i) capacitance transducers directly attached to the testpieces, and ii) a video system.

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Background

Corrosion resistant coatings are routinely applied to hot components in gas turbine engines. In addition to their corrosion resistance the coatings must also have adequate strain tolerance to withstand the system strains imposed during operation of the engine. The cyclic operation of a hot- section gas turbine blade causes out-of-phase temperature and strain cycles, and ultimately coating cracking occurs. Conventional TMF testing requires both complex testpiece geometry and test equipment. The objective of the current work was to develop a simplified method based on the principles of the NPL electro- thermal mechanical test (ETMT) [1].

Operating Cycle for TMF

Typically gas turbines blades will have a range of different temperatures. Thus, for example, during heating hot spots will be constrained by the cooler parts of blade and be subject to compression. Freqently also the mechanical strain can be out-of- phase with the temperature cycle. If a coating is also present, then depending on the ductile brittle transition temperature (DBTT) the accumulated elastic strain during heating can be relieved by creep. On cooling the coating is now placed into tension and cracking occurs if the critical fracture strain exceeded, see Figure 1.

Figure 1: Simulated TMF cycle for substrate and coating

Principles of ETMT Rig

Essentially a small testpiece is heated resistively and strain cycles applied using a servo-motor. The temperature and strain are monitored and Lab View® software is used to control the experimental parameters.

The ETMT rig used for the development of the test had the following specification:

- An environmental chamber (500 x 250 x 120 mm) with comprehensive electrical lead-throughs, water cooling and inert gas supply facilities.

- A computer controlled DC heating power supply (200 A), with testpiece resistance and thermocouple measurement facility. With nickel-base superalloys testpieces typically 2 x 1 mm in cross-section heating rates up to about 106 K h^{-1} are possible. Cooling rates are determined by thermal diffusivity of the testpiece and loss of heat to the grips. This can be about 105 K h^{-1}. The temperature is measured directly from a thermocouple welded to the centre of the testpiece. The maximum operating temperature is dependent on the melting point of the material under test. Tests have been performed at up to 1600°C with testpieces 2 mm^2 in cross-section.

- A mechanical loading assembly (± 1.0 kN maximum), with a drive assembly and capacitance displacement transducers (0.4 I1m resolution) arranged in parallel with the long axis of the testpiece. A flexible grip system and load cell (0.2 N resolution), with computer controlled motor for null, mean, ramping or fatigue load capability (in or out-of-phase dc current cycle) or constant displacement tests for thermal shock experiments. The motor response is set to about 200-1000 N s^{-1} for fatigue experiments.

- Software is used to monitor and control thermoelectro-mechanical tests and temperature cycles by appropriate feedback control.

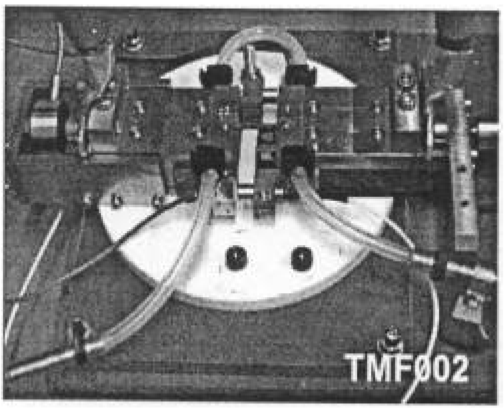

Figure 2: Photograph of the modified ETMTrig

Application to Coated Ni-base Testpieces

Heating/cooling rates

Early trials with coated testpieces 2 x 1 mm in cross-section indicated that edge effects dominated the response with clear evidence of coating cracking initiating at the edge of the testpiece. To overcome this effect larger testpieces are needed and a 3 x 2 cross-section was tried. It was now apparent that the high heating rates achieved with the smaller testpieces could only just be obtained, and as shown in Figure 3 the maximum heating rate achieved to only a modest maximum temperature of 600°C was about 9 x 104 K h^{-1}. It is envisaged that even larger test testpieces with a cross-section of 10 mm^2 will be required in future. It is also considered that testpieces should be circular in cross-section and thus eliminate the edge effect altogether. This may not always be possible, particularly when dealing with small test testpieces coated by line of sight processes.

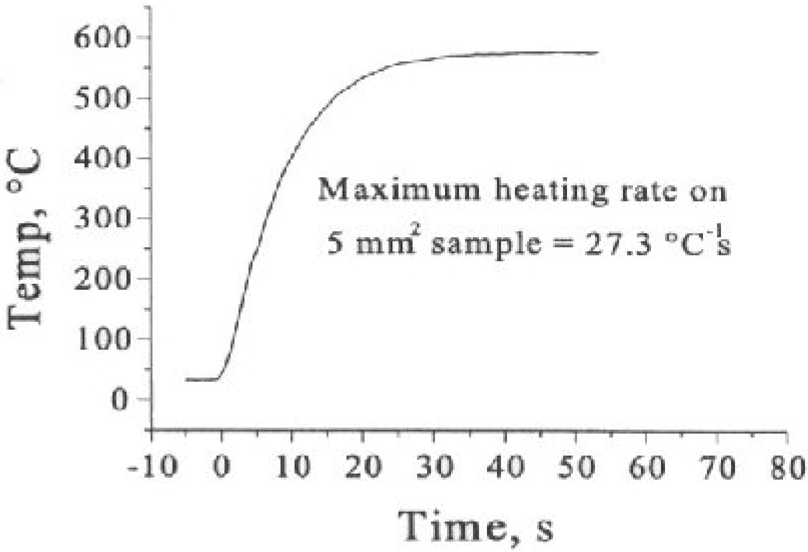

Figure 3: Maximum heating rate for a 5 mm^2 cross-section testpiece

Loading and measurement of strain

The larger testpieces required for coated testpieces could not be strained to the required amount with the servo-motors on the standard design which have a maximum capability of 1 kN. In assessing the performance of the instrument when working at high loads with the motors in parallel with the testpiece, it was determined that significant skewing of the testpiece gripping assembly occurred. Hence the testpiece was also skewed which lead to uncertainty in the measurement of strain. The rig was re- designed to allow the motors to be mounted in-line with the testpiece and so overcome the skewing; this is now the standard design for the NPL ETMT rig.

Again, because of the high loads required for this work, there was some concern that strain measured from the capacitance transducers not in direct contact with the testpiece may give misleading results.

Two options have been investigated which are expected to work. Firstly, it is possible to connect the capacitance transducers directly to the testpieces, or secondly, if the testpieces can be produced with readily identifiable features in the zone of interest, a video strain measuring system can be employed. The strain measurement system that uses capacitance transducers directly attached to the testpiece is shown schematically in Figure 4.

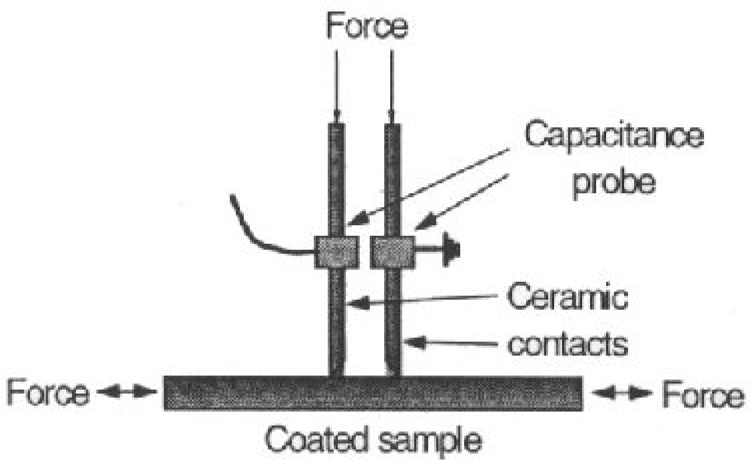

Figure 4: A schematic diagram of the capacitance probes directly attached to the testpiece for the measurements of strain

A schematic diagram of the re-designed ETMT system for measurement of TMF resistance of coated testpieces is shown in Figure 5. This concept uses hydraulic actuators which has the advantage of being stiffer and also able to apply higher loads. Strain measurement is by capacitance probes directly attached to the testpiece using spring-loaded ceramic contacts.

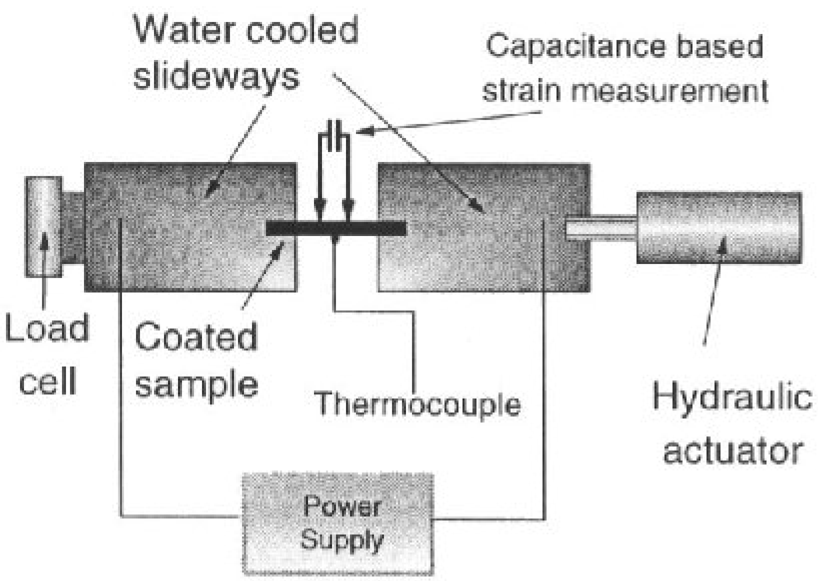

Figure 5: Schematic diagram of the re-designed ETMT-TMF rig

Reference

1. B Roebuck and M G Gee, Miniaturised Thermomechanical Tests on Hardmetals and Cermets, *Materials Science and Engineering,* A209 (1996) 358-365

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