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Studies for improved damage tolerance of ceramics against ballistic impact using layers

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Abstract

Ceramics are lightweight alternatives to metal armour. However, brittle behavior of monolithic ceramics impedes their application to armour. One approach for improving toughness of ceramics could be by using layered ceramics. In this study, we evaluated layered ceramics for armour applications based on numerical analysis validated with experiments. Consistent to the trends in literature, we observed that layers degrade the resistance to ballistic impact. However, improved energy absorption is demonstrated by layered ceramics. These conflicting dual trends were not presented and quantified in any earlier studies conducted elsewhere. Another new observation not documented earlier is the effect of interface strength. Using an interface material of sufficient strength, penetration resistance of layered ceramics can be improved beyond monolithic ceramics. Using these findings, new layered ceramic armour can be designed that is cost-effective and better performing than monolithic ceramics.

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Keywords: composites; armour; interface; material models;

1. Introduction and review

Composite integral armour (CIA) has been evaluated by researchers, more recently by Mahdi et al. [1, 2] and Mahfuz et al. [3]. French [4] found a number of advantages of using CIA for armoured vehicles such as weight reduction, reduced part count and elimination of parasitic masses. Finite element modeling of ballistic impact on

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CIA has been attempted by researchers using different strength and failure models for ceramic layer, FRP layer and the metal projectile.

Johnson-Cook strength and failure model [5] was widely used for the metal projectile [6, 7]. Various strength and failure models such as Johnson-Holmquist [6], Rajendran-Grove [8] and Espinosa model [9] have been proposed for ceramics subjected to ballistic impact. Johnson-Holmquist model is phenomenological whereas Rajendran-Grove and Espinosa models are microstructural. A review of various ceramic models is included in Rajendran et al. [10]. Similarly, models have been proposed for FRP composites subjected to ballistic impact incorporating orthotropic stiffness, strength and failure such as Chen et al. [11], Rotem [12], Chang et al. [13], Anderson et al. [14] and Clegg et al. [15].

Holmquist et al. [6] developed a constitutive model of AlN based on the Johnson-Holmquist model. The constants of the material model were obtained using laboratory and ballistic experiments. They studied the effect of layers. Specimens with 1, 2, 3 and 6-layer ceramic targets were evaluated. Continuous degradation in penetration resistance as the number of layers increases was reported.

Yadav and Ravichandran [16] conducted an experimental study on ceramic tiles laminated with thin layer of polymer in-between. They reported more resistance offered by specimens with 3 tiles than monolithic ceramics. However, specimen with 6 tiles offered less resistance. Tasdemirci and Hall [17] studied the performance of four variants layered composite armour of which two variants had monolithic ceramics, and the remaining two variants had two layers of ceramics each. Delay in the rise of stress and drop in peak stress was observed due the presence of interlayers.

Based the results reported in literature on layered ceramic armour, we observed that utility of layers in ceramics is not established. It has been seen that more layers degrade performance. Improved attenuation of the stress wave in the impacted area due to the presence of layers was also reported.

2. Model for studying the effect of layers

A projectile of 5 mm diameter and 15 mm length is chosen. The projectile mass is 2.3 gm. It impacts a target of size 25 mm × 25 mm. The target is made of 5 mm thick ceramic tile backed by 5 mm thick aluminum alloy plate. In a layered ceramic target, thickness of the layers is chosen such that the total thickness of the ceramic component is 5 mm, same as in the monolithic target. The ceramic layers are bonded together by a 0.1 mm thick polymer adhesive layer. A model for target and projectile is shown in Figure 1. Targets with monolithic ceramics, 5-layer and 50-layer ceramics are illustrated. A schematic view with dimensions of projectile and targets for monolithic and 5-layer ceramics is shown in Figure 2.

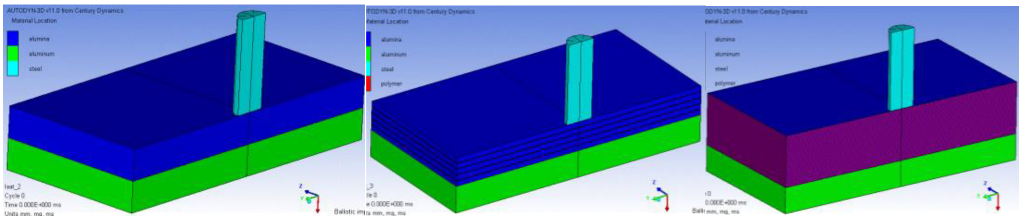

Figure 1: Finite element model for monolithic ceramic target with aluminum backing, 5-layer ceramics target and 50-layer ceramics target

Johnson-Holmquist material model [6] is used for ceramics. Johnson-cook model [5] is used for the steel projectile, aluminum backing and polymer interface. Material properties used are listed in Table 1. Projectile material properties correspond to hardened steel alloy 4340, ceramic material properties correspond to Alumina, aluminum backing properties correspond to aluminum alloy 6061-T6 and polymer interface material properties correspond to epoxy. Explicit dynamic lagrangian finite element (FE) code AUTODYN™ [18] is used for the simulations.