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Equivalent Heat Load Test on Hot Aircraft Engine Components

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Abstract

The paper presents the assumptions and methodology for investigating equivalent heat load testing of hot aircraft engine components. The basic heat loads occurring in an aircraft engine during aircraft flight are characterised. Diagrams of the proposed heat loads are presented, together with the number of cycles, and a test bench is characterised and shown to enable equivalent heat load testing of aircraft engine components.

Keywords: Heat load, Heat barrier, Aircraft engines

1. Introduction

The evaluation of the performance of coating thermal barriers of gas turbine components, as well as the testing of the high-temperature corrosion of alloys used for hot components of aircraft engines, is carried out by means of the heat load test. In the technical literature you will find results of tests obtained using different heat load schemes. Due to the way the samples are heated, they can be divided into two groups. In the first, samples are heated by placing them in a furnace at a pre-set temperature; in the second, samples are heated with a concentrated heat flux by using, for example, a gas burner (burner test ring method). The heated samples are then cooled in a stream of compressed air.

In work [1], samples covered with a coating thermal barrier were heated by a torch to 1000°C and then cooled in compressed air to 60°C. In the burner test ring method [2], samples coated with a coating thermal barrier are heated on one side with a gas burner to 1100°C, soaked for 4-6 minutes and cooled with a compressed air stream for 2 minutes. Heat cycles are repeated until damage to the ceramic layer occurs. In work [3], samples of the MAR M-247 alloy were soaked in a furnace at 727 ÷ 927°C for 4 - 120 hours in an air atmosphere. In work [4], high-temperature corrosion of nickel alloys was studied according to the following scheme: heating time of samples to 1100°C - 2 minutes, soaking at this temperature for 40 minutes, cooling to 100°C for 5 minutes. The test included 100 cycles and lasted for 1000 hours. In work [5], samples of the INCONEL 738 nickel-based alloy were cyclically soaked in a furnace at 980°C for 1 hour with subsequent cooling in air for 5 minutes. The testing included 205 cycles.

The results of work to date indicate that there is a lack of testing methodology that would create thermal loading conditions similar to those found during the operation of an aircraft engine.

In addition, the effect of using different heat loading schemes in the study of coating thermal barriers on aircraft engine components and the high-temperature corrosion resistance of nickel and cobalt superalloys is that it is not possible to compare the functional effects of the work carried out. The heat loading schemes of the test specimens should be similar to the actual heat loading of hot aircraft engine components. Therefore, the aim of this paper is to present a test methodology and a test bench that allow the thermal loading of the specimens to be carried out similarly to the equivalent durability test of an aircraft engine.

2. Equivalent durability test for aircraft engines

Research into improving the performance of hot aircraft engine components requires the development and use of a laboratory equivalent durability test. This test must reproduce, as closely as possible to real conditions, the operating conditions of aircraft engines and allow their influence on thermal barrier and erosion control properties to be determined, as well as on high-temperature corrosion, microstructural changes, creep resistance, high-temperature creep or high-temperature fatigue strength.

The idea of the equivalent heat load test is based on the concept of the equivalent durability test of the PZL-10W engine in the amount of 2250 high temperature cycles for confirm the service life (repair interval) of 1500 hours and determine the need for repairs. The engine in the equivalent test was run on the dynamometer bench with repeated repetition of the basic duty cycle (Fig. 1) and with repetition of two cycles containing respectively Extraordinary Range II (30 min.) (Fig.2) and Extraordinary Range I (2.5 min.) (Fig.3). The diagrams show the durations of the various stages of the PZL-10W engine duty high temperature cycle with the corresponding shaft power and internal glow tube temperature values.

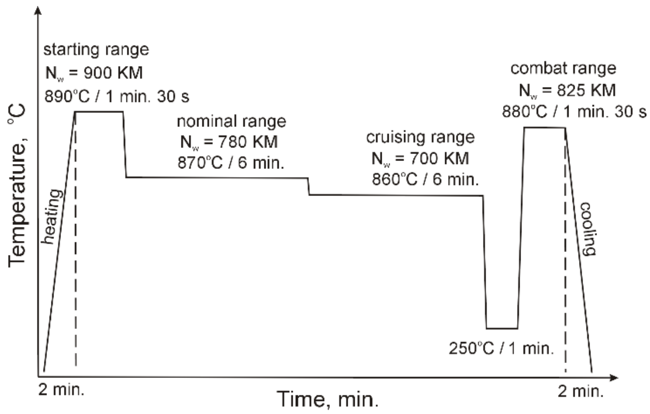

Fig. 1. Diagram of the basic high temperature cycle of the equivalent durability test of an aircraft engine PZL-10W and the values of power at the main engine shaft corresponding to its individual stages, N_w and the values of the internal temperature of the engine combustion chamber glow tube

The basic cycle illustrates the situation when the aircraft performs a smooth flight after take-off. After the flight, the aircraft proceeds to land, which it conducts with a reserve of power for a possible uplift. A cycle with pronounced Extraordinary Range II may occur when engine problems are observed after take-off and the aircraft has to leave an area where it cannot land, such as urban areas. The pilot then decides to apply Extraordinary Range II. The operating time in this range, due to the high heat load on engine components, is limited to 30 minutes. The duty cycle with pronounced Extraordinary Range I is used in an emergency situation, for example when there is only one motor left in operation. The working time in this range should not be longer than 2.5 minutes. According to the basic technical data of the PZL-10W engine, Extraordinary Range I of engine operation can occur once per service life.

The load according to the basic cycle was carried out 2250 times. A cycle covering Extraordinary Range II was carried out after every 100th basic cycle. A cycle covering Extraordinary Range I was carried out after every 250th basic cycle.

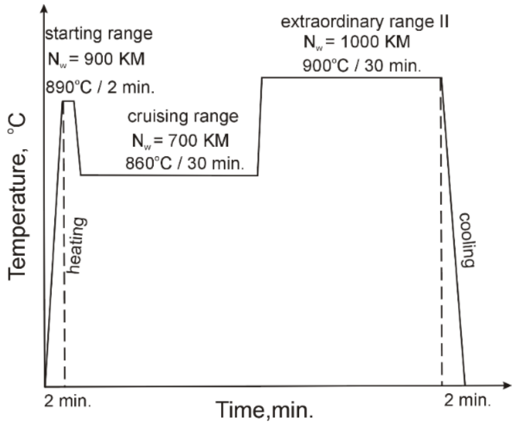

Fig. 2. Diagram of the basic high temperature cycle with a pronounced extraordinary range II of the equivalent durability test of an aircraft engine PZL-10W and the values of power at the main engine shaft corresponding to its individual stages, N_w and the values of the internal temperature of the engine combustion chamber glow tube

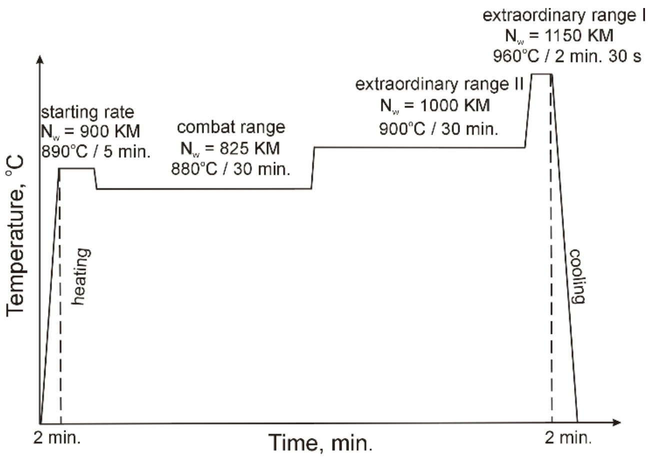

Fig 3. Diagram of the high temperature cycle with a pronounced extraordinary range II and extraordinary range I of the equivalent durability test of an aircraft engine PZL-10W and the values of power at the main engine shaft corresponding to its individual stages, N_w and the values of the internal temperature of the engine combustion chamber glow tube

When preparing the laboratory equivalent test, the shape of the test samples should be as close as possible to that of the engine components being tested. For example, in tests on engine blades, the samples should be flat. In the case of high temperature fatigue testing, finished specimens are subjected to thermal loading so that the effect of changes in the microstructure of the samples can be captured. The decisive load on the sample material is the high-temperature action of the atmosphere. The impact of the jet fuel exhaust atmosphere requires additional instrumentation. If such an atmosphere is required, the necessary module can be added. To determine the effect of the adverse effects of sulphur that may be present in aviation fuel on the material during thermal loading, a solution is used in which samples are coated with sulphuric acid salts [3]. In the case of moving engine components, such as turbine blades, for example, no centrifugal stresses are anticipated at this stage of the laboratory bench.

3. Test bench design

The test bench consists of a resistance furnace positioned either vertically or horizontally, a retractable sample basket with its displacement mechanism and drive.

The sample basket is soaked in the centre of the furnace over a chamber length of 100 mm. At a temperature of 900°C. The temperature difference in this furnace zone is ±2°C. To stabilise the temperature in the centre of the furnace, plugs made of insulating material, each 40 mm long, are led behind and in front of the basket. After the basket has been removed from the furnace, the insulation plug in front of the basket (trolley) covers the opening of the heating chamber of the furnace minimising heat loss. When the basket enters the furnace, the insulation plug behind the basket closes off the furnace chamber.

A diagram of the test bench is shown in Figure 4.

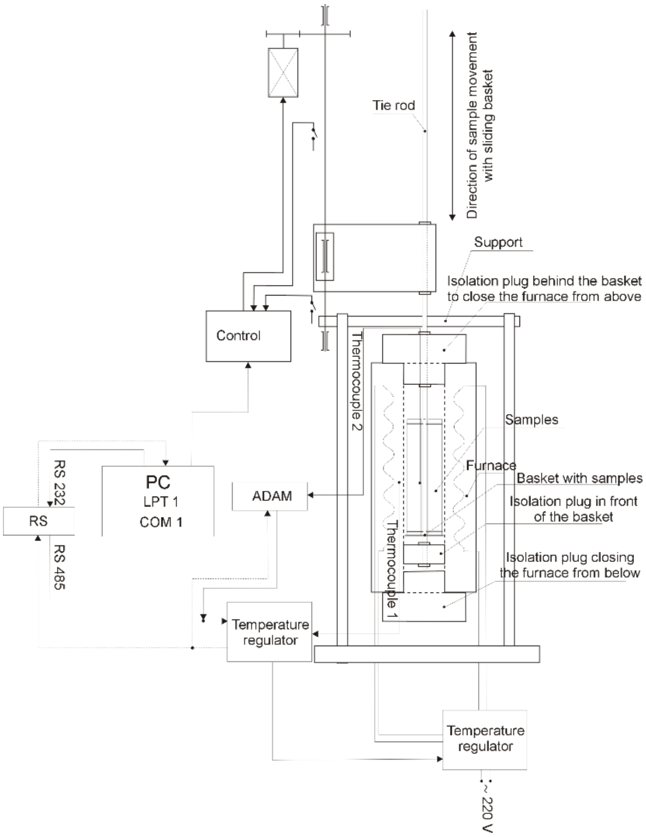

Fig. 4. Test bench diagram

The temperature in the furnace is controlled by a thermocouple mounted in the centre of the furnace. The control thermocouple is a thermocouple attached to one of the test samples midway along its length.

The cycles of heat loading of the samples in the equivalent durability test were programmed in the furnace control panel and the position of the basket (trolley). The position of the basket with the samples is determined by the actual (measured) temperature of the samples and the temperature value and endurance time of the samples predicted by the heat load scheme. The course of each cycle is recorded by computer.

4. Conclusions

- A literature review of the thermal treatments used by a number of authors in attempts to assess the durability of coating thermal barriers and the resistance to high-temperature corrosion of hot aircraft engine components, shows that they are not related to the actual conditions of thermal loads occurring during the operation of aircraft engines.
- The thermal loading schemes presented in the paper, based on the aircraft engine durability test bench and test stand used in practice, should find application not only in the study of coating durability and corrosion resistance, but also for capturing microstructure changes and their impact on the performance of alloys used for hot aircraft engine components.
- An important advantage of the approach proposed in the paper to the problem of testing materials for hot components of aircraft engines is the elimination of costs associated with the consumption of a large amount of aviation fuel in bench tests. Technological engineers of an aviation company, to whom the problems presented in the paper were presented, also suggested the possibility of using the proposed bench for testing cheaper and hard-to-find materials for combustion chambers, in particular for the PZL-10W engine, many copies of which are still in service at home and abroad.

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