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Received 29 May
and accepted 10 July 1980.

M. R. ANSEAU*,
E. DI RUPO
F. CAMBIER*
University of Mons,
Department of Materials Science,
Avenue Maistriau,
7000 Mons, Belgium.

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*Present address: Centre de Recherche de l'Industrie Belge de la Céramique, 4, Avenue Gouvernaucorney, 7000 Mons, Belgium.

The possibility of proof testing ceramics against thermal fatigue by mechanical stress

Proof testing is thought to be a requisite for the confirmation of reliable use of ceramics. It is therefore being practically applied to some ceramics. Recent studies on proof testing have confirmed that it is effective for soda-lime glass [1] and for silicon nitride [2]. The application, however, seems to have been limited to ceramics which are used under mechanical stress or under an atmosphere similar to the one used under testing. The proof test will be useful for ceramics under thermal shock on the assumption that the flaw sensitive to the thermal shock is identical to the one which is sensitive to mechanical stress. On this assumption, a method for mechanical proof testing against thermal fatigue failure has been proposed [3]. The assumption, however, is not always valid, because a ceramic has flaws of various types, which are susceptible to stress as well as the atmosphere.

On the assumption that the flaw sensitive to mechanical stress under ambient atmosphere is not identical to the one sensitive to other types of stress, such as, thermal stress caused by water quenching, the ceramics surviving the proof test under ambient atmosphere should include those with both a high and low thermal fatigue life after water quenching. In other words, the distribution of the thermal fatigue life of ceramics surviving the proof test will be similar to that of ceramics without the proof test.

To examine the differences between the flaw sensitive to water quenching thermal stress and that sensitive to bending stress in an ambient atmosphere, the following experiments were carried out.

A soda-lime silica glass rod of diameter 4 mm, was cut into specimens of 150 mm in length. The specimen was loaded by four-point bending (Fig. 1) for 10 sec. The stress was chosen so that the survival probability was about 74% (Test I) and about 62% (Test II). The value of the stress for 74% survival was about 9.9 kg mm^{-2} and that for 62% about 10.3 kg mm^{-2}. Unloading was carried out rapidly ($\lesssim 0.1$ sec).

After testing, the specimen was cut with a diamond blade just outside the two supporting points (E and F in Fig. 1). The cut specimen was mounted onto a specimen holder, so that three-point bending stress was applied to the specimen. Thermal stress was applied by repetition of heating and water quenching (Fig. 2). The three-point bending stress was applied during the thermal cycles. The bending stress was applied in such a way that the surface of the specimen subjected to tensile stress in the proof test was, also, under tensile stress in the thermal fatigue test. The heating time was about 30 min. The time for transferring the specimen from the hot zone to water was about 1.6 sec. The heating temperature was about 190° C. For comparison, glass rods without the proof test were also examined.

The survival probability, P, was calculated by dividing the number of surviving specimens after N cycles of thermal shocks by the sum of specimens (= 9).

The value of P plotted against the thermal cycles, N, is given in Fig. 3. As shown in the figure, the value of P as a function of N follows the Weibull statistics for the specimens without the

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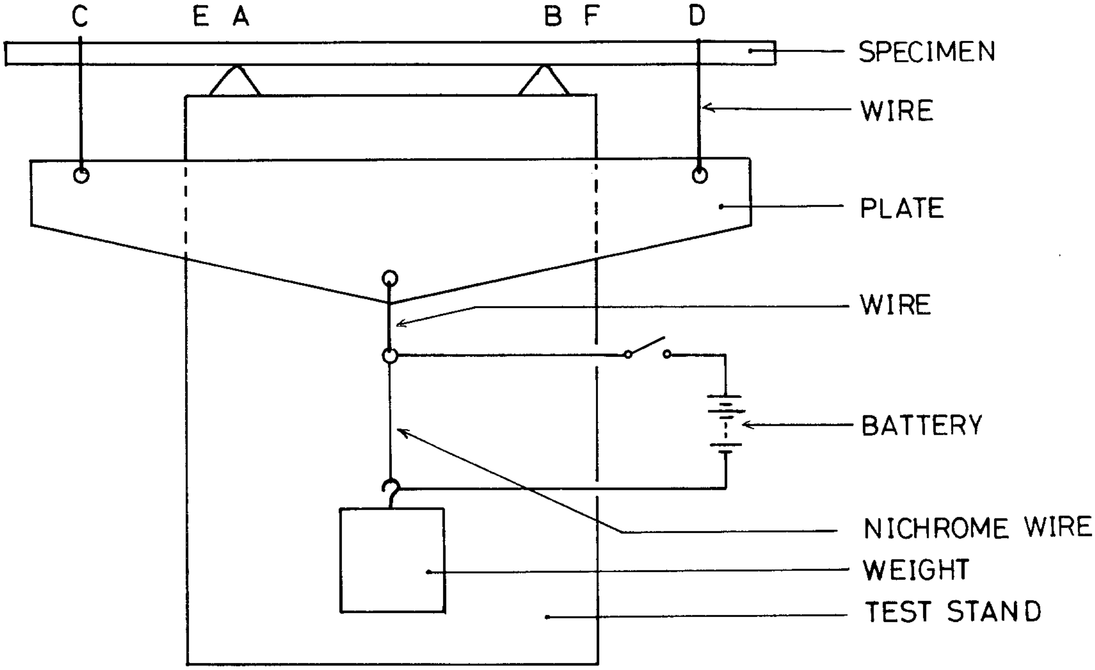

Figure 1 Schematic diagram of the proof test apparatus. The unloading was carried out rapidly (≤ 0.1 sec) by burning out of the nichrome wire with a large electric current. (A–B = 60 mm, C–D = 120 mm and E–F = 75 mm).

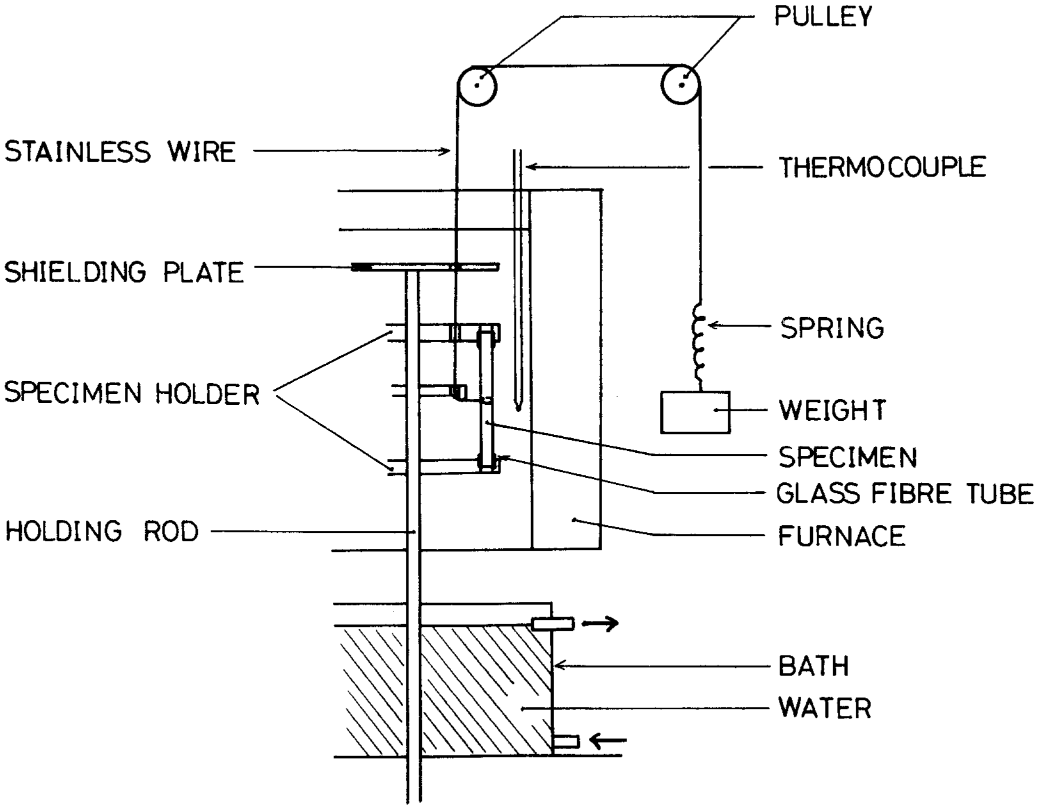

Figure 2 Schematic diagram of the thermal fatigue test apparatus.

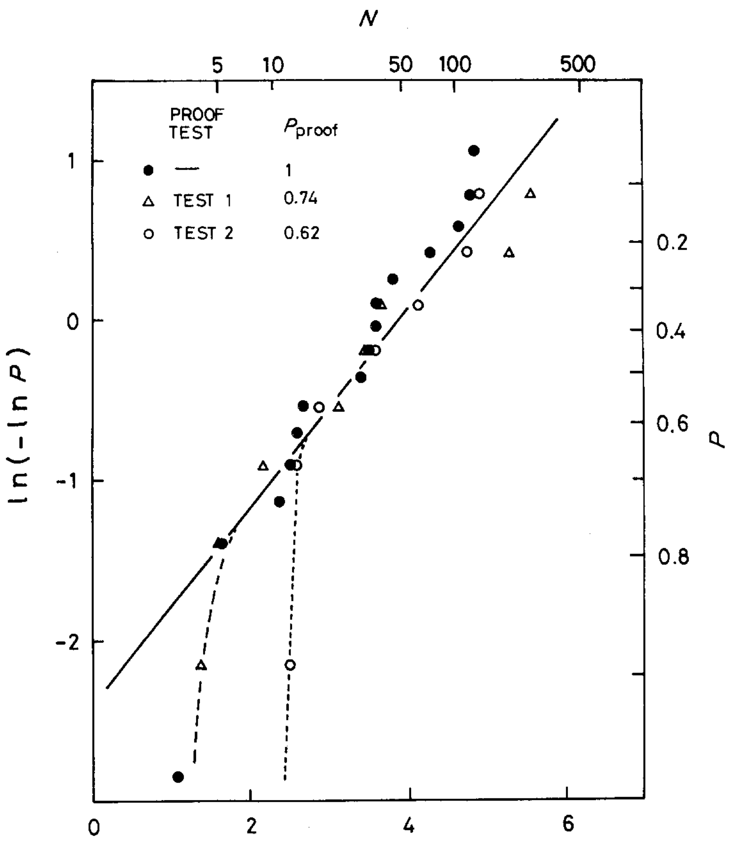

Figure 3 The distribution of thermal fatigue life of soda-lime silica glass before and after proof test by mechanical stress.

proof test. P for the specimens surviving Test I, follows the statistics for $P \leqslant 78\%$ $(= P_1)$ and the curve has a sharp knick at P_1. The value of $P_1(\doteqdot 78\%)$ is very near to the value of the population of the ceramics surviving the proof test (Test I).

The specimens surviving Test II, have a curve with a sharp knick at $P \doteqdot 64\%$ $(= P_2)$. The value of P_2 is, also, very near to the value of the population of the ceramics having survived the proof test (Test II).

These results show that the flaw sensitive to the thermal stress by water quenching is identical to that sensitive to mechanical stress.

Regardless of such differences as atmosphere and stress types, the flaw sensitive to the mechanical stress and to the thermal stress have been shown to be identical. In most cases, therefore, the assumption of mono-type of flaw will be reasonable, at least, for ceramics containing glass or silica.

The mechanical proof test can be successfully applied to thermal fatigue failure under a water or high humidity atmosphere.

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Received 31 January
and accepted 11 July 1980

N. KAMIYA
O. KAMIGAITO
Toyota Central Research and
Development Laboratories, Inc.,
Aza Yokomichi,
Oaza Nagakute,
Nagakute-cho,
Aichi-gun,
Aichi-ken,
480-11 Japan