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Optimisation of start and restart procedure in TMF fatigue testing

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Abstract

Thermomechanical fatigue is a technique that is going to be widely used for the characterisation of gas turbine components. As the experimental technique is quite complex, it requires a defined procedure to initialise the experiments. In particular the evaluation of the systematic temperature-mechanical strain shift due to the equipment response and the thermal strain compensation during thermal cycling, the verification of zero stress before starting have to be defined in order to produce TMF tests comparable from different laboratories.

This paper describes the experimental activity carried out in order to determine a procedure for the evaluation of thermal strain, for the optimisation of the phase between temperature cycle and mechanical strain and for the selection of the best point at which test should start. The zero stress test performed before TMF test is described and confirms its utility to ensure a correct start of TMF testing.

TMF tests have been performed on Nimonic 90 nickel-base superalloy in the temperature range of 400–850 °C and 180° out of phase cycle. Some tests were stopped and restarted in order to determine the influence of such stops on TMF life and the best restart procedure.

At the end few tests have been planned for the verification that the adopted procedure is generally correct.

Keywords: Thermomechanical fatigue; Nickel-base superalloy; Start procedure; Restart procedure; Code of practice

1. Introduction

Thermomechanical fatigue (TMF) is a technique widely used for the design and verification of structural materials for components operating at elevated temperatures. As testing is relatively complex, it is important to define an experimental procedure in order to compare TMF results obtained in different laboratories.

Besides some verifications as testing machine alignment, the temperature profile in the specimen and other standard procedures also requested by isothermal low cycle fatigue standard, it is also necessary to define the starting procedure and the restart procedure in case of unexpected test stop.

In order to standardise as well as accomplish the TMF testing, the TMF-STANDARD European project has conducted research activities with the final goal of the definition of the best procedure for TMF testing and the inclusion of the results in a code of practice. The previous experience of our laboratory in TMF testing [1–4] has been useful in defining the experimental approach to determine the best procedure for test start and restart.

2. Experimental technique and calibration procedure

The TMF system principally consists of a 250 KN servo-hydraulic machine and an induction heating equipment. The heating device is composed of a radiofrequency induction generator (the frequency ranges from 100 to 400 kHz in function of the power required), a low voltage transformer and a water cooled copper coil. Temperature is measured by a thermocouple type K (Chromel–Alumel), which is spot-welded outside the gauge length in order to avoid crack initiation at the thermocouple weld position.

Tests have been performed on the nickel-base superalloy Ni90. The temperature range was from 400 to 850 °C with triangular wave-form and a temperature rate of 5 °C/s. The

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mechanical strain cycle was also triangular and 180° out of phase with temperature cycle. The level of mechanical strain was ±0.4%.

Before experiments on the selected material, the temperature profile has to be adjusted using a specimen on which three thermocouples are welded along the gauge length in addition to the thermocouple used for temperature control. Fig. 1 shows the specimen drawing and the thermocouple positions.

Thermocouple 3 is in the middle of the gauge length; thermocouples 2 and 4 are 7 mm from the middle. Thermocouple 1 (the upper position of the specimen when mounted between grips) is used for temperature control and the fifth one is for temperature check during TMF testing.

A calibration procedure is necessary in order to record the temperature profile and the thermal strain before TMF test series. This procedure is the following.

Using the specimen of Fig. 1 (with the five thermocouples) the selected TMF cycle is applied with the temperature control by central thermocouple. The response of the external thermocouple is recorded after the necessary stabilisation of the thermal cycle (generally 5 cycles are enough). This cycle is used (automatically saved as file A) for producing the thermal cycle in the gauge length. During this procedure the delay of the system in temperature control is also checked and compensated. In our system this delay is about 1.8 s and for this reason the temperature command is anticipated with the same value.

During the temperature cycling (controlled by the external thermocouple) the temperature of the central thermocouple and the thermal strain are recorded and saved as file B.

As soon as this procedure is completed, a testing specimen, on which only the external thermocouples 1 and 5 are spot-welded, is mounted on test system. File A is used for controlling the temperature, while file B gives the central temperature (the central thermocouple is not present in this sample used for TMF test), which can be plotted with the thermal strain recorded in this specimen. Also in this step a series of stabilisation cycle is required before the thermal curve recording which is the mean of 5 cycles. The stabilisation cycles are introduced in order to have a thermal cycle in which the values are almost the same. In particular the maximum and minimum thermal strains are similar. In our case this is verified after 3 cycles and it is reasonable to define 5 cycles before recording the thermal strain. It is apparent that the number of stabilisation cycles can be different from equipment to equipment and a particular attention is required to verify this aspect. In our case 5 cycles are considered largely conservative.

The thermal strain curve, obtained by the mean of 5 cycles, is superimposed to the mechanical strain in order to obtain the total strain that controls test.

3. Start procedure

After the calibration procedure described in the previous chapter, it is necessary to define the steps to be performed before the TMF test start.

First it is necessary to verify if the machine and specimen alignment, the temperature distribution and the extensometer set are correct. The best way is the elasticity modulus measurement in the temperature cycling range. The measurement can be performed at constant or cycling temperature. In our laboratory the measurement is performed at constant temperature with steps of 50 °C from minimum to maximum temperature.

Once this measure has been completed, it is necessary to evaluate the thermal strain component in function of the temperature cycling. These values have to be added to the mechanical strain in order to obtain the total strain curve that controls test. Before recording these values, a few cycles are necessary for system stabilisation. As the stabilisation cycles and the recorded cycles could affect the TMF behaviour, some tests have been performed changing the number of stabilisation cycles (when the thermal strain peaks are constants) and recorded cycles. As a final verification of the correct procedure adopted before test starting it is recommended to perform few cycles (usually we run from 6 to 10 cycles) in strain control applying the thermal strain recorded previously. In these conditions the stress response should be as low as possible (usually below 50 MPa), confirming that the experiment is correctly set up. Fig. 2 shows an example of a recorded cycle.

The TMF start condition can be defined in function of the cycle selected. If it is not necessary to select particular start conditions (for example in investigating complex temperature cycles or particular pre-strain conditions), the most common starting point is selected as the minimum temperature or as the zero mechanical strain.

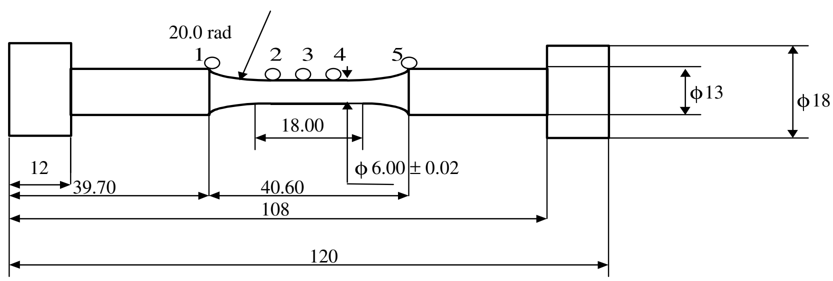

Fig. 1. TMF specimen showing the thermocouple positions (1–5).