



Modeling and Numerical Simulation of Ballistic Impact on Sandwich Composite Materials

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Abstract. The objective of this work is to investigate the ballistic affect energy absorption behavior manufactured from Kevlar and jute-epoxy fiber sandwich composite materials by using finite element analysis and simulation techniques for impact protective helmet applications. Energy consumed and bullet speeds for these composites are examined analytically and using finite element analysis (FEA). Finite element analysis of Kevlar (KM2) plates is carried out at distinctive thicknesses (12 mm, 14 mm, and 24 mm). The analytical results of KM2 and KM2 with JE sandwich plates agree well with the results obtained from FE analysis with a maximum error of 1.14 m/s. The study on the KM2 composite plate uncovers that thickness has a noteworthy impact on the energy absorption properties. The energy absorption of the KM2 sandwich is 78.167% greater than the KM2 plates.

Keywords: Ballistic impact · Energy absorption · Sandwich composite

1 Introduction

The high-speed impact shot defensive shields comprised of mud, concrete, wood, and metals, and so forth have been utilized in old times to ensure humanity [1]. Those bullet-proof armors are made relying on different degrees of protection. Components to be considered are the heaviness of the slug and armor, sort of projectile, the speed of the shot, and solace. At the point when a projectile hits the shield, the energy of the slug is scattered onto the protective layer by disfiguring the shot. The shape of the deformed slug is called mushroom-molded. The inflexible reinforcement as a plate is embedded into the pockets of the vest [2]. The dynamic energy of the shot when affected by the objective is dispersed and consumed in different manners by the objective [3]. Personal armors ordinarily are exposed to high-speed projectile effect, so while planning the personal protective layers energy engrossing limit of the plate is essential to know. The energy-retaining limit of composites relies upon numerous elements like fiber properties, matrix properties, interfacial strength, thickness; fiber direction, and so forth [4–7]. The ballistic effect is the examination of that conduct of material disappointment

brought about by the effect of shot/projectiles. This is especially essential to ensure people are just as apparatus in atomic and military applications. The effect conduct of composites relies upon the size, shape, mass, impact speed, and material of projectile [8, 9].

Analytical models for ballistic effect dependent on various speculations, for example, hydrodynamic and wave hypotheses are created to consider the conduct of the composites [10–13]. Mathematical investigation utilizing finite element analysis (FEA) is likewise investigated [14, 15] for the ballistic investigation of composites. through approval, FEA strategies have been found to foresee the conduct, very realistically [16–18]. The energy dissemination systems of jute texture composite were examined by checking electron microscopy and discovered to be the burst of the weak epoxy lattice just as the connection of the jute strands with the post-sway fragments [19]. The aftereffects of their examination demonstrated that thicker targets are more productive ballistically particularly against gruff projectiles [20].

One of the limitations of most previous researches is the absence of detailing in the modeling and impact analysis of the shot. Since the state of the shot assumes a crucial part in the disappointment system it is essential to create mathematical models with sensible calculations and materials. The material conduct of the shot likewise impacts the failure mechanism hence the usage of reliable material parameters for the analysis main consequence [21]. The fundamental utilization of bulletproof material isn't just to hinder high-velocity projectiles, yet in addition to guard the client against mounted guns shells, mortars, explosives, and other separating contraptions. As far as aviation applications, ballistic materials shield the body of the rocket from outside objects when it is flying at a high speed. Tactical armor carriers and protective caps or any ballistic-safe materials are known to contain high-strength [22].

In this paper, the current work is to examine neat Kevlar (KM2) texture, and Kevlar (KM2) – jute-epoxy sandwiches under the high-speed effect of the shot. Investigation of the ballistic exhibition of those composite materials has been completed utilizing scientific and FEM approaches. The examination has been done for one speed and four distinct thicknesses of the objective plate. To assess assimilated energy absorption, perforation velocity, and residual velocity with various layers on the mathematical investigation of 7.62×51 mm APM2 projectile penetration through composite material.

2 Methodology

Composite plate and sandwich made of unadulterated Kevlar and jute-epoxy focus are proposed for energy maintenance under ballistic impact whose configuration is showed up in Fig. 1(a) for wonderful Kevlar and Fig. 1(b) for Kevlar (KM2)- JE sandwich. The unrefined materials used are woven Kevlar surfaces. The holding/interfacing state of texture layers impacts the wave proliferation of the cross over the way and subsequently the energy ingestion system of the texture reinforcement [23].

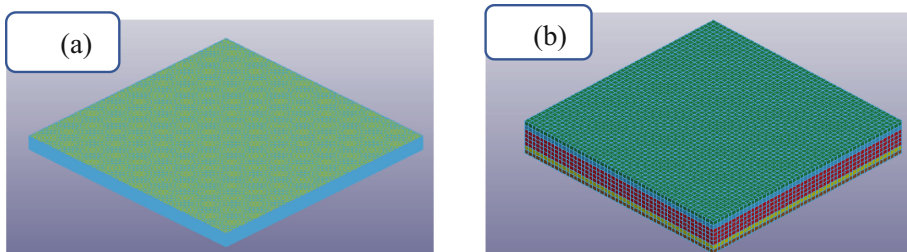


Fig. 1. (a) Schematic model of pure Kevlar and (b) for Kevlar (KM2) - JE sandwich

2.1 Analysis of Composite for Ballistic Effect

A created analytical model to compute the decrease in kinetic energy and leftover speed of shot infiltrating targets made out of diverse planer woven textures of Kevlar and natural fiber. The primary point of the analytical model is to predict the left speed of the shot when the board has been infiltrated. The shot infiltration closes when either the speed of the shot becomes zero or the last layer of texture in the numerous layered board's fizzles. The sensible model created for finding the remaining rate (V_r) of a plate presented to customary impact by a rigid shot is tended to by Eq. (1) [17, 24].

$$V_r = \frac{1}{1 + \Omega(D/d)^2 \left(\frac{T}{L}\right)} (V^2 - V_{xn}^2) \tag{1}$$

Where V = velocity of impact (m/s)
 V_{xn} = minimum perforation velocity (m/s)

$$V_{xn} = \frac{4\Omega T^2 \psi \eta}{Ld \left\{ 1 + \left[\frac{L + \Omega T}{\Omega T} \left(1 + \frac{d}{\rho_s T \eta \psi} \right) \right]^{0.5} \right\}}$$

and

$$\psi = \frac{\rho_p C_p + \rho_s C_s}{\rho_p C_p \rho_s C_s}$$

$$C = \left[\frac{k}{\rho} \right]^{0.5}$$

$$k = \frac{E}{3(1 - 2\nu)}$$

$$\eta = 0.5\sigma_u$$

Where, C_p and C_s – sonic velocity within the project and plate (m/s), ρ_p and ρ_s the density of project and plate (kg/m^3), T -thickness of the plate (m). Ω = ratio of plate and

projectile material densities, (dimensionless), D-plug diameter of plate = 0.00762 m, d-Diameter of the projectile (Pa), $\sigma_u = 82 \times 10^6$ Pa. k- bulk modulus (Pa) computed using values from Table 1 characteristic of composite target plates. From the remaining speed, energy consumed by the material can be determined utilizing Eq. (2) [25, 26].

$$E_{ab} = 0.5m_p(V_i^2 - V_r^2) \quad (2)$$

Where, E_{ab} = energy absorbed by the specimen(J), m_p = mass of the projectile(kg),

V_i = Velocity of impact or input or initial velocity(m/s) V_r = the residual velocity (m/s). residual velocity and energy assimilated are used processed Eqs. (1) and (2) for composite objective plates.

2.2 Finite Element Examination of Composites for Ballistic Impact

FE examination finished for composite plates is created utilizing a composite plate (unadulterated Kevlar (KM2), and JE) of 100 mm \times 100 mm with different thicknesses is considered for FE assessment. The FE model of the composite plates is made using the business FE programming model LS-DYNA. The composite target plate is considered as deformable, however, the shot of 7.62 mm broadness, the weight of 5 g is considered for the examination to address the slug/fired of self-stacking rifle (Fig. 2). For a high-energy 7.62 mm diameter of shot, multi-layered protection systems, additionally called composite defensive layers are generally favored [27–29]. The shot and target plate estimations are made, discretized, following which material properties are appointed. Concurred shot and target plate with limit conditions are fixed in each layer in all directions. FE examination of the composite is finished at different thicknesses 12 mm, 14 mm, and 24 mm at the speed of the shot is 350 m/s the mass of the bullet 5 g for neat kevlar plate and Kevlar sandwich with JE center of 8 mm plate.

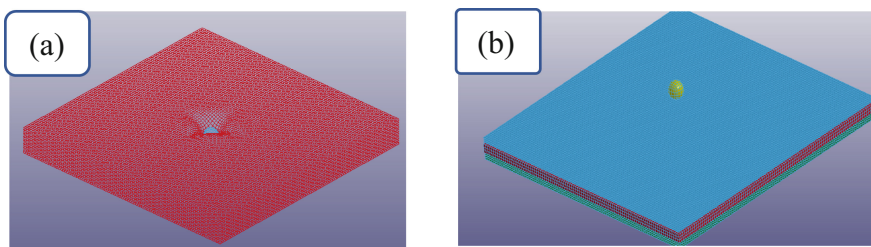


Fig. 2. (a) FE analysis of Kevlar (KM2) (b) Kevlar (KM2)-jute sandwich composite with under impact conditions

Table 1. Material properties of target plates [30–33]

Sample	Properties	Values
Steel Bullet Projectile	Young’s modulus Poisson’s ratio Density	$E = 210 \text{ GPa}$ $\nu = 0.3$ $\rho = 7.85 \text{ g/cm}^3$
Kevlar (Km2) Fabric	Young’s modulus Poisson’s ratio	$E_1 = 1.34 \text{ Gpa}$, $E_2 = 84.62 \text{ Gpa}$, $G_{13} = 24.4 \text{ Gpa}$ $\nu_{31} = 0.6$, $\nu_{12} = 0.24$ $\rho = 1.44 \text{ g/Cm}^3$
Jute–Epoxy	Young’s modulus Poisson’s ration Density	17.57 GPa 0.3395 Density 1.3375 g/cm^3

3 Result and Discussion

Residual velocity and energy assimilation are processed from both analytical and FE models for Kevlar (KM2) plates of the thickness of 12 mm, 14 mm, and 24 mm as shown in Table 2. The sandwich plate thickness of 14 mm is a better result than other sandwich and pure Kevlar plates with analytical and FE analysis. The Kevlar (KM2) plate with greater thickness of 24 mm shows lower residual velocity and higher energy retention, and higher energy absorption. The consequence of FE examination is nearness with insightful estimations of remaining speed and energy assimilated. The most extreme mistake in remaining speed is about a similar thickness of 1.14 m/s and then, the FE model is viewed as approved for Kevlar (KM2) composites. The Kevlar (KM2) plates of various thicknesses to assess the ballistic properties. An expansion in energy absorption from 12 mm to 14 mm thick plate of Kevlar (KM2) jute-epoxy sandwich plate could be utilized for bulletproofing. The after-effects of Kevlar (KM2)-jute sandwich and Kevlar (KM2) plate of the equivalent thickness of 14 mm. FEA aftereffects of Kevlar (KM2)- jute sandwich plate energy retention is more prominent than Kevlar (KM2) plate about the thickness 78.167%. Figure 3 shows that the energy assimilation of three distinct plates is varied the result upon the platelayers, thickness, and material synthesis. The sandwich plate exhibited significantly higher energy absorption and lower residual velocities. At the thickness of 14 mm for a sandwich, the plate is to show higher energy assimilation and block of the bullet up to least effect load-incited, at that point after getting back to the way to deal with the first situation to show the Fig. 3 for red color, while unadulterated Kevlar (KM2) plates of 14 mm thickness within a similar speed for 350 m/s effectively penetrate and lower energy assimilation limit. Figure 3 shows the sandwich plate for the FE and the analytical analysis result is approach values obtained. In Fig. 3 the kinetic energy of the three plates is different based on different parameters considered to affect the results. The higher kinetic energy absorption of the sandwich plate in 14 mm thickness. Figure 4 shows that the energy absorption of three different plates is different depending on the platelayers, thickness, and material composition. At the thickness of 14 mm for a sandwich, the plate is to show higher energy absorption and resistance of the bullet up to minimum impact load-induced, then after return to approach to the original position

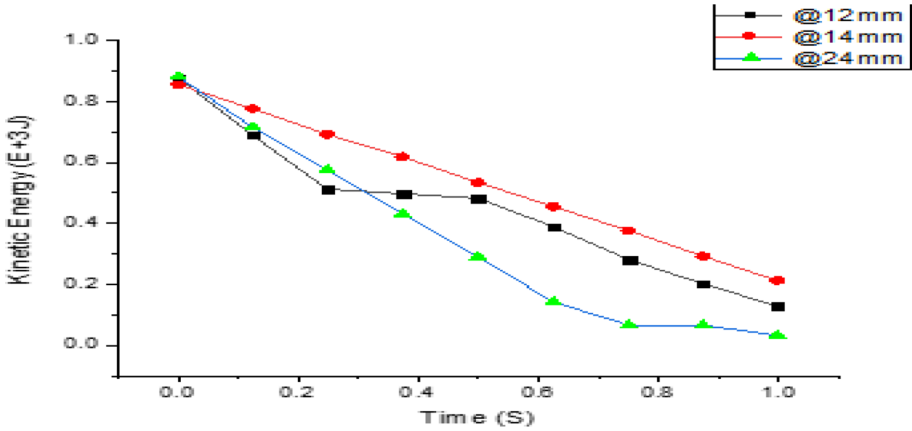


Fig. 3. Kinetic Energy of sandwich (12 mm and 14 mm) and neat Kevlar (24 mm) plate (Color figure online)

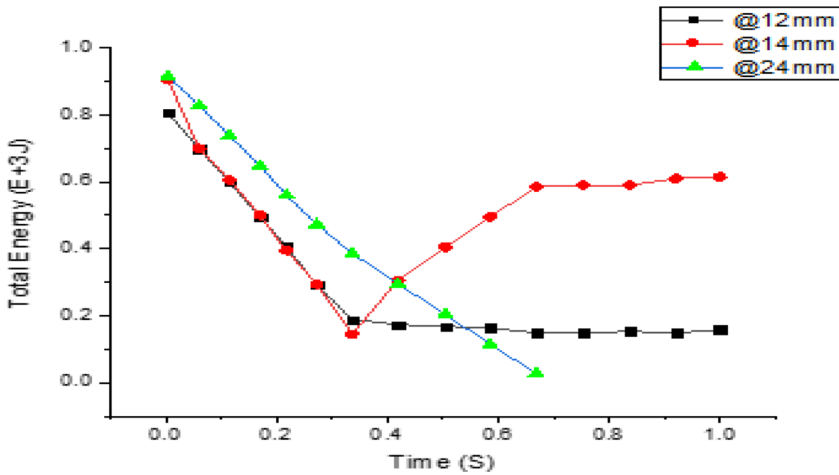


Fig. 4. Energy absorption of sandwich (12 mm) and neat Kevlar fabrics (14 mm) plate (Color figure online)

to show the in-Fig. 4. for red color, while pure Kevlar (KM2) plates of 24 mm thickness with in the same speed for 350 m/s easily penetrate and lower energy absorption capacity. The dynamic energy of the three plates is diverse dependent on various boundaries considered to influence the outcome. The energy absorption of the sandwich plate for distinctive thickness shows improvement compared to the pure plates.

Form Fig. 5 shows the residual velocity of the unadulterated Kevlar (KM2) and sandwich plate developed various outcomes. In the sandwich plate, the residual velocities are higher than pure (KM2) plates for FE analysis and analytical analysis

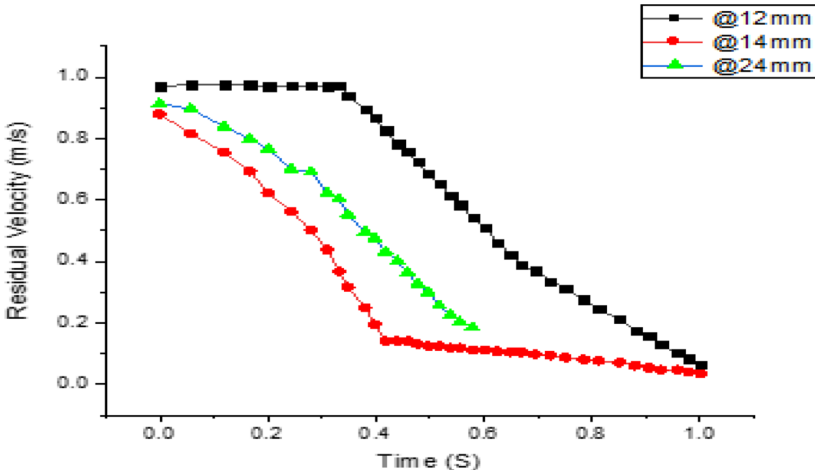


Fig. 5. Residual Velocity of sandwich (12 mm and 14 mm) and pure-Kevlar (24 mm) (Color figure online)

results. Residual velocity and energy absorption are calculated from both analytical and FE models for Kevlar (KM2) plates of the thickness of 14 mm and 24 mm are done in Table 2. The Kevlar (KM2) plate of the higher thickness exhibit lower residual velocity and higher energy absorption. The result of FE analysis is proximity with analytical values of residual velocity and energy absorbed. The maximum error in residual velocity is about the same thickness of 1.14 m/s and thus the FE model is considered to be validated for Kevlar (KM2) composites. The Kevlar (KM2) plates of different thicknesses to evaluate the ballistic properties. An increase in energy absorption from 12 mm to 14 mm thick plate of Kevlar (KM2) jute-epoxy sandwich plate could be used for bulletproofing. The results of Kevlar (KM2)-jute sandwich and Kevlar (KM2) plate of equal thickness of 14 mm. FEA results of Kevlar (KM2)-jute sandwich plate energy absorption is greater than Kevlar (KM2) plate about the thickness 78.167%. This behavior could be analyzed from different thickness values simulated in FE for the sandwich plate and untreated Kevlar plate.

Table 2 shows analytical and FE approaches the perforation velocity increases the energy absorption capacity of the target plate increase absorption, whereas the residual velocity will decrease both analytical and FE approaches. The sandwich plate improves energy absorption capacity based on the influence of layer, thickness, and material composition. The residual velocity of the target plates are different results, but the maximum error of the analytical and finite element analysis of residual velocity result is 1.14 m/s in the thickness of 24 mm of pure Kevlar (KM2) plates. The perforation velocity of pure-Kevlar (KM2) and sandwich plates are different results. The highest perforation velocity was attained in the sandwich plate at the thickness of 14mm the perforation velocity of 21.36 m/s. the sandwich material will be a great role to improve perforation velocity results and energy absorption capacity. The energy absorption output of different target plates shows different results. When different thicknesses and

Table 2. Residual velocity and energy absorption of pure-Kevlar and Kevlar-jute-epoxy sandwich obtained by analytical and FE approaches

Sample	Thickness	No. layers	Initial velocity (m/s)	Analytical			FE		
				Perforation velocity (m/s)	Residual velocity (m/s)	Energy absorption	Residual velocity (m/s)	Energy absorption (J)	
Sandwich plate	12 mm	6 Layers and 8 mm core	350	13.26	340.48	16.4299	339.56	17.98	
Sandwich plate	14 mm	10 Layer and 8 mm core	350	21.36	338.13	20.4074	337.03	22.27	
Neat Kevlar (KM2) fabric	24 mm	22	350	18.67	334.46	26.5872	333.32	28.49	

constant initial velocity are used the result of sandwich plates shows greater energy absorption than pure Kevlar (KM2).

Figure 6 illustrate the impact surface of the plate with different thicknesses of the plate with the same velocity and different surface damages. The damage of the target plate in the 12 mm sandwich target is a greater damage surface for the front face but does not penetrate the back face of the target plate. For the damaged surface of pure Kevlar (KM2) materials thickness of 14 mm easily penetrate and lower the damaged surface. The total energy absorption of the target plate indicates thickness and material compositions. The stress distribution of the plate within different plates due to the energy absorption effect is different results in Fig. 6. The greater energy absorption of the target plates it occurs greater stress results.

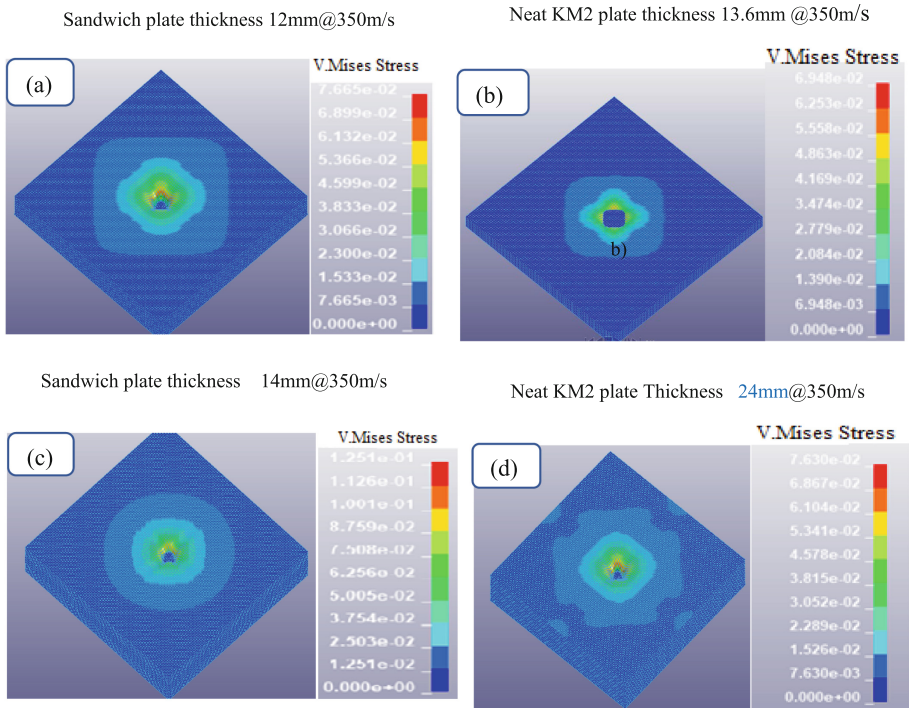


Fig. 6. V. Mises stress analysis of Sandwich fabric (jute epoxy with Kevlar (KM2)) and Neat Kevlar (KM2)

4 Conclusion

The results obtained indicate that sandwich materials can improve the ballistic impact energy retention properties significantly. FE investigation leads to conclude that Kevlar (KM2) plates which involve easy expansion on the material thickness, enhances its energy absorption capacity. The penetration velocity of the impact was higher which

improves the energy absorption of the target plate. For the sandwich plate thickness of 14 mm, the energy retention was expanded by 78.167%. The energy absorption properties of the sandwich plate were increased compared to the unadulterated Kevlar (KM2) plates. The Kevlar (KM2) - jute-epoxy sandwich plate could be promising materials for a helmet design applicable for bulletproofing.

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