IBS 2011 – A Computational Constitutive Model for Glass Subjected to Large Strains, High Strain Rates and High Pressures

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Abstract

This article presents a computational constitutive model for glass subjected to large strains, high strain rates and high pressures. The model has similarities to a previously developed model for brittle materials by Johnson, Holmquist and Beissel (JHB model), but there are significant differences. This new glass model, presented in Fig. 1, provides a material strength that is dependent on the location and/or condition of the material. Provisions are made for the strength to be dependent on whether it is in the interior, on the surface (different surface finishes can be accommodated), adjacent to failed material, or if it is failed. The intact and failed strengths are also dependent on the pressure and the strain rate. Thermal softening, damage softening, time-dependent softening, and the effect of the third invariant are also included. The shear modulus can be constant or variable. The pressure-volume relationship includes permanent densification and bulking. Damage is accumulated based on plastic strain, pressure and strain rate. Significant features of the model are the ability to compute size effects (small scales are stronger than large scales), surface effects (smooth surfaces are stronger than rough surfaces), and high internal tensile strength (as demonstrated by spall plate-impact experiments). Simple (single-element) examples are presented to illustrate the capabilities of the model.

Several example computations are presented in Figs. 2-4 to demonstrate the ability to compute more complex, high-velocity-impact conditions. Figure 2 presents computed results for a gold projectile impacting a borosilicate target with a copper buffer attached to the impact surface. The computed results produce interface defeat (no glass penetration) at V_s = 800 m/s and prompt penetration at V_s = 900 m/s. This is consistent with the test results provided by Anderson *et al.* [1]. Behner *et al*. [2] performed experiments using no buffer (gold rod impacting bare glass) which produced penetration at much lower impact velocities. For these experiments the penetration velocities were determined using a series of flash x-rays and are presented as a function of impact velocity in the lower protion of Fig. 3. Also shown are the computed penetration velocities for V_s = 900 m/s and V_s = 2400 m/s. The computed results are in good agreement with the experiments. Anderson *et al.* [3] also performed experiments using a pointed steel projectile impacting thin plates of borosilicate glass at three different scales. The smaller scale targets were stronger than the larger scale targets. Figure 4 demonstrates the capability to compute size effects. Computed results are presented for the 0.50-cal (scale = 1.0) and the 0.22-cal (scale = 0.44) projectile for V_s = 300 m/s and V_s = 400 m/s. At 300 m/s the 0.50-cal projectile exits the target at V_r = 22 m/s but the smaller scale 0.22-cal projectile is stopped. As the impact veloicty is increased the computed size effect diminshes as shown at V_s = 400 m/s. The ability for the computations to produce size effects is due to the time-dependent features in the model.

[1] Anderson, C. E., Jr., Behner, Th., Holmquist, T. J., Wickert, M., Hohler, V., and Templeton, D. W., 2007, "Interface Defeat of Long Rods Impacting Borosilicate Glass," Proceeding of the 23rd International Symposium on Ballistics, Tarragona, Spain, pp. 1049-1056.

[2] Behner, T., Anderson, C., Jr., Orphal, D., Hohler, V., Moll, M., and Templeton, D., 2008, "Penetration and Failure of Lead and Borosilicate Glass against Rod Impact," International Journal of Impact Engineering, **35**, pp. 447-456.

[3] Anderson, C. Jr., Weiss, C., and Chocron, S., 2009, "Impact Experiments into Borosilicate Glass at Three Scale Sizes," Technical Report No. 18.12544/018 Southwest Research Institute, San Antonio, TX.

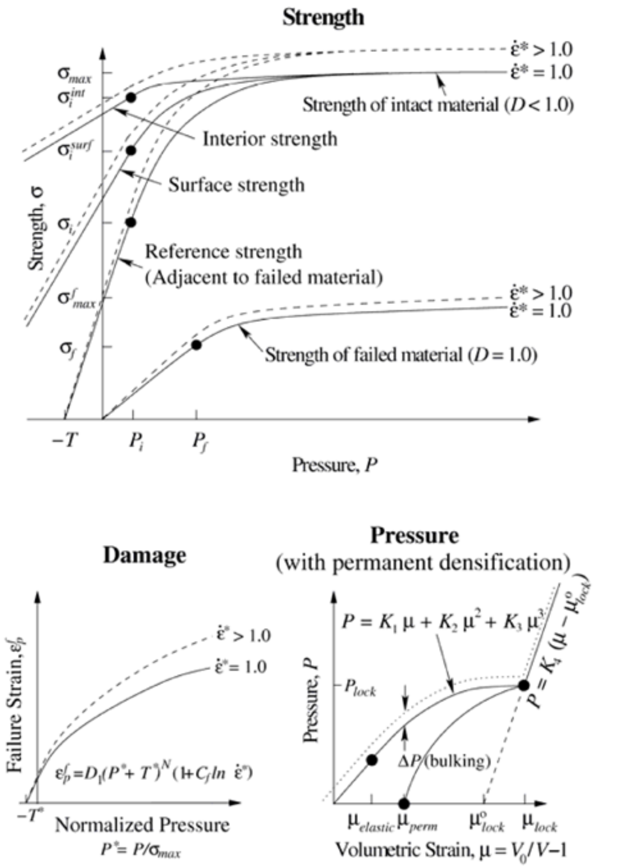

Fig. 1. Description of the glass model

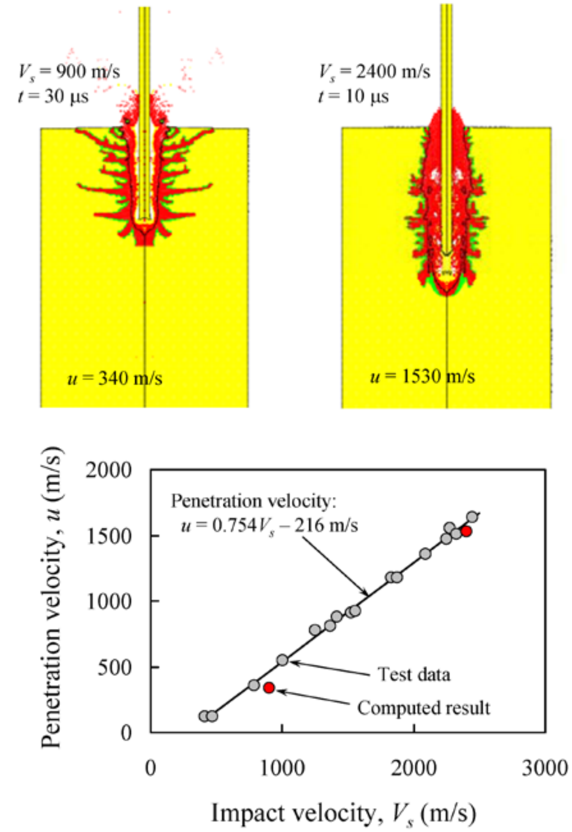

Fig. 3. Comparison of computed and experimental results for a gold rod impacting borosilicate glass.

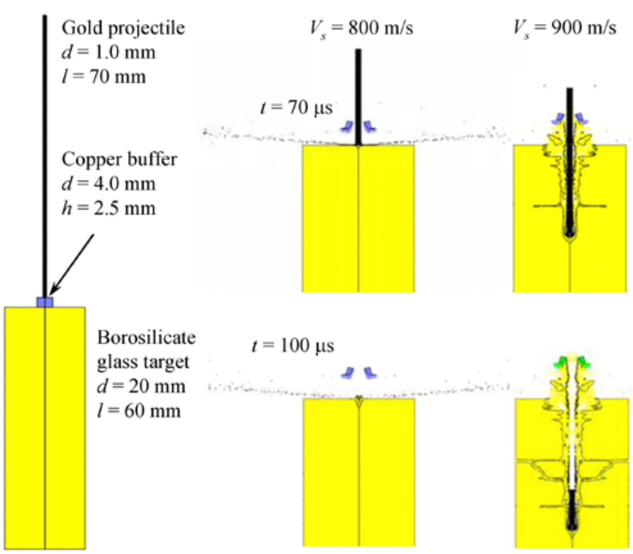

Fig. 2. The initial geometry and computed results for a gold rod impacting a borosilicate glass target with a copper buffer at V_s = 800 m/s and V_s = 900 m/s.

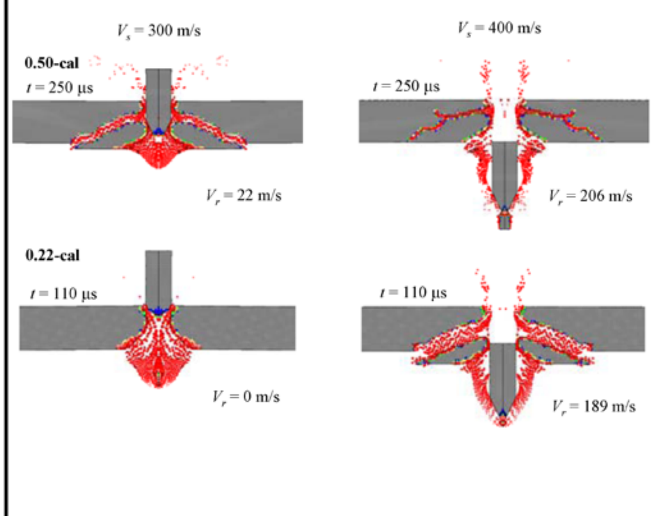

Fig. 4. Comparison of computed results for a steel projectile impacting borosilicate glass at two scales.