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High-Temperature Flexural Strength of Engineering Ceramics

A. Marsh & D. A. Bell

Refract. & Ind. Ceramics Division, British Ceramic Research Limited,
Queens Road, Penkhull, Stoke on Trent ST4 7LQ, UK

1 INTRODUCTION

Strength measurements on ceramic materials are regularly made under conditions of flexural loading, since this method is relatively easy to use. Failure stress and strain can be calculated, provided that simple beam theory is applicable. This requires the following assumptions:

(a) Stress–strain behaviour in tension and compression is identical.
(b) The beam is bent into an arc of a circle between the outer contact points.
(c) Frictional effects at contact points are negligible.

These idealised conditions never fully apply but if specimen length is great compared to width and depth, upper and lower specimen surfaces are flat and parallel, contact points are free-moving rollers made from a hard material and the specimen deforms only a little before failure, then the results obtained are of value.

When high-temperature testing is contemplated, it is essential to design an apparatus that is easy to use and will generate results at an economic rate. Working within the imposed test limitations, a high-temperature flexural strength apparatus has been designed at British Ceramic Research Limited (BCRL). The system is computer controlled and permits testing up to 1500°C. Efficiency—both in terms of results obtained and cost per test—has been proven over a number of years, tests being performed over a wide range of temperatures and on numerous ceramic materials.

2 BCRL TEST FACILITY

When performing 3- or 4-point flexural tests, the use of free-moving rollers is necessary if the simple beam theory is to be applicable. However, the use of free-moving rollers makes the introduction of specimens into a hot furnace impossible—specimens have to be introduced singly at ambient temperature. Although this makes it possible to achieve good reproducibility of loading conditions, it severely limits the number of specimens which can be tested in a working day. The solution is to design a furnace and heating system capable of very rapid temperature changes. The design chosen was in many respects original although loosely modelled on apparatus described by Shetty & Gordon (1979), capable of accurate strain measurement at temperatures up to 1600°C.

A small low-thermal-mass chamber was constructed using rigid alumina fibre-board in a thin aluminium casing in which molybdenum disilicide heating elements were installed. These components can withstand high temperatures (in excess of 1600°C) and have excellent resistance to thermal shock. The thermal stability of the system is low, however, since steady state conditions are not attained during normal operation. A virtual necessity for computer control arose, since single-channel temperature programmers were unable to cope with the thermal gradients in the furnace chamber (these can attain $100\mathrm{K\,cm^{-1}}$ during heating but fall to about $2\mathrm{K\,cm^{-1}}$ after a 10 min hold period). A computer program was therefore written to control the heating of the furnace.

The main support columns for the loading system were cut from recrystallised alumina, while the loading rollers were fabricated from hot-pressed silicon carbide and dense silicon nitride. Load is applied through a hemispherical button by a solid alumina plunger, attached via a load cell to the moving crosshead of an Instron 1195 Universal Testing Machine. Deformation measurements are made by an extensometer, mounted below the furnace in a water-cooled housing, connected to an alumina rod and tube: the rod bears on the tensile face of the specimen (a small button of suitable material may be placed on the top of the rod to prevent chemical reaction) while the concentric tube rests on the loading plate (Fig. 1). Although this design embodies the use of part of the loading system (the lower plate and rollers) in the dilatometer, it is considered that the error introduced is very small, since the rollers are of very stiff material and the lower support plate is massive and supported beneath the roller contact points. It is further considered that the alternative (i.e. use of an averaging extensometer with three alumina rods bearing on various points of the specimen) would introduce errors of a different kind owing to temperature variations within the extensometer. Since the rod and tube are substantially

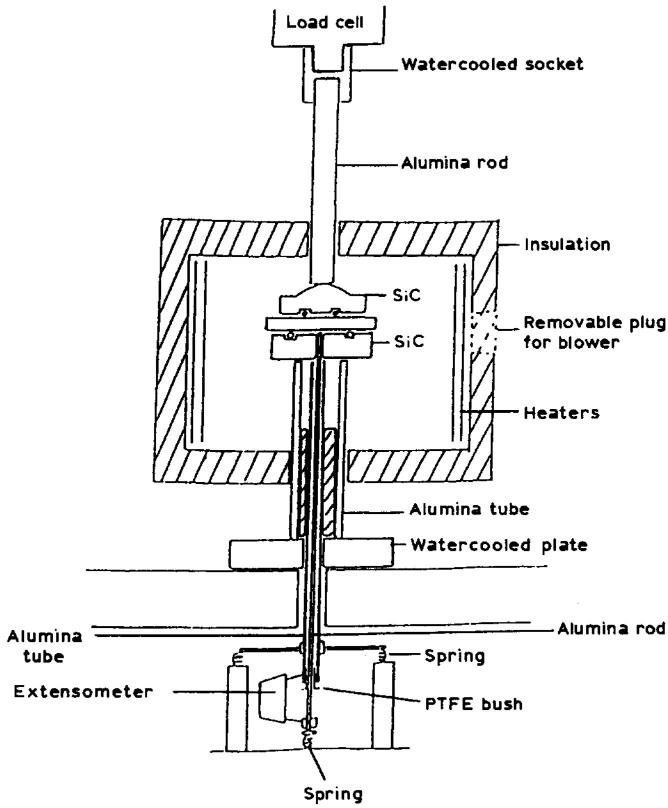

Fig. 1. Schematic diagram of high-temperature flexural strength apparatus.

at the same temperature along their heated lengths, compensation for thermal expansion effects is good. The entire dilatometer assembly is spring-loaded, maintaining a constant force of about 0·1 kgf against the specimen to ensure that it does not slip off the rollers during heating. A removable panel in the side of the furnace chamber permits accelerated cooling by an air blower once a test is completed. In this way, it is possible to cool the furnace from 1400°C to below 100°C in 20 min.

Sophisticated microprocessor controls on the Instron 1195 facilitate constant-load-rate/constant-deformation-rate testing (including creep and stress relaxation) and triangular wave load or deformation cycling at frequencies up to 0·1 Hz. Load and deformation are constantly monitored during testing using the controlling computer, which can scan the two channels as often as 50 times per second, if necessary. Stresses and strains are calculated and are generally available as hard copy by the time the furnace has cooled sufficiently for the next specimen to be inserted. A colour

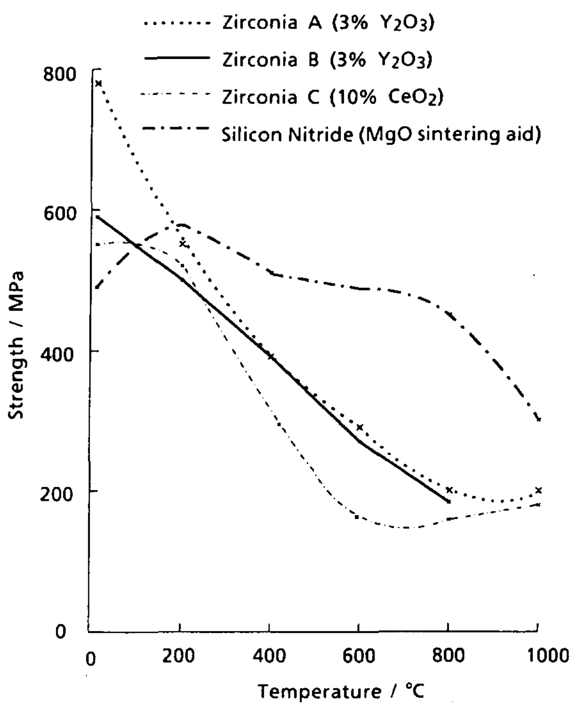

Fig. 2. Strength of engineering ceramics at elevated temperatures: four-point flexure.

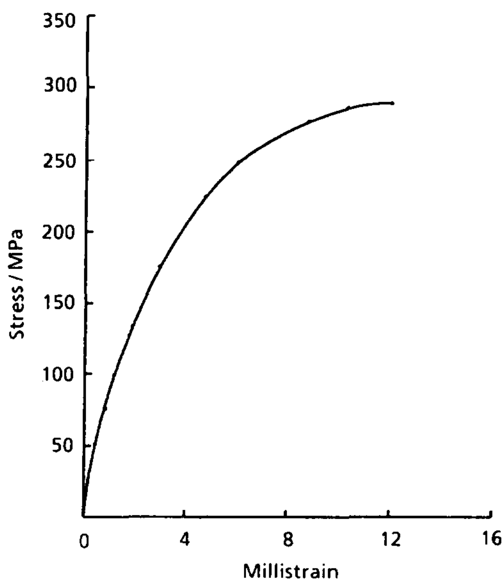

Fig. 3. Strength of Si_3N_4 reinforced with SiC whiskers at 1400°C: three-point flexure.

graphics plotter, also associated with the computer, plots stress–strain and temperature–time for each specimen.

3 TEST PROCEDURE

A bar (50 mm × 3 mm × 3 mm) of engineering ceramic material is loaded into the furnace at room temperature. An initial load of 0·1 kgf is applied. The bar is heated to the required temperature in about 20 min, with the 0·1 kgf load being maintained throughout. After a 5 min hold period, the bar is deformed at 0·5 mm min^{-1} until failure. Load and deformation are measured 5 times each second and plots of stress against strain are generated: because of the 1 N spring force, stress–strain plots do not begin at the origin. For typical stress–strain results see Figs 2 and 3.

4 SUMMARY

The BCRL high-temperature flexural strength facility has been developed using the most suitable methods reported in the scientific literature. Temperature monitoring and control, together with stress–strain measurement are performed by a microcomputer with 16-bit analogue-to-digital converters, and the results are outputted to an intelligent plotter. The equipment is suitable for measurements on high strength ceramics and has been fully evaluated on a wide range of engineering ceramic materials.

REFERENCE

Shetty, D. K. & Gordon, R. S. (1979). Stress–relaxation technique for deformation studies in four-point bend tests: application to polycrystalline ceramics at elevated temperatures, *Journal of Materials Science*, **14**, 2163–71.