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A High-Temperature Tensile Testing Rig for Ceramic Materials

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1 INTRODUCTION

This paper is concerned with the evaluation of a high-temperature tensile testing rig which has been designed for the high-strain, high-temperature tensile testing of superplastic ceramic materials. The same design should also be useful for the testing of more brittle ceramic materials under conditions of either constant strain-rate or dead-load creep testing.

A number of different approaches have been made to the design of apparatus for the tensile testing of ceramic materials (see for example: Mecholsky (1986)). It is apparent that a self-alignment configuration is generally necessary for the tensile testing of ceramic materials. Most of these materials are inherently brittle and therefore a near-perfect alignment is necessary in order to avoid the development of bending stresses in the specimen. A suitable self-alignment configuration can consist of a spherical ball attachment at either end of the load-train and in the near vicinity of the specimen. The hydraulic self-alignment grip system developed by Liu & Brinkman (1986) is another arrangement which results in near-zero bending moments in the specimen. Further difficulties are imposed when testing has to be carried out at very high temperatures (e.g. over 1200°C) and the present work presents a promising design for overcoming both problems of alignment and gripping at these elevated temperatures.

2 DESIGN OF THE TENSILE TESTING RIG

The design principles for the high-temperature tensile testing rig are illustrated in Fig. 1. There is a water-cooled bearing bed (1) at either end of

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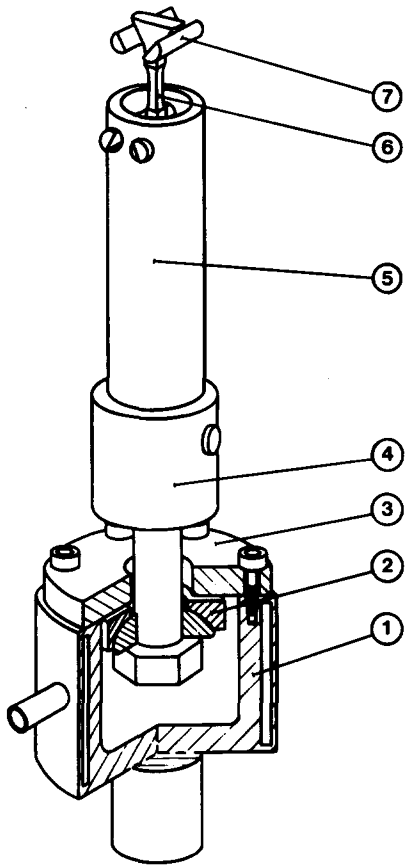

Fig. 1. Schematic illustration of the tensile rig. (1) Water-cooled bearing bed. (2) Spherical bearing. (3) Bearing bed cover. (4) Stainless steel tube attachment. (5) Alumina tube. (6) Y-TZP zirconia specimen. (7) Tangentially ground alumina gripping pins.

the rig. The function of this bearing is to allow for alignment of the load-train in order to minimise bending stresses in the tensile specimen. The surfaces of the spherical bearings (2) are coated with Teflon in order to minimise frictional forces which could hamper alignment. The spherical bearing is kept in position by the bearing bed cover (3). The load-train from the bearing bed consists of a tube attachment (4) in stainless steel which holds an alumina tube (5) that carries the load into the furnace. The fish-tailed tensile specimen (6) is held by two tangentially ground alumina pins (7) that are free to rotate to fit the geometry of the grip-section of the sample. Load is transferred from the alumina tube (5) to the specimen (6) via the tangentially ground alumina pins (7) which fit into suitable holes ground into the alumina tube.

3 TENSILE TESTING

High-temperature tensile tests have been carried out on a superplastic yttria stabilised tetragonal ZrO_2 (Y-TZP) material. Specimens were fabricated by cold isostatic pressing of Y-TZP powder (TZ-3Y powder, Toyo Soda Inc.) and sintered in air to 96–99% theoretical density. The sintered material had an average grain size of 0·3 μm. The tensile specimens had a gauge length of 14 mm and square cross-section of 4·4 mm.

The tensile tests were carried out in air in the temperature range 1250–1450°C at constant cross-head speeds in the range 0·0024–2·0 mm min^{-1} and to various strains (see Fig. 2). The heating took place in a

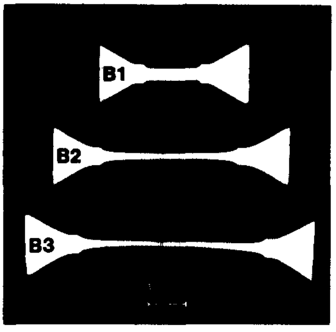

Fig. 2. Superplastic tensile deformation of Y-TZP ZrO_2. (*B*1) As-sintered specimen prior to testing. (*B*2) Strained 164% at $\dot{\varepsilon} = 1{\cdot}9 \times 10^{-4} s^{-1}$ and 1450°C. (*B*3) Strained to fracture (246%) at $\dot{\varepsilon} = 4{\cdot}8 \times 10^{-5} s^{-1}$ at 1450°C.

conventional furnace with Super Kanthal ($MoSi_2$) elements. During heating and prior to testing, the specimen was subjected to an initial stress of about 1 MPa due to the weight of the load-train but this is believed not to give any significant effects on the results. The strain was determined from the movement of the cross-head of the machine. Some specimens were strained to fracture and engineering stress–strain curves for these tests are shown in Fig. 3a. Derived true stress–true strain relationships are shown in Fig. 3b. The initial strain-hardening evident in these curves was probably due to grain growth enhanced by the strain while the subsequent strain softening was due to a combination of necking and the development of internal cavitation (Hermansson, Lagerlöf & Dunlop, 1988).

Estimated true stress–true strain-rate relationships at 1250, 1350 and 1450°C are shown in Fig. 4. These relationships were linear over a fairly wide range of strain-rates. The stress exponent, *n*, in the creep equation;

$$\dot{\varepsilon} = A\sigma^n \exp(-Q/RT) \quad (1)$$

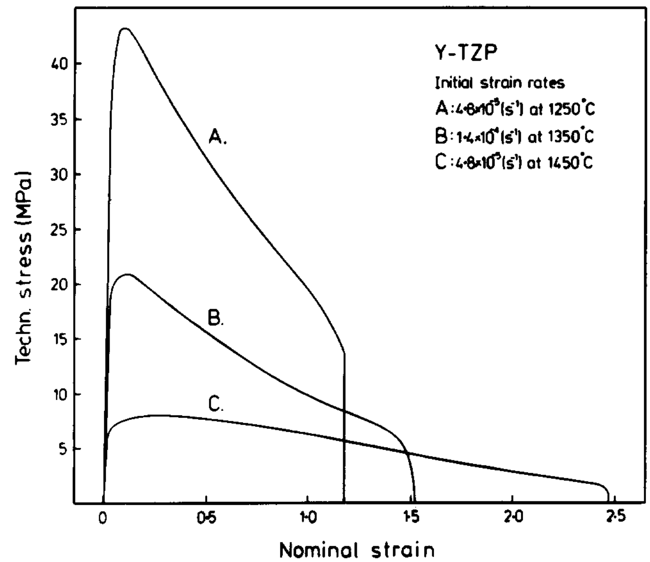

Fig. 3a. Engineering stress v. nominal strain for tensile tests of Y-TZP ZrO_2 at various temperatures and initial strain rates.

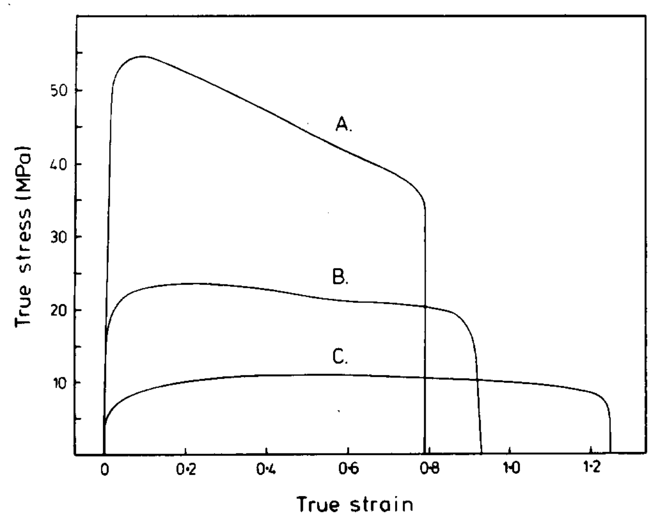

Fig. 3b. Derived true stress v. true strain curves for the superplastically deformed specimen. (A) Initial strain rate, $\dot{\varepsilon} = 4{\cdot}8 \times 10^{-5}\,s^{-1}$ at 1250°C. (B) $\dot{\varepsilon} = 1{\cdot}4 \times 10^{-4}\,s^{-1}$ at 1350°C. (C) $\dot{\varepsilon} = 4{\cdot}8 \times 10^{-5}\,s^{-1}$ at 1450°C.

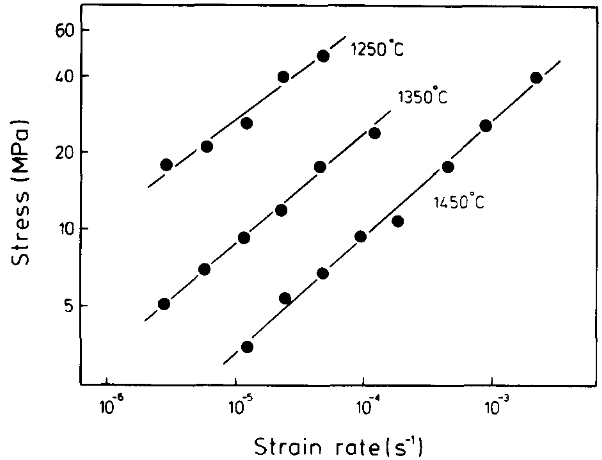

Fig. 4. True stress v. true strain-rate curves for superplastically deformed Y-TZP at 1250, 1350 and 1450°C. The stress exponent, n, varies between 2·0 and 2·2.

as given by the slopes of these curves was found to be in the range $2{\cdot}0 < n < 2{\cdot}2$.

4 EVALUATION OF THE TENSILE RIG

The compliance of the tensile testing rig was as follows: 5300 N mm^{-1} at room temperature; 2660 N mm^{-1} at 1250°C; 1280 N mm^{-1} at 1350°C and 500 N mm^{-1} at 1450°C. Measurements at room temperature of the total strain on a specimen after high temperature deformation were 7% less than the value given by the ε/t curve obtained from the testing machine. This specimen had an initial gauge length of 14 mm which was elongated to 34·5 mm (154%) at 1450°C and an initial strain-rate of $1{\cdot}9 \times 10^{-4}\,s^{-1}$. Of the 7% difference, 1·1% can be explained by thermal contraction of the strained part $(l - l_0)$ of the specimen between the testing temperature and room temperature; 0·3% is due to elastic relaxation of the specimen; 0·9% is due to the compliance of the testing rig; and ~4·7% is attributed to deformation of the grip section of the specimen.

As a rough estimate of the self-alignment ability of the rig, the bending strain introduced in a sample was evaluated using a perspex tensile specimen machined to the same dimensions as the Y-TZP specimens. Four resistance strain gauges were placed parallel to the strain axis on the faces of the gauge length of the perspex specimen. The bending strain B provided by the resistance strain gauges was calculated (Christ & Swanson, 1976) to be ~ ±5% of the mean tensile strain at 1% tensile strain and a load of 500 N.

So far the maximum load on the tensile rig has been 680 N at 1250°C. The maximum time under load has been 15 h at 1450°C during which time the maximum load was 120 N. No degradation or creep deformation of the rig has been detected following the testing programme to date.

5 CONCLUSIONS

(i) A high-temperature tensile rig has been designed and constructed for testing of superplastic ceramic materials.
(ii) The rig has a unique self-alignment design which enables the gripping of simple tensile specimens with fish-tail grip sections without the transfer of significant lateral or bending stresses.
(iii) Resistance strain gauge measurements show that the maximum bending strain on the tensile specimen is $\pm 5\%$ of the mean tensile strain at a load of 500 N.
(iv) The rig has withstood loads up to 680 N at 1250°C and testing temperatures as high as 1450°C without detectable degradation or creep damage in the load train.

6 ACKNOWLEDGEMENT

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