JOURNAL OF MATERIALS SCIENCE LETTERS 1 (1982) 327–329

# Memory effect of crack resistance during slow crack growth in notched $Al_2O_3$ bend specimens

R. KNEHANS, R. STEINBRECH
*Lehrstuhl für Werkstoffwissenschaften, Abteilung Chemietechnik, Universität Dortmund, West Germany*

In pre-notched alumina bend specimens the crack resistance (force) $R$ increases with slow crack growth ($R$-curve) [1, 2]. The rise of $R$ is usually explained by an additional dissipation of energy which takes place in a zone of microcracks in front of the crack tip [3, 4]. In this model the $R$-curve then can be interpreted in terms of a change of the zone size and/or a change of microcrack distribution and density.

However the assumption of an energy dissipating mechanism in front of the crack is not in full agreement with experimental observation. Three-point bend tests show that there exist different $R$-curves for different notch depths, as illustrated in Fig. 1. $R$ is plotted as a function of relative crack length $a/w$ ($a$, crack length; $w$, specimen height). Starting from different notch depths ($a_n/w$) the $R$-curves are clearly separated. This leads to different $R$-values for the same crack length, i.e., for $a/w = 0.6$ $R$-values of about 20, 60 and 90 N m$^{-1}$ result from $a_n/w = 0.6$, 0.4 and 0.2, respectively. The notch depth "memory" of the crack can hardly be affected by energy dissipation mechanisms in front of the crack tip.

Thus it appears to be more reasonable to take into consideration mechanisms in the rear part of the crack and to look at the range from notch depth ($a_n/w$) to crack tip ($a/w$). If the mechanisms which lead to the "memory effect" are localized along or in the volume close to the crack walls, then as a consequence it should be possible to influence the $R$-curves by simply cutting away material from the crack walls.

To check this assumption, double notching experiments have been performed. A commercial alumina quality (A1 23, Fa. Friedrichsfeld, Mannheim) was chosen because the $R$-curves rise more steeply than those of the alumina in Fig. 1, and thus the memory effect is easier to observe. Pre-notched A1 23 specimens (7 mm × 5 mm × 62 mm, $w = 7$ mm, notch width $r \simeq 150\,\mu$m) were loaded in a stiff three-point arrangement mounted in an Instron 1195 testing machine. The load-deflection curves, recorded under conditions of slow crack growth, were analysed as described by Steinbrech *et al.* [2]. In order to simplify the re-notch procedure the experiments were performed in $H_2O$. It has been proven that this has

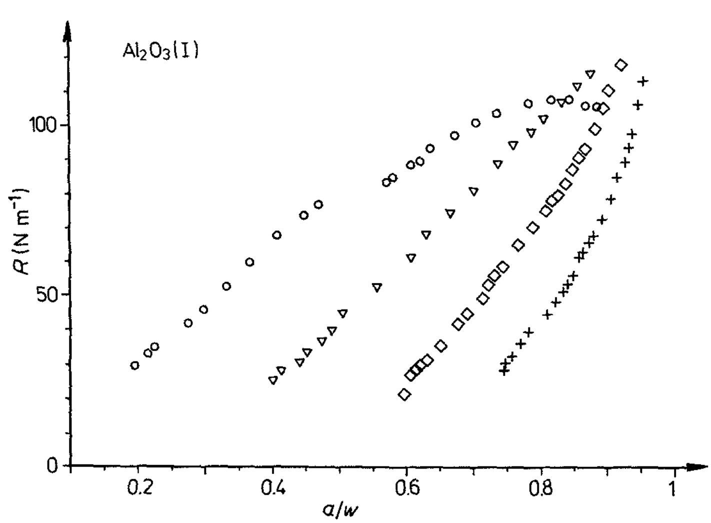


*Figure 1* $R$-curves for different notch depths [2].

  

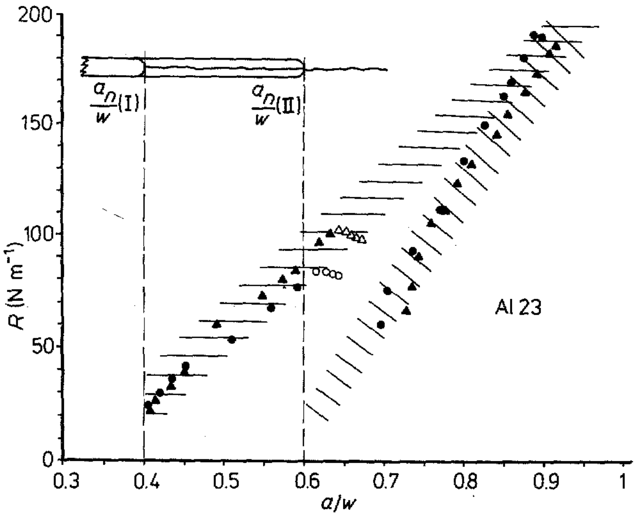


*Figure 2* $R$-curves of double notching tests (individual symbols). Hatched areas represent the $R$-curve countour from specimens notched only once. Dotted lines mark the double notch depths.

no significant influence on the slope of the $R$-curves as compared to an inert environment such as silicone oil.

Firstly, complete $R$-curves for notch depths $a_n/w = 0.4$ and 0.6 were determined from at least three specimens. The hatched areas in Fig. 2 show these $R$-curves and their corresponding scatter band. The initial $R$-value is almost identical for both notch depths ($R(a_n/w) \simeq 20.5 \pm 3.8$ N $m^{-1}$) but the $R$-curves clearly rise more steeply for the larger notch depth. At large crack length ($a/w \simeq 0.9$), the $R$-values coincide.

The double notching experiments were carried out with two specimens using the following procedure (see Fig. 2). The specimens were pre-notched to $a_n/w$ (I) $= 0.4$ and the crack was propagated up to a length $a/w \simeq 0.62$ (cross-head speed $V_T = 10\,\mu m\, min^{-1}$, crack velocity $\dot{a} \simeq 1.5 \times 10^{-2}\, mm\, sec^{-1}$). The evaluated $R$-values (solid symbols) fit in the hatched area for specimens with $a_n/w = 0.4$. At this crack length the movement of the cross-head was stopped. After some relaxation (open symbols) the crack stopped too, having reached a length of about $a/w \simeq 0.66$. Unloading of the specimens caused a further crack growth to $a/w \simeq 0.72$, as determined by microscopic observation of the specimen surfaces. Now the notch was deepened by a second saw-cut to $a_n/w$ (II) $= 0.6$, i.e., slightly less than the crack length obtained by loading. The specimens were then loaded again. The $R$-values of these double notched specimens are now clearly within the hatched $R$-curve contour for those pre-notched to $a_n/w = 0.6$. To confirm this result it must be emphasized that the $R$-values of specimens treated following the same procedure (loading, relaxation, unloading, reloading) but without re-notching remain on the original $R$-curve contour.

It is obvious that the "memory" of the crack of the pre-notch depth can be cut away by deepening the notch. This result indicates that the position and the slope of the $R$-curves are determined to a lesser extent by mechanisms in front of the crack tip than by those at the rear part of the crack.

Two alternative mechanisms which could be active in the rear part of the crack can be considered: 1. change of the structure of remaining microcracks in the volume close to the crack walls; and/or 2. friction of serrated crack walls. Both mechanisms could equally well explain the increase of $R$ with crack extension, but neither is yet capable of giving an explanation for the different slopes of the $R$-curves for different notch depths. Further experiments are in progress to distinguish between these two mechanisms and to clarify their influence on the slope of $R$-curves. It seems imperative to obtain information about the stress distribution at the rear part of the crack which is known to substantially influence the $R$-curves of alumina.

## Acknowledgements

The authors are grateful to Professor W. Schaarwächter for his useful comments and to Mrs U. Woestmann for her help in conducting the majority of the tests reported here.

## References

1. F. W. KLEINLEIN and H. HÜBNER, in "Advances

in Research of the Strength and Fracture of Materials", edited by D. M. R. Taplin (Pergamon Press, Oxford, 1978) p. 883 ff.
2. R. STEINBRECH, R. KNEHANS and W. SCHAARWÄCHTER, *J. Mater. Sci.* (submitted).
3. F. E. BURESCH, ASTM STP 678 (American Society for Testing of Metals, Philadelphia, 1979) p. 151 ff.
4. K. KŘÍŽ, H. HÜBNER and F. W. KLEINLEIN, DVM-Bruchvorgänge, Darmstadt, 1978, in "Vorträge der 10, Sitzung des Arbeitskreises Bruchvorgänge" (DVM, Berlin, 1979) p. 87 ff.

*Received 31 March and accepted 23 April 1982*