NUMERICAL STUDY OF PENETRATION IN CERAMIC TARGETS WITH A MULTIPLE-PLANE MODEL H.D. Espinosa, G. Yuan, S. Dwivedi, and P.D. Zavattieri

School of Aeronautics and Astronautics, Purdue University, West Lafayette, IN 47907

The penetration mechanics in different material/structure systems has been investigated by numerical simulations with the finite element code EPIC95. A multi-plane microcracking model was implemented to simulate ceramic fragmentation and comminution. Two kinds of confined structures, depth-of-penetration (DOP) and interface-defeat (ID) configurations, were examined in the simulations. The results revealed that the penetration process is found to be less dependent on the ceramic material than usually assumed by most investigators. By contrast, the penetration process is highly dependent on the multi-layered configuration and the target structural design (geometry, and boundary conditions). From a simulation standpoint, we found that the selection of the erosion parameter plays an important role in predicting the deformation history and interaction of the penetrator with the target. These findings show that meaningful light weight armor design can only be accomplished through a combined experimental/numerical study in which relevant ballistic materials and structures are *simultaneously* investigated.

INTRODUCTION

Design of light weight armor depends on fundamental understanding of material performance, constitutive/failure models, and structural performance. Ceramics have high hardnesses and low densities and have been considered good candidates materials for defeat of longrod tungsten projectiles.

During the past ten years, several constitutive models for brittle materials have been developed to describe impact behavior. A multipleplane model (MPM) that can predict damage induced anisotropy was developed by Espinosa et al. (1). It appears that the MPM can provide relevant insight into the design of ceramic armor material/structure systems. Hauver et al. (2) found that the performance of ceramic targets during penetration depends on the nature of ceramic confinement. They proposed a new structure known as interface defeat (ID) configuration. The objective is to keep the confinement on the ceramic plate so that the penetrator is consumed by lateral flow at the ceramic-cover plate interface.

In this paper, a parametric study is carried out for the penetration of two different multilayered confined ceramic target plates. Basically, the DOP and ID configurations are simulated with a particular emphasis in understanding the variation of measurable quantities as a function of target configuration, ceramic type and confinement. In all calculations, a penetrator striking velocity of 1.5 Km/s is used.

MODEL

The multiple-plane microcracking model, used in this study, is based on the assumption

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FIGURE 1: Contours of effective plastic/cracking strain for DOP (a-b) and ID (c-d) configurations with alumina, d/L=0.05, and erosion=1.5. Dimensions are given in meters.

that microcracking and/or slip can occur on a discrete number of orientations. Slip plane properties, friction, size, density, etc. and their evolution are *independently* computed on each plane. The macroscopic response of the material is computed by additive decomposition of the strain tensor into elastic and inelastic parts. In contrast to scalar representations of damage, the present model is broad enough to allow the examination of damage induced anisotropy and damage localization in the interpretation of impact experiments. In particular, the effective behavior of the solid is predicted to be rate dependent due to crack kinetics effects. Model parameters were identified independently through plate and rod impact simulation of experiments.

ANALYSES AND RESULTS

Effect of ceramic material: The DOP target plate has been analyzed with both Al_2O_3 and SiC ceramics for a penetrator with d/L of 0.05.

The erosion parameter has been chosen as 1.5 and analyses carried out till the elapsed time of 150 μ s. The penetration of alumina at two time cycles together with a plot of effective plastic/cracking strain is shown in Figure 1. It was found that the response of Al_2O_3 and SiC to penetration are similar without much appreciable difference. However, the crater shape in the case of the SiC target is larger than that in Al_2O_3 , specially at the ceramic-steel interface. This may be due to the higher wave speed in SiC which results into more time for wave interactions at the interface.

Effect of target structure: As mentioned earlier, Hauver proposed the ID configuration in which the ceramic is maintained under constant confinement with the help of a cover plate and an interface layer made of softer graphite material. Analyses have been carried out for a d/Lof 0.05 for both the DOP and the ID configurations. The ceramic used in the simulations was

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FIGURE 2: Contours of effective plastic/cracking strain for erosion values of 1.5, 3, and 9, respectively.

 Al_2O_3 and an erosion effective cracking strain of 1.5 was chosen. The target width and layer thickness were selected such that a meaningful comparison can be made. Figure 1 shows the penetration event together with the plot of effective plastic/cracking strain at various time cycles. Significant wave damage in the ceramic is observed in the the DOP configuration. see Fig. 1a. In the case of ID, the nose of the penetrator reaches the surface of the ceramic at 27 µs after defeating the cover plate. At this time, the tail velocity of the penetrator is identical for both structures. Subsequently, it reduces significantly more in the ID configuration than in the DOP configuration. Moreover, wave damage in the ceramic, for the ID configuration (see Fig. 1c), is much less than it is for the DOP configuration. This is expected from variations in ceramic confinement. Hence, the model predicts a superior behavior in the case of multi-layered ceramic target structures in confirmation with experimental evidence. However, our experimental observations (3) indicate that the penetrator nose can be partially spread in the lateral direction during interface defeat. This feature can be seen as lateral flow of graphite in the present simulation, see Fig. 1c. Also, the penetrator perforates the target in agreement with our experimental observations (3), see Fig. 1d.

Effect of erosion parameter: EPIC95 employs a critical effective plastic/cracking strain as an



FIGURE 3: Penetrator tail velocity for different values of the erosion parameter.

element erosion parameter. A higher value of the erosion parameter means that it is more difficult to erode the material. In all the above analyses, its value has been kept constant as 1.5. In order to study its effect on penetration, the ID configuration has been analyzed for two additional values of the eorsion parameter, namely, 3.0 and 9.0. The results show that for increasing values of the erosion parameter, the penetrator material flows upwards and develops a triangular nose, see Fig. 2. The sharpness of the nose increases as the penetration continues which facilitates further penetration by focusing the inelastic deformation right ahead of the penetrator. As a result, the penetrator reaches the graphite-



FIGURE 4: Axial stress at ceramic-back plate interface for two values of the erosion parameter.

ceramic interface at 27, 24 and 16 μ s for erosion values of 1.5, 3.0 and 9.0, respectively. The difference in the nose shape provides different initial conditions when the penetrator hits the ceramicgraphite interface. Despite the faster rate of penetration, with increasing erosion value, overall penetration of the projectile is not achieved when the erosion value is set to 9. The erosion value affects not only the deformed shape of the penetrator but also the whole history of stresses and particle velocities. Penetrator tail velocity histories and in-material stress histories, for various values of the erosion parameter, are given in Figs. 3 and 4 respectively.

CONCLUSIONS

The above analyses show that the response of multi-layered ceramics targets is relatively independent of the ceramic material for the two types of ceramics considered, i.e., Al_2O_3 and SiC. The interface defeat (ID) configuration proposed by Hauver has distinct advantages over the depth of penetration (DOP) configuration. Ceramic wave damage is less in the case of ID and its resistance to penetration dramatically improved by the confinement provided by the cover plate.

The value of the erosion parameter is an important input for the simulation. The above analyses show that the penetrator nose deforms and gains a conical shape as the value of the erosion parameter is increased. This facilitates penetration initially. However, the presence of hardened material reduces the velocity of the penetrator and the peak stress more efficiently. Therefore, the selection of an erosion parameter needs detailed experimental measurements of inmaterial stresses, free surface velocities and recovered penetrator shapes.

It can be concluded that the integration of a multiple-plane microcracking model into the finite element code EPIC95 has been successful. It is able to predict the response of different types of the multi-lavered ceramic target in confirmation with experimental evidence. Limitations have been encountered in the use of EPIC95. Only one erosion parameter can be selected for the penetrator and various target plates. Interfaces need to be modeled as perfect or frictional interfaces without the possibility of modeling progressive decohesion. Mesh adaptivity is not available to avoid excessive mesh distorsion Erosion is needed to advance the calculation with a reasonable time step. All these features have been addressed by Espinosa et al. (1). Software capable of simulating the interface defeat configuration without erosion is currently under development.

ACKNOWLEDGMENTS

The research reported in this paper was supported by the Army Research Office through award Nos. DAAH04-96-1-0142 and DAAH04-96-1-0331.

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