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DYNAMIC PENETRATION OF CERAMICS

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ABSTRACT

A constitutive model is presented for the inelastic deformation and fracture of ceramics that incorporates micro-cracking and plastic slip. The model comprises three essential features: (i) micro-crack extension rates based on stress intensity calculations with a crack growth law; (ii) the effect of the crack density on the stiffness, inclusive of crack closure; (iii) plasticity at sufficiently high confining pressures. The model parameters represent 99.5 $\alpha - Al_2O_3$ containing initial flaws that scale with the grain size. Predictions of stress/strain responses for a range of stress states demonstrate that the model captures the transition from deformation by micro-cracking at low triaxiality to plastic slip at high triaxialities. Moreover, the dilation (or bulking) upon micro-cracking, as well as the increase in the shear strength of the damaged ceramic with increasing triaxiality, are shown to be natural outcomes of the model.

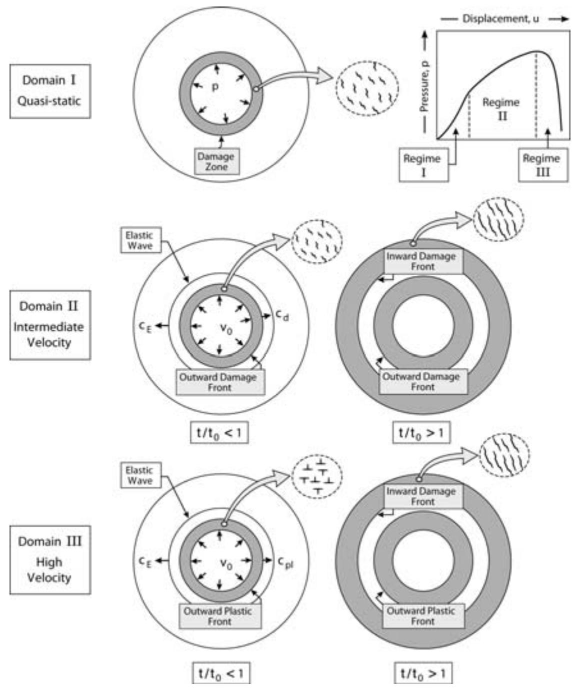

Fig.1: An illustration showing the three domains that arise in cavity expansion

Cavity expansion calculations are used to extract some key physics relevant to the penetration of ceramics. Three domains (Fig. 1) have been indentified: (i) Quasi-static where the ceramic fails due to the propagation of a compression damage front; (ii) Intermediate velocity where an outward propagating compression damage front is accompanied by an inward propagating tensile (or spallation) front caused by the reflection of the elastic wave from the outer surface; (iii) High velocity wherein plastic deformation initiates at the inner surface of the shell with failure due to a tensile damage front reflected from the outer surface. The cavity pressure is sensitive to the grain size under quasi-static conditions but relatively insensitive under dynamic loadings.

Experimental Comparisons: In a quasi-static context, Lawn [1] reported that the indentation response is sensitive to the grain size: specifically, the indentation strength decreases and the inelastic zone diameter increases with increasing grain size. These trends are revealed upon using the model to calculate the indentation of alumina by a WC sphere (Fig. 2). Note that the damage for the given load (2 kN) increases with increasing grain size, consistent with the observations.

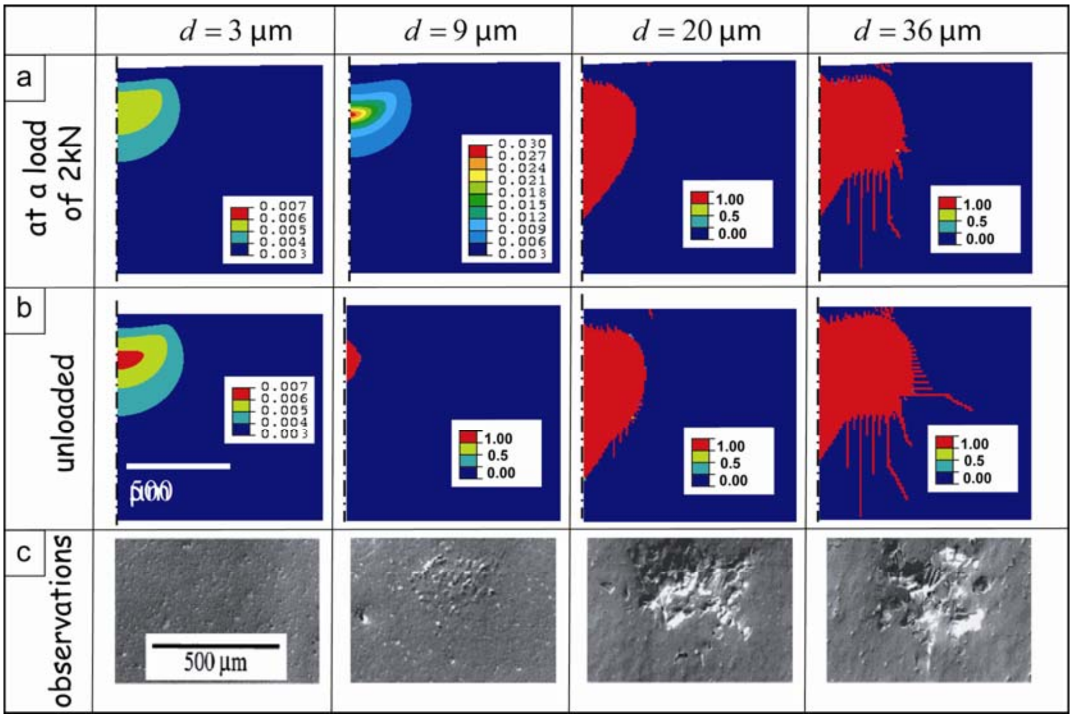

Fig.2: Comparison between the FE predictions and observations of the indentation damage zone in alumina. The comparison is shown for five different grain sizes, all indented by a 3.18mm diameter WC sphere to a load of 2 kN. The observations are from Lawn [1].

By contrast, in a high velocity impact context, James [2] revealed that, in adequately constrained ceramic blocks, the penetration resistance as characterized by ballistic efficiency is insensitive to the grain size. This insensitivity is also accurately predicted by the above constitutive model. *The model thus appears to capture the apparent paradox that the grain size has a substantial influence on the quasi-static indentation response but minimal effect on impact resistance.*

REFERENCES

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