Double-torsion measurements with and without a guiding notch

The double torsion technique (DT), first proposed by Outwater and Jerry [1], is very popular for studying crack growth behaviour in ceramic materials due to its supposed analytical simplicity and the ease with which experiments are carried out. In most cases the double torsion specimen is used with a guiding notch to avoid the deviation of the crack path from the midplane. However, it is possible that, owing to notching, effects from inaccurate dimensioning or inhomogenities in the structure may be suppressed. Moreover, the width of the notch and the geometry of the notch tip could influence the data.

An investigation of the effect of notching was made using the constant load technique. The test specimens had different lengths ($L = 80$–40 mm) but similar widths ($w = 24$ mm) and thicknesses ($d = 2$ mm). Notches with widths of 1 and 0.5 mm were introduced. Notches with a width of 1 mm had a square shaped notch-tip geometry, whereas for the 0.5 mm wide notch, the notch-ground geometry was rounded (Fig. 1). The data for these specimens were compared with those of a smoothed DT-specimen. Specimens without a guiding notch require a well finished surface as well as an extremely balanced loading device. Special attention must be paid to keeping the specimen thickness, d, constant along the specimen length, L. In our case the maximum deviation of d was 0.03 mm. A high precision notching device guarantees a constant notch depth of 0.7 mm which, together with a constant notch width and a constant notch-tip geometry, allow reliable, comparative measurements.

An initial crack length was introduced using a thin (60 μm) diamond saw. The specimen was then precracked by increasing the load slowly

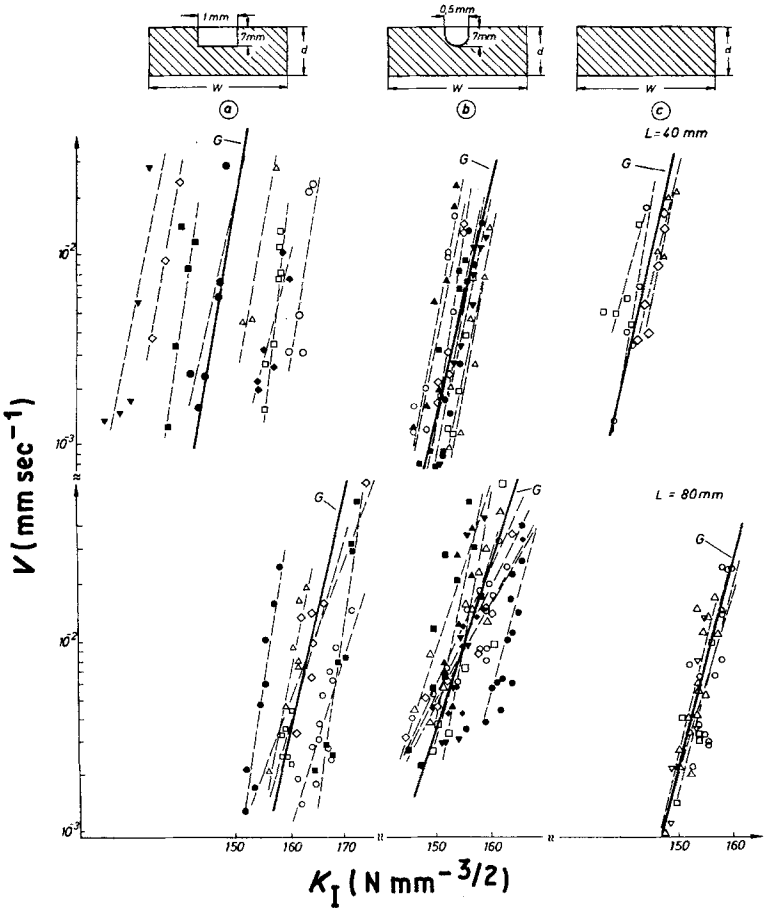

Figure 1 Log v–log K_I curves (materials function $v = AK_I^n$) measured from DT-specimens (constant load technique) of different length, L, with and without a guiding notch. G = best fit curve evaluated from single specimen curves.

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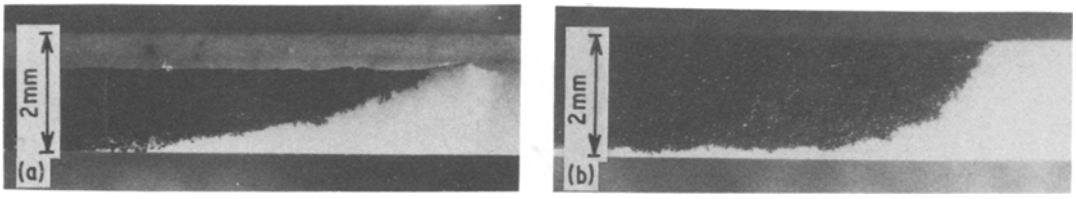

Figure 2 Crack front geometry: (a) with a guiding notch of width 1 mm, and (b) without a guiding notch.

until a material-specific crack front geometry of the running crack had built up. It should be emphasized that for specimens without a guiding notch the position of the crack front may be observed by reflecting light [2]. It is possible therefore to examine the region where K_I is independent of the crack length, a.

It was noted, that the crack front geometry with a notch width of 1 mm was flatter compared to the geometry developed in a specimen without a guiding notch (Fig. 2).

A commercial Al_2O_3 material was used with Young's Modulus, $E = 3.8 \times 10^5\ N\,mm^{-2}$, density $3.83\ g\,cm^{-3}$, purity 99.7% and grain diameter $\bar{d} = 19\,\mu m$.

The results of n-values are given in Fig. 1 and Table I. DT-specimens of length $L = 80$ mm show the highest n-values and the largest standard deviation for a guiding notch width of 1 mm. It is possible that the stress intensity is enhanced at the square-formed edges of the ground notch which acts to accelerate the crack extension. Crack extension at the edges of the notch is supported by a notch-ground geometry whose plane does not extend parallel to the specimen surface.

Concerning a rounded notch-tip geometry as in the case of the notch with a width of 0.5 mm, the crack tends to run along the flanks of the notch at alternating distances from the bottom. This may decrease the crack velocity and hence n. The results of a guiding notch of width 0.5 mm appear to agree well with most data reported in the literature [3] for the material used.

Data evaluated from specimens without a guiding notch exhibit the smallest standard deviation. The median values occur between the results of specimens with notch widths of 1 and 0.5 mm. As it was possible to watch the crack growth visually, a constant region of $20\ mm \leqslant a \leqslant 50$ mm could be detected where K_I is independent of crack length, a.

Short DT-specimens ($L = 40$ mm) show the largest n-values. The main reason may be that with the dimensions used, there exists no region where K_I is independent of crack length. Crack velocity always increases for constant load, hence the $\log v$–$\log K_I$ curve is steeper. Similarly for the larger specimens, the n-values are highest with a guiding notch of width 1 mm. Furthermore, the data without a guiding notch lie between those for notch widths of 1 and 0.5 mm, with a larger standard deviation compared to larger specimens.

The fracture toughness K_{IC} was also measured with and without a guiding notch and compared to those evaluated from notched (notch width 50 μm), four-point bend specimens (dimensions:

TABLE I Data of the subcritical crack extension parameters n, A (materials function $v = AK_I^n$) and fracture toughness K_{IC} as functions of DT-specimen length L and widths of the guiding notches

L (mm)	Notch width (mm)	Number of DT-specimens	n	$-\log A$	K_{IC}* ($N\,mm^{-3/2}$)
80	1.0	6	48 ± 19	109 ± 42	168 ± 5
80	0.5	9	31 ± 13	70 ± 28	161 ± 2
80	0	4	41 ± 5	92 ± 10	155 ± 1
40	1.0	8	64 ± 19	141 ± 40	–
40	0.5	4	53 ± 13	115 ± 28	–
40	0	8	60 ± 9	133 ± 19	–

*For comparison: $K_{IC} = 127 \pm 3$, notched four-point bend specimen.

width 7 mm, thickness 3.5 mm, length 60 mm, outer span 54 mm, inner span 18 mm) (Table I). The DT-values always exceed the data measured with bend specimens. K_{IC} decreases with notch width and is lowest for DT-specimens without a guiding notch. The same may be said for the standard deviation.

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Elastic constants of single crystal manganese–zinc ferrite

Manganese–zinc ferrites find their application in magnetic recording. Both polycrystalline material and single crystals are used for this purpose. The manganese–zinc ratio is chosen for optimal magnetic behaviour. The elastic behaviour of the monocrystalline form of this material is only partly known. Apart from the work of Kawai and Ogawa [1] no data are available. To obtain further information we measured the elastic constants of a Mn–Zn ferrite single crystal.

A Mn–Zn ferrite single crystal was grown in the (1 0 0) direction in an oxygen atmosphere using the Bridgman technique. Details of the experimental set-up will be published separately. The dislocation density in the crystal was approximately 10^6 cm^{-2}. A (1 1 0) slice, oriented within $\frac{1}{2}$ degree of an arc and approximately 1.5 mm thick, was sawn from the crystal. This slice was of uniform thickness, within 2 μm. The composition was checked with the X-ray fluorescence method (Table I). The density was measured by the Archimedes method as elaborated by Prokic [2]. The lattice constant was determined from a powder sample using CuKα radiation. Good agreement was found for the measured and calculated densities. Longitudinal and shear ultrasonic wave velocities, v_l and v_s, were measured at 10 and 20 MHz respectively, using the pulse echo method. From the wave velocities and density the elastic constants c_{11}, c_{12} and c_{44} were calculated [3]. Relative standard deviations were estimated at 0.5%. The results are given in Table I.

Recently Kawai and Ogawa [1] determined Young's modulus in a (1 1 0) bar of single crystalline Mn–Zn ferrite with composition $Mn_{0.53}Zn_{0.35}Fe_{2.12}O_4$. They measured the bar velocity using 125 kHz longitudinal waves and found Young's modulus to be 154 GPa. Calculation of Young's modulus in the (1 1 0) direction from the elastic constants are given in Table I and this results in a value of 188.8 GPa. A difference of roughly 20% is thus found. Apart from the small difference in composition there is no obvious reason for this discrepancy.

From the single crystal elastic constants one can estimate Young's modulus E and Poisson's ratio ν for the fully dense polycrystalline material using the Voigt–Reuss–Hill [4] or Hashin–Shtrikman [5] averaging scheme. This results in $E = 180$ GPa and $\nu = 0.326$. These values agree very well with $E = 177.7$ GPa and $\nu = 0.326$ as determined by Tanaka [6] for dense polycrystalline Mn–Zn ferrite with a composition comparable to that of the ferrite used in this investigation. However, these measurements were done on a mag-

TABLE I Properties of single crystal Mn–Zn ferrite

Property	Value
Composition	$Mn_{0.45}Zn_{0.50}Fe_{2.05}O_4$
Density	5.133 g cm^{-3}
Lattice constant	0.8480 nm
v_l (1 1 0)	7.339 km sec^{-1}
v_{s_1} (1 1 0)	4.152 km sec^{-1}
v_{s_2} (1 1 0)	2.980 km sec^{-1}
c_{11}	234 GPa
c_{12}	142 GPa
c_{44}	88.5 GPa

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