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Shock-Wave Properties of Glass with Implications for Failure Kinetics

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Physically-based models of the dynamic mechanical behavior of brittle solids such as ceramics and concrete are essential to confident computational analysis of impact and penetration in targets containing brittle materials. This need has been well recognized and a number of such models have been developed which have demonstrated varying degrees of success over a wide range of problems involving brittle solids in warhead-target interaction events.

Within the past few years experimental evidence has revealed unexpected dynamic material response behavior in brittle solids in the form of waves of delayed failure (failure waves). Although the underlying physics of failure waves is not fully understood, as is evidenced by several conflicting explanations in the recent literature, implications are that of a complex transient strength not currently treated in concrete and ceramic models.

To date the preponderance of experimental evidence for failure wave behavior in brittle materials has been generated on glass because of the beneficial characteristics of this material in research driven studies [*e.g.* Kanel' *et al.*, 1992; Dandekar and Beaulieu, 1995]. One particular soda-lime (Na/Ca) glass has received particular attention and a wide range of experimental and ballistic data exists. Deep penetration experiments on this glass have been reported by Anderson *et al.*, (1993). Static strength and partial shock

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wave data have been provided by Holmquist *et al.*, (1995), and extensive dynamic fracture properties have been determined by Senf and Strausberg (1994). Computational model development and computational analysis of penetration and dynamic test data have also been reported [Anderson *et al.* 1993; Holmquist *et al.* 1995].

In the present study we report on new time-resolved shock wave data for this particular glass. These data span the impact stress range over which failure wave effects are expected in the present material. The full set of data cover the stress range relevant to conventional kinetic energy penetration and will constrain shock equation of state aspects of response models.

The data shown in Figure 1 were acquired through planar impact experiments in the form of time-resolved interface velocities between test glass and lithium fluoride window

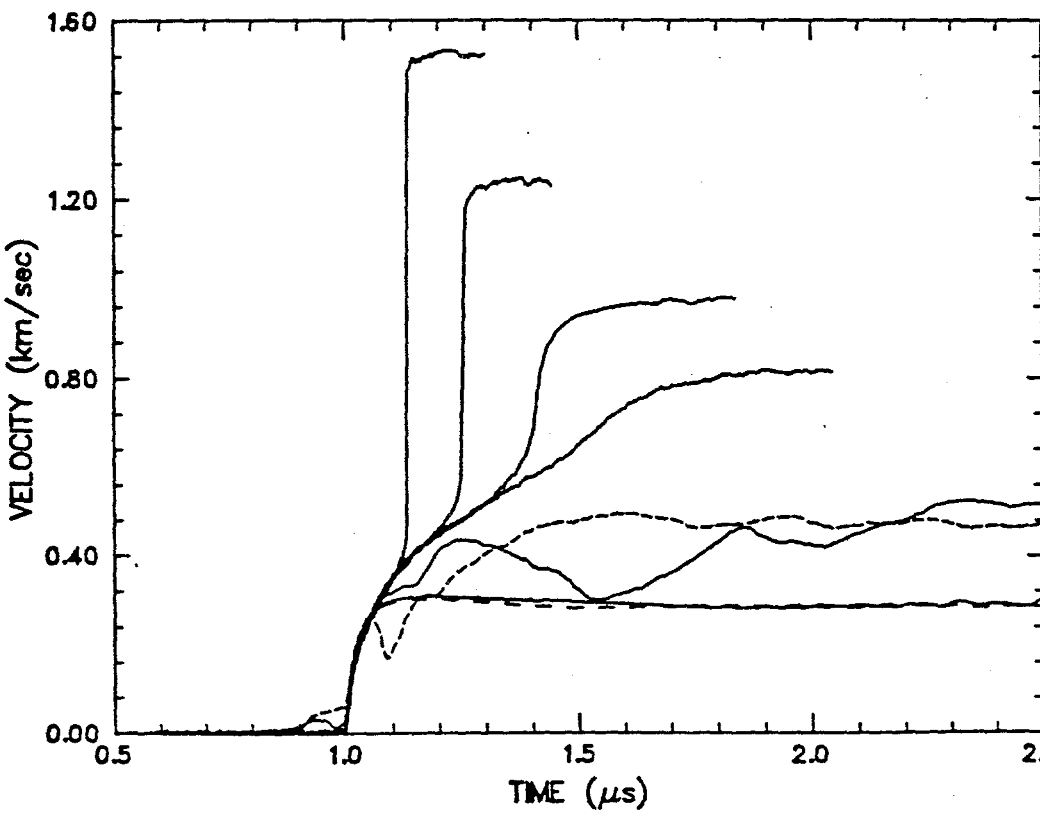

Figure 1. Experimental shock-wave velocity history profiles after propagation through approximately 6-mm soda-lime glass plates. Wave profiles are measured with velocity interferometry at the interface between glass plates and lithium fluoride laser windows.

material using velocity interferometry techniques [Barker and Hollenbach, 1972] and exhibit both shock compression and decompression characteristics of this glass. These data exhibit the anomalous compressibility characteristics of most glasses, and compressive shock structures not previously revealed by lower resolution test techniques.

Data near the dynamic strength limit and in the region expected for failure wave behavior exhibits a chaotic velocity history indicative of a coarse shear-fracture failure mechanism. Arguments will be made that these wave profile features are related to the dynamic fracture kinetics governing the failure wave phenomena.

Additional supporting results will be introduced and the proposition will be pursued that failure waves are a manifestation of deformation kinetics in which several deformation mechanisms with markedly different characteristic times are activated.

In summary new previously unpublished shock wave data on soda-lime glass are presented. These data are examined in light of recent experimental evidence for failure wave behavior in brittle solids. An underlying physical basis for failure waves is explored in terms of inelastic deformation kinetics processes.

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