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Computational Simulations of Interface Defeat

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Abstract

The widespread use of modeling and simulation for design of armor systems is critically dependent on the accuracy of the underlying structure of such simulations. Acceptance of these tools hinges upon end user trust in the predicted results. As the overall implementation of a design code can be composed of a number of material models, it is essential that those models accurately reflect true physical behavior. Computations are performed using the Johnson-Holmquist (JH) constitutive model for brittle materials for penetration problems into ceramics, as implemented in both the Eulerian CTH and the Lagrangian EPIC shock physics codes. The results of the computations are compared and the influence of the numerics and material model coupling are evaluated. A description of some important computational features involving finite elements and meshless particles are also outlined, with observations on the direction of future code and model development.

Keywords: Ceramics, Interface Defeat, Simulation

Introduction

The wide spectrum of ballistic threats to ground vehicles runs from small arms and low-velocity shrapnel from numerous sources to high-energy kinetic penetrators. However, designing, integrating and fielding a vehicle armor configuration for the highest order threat has become impractical from both weight and cost standpoints. As the US Army acquires an expanded role in areas other than direct combat (such as Somalia or Bosnia), armor packages more closely matching, rather than grossly overmatching, the expected threat becomes essential. In order to meet this requirement in a time and cost effective way, increased emphasis is being placed on simulation and modeling to replace the expensive process of build, shoot, build.

Potential armor configurations can be modeled and tested against a large number of threats via computer simulations. In this way unacceptable or marginally performing designs can be eliminated before committing to fabrication and ballistic range tests, saving both time and money. However, the utilization of these tools for end design of

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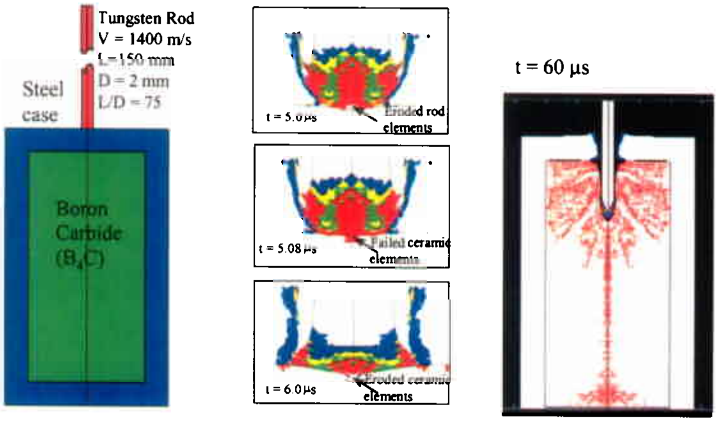
armor systems is dependent on the accuracy of the underlying structure of such simulations. Widespread user acceptance of simulation tools hinges upon trust in the predicted results. Since the design code can be composed of a number of material models, it is essential that those models reflect true physical behavior accurately. Different material models should, ideally, give identical results independent of the computer code used and conform to experimental data.

Recently, an initial computational study compared two ceramic models implemented in two different hydrocodes [Templeton *et al.*, 2001]. The two ceramic models: 1) Johnson-Holmquist (JH-1), and 2) Rajendran-Grove (RG), compared in that paper are distinctly different. JH-1 [Johnson and Holmquist, 1990] is a phenomenological model developed for brittle materials subjected to large strains, high strain rates and high pressures. RG is a micro-crack based constitutive model [Rajendran, 1994]. The two computer codes used were the Eulerian CTH wave code [Mcglaun *et al.*, 1990] and the Lagrangian EPIC hydrocode [Johnson *et al.*, 1997].

Comparisons of interest included computational results for two target configurations where silicon carbide type-B ceramic is used, 1) ceramic dwell as described by Lundberg, et. al, [2000] and 2) semi-infinite penetration in ceramics as described by Orphal and Franzen [1994]. These choices were made due to the availability of the experimental data in the literature such that comparisons could easily be made to the experimental results and because of their direct applicability to specific Army problems. Computations were also presented for a tungsten penetrator impacting a steel target over a large velocity range. The primary purpose of performing these computations was to investigate the accuracy of the two numerical schemes using well-defined material behavior.

The EPIC computations were performed with finite elements and meshless particles; the initial grids were composed entirely of finite elements in 2D axisymmetry, and the elements were automatically converted to particles as the elements became highly distorted [Johnson *et al.*, 2001]. The particles take on all the characteristics of the replaced elements (mass, velocity, stress, strain and internal energy, etc.). The initial finite element grid is partially converted into particles as the solution progresses. The elements are converted into particles at an equivalent plastic strain of about 0.4 to 0.5. A Generalized Particle Algorithm (GPA) is used to perform the meshless particle computations [Johnson *et al.*, 2002]. The initial computational grid for all of the problems uses three sets of crossed triangular elements (four triangles in a quad) across the radius of the rod/projectile, and similar sizes elsewhere. An important point to consider is shown in Figure 1, which shows the difficulty encountered when using erosion to simulate dwell. When an element is eroded it introduces a void, which allows surrounding material to expand into the void. The expansion of material into the void causes the material to lose pressure. In some cases the loss of pressure is so great that tensile stresses are developed. If the material strength is pressure dependent (like ceramics) the pressure drop will cause the material strength and ductility to also drop which may lead to increased material damage. If the material goes into tension the material may actually break during this process. Figure 1 demonstrates this numerical phenomenon. The example uses the JH-2 material model, and uses damage constants that do not allow the ceramic material to fail in compression (only tensile failure is allowed). At 5 μs after impact some elements have eroded at the tip of the penetrator, which was in contact with the ceramic surface.



(a) (b) (c)

Figure 1. Effect of material erosion on ceramic dwell and interface defeat. (a) Initial 2D geometry. (b) Enlargement of the penetrator/ceramic interface showing rod erosion, ceramic failure and ceramic erosion. (c) Computed result at 60 μs after impact showing ceramic penetration.

The ceramic wants to move into the void created by the eroded penetrator, causing the ceramic to go into tension. The tensile strength of the ceramic is exceeded and the ceramic fractures/fails. Ceramic strength is then reduced allowing more deformation to occur and eventually the failed ceramic erodes. This process of "numerical tensile failure" continues and the penetrator penetrates the ceramic. The process of "numerical tensile failure" that occurs due to erosion makes is extremely difficult to simulate ceramic dwell. Replacing the distorted elements with particles does not introduce a void and ceramic dwell can be simulated.

The CTH computations were performed with the mix=1 option, where the yield strength in mixed material cell is sum of volume fraction weights of individual materials and single material cells with voids have decreased yield strength, and the metals were modeled with Mie-Gruneisen EOS, Johnson-Cook strength and fracture, using the same material parameters used in the EPIC simulations. Recently, a new version of CTH incorporating automatic mesh refinement (AMR) was used to repeat the JH in CTH computations [Leavy, 2002].

Ceramic model constant determination is not a straightforward process and will not be presented in detail here. The process to obtain constants for the JH-1 model is presented in detail by Holmquist and Johnson [2002]. All the constants for silicon carbide (except for two) were obtained explicitly from the test data. The remaining two constants were obtained by "backing them out" of the computations. The process used to get these two constants was applied in the same manner for both EPIC and CTH. All the JH-1 constants were the same for both EPIC and CTH with the exception of the two constants that were determined using the computations.

Computations

One of the most interesting ceramic characteristics is that of ceramic dwell and interface defeat. Dwell occurs when a high velocity projectile impacts a ceramic target and is eroded on the surface of the ceramic with no significant penetration. If the dwell phenomenon continues until the entire penetrator is consumed, the event is termed interface defeat (of the penetrator). Ceramic dwell is an important characteristic of ceramic behavior and must be reproduced computational by ceramic models. Lundberg *et al.* [2000] demonstrated ceramic dwell for silicon carbide (SiC-B) in a series of ballistic experiments. The two highest impact velocities were used to get the remaining two JH-1 model constants as discussed earlier. Templeton *et al.*, [2001] showed that the JH-1 model, as implemented in both EPIC and CTH, was capable of reproducing dwell, dwell-penetration transition and high velocity penetration. It should be noted that the two constants obtained from computations were very different for the two codes.

CTH required constants that effectively made the material softer, probably due to the fact that the ceramic material was fixed to the confinement steel and in the EPIC computations it was allowed to slide. When the JH-1 values obtained using the EPIC code were used in CTH the computations produced no penetration for the 1645m/s experiment. The two constants, failure strain and failed strength, were changed to reproduce the correct dwell phenomena. No initial confining pressure was included in the simulation setup. Ten cells across the penetrator diameter were used for the mesh. Figure 2 shows repeated computational results, and comparisons to experiments, using CTH-AMR [Leavy, 2002] The failure strain and failed strength values were changed back to the more physically reasonable EPIC values and the CTH results now exhibit good agreement with the EPIC results.

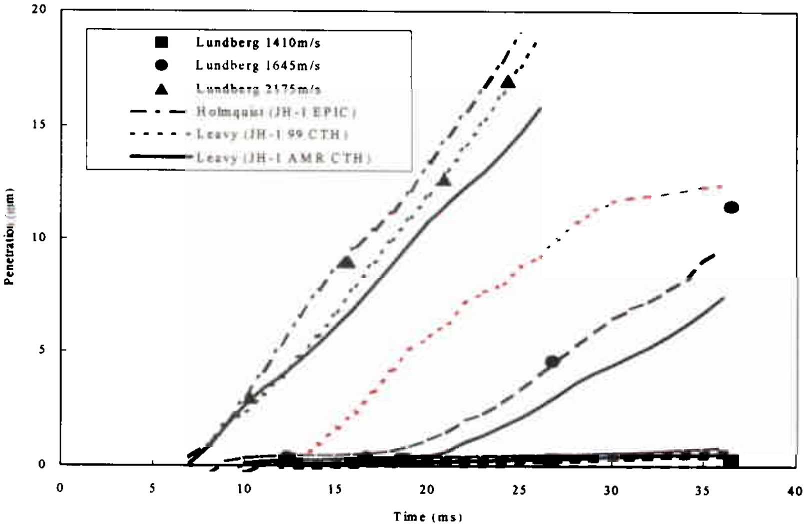


Figure 2. Computational results compared to experiments with CTH-AMR.

Computations were also performed into semi-infinite ceramic targets as defined by Orphal and Franzen [1997]. These computations covered a wide range of impact velocities and were in effect "validation computations" inasmuch as the constants were not determined from the experiments. Figure 3 presents penetration as a function of impact velocity for the experiments and the computations. The JH-1 model, as implemented in EPIC, produces good results at velocities up to 2000 m/s, but tend to under-predict penetration at the high velocities (3000 – 4000 m/s). It is interesting to note that all the computations, independent of what model or computer code was used, significantly under predicted the experimental results at the high velocities. Figure 6 again shows the repeated computational results, and comparisons to experiments, using the CTH-AMR. The results tend to follow the general shape of the experimental data, but still significantly under-predict penetration.

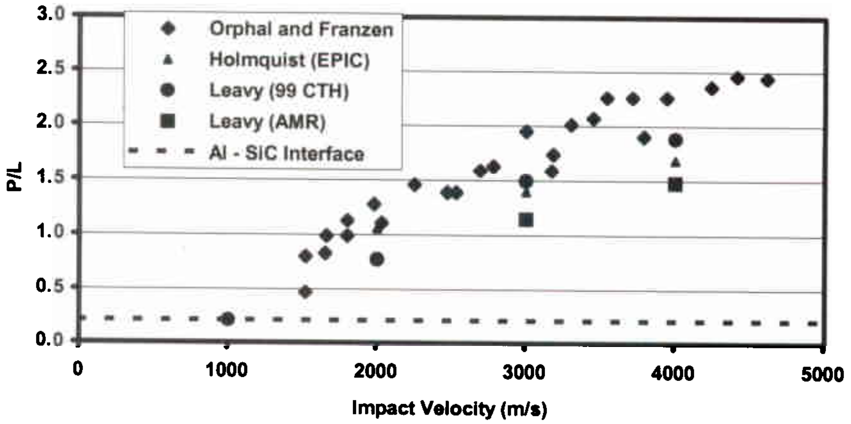


Figure 3. Computational results compared to experiments with CTH-AMR.

Conclusions

Computations were performed using the JH-1 ceramic model as implemented in the CTH and EPIC computer codes. Computations of a tungsten rod into a steel target demonstrated that both CTH and EPIC produced very similar results consistent with experimental data over a wide velocity range. Computations were also performed of dwell, dwell-penetration transition and high velocity penetration. The JH-1 model produced good results using both EPIC and CTH. A key enabler for EPIC is the use of GPA. As discussed above, there are important advantages to converting distorted elements into particles rather then eroding (or removing) the distorted elements. Of most importance is the ability to simulate ceramic dwell and interface defeat. Likewise, the use of CTH-AMR, much like the introduction of GPA in EPIC, yielded more accurate results. Notable numerical and refinement problems in the CTH99 simulations were resolved with AMR including capability of modeling dwell. Future needs include optimizing the AMR mesh and interfaces. Computations were performed. Both implementations tended to under-predict the penetration into the semi-infinite ceramic targets, but results followed the general trend of the experimental data. Future work will include model refinement to allow better match to experimental data and investigations considering different computational platforms and serial versus parallel processing.

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