INFLUENCE OF LOADING CONDITIONS ON FRACTURE MECHANICAL PARAMETERS OF ALUMINA

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Experimental results from small angle x-ray measurements show in qualitative agreement with theoretical modelling that the crack resistance of two aluminas increases with microcrack-density and size of process zone.

With this work it will be shown experimentally as well as theoretically that crack growth in ceramics is accompagnied by stress induced microcracking which arise in a frontal process zone of size 2ψ. During stressing a ceramic microcrack nuclei are activated. This is observed especially during a bend or tensile test with a rising load. The elastic limit is characterized by the activation of favorably oriented microcrack nuclei such as stress concentrations on pores or triple points of grain junctions due to a very high internal strain energy density. Above the elastic limit more and more microcrack nuclei with smaller internal strain energy density are activated. Thus the microcrack density inside the process zone increases up to a critical strain energy density e_o and favorably oriented microcracks join together to or with a macrocrack.

During stable crack growth in ceramics with large internal strain energy density, such as ZTA-ceramics or coarse grained alumina, the dissipative energy rate dU_{diss} due to an incremental crack growth dA is comparable to or larger than the linear elastic energy release rate G_I. Thus the crack resistance of this type of ceramics is given by /1,2/

$$J_R = \frac{\gamma}{a_m}\left(\bar{I}_m^2\, 2\psi + \frac{d}{dA}\,\bar{I}_m^2\,\psi^2\right) \qquad (1)$$

γ is the specific surface energy, a_m is the size of a characteristic microcrack and I_m is the elastic interaction parameter which is a measure of the stress intensity (SIF) of the microcrack field with respect to the macrocrack. Generally the SIF is lowered by a high density of parallel oriented microcracks in a large process zone. I_m^2 depends linearly on the microcrack density.

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Stress induced microcracks can be observed by acoustic emission analysis, by microscopic observation with a decoration technique /3/ or by small angle x-ray scattering (SAXS). /4/ Fig. 1 shows the frequency distribution of scattering particles from SAXS-measurements of alumina AF 997.

The SAXS-measurements are made on small discs which contain the fracture surface and also from discs which are cut from the as-received material. The details are published elsewhere /4/. It can be seen that the frequency of scattering particles is enhanced within the limits of the fracture zone as compared to the as-received material up to a factor of 4. In addition, the peak value of the frequence distribution is shifted from a particle diameter of 140 nm for the as-received material to lower particle diameters down to about 40 nm. Obviously the diameter of scattering particles decrease with increasing distance from the fracture surface. We conclude from this measurements, that the increase of the frequency distribution of scattering particles is a consequence of stress induced microcracking in the damage zone of width $\psi \sim 300\,\mu m$. Fig. 2 shows in detail the frequency distribution of stress induced microcracks for the alumina AF 997 with the distance from the fracture surface inside the damage zone being the parameter.

In Fig. 3 the peak values of the frequency distributions are related to the distance from the fracture surface. In addition the same dependance is shown for the alumina B40. Fig. 4 shows the increase of crack resistance J_R with slow crack growth Δa for these two materials. It is obvious from the Figs. 3 and 4 that J_R increases with increasing microcrack density and size of process zone.

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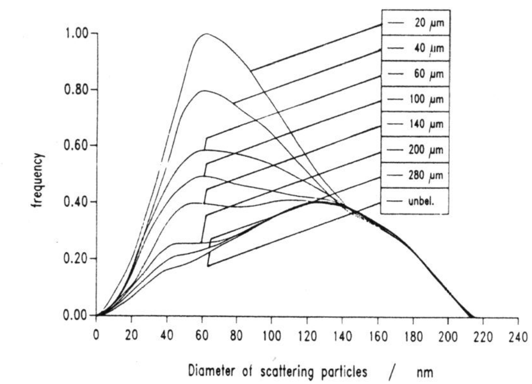

Fig. 1: Normalized frequency distribution curves of scattering particles in alumina AF 997 after slow crack growth with distance from the fracture surface as parameter.

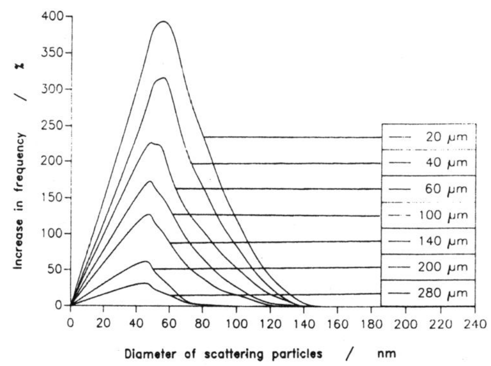

Fig. 2: Increase in frequency of stress induced particles in the fracture zone of alumina AF 997 after slow crack growth with the distance from the fracture surface as parameter.

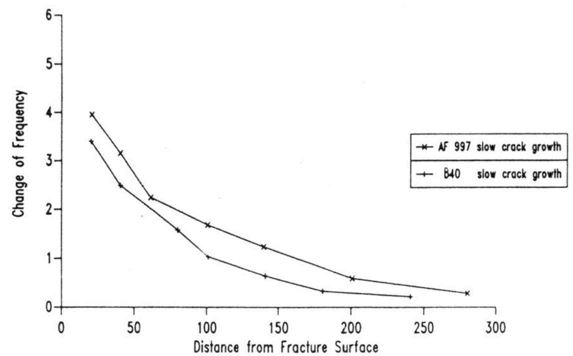

Fig. 3: Peak values of the frequency distribution curves of stress induced particles of two aluminas, (AF 997 (Fig. 3) and B40) vs distance from the fracture surface.

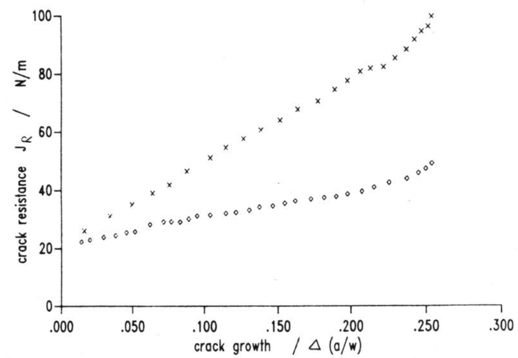

Fig. 4: Crack resistance of two aluminas vs normalized slow crack growth, values from R.W. Steinbrech /5/.