

Finite Element Analysis of Material and Parameter Effects in Ballistic Armors

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Abstract

The literature about the ballistic armors are mostly focused on 2 or 3 different parameter effects. The aim of this study, differently, is to find and compare the effects of specific materials on protection of composite ballistic armor plates against high-velocity projectile impact. The effects of stacking sequence for different materials, projectile type, target plate shape and impact obliquity are investigated individually. It is shown that the proposed stacking sequence decelerates the residual velocity of the projectile better than the other considered arrangements. The average percentage of kinetic energy absorption of rectangular shaped Kevlar 29/epoxy plate is considerably higher than that of circular shaped Kevlar 29/epoxy plate.

Keywords: composite, ballistic, armor, impact, finite element

Discipline: Mechanical Engineering

INTRODUCTION

Composites are very important materials in defense applications, especially in production of bulletproof systems. Bulletproof composites are used in covering the most important body parts as in helmets, vests and shields. Despite all the advantages of composite armors like mobility and lightness, they still need to be improved because their protection efficiencies against high-velocity projectile impact are not perfect. Even when the impact energy is almost absorbed and the contact of projectile with the protected asset is blocked, the residual impact energy transferred to the protected surface is still high and should be decreased.

Garcia-Avila et al. [1] manufactured high-performance light-weight composite armor system using different materials and different manufacturing methods and evaluated the ballistic tolerance of this composite armor system. They performed finite element analysis to study failure mechanisms and energy absorption of the plate. Min et al. [2] studied effect of reinforcement continuity on ballistic performance of composites made from multiply plain weave fabric. After producing continuous and discontinuous plain weave fabrics, they examined the damage morphology and confirmed the superiority of the continuously reinforced composites. Wicklein et al. [3] derived and validated of a numerical material model that predicts the highly dynamic behavior of CFRP under high velocity impact. Additionally, they compared the numerically predicted damage within the CFRP to the delamination areas found in ultrasonic scans. Zhou et al. [4] used finite element models to predict the response of woven fabrics with different structural parameters. They confirmed that the plain woven fabric shows superior energy absorption over other structures in a ballistic event. Rizov [5] investigated low velocity impact behavior of two densities of ductile polyvinylchloride foam and post-impact creep response of this foam. He studied development of a damage tolerance design approach for structural foams. Toqueboeuf et al. [6] conducted dynamic compressive tests in different configurations and they found that the initial multi-axial prestress of polyurethane is one of the most important parameters for material and layered response. Deka et al. [7] investigated the response of laminated composites subjected to high velocity, multi-site impacts from a modeling and experimental viewpoint. They compared energy absorption, new surface creation and failure mechanisms from sequential and simultaneous multi-site high velocity impacts.

Ansari & Chakrabarti [8] studied numerically on a validated model. The model consisted of 19 layers of Kevlar 29 and it was impacted by blunt nosed steel projectile. The impact velocity gap was from 25 m/s to 1000 m/s and they compared residual velocities of projectile as results. In addition, the ballistic limit variation, residual velocity of projectile, failure propagation in the impacted plate and in the projectile, penetration depth, kinetic energy of the projectile, deflection and radius of damaged zone were investigated.

The literature review reveals that most of the ballistic studies are focused on 2 or 3 different parameter effects. In this study, it is intended to find and compare the effects of specific materials on protection of composite ballistic armor plates against high-velocity projectile impact. In addition, the effects of stacking sequence for different materials, projectile type, target plate shape and impact obliquity are investigated individually.

METHOD

In this study, it is intended to find and compare the effects of specific materials on protection of composite ballistic armor plates against high-velocity projectile impact. In addition, the effects of stacking sequence, shape of projectile and shape of target plate are investigated individually for different impact velocities. ANSYS/AUTODYN solver is used for modelling, numerical study and simulations.

The applicability and the accuracy of the present finite element model is validated by comparing the results with those of Ansari & Chakrabarti [8]. The present study provides results in good agreement with their results, as seen in Table 1.

Table 1. Comparison of present impact results with those of [8]

Impact velocity (m/s)	Residual velocity (m/s) [8]	Residual velocity (m/s) (present study)
200	-48,93	-48,64
300	-44,72	-38,4
500	267,24	265,49
650	442,1	431,38
850	670,5	629,17

RESULTS

The modelled plate is impacted by a flat nosed projectile made of Steel 4340 and its boundary conditions are all-clamped. Considering the unit layer weight and absorbed kinetic energy of the projectile, UHMWPE layers perform best with Kevlar 29/epoxy woven layers. The results show that the stacking sequence in which UHMWPE layers are placed in between Kevlar 29/epoxy layers one by one, decelerates the residual velocity of the projectile better than the other considered arrangements. For a unit plate area (100 mm × 100 mm), the final model ($[(K/U)_{11}/K]$) is 4,4 g lighter and slow down the projectile by 9,187% better than the 19 layers of Kevlar 29/epoxy model. Residual velocities of flat nosed cylindrical projectile for different secondary materials of target plate are presented in Table 2. On the other hand, comparison of 500 m/s impact results of full Kevlar 29/epoxy and Kevlar 29/epoxy – UHMWPE plates are shown in Table 3.

Table 2. Residual velocities of flat nosed cylindrical projectile

Material	Layer weight (g)	Total weight of the plate (g)	Residual velocity (m/s)
Pure Kevlar 29/epoxy	8,250	156,750	265,490
H100 foam	0,500	87,000	360,000
Polyurethane	6,325	139,426	330,180
UHMWPE	4,850	126,150	300,600
Graphite	11,250	183,750	299,280
S2 Glass	9,250	165,750	316,380

Table 3. Comparison of 500 m/s impact results of full Kevlar 29/epoxy and Kevlar 29/epoxy – UHMWPE plates

Composition	Total number of layers	Total thickness (mm)	Total weight (g)	Residual velocity of the projectile (m/s)
Kevlar 29/epoxy	19	9,5	156,75	265,49
Kevlar 29/epoxy - UHMWPE	23	11,5	152,35	241,10

Effect of projectile type is investigated and the tests show that the average percentage of kinetic energy absorption of Kevlar 29/epoxy - UHMWPE plate impacted by flat nosed projectile is 62,81%. For the case with conical nosed projectile, the average percentage of kinetic energy absorption of the plate is 51,96%. The impact responses are illustrated in Figures 1 and 2.

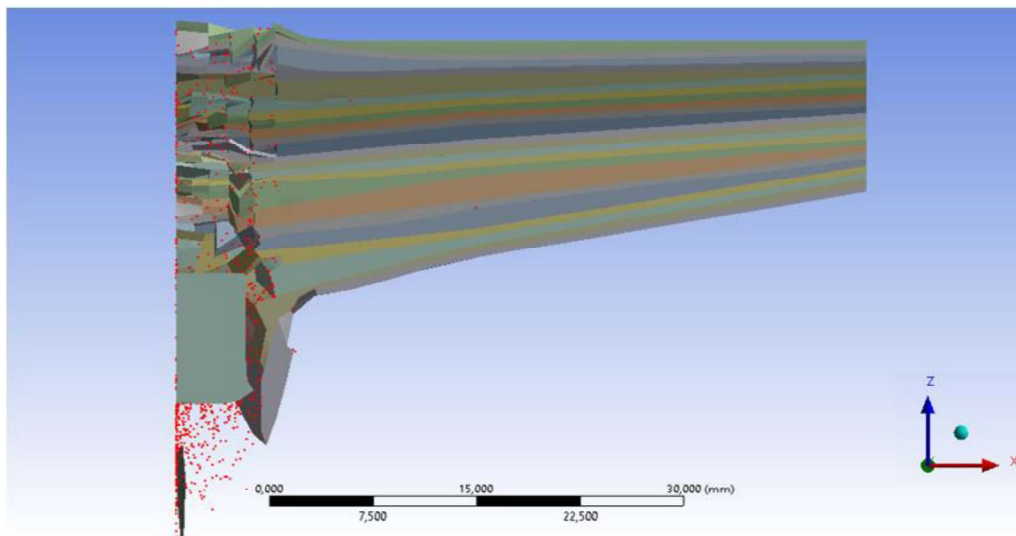


Figure 1. Impact response of 23 layers of Kevlar 29/epoxy - UHMWPE plate to rectangular nosed Steel 4340 projectile with 500 m/s impact velocity.

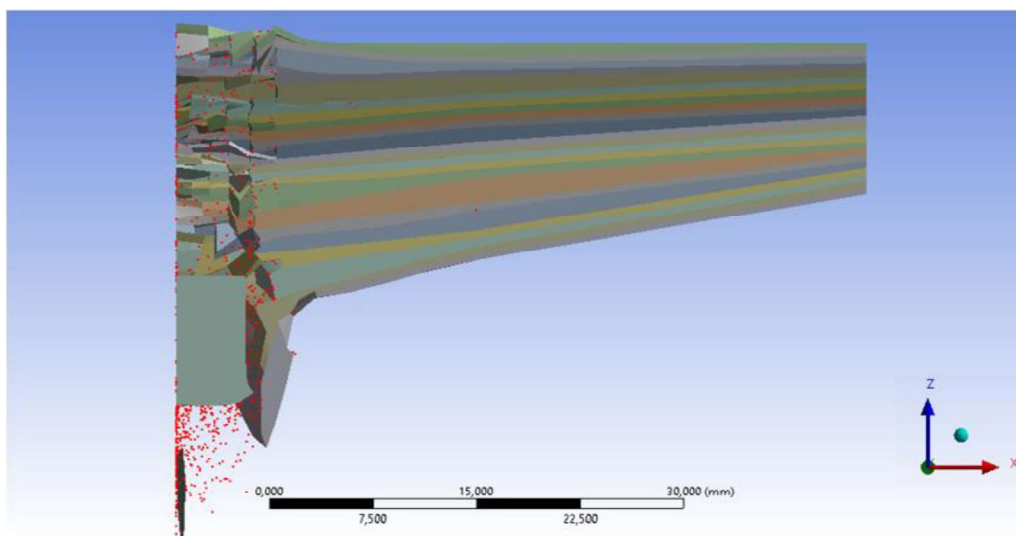


Figure 2. Impact response of 23 layers of Kevlar 29/epoxy - UHMWPE plate to conical nosed Steel 4340 projectile with 500 m/s impact velocity.

Figure 3 illustrates the comparison of the velocity variations of conical nosed and flat nosed projectiles during penetration of Kevlar 29/epoxy – UHMWPE plate for impact velocity of 500 m/s.

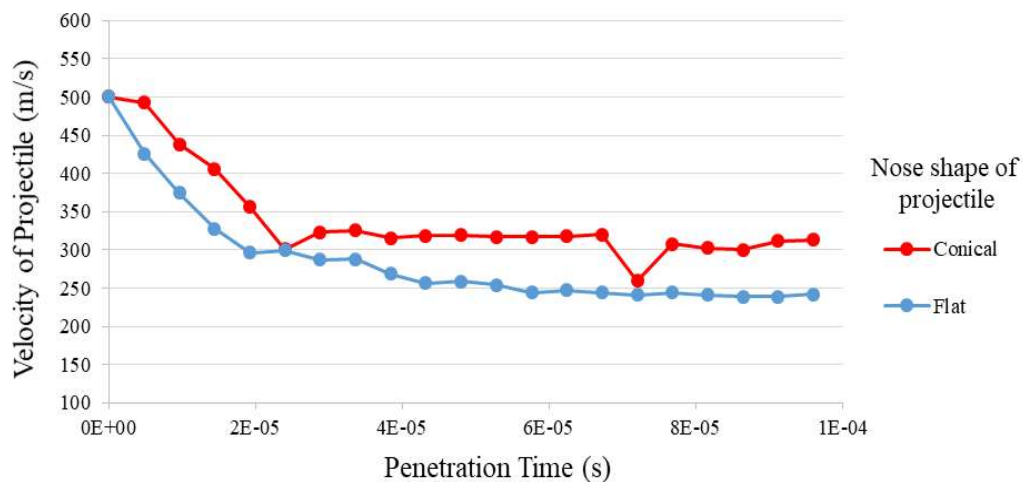


Figure 3. Comparison of the velocity variations of conical nosed and flat nosed projectiles during penetration of Kevlar 29/epoxy – UHMWPE plate for impact velocity of 500 m/s.

Effect of target plate shape is investigated and the tests show that the average percentage of kinetic energy absorption of rectangular shaped Kevlar 29/epoxy plate is 71,81% while the average percentage of kinetic energy absorption of circular shaped Kevlar 29/epoxy plate is 56,71%. 500 m/s impact results of different shape parameters for plate and projectile are compared in Table 4.

Table 4. Comparison of 500 m/s impact results of different shape parameters for plate and projectile

Shape parameter	Residual velocity of the projectile (m/s)
Rectangular shaped Kevlar 29/epoxy plate impacted by conical nosed projectile	314,00
Rectangular shaped Kevlar 29/epoxy plate impacted by flat nosed projectile	265,49
Circular shaped Kevlar 29/epoxy plate impacted by flat nosed projectile	328,97
Circular shaped Kevlar 29/epoxy plate impacted by conical nosed projectile	340,56

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