DOUBLE TORSION TESTING*
EVALUATION FOR ASTM E-24.07.02

by

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Introductory comments

Our equipment for double torsion testing had been specifically designed for testing large and long polymer (e.g. PMMA) double torsion samples.

Consequently:

- (a) Only two samples could be cut from each 6"x6" plate in order to fit our equipment. The sample length was only about twice its width.
- (b) The compliance and relaxation in the machine and loading fixture was too large for performing the present test under optimum conditions. Although this has no effect on the measurement of K_I , a stiff machine/loading fixture relative to specimen stiffness is desirable for more stable precracking, i.e. short precracks. A low-relaxation machine/loading fixture is desirable for using the load relaxation method of determining the crack length.

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*This work was supported by U.S. Department of Energy.

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Nevertheless, K_{IC} data were obtained for pyroceram 9606, and sub-critical crack growth data were obtained for the soda lime glass supplied.

Loading apparatus

4-point loading device mounted on an INSTRON testing machine, floor model 1115 (see Fig. 1 and Fig. 2).

W_M , adjustable, was chosen equal to 24.8 mm.

Specimen dimensions and fabrication technique

Pyroceram 9606 and soda lime glass specimens were cut to size with a diamond wheel saw. The V-shape side grooves were also machined with a diamond wheel of the corresponding profile (see Fig. 3).

Specimen dimensions are indicated in Table I.

Precracking technique and precrack length

No special machining was done for the purpose of precracking. Instead, a clamp was fixed on the sample in such a way as to (hopefully) prevent the loaded sample from twisting and cracking below that clamp (see Fig. 4). The sample was then progressively loaded in the 4-point loading device (samples A), or loaded in a vice with a 3-point loading arrangement (samples B), until a crack would initiate and jump. The sample was in contact with water during precracking.

The first clamp which was used (on samples A) was not rigid enough and the precrack jumped to a position past the location of the clamp on the sample. Another clamp, more rigid, was used for precracking the samples B. The precrack then jumped to a position before, or about at, the location of the clamp on the sample (see Table II). Precracks on

samples B were observed to deviate from the bottom of the groove. An attempt to precrack the other end of glass sample B resulted in the same problem. We now realize that this crack deviation occurred because a small diameter rod was used as the middle loading point and produced a very unsymmetrical loading as the precrack was formed. This problem could have been avoided by using a middle loading "point" of a large contact area to assure relatively symmetrical loading.

After removing the clamp, the sample was placed in the DTT device and stepwise loaded (crosshead velocity $\dot{X} = .001$ mm/s during active loading). The precrack was allowed to extend via subcritical crack growth while the crosshead was at rest. During this process, the precracks which had previously deviated from the bottom of the groove came back to follow the bottom of the groove.

The precrack lengths at instability for the K_{IC} tests on 9606 glass ceramic were deducted from the observation of the fracture surface of the broken samples and from the known loading histories (Table II).

Testing conditions

- The tests were performed in distilled water at 21°C (room temperature).
- The crosshead velocity, $\dot{X}$, during active loading was .001 mm/s.
- The rates of increase in K_I , $\dot{K}_I$, during K_{IC} testings are indicated on Table III.
- The side groove was on the tensile surface of the specimen.

Crack length measurements

Crack length is here defined and measured by the distance between

the loading end of the specimen and the position of the leading edge of the crack on the tensile surface (i.e. the bottom of the groove).

- Glass specimen

Direct measurement by optical method during subcritical crack growth was easily achieved by using a telemicroscope and proper specimen illumination (Fig. 2). Subcritical crack growth data could therefore be obtained by recording the crack length, and the corresponding load, as a function of time.

- Pyroceram 9606

It was found extremely difficult to locate the crack tip with our instruments. Polishing the bottom of the groove with 280 grit paper helped seeing better the crack but the magnification of our telemicroscope was not high enough. No direct crack measurement could therefore be obtained. The compliance method for calculating the crack length from load relaxation at constant displacement X could not be used either as our machine exhibited too large a relaxation. No subcritical crack growth data could therefore be obtained for this material.

Calculation of stress intensity factor

$$K_I = P W_M [2(1-\nu) c_1 d^3 W d_n]^{-1/2}$$

with
$$c_1 \approx \frac{1}{3} - .21 \left(\frac{d}{W}\right) + .0175 \left(\frac{d}{W}\right)^5$$

and
$$\nu = .22 \text{ for soda lime glass}$$

$$\nu = .245 \text{ for pyroceram 9606}$$

Experimental results

• Pyroceram 9606

A total of three instabilities (defined as a sudden drop in load accompanied by fast crack growth) were observed while loading the samples. They provided three values for K_{IC} , equal to each other within 3% (see Table III). Their average value is:

$$K_{IC} = 2.15 \times 10^6 \text{ Nm}^{-3/2}$$

As explained above, no subcritical crack growth data could be obtained, although subcritical crack growth was qualitatively observed to occur.

• Soda lime glass

Figure 5 shows subcritical crack growth data obtained on Sample B, while the crosshead was stopped at two passive loading positions. Open circles on Fig. 5 are for the first crosshead position ($X = 51 \mu\text{m}$) and correspond to a crack growing from a length of 34.5 mm to a length of 53.9 mm. The crosshead was then moved by another 14 μm (new $X = 65 \mu\text{m}$) to increase the load on the sample, and again let the crack grow while the crosshead was stopped. The full circles on Fig. 5 correspond then to the crack growing from 57.4 to 88.4 mm.

Since the effective length of the sample is only 1.8 times its width, it would not be surprising that the open circle data at short crack length (i.e. higher velocity region of open circle data) would correspond to overestimated values of K_I and the full circle data at long crack length (i.e. lower velocity region of full circle data) would

correspond to under-estimated values of K_I .

As the crack length was equal to 88.4 mm, the crosshead was moved again at a velocity $X = .001$ mm/s in an attempt to reach instability and obtain a K_{IC} value. However, as the load increased, the crack velocity increased continuously until the load started to decrease because the crack length was approaching the length of the sample (i.e. in the region of non-linearity between compliance and crack length). No valid K_{IC} value could therefore be obtained on this glass specimen. A K_{IC} test could most probably have been performed on the sample if the starting crack length for the K_{IC} test had been shorter and/or the crosshead velocity higher.

Note that the crack velocities indicated on Fig. 5 are the apparent crack velocities and that the average true crack velocities, because of the curvature and angle of the crack front with the specimen surface, are lower by a factor ϕ . A method to calculate ϕ from the observed shape of the crack front has been proposed by Pollet and Burns (see enclosed copy).

TABLE I: Specimen dimensions

Specimen		W mm	d mm	c_1	d_n mm	L mm
Soda lime glass	Sample A					
	Sample B	34.96	5.58	.300	3.52	150 (original) 128 (equivalent)
9606 glass-ceramic	Sample A	35.24	7.67	.299	4.96	153
	Sample B	35.52	7.66	.288	5.02	153

TABLE II: Precracking technique and precrack length

Specimen		Clamp type	Clamp position L_C cm	First precrack length cm	Precrack length at instability for K_{IC} cm
soda lime glass	Sample A	A*	~5	~6(?)	-
	Sample B [†]	B**	~5	2.5	-
9606 glass-ceramic	Sample A	A*	~5.8	9.0	9.0
	Sample B	B**	~5	5.5	9.3 (1) 10.2 (2)

* First clamp used: found not to be rigid enough.

** Second clamp used: more rigid than first one.

† Precracked at both ends.

TABLE III. K_{IC} for pyroceram 9606

Pyroceram 9606	P_{inst} N	K_{IC} $Nm^{-3/2}$	K_{IC} $Nm^{-3/2} s^{-1}$
Sample A	500	$2.12 \cdot 10^6$	$1.15 \cdot 10^4$
1	506	$2.13 \cdot 10^6$	$1.35 \cdot 10^4$
Sample B	516	$2.17 \cdot 10^6$	$.58 \cdot 10^4$

aver. $2.15 \cdot 10^6$

Fig.1 : loading device for D.T.T.

Fig.2: Photo of loaded Specimen

Fig. 3 : Specimen for double torsion testing .

Fig. 4 : Clamp arrangement for controlling the crack length during precracking .

Fig. 6 : Fracture Surfaces