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Review Article

Ballistic Impact Performance of the Layered and Laminated Composites: A Reviews

Kannan Rassiah[1, 2*], M.M.H Megat Ahmad[1] and Aidy Ali[1]

[1]*Department of Mechanical Engineering, Faculty of Engineering, Universiti Pertahanan Nasional Malaysia, Kem Sg. Besi, Kuala Lumpur, Malaysia*

[2]*Department of Mechanical Engineering, Politeknik Merlimau Melaka, KB 1031, Pejabat Pos Merlimau, Melaka, Malaysia*

ABSTRACT

This paper presents an overview topic of layered and laminated fibre composites. The review presents an investigation on the effect of varying the properties of fibre and the matrix of layered and laminated composites and identifies the fundamental parameters determining ballistic impact protection. The advantages of layered and laminated reinforced composites with different thicknesses for further enhancing ballistic penetration resistance of the laminated fibre composite have been reviewed. Lamination of multiple layers of composite material can give better ballistic performance.

Keywords: Layer, laminate, ballistic impact, composites

INTRODUCTION

A variety of fibre composite materials are found to be increasingly used in different industries including concrete structural, automotive, aerospace and defence applications. The characteristics of composites, such as strength and stiffness, allow for the structure of safe automobiles, aircraft with high scope and light-machine components (Naik *et al*,. 2005; Castillo *et al*., 2012; Borvik *et al*., 2009). Today, this material is an increasingly important component used in many defence and commercial systems where it is a component of structural panels, control arrangements, configurations of insulated armour and in reinforcement parts.This is due to its mechanical and physical properties compared to the properties of the components taken separately (Kuan *et al*., 2009). Another

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E-mail addresses:
kannan@pmm.edu.my, kannan780915@gmail.com (Kannan Rassiah),
megat@upnm.edu.my(M.M.H. Megat Ahmad),
aidyali@upnm.edu.my (Aidy Ali)
*Corresponding Author

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reason for its high demand is due to its reduced structural weight that makes it suitable for use in lightweight materials (Grujicic *et al*., 2006). Here, the design of composite systems for enhanced material performance in engineering has created lightweight structures.

Moreover, composites used in reinforced plastics possess the benefits of fabrication advantage, crushing steadiness and high energy absorption recital. This makes the material suitable for use in defence application as the criteria for defence application call for materials that are durable, strong and ableto absorb impact energy (Kuan *et al*., 2009; Carrillo *et al*., 2012; Dimeski *et al*., 2011). High mechanical properties are extensively used for military purpose, for instance, in personnel armour, vehicles and arms, which are all important and necessary for the protection of military personnel. The selection of material used for defence protection, however, is affected by different criteria such as cost and weight.

Although the use of composites is gaining interest, it faces several challenges. The first is that laminate structural composites are formed not only by the class of matrix and reinforcement materials. Second, it is dissimilar from composition design of the reinforcement. Third, it depends on how to lay up conventional kevlar, fibreglass, nylon, ramie and aluminium in laminate structural and functional stability during storage and use. Several studies have shown that a composite of kevlar, fibreglass, natural rubber, ceramics or aluminium provides a method to improve ballistic impact and effect in different configurations (Carrillo *et al*., 2012;Naik *et al*., 2008;Kyziol, L, 2007; Huang *et al*., 2007 and Ali *et al*.,2010).

This paper reviews research work published in the field of ballistic impact layered and laminated composites with special reference to the laminate thickness ballistic impact and the properties of the composites. The single, combining two or more layers of material together and the process of producing a laminar by stacking a number of thin layers of fibres and matrix and consolidating them into desired thickness is considered.

LAYERED AND LAMINATED PLATE COMPOSITES

The laminate fibre reinforced composites appealing to the military, the navy and the construction sector (Nunes *et al*., 2004; Ramadhana *et al*., 2012; & Deka *et al*., 2006). The study considered the stacking of a number of layers with different forms of reinforcement fibres and matrix in the desired thickness. The layered and laminate investigation gives the benefit ballistic protection. Iqbal *et al*.(2011) investigated ballistic limit, which increased with an increase in the thickness of the monolithic and layered target plate. Besides that, according to Huang *et al*.(2007), depth of penetration was dependent on ceramic thickness. Carrillo *et al*. (2012) found that adding a thermoplastic layer matrix increased ballistic performance. Table 1 shows the experiment results of ballistic limit velocity for all specimens, which correlated well with layered application and thickness (Buitrago *et al*., 2010; Sabet *et al*., 2011; Iqbal *et al*., 2011).

DESIGN OF BALLISTIC IMPACT THROUGH THICKNESS IMPROVEMENT

During ballistic impact tests the resolution of ballistic limit is of leading consequence indevising protective structures, military vehicles and body armour. The influence of target thickness can be one of the factors in impact resistance application. The thickness and layeredness of the body play an essential role in energy absorption or delamination area of materials and by increasing the thickness (Barcikowski, 2008); the body structure can endure more load and more energy absorption (Balakrishnan *et al*., 2012; Demir *et al*., 2008; & Satoto *et al*,. 2009). Three parts were observed in this study: i) single layer, ii) composite laminate, iii) hybrid laminate.

TABLE 1: Ballistic Impact Test

Fabric type	Laminate Thickness (mm)	Ballistic Limit (m/s)
Monolithic	3	212
Monolithic	6	332
Monolithic	12	550
5 layer Cross Play	5	95
6 layer Cross Play	6	98.4
10 layer Cross Play	10	140
2 Layer Plate	0.5	51.22
3 Layer Plate	0.71	64.52

Single Layer of Thickness

Balakrishnan etal. (2012) studied the effect of plasma-transferred arc hard-faced interlayer thickness on ballistic performance using three different thicknesses (4, 5.5 and 7 mm) hard-faced middle layer. The researchers found that all the three joints with three different thicknesses of hard-faced material successfully stopped the projectile and the bullets were shattered. Meanwhile, according to Sabouri *et al*. (2011), using different aluminium thickness in varies locations shows better ballistic resistance with the thickness of glass/epoxy layers remaining stable.

Sheikh *et al*. (2009) investigated the performance of single and multiple laminated panels with simple layered shell elements. The result shows that the particular energy absorption ability of the thin laminate with five layers is found to be more than that of the thick laminate of 10 layers; however, the double laminated panel with two five layers has enhanced energy absorption capacity than that of the thick laminate of 10 layers.

However, according Iqbal and Gupta (2011) the nose-shaped projectile affected the thickness of the plate whether in single or multiple layers. The result shows that the thin monolithic target plates as well as the layered connection of plates presented the lowest ballistic resistance.

A similar method conducted by Babu *et al*. (2007) used hard steel cylindro-conical projectiles for unidirectional glass-fibre reinforced epoxy composite plates. Table 2 shows that the changeable stacking sequence, thickness, layered laminated and symmetric laminated has been tested. The ballistic limit for thin targets plays a major role with the rising thickness of the laminates and with nose geometry of weighty projectile that has less control of the energy absorption.

TABLE 2 : Ballistic Limit of Laminates for Different Nose Geometry and Thickness

Projectile Nose Geometry	Ballistic Limit (m/Sec)				
	4 layers (0,90)	6 layers symmetric	6 layers symmetric	6 layers symmetric	6 layers symmetric
	2.3 mm	3.2 mm	4.9 mm	3.2 mm	4.9 mm
Sharp nose	30	67	67	45	46
Blunt nose	32	40	39	50	49
Truncated nose	36	46	45	58	58

Madhu and Bhat (2003) studied the standard and oblique impacts on single and layered mild steel and aluminium plates in the range of 10 mm to 40 mm. The proportion of plate thickness to the diameter of the projectile is in the range of 1.5 to 13.0 with of an ogive-shaped, hard steel projectile. The residual velocities for combined target in plates of intermediate thicknesses were of the same order as in the case of a monolithic target.

In addition, the thicker single or monolithic plate can improve ballistic impact limit and perform as the ballistic penetration resistance. The ballistic limit increased with an increase in the thickness of the monolithic target plate.

Laminated Composites

Demir *et al*. (2008) studied the laminated composite performance of the mechanical properties of the support plate and the areal density. The composite targets were subjected to the thickness of the alumina tiles as 6 mm and steel backing plates of five different thicknesses (4, 5.9, 7.8, 9.7 and 11.6) were used. The ballistic recital of the laminated alumina steel composites increased with respect to the areal density and hardness of the composite.

Hohler *et al*. (2001) investigated the recital of oblique, ceramic/metal, bilayer composite armour by two ceramics, alumina and silicon carbide and two metallic backings, rolled homogeneous armour steel and aluminium, in a variety of combinations. The results show that areal densities of the depth of penetration targets decreased with increasing ceramic thickness.

Deka *et al*. (2008) examined the performance of plain-weave laminated composites of changeable thicknesses under high velocity impact. When the layer content increased from 8, 12 and 16 the velocity was 209.02 ms^{-1}, 294.45 ms^{-1}, and 304.1 ms^{1}, respectively. The finding shows that ballistic limit is linearly correlated to the thickness of the laminated composites where the impact velocity was decreased from the full penetration order to a partial penetration order in unity of V_{50}.

Besides that, according to Patel *et al*. (2004), the penetration occurrence of a cylindro-conical impactor on the Kevlar/ epoxy-laminated composites with thickness of 10, 15 and 20 layered cross ply laminate plates with total thickness of 6.35 mm, 9.525 mm and 12.7 mm correspondingly affect the velocity limit. Here, the results show that ballistic limit velocity is 106.95 m/s, 121.3 m/s and 136.68 m/s, respectively.

Ahmad *et al*. (2007) explored the ballistic impact recital of high strength, high modulus composite coated with natural rubber. The result of different coating techniques and natural rubber modulus were studied. The result showed that ballistic limit of 2 neat layers and 2 coated layers composite was 241 m/s and energy absorption was 31.9 J with areal density 1076 g/m^2. While for the 4 neat layers, the ballistic limit 200 m/s and energy absorption was 22.0 J with areal density of 808 g/m^2, respectively. This shows that energy absorption at the ballistic limit by the combined fibre was higher that by the neat system. The result indicates that the combination of 2 neat and 2 natural rubber coated Twaron composite in the 4-layer composite absorbed more ballistic impact energy than all-neat.

Lee *et al*. (2003) reported on the ballistic penetration of six various configurations of 4 layers Kevlar and 8 ml of shear thickening fluid. The equal target weights and the test result showed that 8 ml shear thickening fluid impregnated in 4 layers of Kevlar had a higher impact velocity of 253 m/s and the lowest penetration depth. The addition of fluid with kevlar fibre enhances the ballistic penetration resistances.

This also shows that ballistic limit is linearly related to the thickness and layeredness of the laminated composites. Laminate of the target plate has considerable influence on the ballistic limit and thickness of the ballistic limit decreased with an increase in the number of layers.

Laminated Hybrid Composites

Hybrid composites composed of two or more different reinforcements in a single matrix dominate over ordinary composites. The impact specimens were fabricated using layers of two types as shown in Figure 1. Material parameters are grave for the ballistic recital of hybrid laminate systems.The researcher evaluated the function of poly methyl methacrylate on the impact response of composites consisting of poly methyl methacrylate and polycarbonate as well as on the polycarbonate - Glass - poly methyl methacrylate - polycarbonate laminates. The outcome was that increasing the thickness of PMMA improved the overall impact capability of these laminates (Hsieh *et al*. 2004).

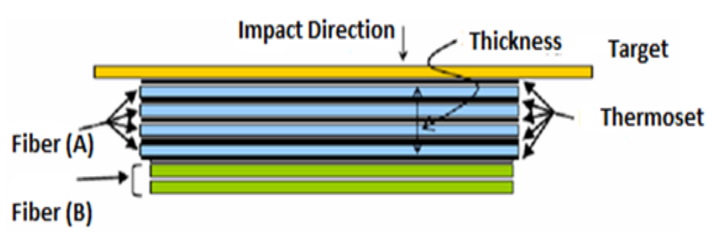

Fig.1: Laminated composites with several layers.

Kyziol (2007) studied the shooting resistance of ceramics, rubber, glass reinforced plastic, natural and modified wood. The outcome was that glass reinforced plastic samples of 16 mm thickness sheltered with ceramic plates of 10 mm thickness can be measured as bullet-proof against bullets of 7.62 mm calibre. The results obtained from the shooting tests of glass reinforced plastic laminate plates point out that the thickness of the ballistic shield plays a key role.

Satoto *et al*. (2009) studied the ballistic penetration show of a composite material collected of woven Kevlar fibre, woven nylon fibre, woven ramie fibre impregnated with compatible resins and hybrid composite construction of these three structures. The researchers found that although the material was composed of 4 layers of Kevlar – A363F showed better performance than the 32-layer composites of nylon-Oxford X7 and 48 layers of ramie fibres, but the ballistic penetration resistance of Kevlar, nylon and ramie fibre is enhanced by impregnation of the fibre with the compatible resin. Impregnated resin fibre composite is shown to give better ballistic defence as contrasted with simple stacks of neat fibre.

In addition to the evolution of new materials that have a higher ballistic impact limit to the thickness and better ballistic penetration resistance, using hybrid materials can be improved through the design process to create materials that are sufficiently stiff, strong, flexible and lightweight. Similar results were obtained by Fink (2000) and Kaufmann *et al*. (2003) in their study of the performance of each layer where it was found that the material significantly influenced the overall performance of the armour. Enhancing performance could be achieved by cross configuration of the fibre layers without increasing panel weight and thickness. Based on that, various configuration analyses can be studied such as shown in Fig. 2, which considers four different hybrids composites (Synthetic fibre A / Synthetic fibre B / resin) in different thickness configuration.

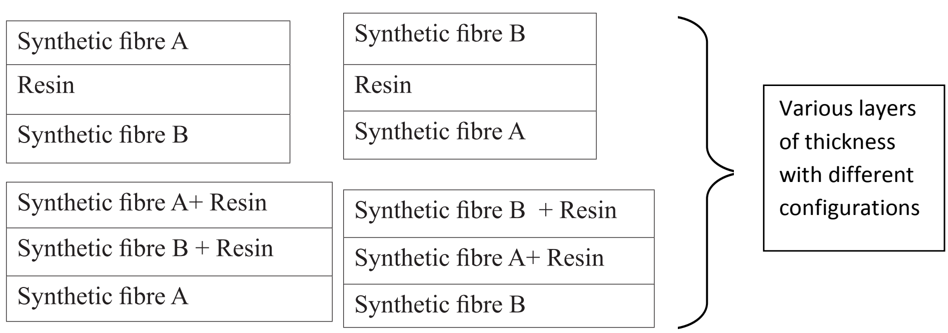

Fig.2: Different configurations.

FUTURE APPLICATIONS AND RESEARCH

The use of layered and laminated hybrid composites in ballistics will ensure optimisation of each subsystem module in composite personnel armour, vehicles and other systems subject to small panels. Using hybrid material design can provide additional important design variables such as thickness, size, materials, shape, distribution and orientation as well as cost (Rao *et al*., 2009; Ma *et al*., 2006). This can be identified by looking at the laminates of the hybrid system as they are superior to multiple with low resin content and can be improved ahead by hybrid systems using fibre layers on the impact side and respectively close fitting composites between the layers.

CONCLUSION

Ballistic impact engineering materials should be considered in selection of the most acceptable armour materials for use by the military. They provide good protection, superior ballistic penetration resistance and high flexibility. The most complicated part of this analysis was increasing the number of fibre layers because of the comprehensive new energy dissipation mechanisms and increased interactions between the different plies of the composite and between the target and projectile. The literature shows that through experimentation, improved ballistic performance can be achieved through the thickness design process. In addition, they also provide better performance.

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