A COMPUTATIONAL MODEL FOR BALLISTIC PENETRATION OF MULTI-LAYERED CERAMIC TARGETS - ACHIEVING TRUE PREDICTIVE CAPABILITIES

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The design of lightweight armor systems has been a goal of the US Army since the Gulf War. The need for transporting heavy armor systems through long distances in a short period of time proved to be crucial in the mission of the agency. Under an ARO-MURI project, Professor Espinosa and collaborators investigated failure mechanisms in multi-layered ceramic targets. Findings reported by Hauver and co-workers, and Bless and co-workers, concerning the design of ceramic targets to achieve interface defeat of long rod penetrators captivated the interest of the armor design community. Professor Espinosa and co-workers examined this feature by extending Hauver's experimental technique to include in-material stress and real time free surface velocity histories measurements. Examination of the post-shot multi-layered ceramic targets revealed complete and partial interface defeat of long rod tungsten heavy alloy penetrators. Targets with extra stiffness, on account of weld and larger bottom plate thickness, achieved *complete defeat* of the penetrator within certain limits in impact velocity. These findings proved that the role of armor structural design could be more significant than the ceramic type employed in the system.

The next challenge addressed by Prof. Espinosa and his students was the development of a model that could provide ballistic penetration *predictive capabilities*. In order to achieve this goal, two distinct models, a multiple-plane microcracking model developed by Espinosa and a granular model, originally developed by Anand and modified by Espinosa and Gailly were combined in a consistent fashion. The idea was to develop a continuum model capable of capturing crack initiation and propagation as well as transition to a pulverized ceramic. Each model was independently calibrated in each regime. The MPM model was calibrated through plate and rod on rod impact experiments, while the granular model parameters were identified through simulation of pressure-shear impact of ceramic powders and cylinder collapse of ceramic powders experiments. These simulations were able to capture, for the *first time*, features such as shear localization and powder dilation/consolidation. The combined model, with a fixed set of parameters, was then employed to simulate ballistic experiments performed by Malaise in France. Not only was interface defeat predicted by the calculation, but also the transition velocity leading to projectile penetration was identified consistently with experimental results. In this presentation we will present the model developments and illustrate how they overcome significant unresolved limitations exhibited by other models in capturing large deformations and *material transition from intact to full pulverization*.