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COMMUNICATION

The effect of the flexure testing procedure on the fracture statistics of glasses

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The effect on the fracture statistics of glass cylinders of two sample supports used in flexural testing, a conventional and a special, compensated, support are described in this communication. It is shown that the supports affect significantly both the average fracture stress and the Weibull modulus of the specimens.

It is commonly observed that brittle materials tested by three or four point bending in different laboratories show a large scatter in both average fracture strength and Weibull modulus. Baratta[1] has analysed and estimated the relative magnitudes of several sources of errors in flexure tests. Hoagland *et al*[2] have demonstrated that parasitic stresses can be significantly reduced if special, compensated, sample supports are employed in the measurements because they minimise misalignments.

We evaluate the magnitudes of experimental errors in fracture statistics parameters when identical specimens are tested in two distinct sample supports; a conventional and a compensated one. Cylindrical specimens of Pyrex glass 4 mm in diameter were tested in four point bending in a Instron model 1127. The distance between the load bearing supports was 50 mm and the load application rate was 5 mm/min.

A set of 55 specimens were tested in a standard holder shown in Figure 1. Another set of 49 specimens were tested in a special compensated support, first suggested by Hoagland *et al* and schematically shown in Figure 2. In that figure the specimen (A) is supported

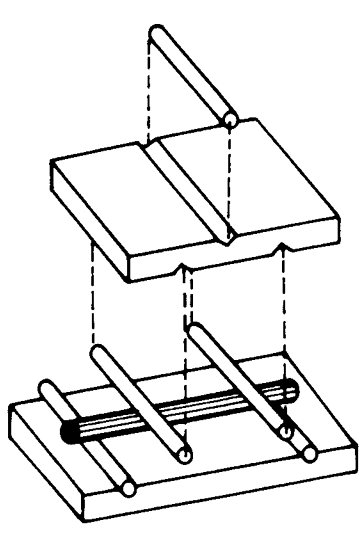

Figure 1. *Standard sample holder*

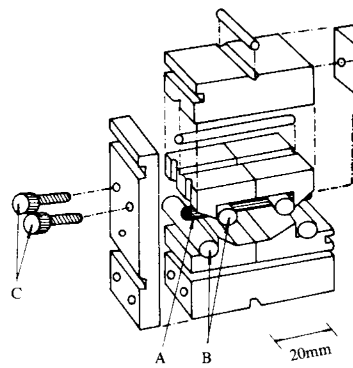

Figure 2. *Compensated sample holder for flexure testing*

Table 1. *Stress and cumulative failure probability for each stress class obtained with a conventional sample holder*

Stress class	*Fracture stress* σ_f *(MPa)*	*Probability* P_F
3	66·0	≤0·11
4	70·5	≤0·38
5	74·9	≤0·55
7	83·8	≤0·69
8	88·3	≤0·85
10	97·2	≤1·00

Table 2. *Stress and cumulative fracture probability for each stress class obtained with the compensated sample holder*

Stress class	*Fracture stress* σ_f *(MPa)*	*Probability* P_F
2	74·55	≤0·14
3	78·89	≤0·29
5	87·58	≤0·55
6	92·92	≤0·69
7	96·26	≤0·84
10	109·29	≤1·00

by rollers (B) and the set is positioned by two screws (C). Additional details of the special support are described by Hoagland *et al.*

In order to determine the average fracture stress and the Weibull modulus, the experimental fracture stress values were sorted by stress classes as described by Migliore Jnr & Zanotto[3] where each class corresponds to a range of values equivalent to one tenth of the difference between the maximum and minimum observed stresses. The cumulative probability of failure was obtained by summing up the number of specimens whose fracture stresses were situated within each stress class, grouping in the next class those with less than five experimental results.

Tables 1 and 2 summarise the stresses and failure probabilities obtained by this procedure for both types of sample support.

In the determination of the Weibull statistics parameters the following relation was assumed for the cumulative fracture probability P_F

$$P_F = 1 - \exp\left[-\left(\frac{\sigma_f}{\sigma_o}\right)^m \frac{V_e}{V_o}\right] \qquad (1)$$

where σ_f is the fracture stress for each class, m and σ_o are the Weibull parameters (material properties), V_e the effective volume and V_o the unit volume.

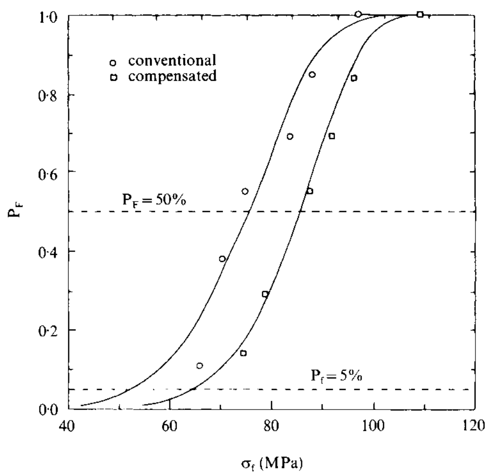

Figure 3. *Nonlinear regression plots and experimental data obtained with both sample supports*

Table 3. *Results of the curve fittings*

	Conventional sample holder	*Compensated sample holder*
m	7·2	9·4
σ_o (MPa)	41·6	52·9
V_e (mm^3)	9·3	7·7
$\sigma_{50\%}$ (MPa)	75·7	85·5
$\sigma_{5\%}$(MPa)	52·7	64·8
$\sigma_{1\%}$ (MPa)	42·0	54·5

Nonlinear, minimum least square,[4] regressions were carried out using the data of Tables 1 and 2. The results are shown in Table 3 and Figure 3 where the experimental data are also plotted.

Table 3 shows that specimens tested in the compensated sample support show an average fracture stress 13% higher than those tested in a conventional holder. The Weibull modulus is 31% higher in the compensated support. Additionally, the fractured surfaces of specimens broken in the compensated support are smoother and more symmetrical than those of samples broken in the conventional holder.

It should be emphasised that due to the different effective volumes under stress, because the spacings between the support cylinders are distinct for the two sample holders, a difference was expected in the average fracture stresses, as shown by the following relation which is derived from Equation (1)

$$\frac{\sigma_A}{\sigma_B} = \sqrt[m]{\frac{V_e^B}{V_e^A}} = \sqrt[8.3]{\frac{7 \cdot 7}{9 \cdot 3}} = 0 \cdot 98 \qquad (2)$$

where σ_A is the average fracture stress in support A, σ_B is the average fracture stress in support B and m is the average of the Weibull modulus of Table 3.

The theoretical result of Equation (2) indicates a negligible effect of V_e in this particular case. Thus, the observed differences in f and m indicate a significant role of the sample supports in the experimentally determined fracture parameters.

This finding has a considerable bearing in the design of brittle materials because, in this case, one should consider the level of stress corresponding to a certain fracture probability (and not the average stress). For instance, let us consider the hypothetical case of development or application of a material whose failure probability at 50 MPa should not exceed 1%. In this particular case, the glass tested here would have been rejected if it had been tested in the conventional sample holder, while it would have been approved in the special support. Therefore, a proper design and optimisation is only possible with improved testing procedures and sample supports.

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