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Novel Test Methods for Mechanical Strength Characterisation of Engineering Ceramics

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1 INTRODUCTION

All new materials for engineering purposes in the aerospace industries are submitted to detailed behavioural studies to determine their suitability for their role as structural components: these studies provide data for design and life predictions.

Material strength and the measurement methods used are obviously of the utmost importance. Possibly the simplest and most convenient method of strength measurement is via a simple, but carefully prepared, rectangular beam specimen subjected to bending under three- or four-point loading. However, the stress gradients produced in these bending modes means that very small volumes of material are subjected to tensile stress. Also, because of the variability of defect distribution to be found in these materials, it is necessary to carry out large numbers of tests which are then subjected to statistical analyses. At this stage the results can be presented in the form of nominal bend strength together with a numerical reliability factor (Weibull Modulus). This form of presentation gives little aid to the designer, since it takes no account of 'size effect'. A useful 'tool' for the designer is the adoption of the Unit Strength Concept which takes account of size effect; this approach was devised by Stanley *et al.* (1976) and translates the results into tensile strength per unit volume or area.

However, as well as the problems presented by the stress gradients in this type of test, another problem which should be considered is the friction at the loading points that causes errors; this problem is not easy to solve at elevated temperatures. Therefore, there is a requirement for a mechanical

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test which can examine significantly large volumes of material and is not hampered by friction. One answer to this problem is the adoption of the axial tensile test. The axial test is superior in every facet, i.e. modulus of rupture, stress rupture, dynamic fatigue, etc.

Last, but not least, in the turbine field there is a need to examine material under the effects of environment (corrosive atmospheres) with complex thermo-mechanical load cycles. The axial test can be adapted to meet these requirements.

2 EXPERIMENTAL TECHNIQUES AND DISCUSSION

2.1 High-temperature multiple bend testing

Despite the previously discussed disadvantages of this system, the bend test is probably the most popular means of characterising the strength of engineering ceramics for the reason that the rigs are relatively inexpensive, simple to manufacture and simple to use.

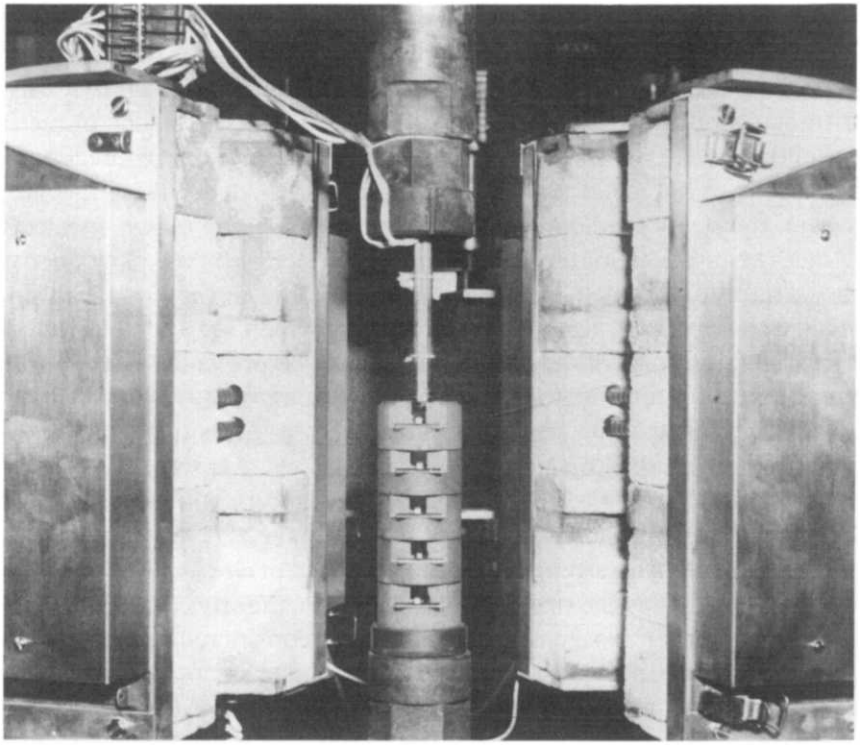

Fig. 1. The Rolls-Royce Leavesden high-temperature multiple bend rig.

With most ceramic materials, the interpretation of strength and reliability is through statistical analyses; hence, there needs to be significant numbers of tests performed in order to obtain meaningful data. Thus a simple multiple bend test system was devised by the Rolls-Royce Leavesden Laboratories prior to an early materials investigation programme.

This test method (Fig. 1) involves five bend tests carried out sequentially in one furnace load. The specimens are mounted diametrically across cylindrical silicon nitride spacer cylinders on silicon carbide rollers which are recessed into the cylinders chordwise. The cylinders are recessed at each end to produce a concentric fit, one with another, for aligned stacking. The assemblies are mounted on an actuator in an axial servo-screw tensile machine; the third loading point is a silicon carbide plunger mounted on the load-cell end. Each assembly is pushed up in turn, on to the plunger to apply the load. The complete assembly is encased by a split furnace; the 'hot-zone' is produced by Crusilite heating elements, and the thermocouples are mounted in close proximity to the specimens.

This system has been used to measure the modulus of rupture strengths of many hundreds of specimens up to 1400°C in air. Generally, three furnace loads can be tested per working day when operating up to 1200°C, but, due to limitations in furnace design, the machine utilisation is somewhat less at higher temperatures.

2.2 High-temperature axial tensile testing of ceramics

Bend fracture testing of ceramic materials has proved to be a most useful tool for material screening, but the axial tensile mode is a far superior method for precise behavioural measurements, such as: modulus of rupture, creep, stress rupture and dynamic fatigue. Typical reasons for its superiority are: larger volumes of material examined in each test; the measurements are not hampered by interfacial friction; creep measurements in bending can be distorted by friction and by positional changes in the neutral axis, etc.

The Leavesden Laboratories of Rolls-Royce have developed an axial tensile test system which has been proven up to 1400°C, and is possibly capable of efficient testing up to 1600°C (Fig. 2). In the initial design stage, ceramic shackles were considered, but dismissed on the basis of complicated design, durability and expense. The approach adopted was to use a nickel base material (to confine the majority of the heating to the specimen and not to the shackles), to water-cool and to shroud the linkages with ceramic shields.

The test specimens are 'button-headed' and cylindrical which promotes axiality; they are located in the shackle train by precision-split collets fastened over the button-head and the heads of the shackle columns. The

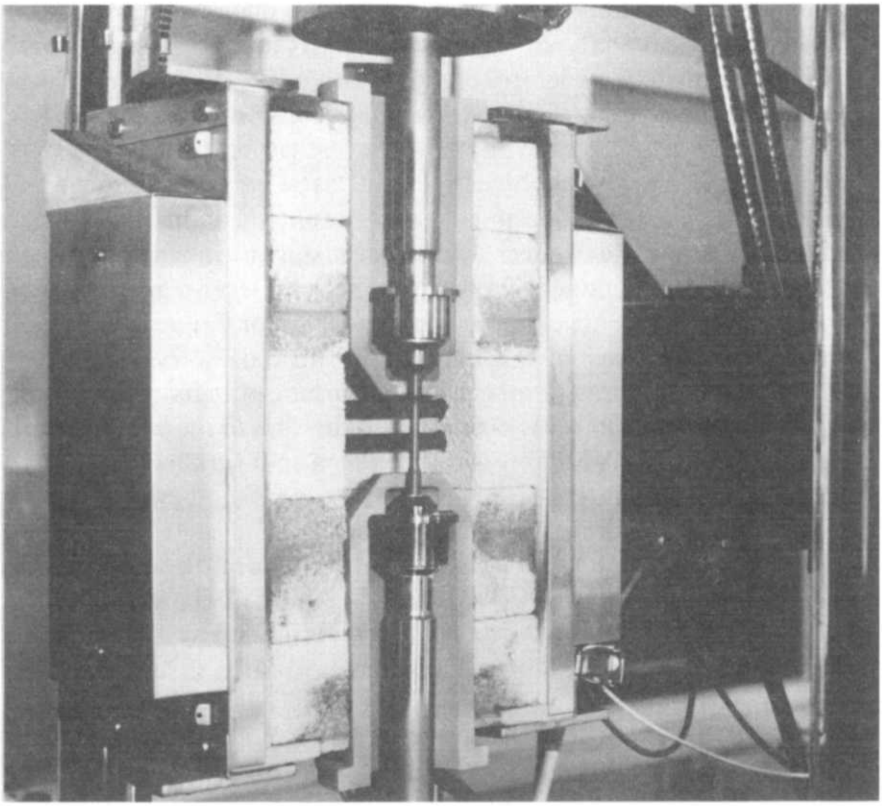

Fig. 2. The Rolls-Royce Leavesden high-temperature axial tensile rig.

compliant interface between the collets and specimen is formed by boron nitride powder which has been used successfully by Lange *et al.* (1979). The final links between the shackle train and the servo-screw testing machine are low-friction universal joints; these aid alignment.

Following assembly of the system, 'fine tuning' of the alignment is attained by a cyclic low-amplitude shake-down. Strain-gauged specimens indicate that the bending component produced in the specimen is certainly less than 1%.

During testing at 1400°C, temperature monitoring indicates that the hottest part of the shackle system is the outer surface of the split collets, which reach a maximum temperature of about 800°C; this is within the capability of the shackle material.

2.3 Complex thermo-mechanical loading

The ability to mimic engine component duty cycles on candidate materials within the laboratory has definite economic advantages for the designer and

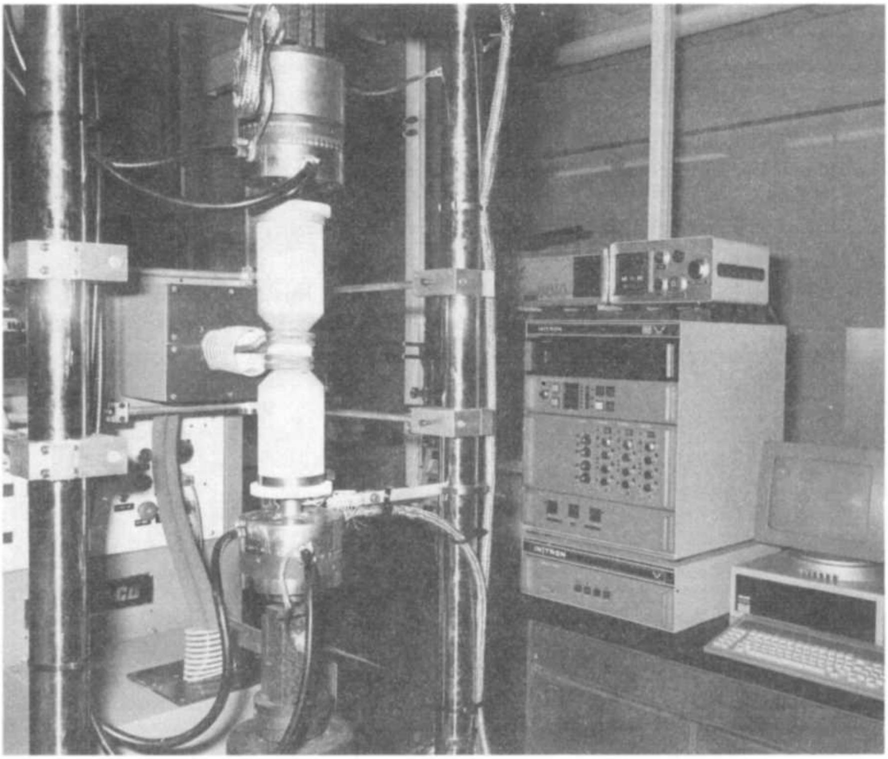

Fig. 3. The Rolls-Royce Leavesden complex thermo-mechanical loading rig.

for material development. Therefore, the testing assembly must be capable of reproducing load-temperature transients; for example, the heating element in a conventional furnace has the distinct disadvantage of thermal lag. With this in mind, the Leavesden Laboratories are engaged in linking an RF induction heater to an axial test facility via a microprocessor, and are also working on the design of induction coils and susceptors (Fig. 3). With this form of focused heating up to 1400°C, specimen temperatures at the ends of the test volume have been shown to be less than 50°C lower than those in the centre; although this has been acceptable in the development phase, current work indicates that these gradients can be reduced by fifty per cent. Temperature measurements on the collets retaining the specimen indicate temperatures of about 500°C.

3 SUMMARY

Rolls-Royce Leavesden Laboratories have demonstrated: (a) a quick, simple and efficient method of producing M.O.R. data up to temperatures of

1400°C; and (b) that with accurate machining processes, it is possible to produce an axial test system which is capable of monotonic and complex cyclic tests at a relatively reasonable cost.

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