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Review Article

Potency of natural and synthetic composites for ballistic resistance: A review

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ABSTRACT

Mechanical characteristics of the laminated composite crafted from fabric type reinforcement perhaps inspired via the weaving method and reinforcement agent's usage due to each layer's constructional parameter. As a result, research on the arrangement configuration between bio composite and synthetic fibre for the material shape was proposed to enhance the composite structure's biodiversity and physical characteristics. Substitute for natural fibre in synthetic fibre composite works has shown the excessive capacity to be explored scientifically. The evaluation focused on the concept and essential of bio composite and the synthetic composite fabric positioned over the years from the previous studies of the preliminary researches. The sorts and features of matrix and fibre filler reinforcement materials in composites were also discussed. This assessment's main findings indicated that the composite centre relied on the weave styles and inter-ply and interplay lamination roles. Therefore, the state-of-the-art intraply for synthetic fibre and bio composite fibre in a composite shape was anticipated performing higher in mechanical energy, particularly within the application of ballistic resistance, besides decreased dependency on artificial fibre. It would ultimately suggest the excellent weave sample designs in the proper combination shape of natural and synthetic fibres embedded with polymers. The statistical results were compared with the experimental parameters available inside the literature review. The review explains approximately the studies and evolution within the enhancement of characteristic fibres reinforced polymer composites in ballistic resistance use. This paper goes over the body armour's profitable and present advancement materials, structure and development procedures, and related works on upgrading ballistic energy captivation and upgrading the mechanical tenacity for high impact resistance applications.

1. INTRODUCTION

A substantial composite is made up of two or higher combination numbers creating properties that differ from its components. It can be effortless because composites are strong and durable, yet mild in weight and the proportions of strength to weight and volume to weight are much superior compared to metals and aluminium properties that plastics, ceramics, and polymers cannot achieve themselves [1]. Natural fibres are in trend with their excellent mechanical properties in the automotive, manufacturing, and aerospace sectors. Such natural fibres include sisal, flax, coir, cotton, jute, kenaf, and more [2]. Composites consist of different sections, in particular the material and matrix for reinforcement. The strengthening materials are generally solid with a low density, and the matrix is versatile and challenging to ensure that the composite can achieve each of its most delicate features [3]. Natural fibres are used to reinforce the current basic material structure. These provide a complex configuration with a crystalline cellulose amorphous lignin or hemicellulose matrix, reinforced by fibril. The critical components of it are cellulose (60 - 80%), hemicellulose (5 - 20%), lining, and humidity (20%) [4]. The chemically modified natural fibre improves the properties compared to untreated fibres. The chemically managed interface grip between fibre roots and polymer matrix has advanced with natural fibres.

More specific research directs on the intensity of impact and fatigue consistency of natural fibre reinforcement. Natural fibres, including sisal and jute fibres, convert glass and carbon fibres because they are easy to use and durable. The use of synthetic fibres is evolving astonishingly, and the reality is that every day, particularly within the automotive industry, the manufacturing sector is advancing [5]. Natural fibre composites were previously intrigued by their biodegradability. Typical strands such as silk, coir, sisal, and jute are low-cost, plentiful and reusable, lightweight, low-fat, robust, and biodegradable. Natural jute strands might use as a substitute for conventional strengthening in compounds for projects that need strict weight control and external weight reductions [6]. Kevlar 29 has been produced primarily from coal-related materials and used as human-made fibre for armour and high impact applications. Reduced oil reserves and green fibre growth have enabled scholars to investigate natural strands' possible usage as a substitute for human-made fibres. Besides that, a combination of natural fibres against human-made fibres can convey the most remarkable attribute that individual fibres are difficult to achieve. This review offers a relative reading of the classification and construction of different ballistic constituents' varieties and the techniques for upgrading shields and distinctive methods employed to facilitate ballistic energy absorption, as shown in Table 1.

2. BALLISTIC ARMOUR CORE

Through nature, body cover, remarkable toughness, and excellent mechanical resilience structure are the essential belongings typically provided through human-made synthetic materials. Nevertheless, work has repeatedly demonstrated that natural fibres can have the same mechanical power as synthetic fibres. Several layers of materials captivate the kinetic energy of the ballistic waves of the missile. As they slide against each other, the load waves' kinetic drive produced at the impact point dissipates by fibrous distortion and inter-fibrous resistance. Every layer of cloth consumes undissipated energy before the projectile eventually starts penetrating completely. Usually, rigid body armour offers more protection than light body armour. Regional law enforcement officers and security forces can wear soft body protection when there is a risk of assault. Even so, this lightweight body protection is versatile and comes with a standard top or jacket for daily usage.

Stiff plates made of polyethylene may also be used. It is thicker than ceramic, but it is not that hard, and it is less weighty. In addition, to use ceramics as a strong protection sheet, layers of essential resin-coated hardness cloth have also been developed to create the required impact resistance shield. National Institute of Justice [7] is responsible for researching, preserving, and distributing appropriate domestic ballistic requirements. Specific performance specifications and ballistic resistance testing methods have been specified in the norm. More attention is paid to the armour panels of selected laminated systems. For example, yarns are impregnated with a resin, which constitutes a single category of structural composites. The use of a limited volume of resin in interlaced materials improves energy consumption and longevity.

Higher resin content contributes to lower internal bonding because small yarns do not easily weaken the strain. Using resin layer mainly on the tissue's bending ability through uncoated material can withstand the tensile membrane strain. The production method transforms into a robust and stable panel in the presence of resin. It strengthens the binding fabric's tolerance to internal deformations and increases the resin/text panel's capacity to improve ballistic performance [8].

3. BODY ARMOUR STRUCTURE

For ballistic protection, woven and unwoven fabrics made of strong threads are graded with a lower cost, longer service life, and a highly energetic permeability. Ballistic competence is believed to solely rely on the ability to captivate energy and disperse energy rapidly. The fibre-based protective covering is supposed to be an essential attribute of fracturing and elongation of fibres. The vest's primary function is to protect the bullet and withstand the crash's shock [9]. The second task of an advanced ballistic shield is to dissolve the kinetic energy in such a way so its impact can be propagated mostly to the body. The projectile's physique and velocity define its kinetic strength, and greater kinetic strength causes further distortion. Once an interlaced material has a kinetic effect, the material's strain stretches out when the projectile trajectory remains within the bounds. The amount of distortion is determined by the compositional configuration [10]. When the projectile's range travels beyond the specified limit, the shot goes over the material. Tissue fabrics require a small energy captivation potential, which is why specific arrangements are needed to withstand the projectile, as the bullet's kinetic energy exceeds the material's energy absorption limit [11,12].

There are two primary forms of body defence guard against various kinds of missile attacks. One is the rigid body shield that incorporates ceramics and composites and is designed to protect against high-speed projectiles (rifles). Simultaneously, the other is the soft body shield, which provides the materials by less-speed (handgun) bullet safety. The soft body shield usually consists of a multilayer fabric commonly known as a protective board and is poured on a substrate made of cloth that is polyester/cotton or nylon-like and can be wrapped in a raincoat (or waterproof) cover. The light body armour used by police officers is designed to defend against stab attacks and weapons, while the armed corps helmet is designed to protect against the destruction risks that are the most frequent victims of modern combat [13]. For body armour systems, small, durable components were also used to defend against different attacks without restricting the user's movement. Highly characteristic synthetic fibres, partially cost-effectiveness and high durability, are now widely used in woven fibre-backed body armour.

Table 1. Summary of previous research on Hybrid Natural Fibres and Synthetic Fibres.

Author(s) / Year / Ref No.	Grouping Identifier (Approach)/Variables/ Concepts	Summary	Methodology	Conclusion	Comments
Ali *et al.*, (2019). [14]	Woven E glass laminated with a saturated polyester polymer solution to tackle a projectile impact from a weapon in the shooting range.	Plain woven bamboo dependently increased ballistic resistance properties.	Producing hand - made hybrid composites of plain, wove bamboo/woven E - glass composites.	Composites can overcome a bullet speed limit of 482.5 m/s ±5, satisfy the NIJ criterion at level two as indicated in **Figure 1**	Woven bamboo was arranged as innermost and outermost with a total layer of 22 configurations, as shown in **Table 2.**
Salman *et al.*, (2016) [15]	Kevlar fabric substituted with standard Kenaf fibre, with different configurations also widths, resulting in US Army helmet standards.	The right installation of woven Kenaf fibre, resin, and fortification system recognised for a shell fabric's specific needs to provide similar assurance at lower costs.	The hybrids referred to as the ballistic tests consisted of 19 layers and produced using a hot press system shown in **Figure 2.**	Nineteen layers of PVB-fortified Kenaf / Aramid meet the fourth NIJ level of quality as described in **Table 3.**	A portion of synthetic replaced with natural fibre, with different configurations and thicknesses, provides competitive ballistic armour performance.
Yahaya *et al.*, (2014) [16]	Non - woven a hard shot studied kenaf Fibres / Kevlar EPOXY Hybrid coats with depths going from 3.1 mm to 10.8 mm at an ordinary rate.	The Kenaf-Kevlar hybridisation has a positive effect on retained energy and intense load.	Hybrid composites were shaped manually in a mould and cured by force of load for 24 hours at room temperature. The composites consist of Kevlar layers with three distinctive shapes and non - woven Kenaf layers. A ballistic test was carried out using projectile at rates from 172 to 339 m/s and is assessed at the beginning and the residual shot distance.	The ballistic limits (V50) and energy absorption of hybrid combinations were lower than the Kevlar / epoxy hybrid composites in the outermost layers, as illustrated in **Figure 3.**	Natural fibre, non-woven or short fibre, is usually sandwiched to the ballistic test as the innermost part shown in **Table 4.**

Author(s) / Year / Ref No.	Grouping Identifier (Approach)/Variables/ Concepts	Summary	Methodology	Conclusion	Comments
Jambari *et al.*, (2017) [17]	The ballistic experiments were carried out to quantify the ballistic resistance of V50 and energy absorption.	A theoretical arrangement of natural fibre with human-made fibre as the composite material is appropriate and extensively studied for high-end products.	Kenaf / Kevlar hybrid yarn composite woven texture for composite production, arranged as shown in **Table 5.**	The compositional Hybrid Yarn Kenaf / Kevlar 30/70 compound's woven texture was the maximum energy absorption with 148.8J.	A fabric's strength comes from the production of fundamental yarn technology. Through building up this yarn core, the material can withstand high load resistance.
Hafiz *et al.*, (2013) [18]	The sandwich board arrangement contains steel plates and Kenaf foam, affecting the resistance and conduct of exploration.	Kenaf is used to strengthen polyurethane to improve its strength and mechanical tenacity.	The quasi-static study runs with a universal testing machine. The sample has a continuous axial compression by 5 mm/min.	The best samples, 20% kenaf with a thickness of 45 mm, can withstand the most substantial bullet waves, as shown in **Table 6.**	One-of-a-kind methods for sandwiching the two parallel panels as ballistic armours is the short fibre Kenaf bonded with polyurethane foam, as shown in **Figure 5.**
Yahaya *et al.*, (2015) [19]	Research on the effect on the mechanical resistance of Kenaf-Kevlar woven compounds of the layering and chemical cure.	The properties of the Kenaf-Kevlar hybrid composites, as shown in **Figure 6** are influenced by the Kenaf-Kevlar laying arrangements.	Woven Kenaf-Aramid Hybrid Compounds produced by the manual assembly by organising Kenaf and Kevlar woven textured layered groups and a 6 % sodium hydroxide (NaOH) diluted sodium treatment Kenaf weave.	Bending, tensile, and characteristics of healed hybrid compounds, based on deep indentation of clay, are better than untreated hybrid compounds.	Layering series and chemical preparation have greatly influenced the mechanical properties of humanmade composites of woven or non-woven bio composites.
Ying *et al.*, (2017) [20]	As shown in **Figure 7**, the low - velocity impact response of hybrid-laminated compounds built from twill pattern was investigated.	The impacts of the hybrid structure on properties like the high load, the ductility index and the damage zone were investigated.	Different sorts of carbon–aramid/epoxy hybrid covers created and tested.	The damage resistance performance of composites with inter-ply hybrid structure is superior to those of other hybrid composites.	The trial with a low-velocity effect simulates the NIJ criterion stage I and II for soft body armour. Intraply and the inter-ply combination resulted in different application performance.
Haro *et al.*, (2018) [21]	High-density polyethylene (HDPE) mechanical performance of chonta palmwood microparticles was successfully loaded with high strain compressive and ballistic impact.	Mechanical HDPE properties enhanced by chonta palm wood particle reinforcement. As shown in **Table 7**, bio composites with 25 wt% wood-based microparticles had the highest strength, rigidity, resistance to impact, and capacity to absorb energy in an impact.	Palmwood microparticles were combined into the HDPE employing to produce bio composite microparticles.	Chonta palm wood microparticles, as a reinforcement for HDPE, to develop bio composites with an increased capacity for dynamic impact loading and energy absorption.	For the compound mixture of hardened high-density polyethylene (HDPE), chonta palm wood composites in micro-size particles behave as fillers.

Author(s) / Year / Ref No.	Grouping Identifier (Approach)/Variables/ Concepts	Summary	Methodology	Conclusion	Comments
Akubue *et al.*, *(*2015) [22]	The manufacture of Kenaf Fibre Reinforced Ballistic Defence Polyethylene Composite as shown in **Figure 8.**	Kenaf fibres were characterised and treated as useful raw material for the ballistic vest (armour) required to appropriately merge between hydrophilic fibre and hydrophobic polymer to produce a compound with superb characteristics.	The samples of alkaline treated kenaf to the necessary dimensions and oriented up and down in fibres were cut and silane-coupled non-woven matted Kenaf combinations with a virgin high-density polyethylene (VHDPE).	The research found the fibre volume is 30% covered from the NIJ Standard III-A Armour Defence Category for the VHDPE composite and is less indented.	Virgin high-density polyethylene (VHDPE) is an excellent option as it offers decent chemical fibre bonding and can be reprocessed several times and lightweight application.
Naveen *et al.*, (2018) [23]	This investigation Analytical Hierarchy Process (AHP) is used to distinguish the most appropriate natural fibre to hybridise with Kevlar 29 fibre as reinforcement within the polymer composites for personal body armour.	Generally, the AHP strategy gives the analyst an option to effectively discover the arrangement for the multi-criteria decision-making issues.	Fourteen natural fibres and seven criteria for hybridisation regarding the body design specification have been selected and analysed.	The sheath of Cocos nucifera that could be a natural woven fibre has the greatest priority and was chosen for hybridisation in a Kevlar 29 body armour as the most promising natural fibre.	Analytical Hierarchy Process is an alternative for the researcher to choose the best fibre option and provides strong justification that includes experimentation, as shown in **Figure 9.**
Cavallaro (2016) [24]	Impact on the damage resistance levels and energy absorption capacity of woven textural enhanced polymer composites (WFRP) of the weave styles and crimp gradients (CGs) as shown in **Table 8.**	Damage tolerances and energy absorption capacity can be extended by fitting the fabric pattern ideally and using crimp gradient designs.	Experiments included bending, short beam shortening, drop impact, flexure-after-impact, ballistic impact, and Hopkinson Split Bar (SHCB) and performed on Kevlar / Epoxy WFRP 20-fold laminates.	Weave pattern determinations and crimp gradients stretch resulting from extreme loading occasions and the fibre / matrix cohesive zone stresses that regularly reduced delamination.	The intraply weaving process in the cloth can be exploited for improved body armour application, as shown in **Figure 10.**
Nascimento *et al.*, (2017) [25]	This research analysed the possibility of substituting KevlarTM with natural fabrics, focused on mallow and jute fibres, to strengthen epoxy mixtures.	Since individual ballistic testing is conducted in each, MAS's values with KevlarTM may vary marginally with another research. Nonetheless, both findings in the variance study (ANOVA) are identical.	Manufactures made of pure mallow, 70% mallow/30% jute, or 50% mallow/50% jute fibres are divided by epoxy to create laminate composite plates.	As in **Figure 11**, indentation depth values caused by the penetration into the clay observer that regenerates the MAS's human body has always been below the protective restriction point.	Replacing Kevlar^{TM} in the Multi-layered Armour system with Jute Reinforced Epoxy showed improved mechanical characteristics related to mallow, as revealed in **Table 9.**
De Assis *et al.*, (2018) [26]	Multi-layered armour systems (MAS) ballistic experiments use polyester fibre reinforced with second-layer non - woven jute.	Particularly between jute non - woven and KevlarTM jute weave compounds the same depth of indentation was found in a shotgun testimony recreating human body protection.	MAS consists of a front panel of hexagonal ceramic tiles as a second layer of a composite Polyester matrix reinforced with 30% of the non-woven jute and an aluminium alloy plate with the third panel shown in **Figure 12.**	Substitute's jute mats give a 5.4 % reduction of the MAS weight and a 474 % reduction in cost.	In multi-layered armour, Jute non-woven mat reinforced polyester matrix composite is tested for reduced body armour costs.

Author(s) / Year / Ref No.	Grouping Identifier (Approach)/Variables/ Concepts	Summary	Methodology	Conclusion	Comments
Ismail *et al.*, (2018) [27]	To study the effects of a low-speed impact investigation on the mixture aggregates of Kenaf and Kevlar.	Its thickness influences the impact dynamics of the specimen. Outcomes indicate the potential of Kenaf-Kevlar hybrid compounds as an alternative to present constituents.	The constituents were invented in a seven-layer laminate arrangement utilising a proportion of 3:1:3 (Kevlar: Kenaf: Kevlar) for a hybrid composite, as shown in **Figure 13.**	The outcomes showed that a seven-layer laminate only withstood impact energy below 30 Joules, and it failed when the impact energy approached 40 Joules.	Natural fibre hybrid composites with human-made Kenaf-Kevlar approached full Kevlar's quality performance.
Sangamesh *et al.*, (2018) [28]	The remaining speed, energy concentration and the ballistic limit for three various materials calculated using 3D modelling at different thicknesses and velocities.	The study used the limited component procedure to show and analyse compounds with jute-epoxy and elastic under the ballistic effect.	Numerical simulation created to extract various data for different target materials, such as the rest of speed, energy assimilation, and ballistic limit, as shown in **Figure 14.**	The ballistic perimeter and energy captivation of Sandwich Composites (Jute-Epoxy) were similar to rubber plates.	The JRE sandwich proposed was supposed to provide superior structural due to the elastic properties.
Suresha, *et al.*, (2018) [29]	Composites of Hemp / Kevlar / Epoxy and Jute / Kevlar / Epoxy are made of hybrid strengthened composites by a simple hand-layout and vacuum bagging technique.	The reinforcement and fabrication process of the compound depends on mechanical strength.	Tensile test after ASTM-D 3039, compression test following ASTM-D1621, flexural test according to unidirectional laminate standards as shown in **Figure 15.** Compression test following ASTM-D1621.	Hemp / Kevlar / Epoxy laminate's tensile strength is more significant compared to Jute / Kevlar / Epoxy, and the Jute / Kevlar / Epoxy laminates increase compression and bending strength.	This study concluded that jute textile has more transverse and bending characteristics than hemp.
Monteiro *et al.*, (2018) [30]	The ballistic performance of polyester matrix composites made of single fabric jute has been investigated as the other film in a multi-layered armour (MAS) system.	Economical, lightweight, and sustainable alternatives to replace synthetic fibre composites are studied for MAS composites reinforced with natural lignocellulose fibres.	Volume fractions of jute fabric were blended with polyester to produce laminated composites from 10 % to 30 volume percent.	The ballistic performance of both natural fibres and fabrics reinforced polymer composites were similar to Kevlar, when used in MAS second films, as indicated by the indentation depth.	Armour vests that use 30 volume % of jute fabric - reinforced polyester compounds, revealed by decent energy dissipated shown in **Table 10.**
Yahaya *et al.*, (2016) [31]	The ballistic influence performance against fragment simulating projectiles (FSPs) of woven kenaf-Kevlar hybrid and non-hybrid composites has been investigated, as shown in **Figure 16.**	The study examined dualistic limits: ballistic limit speed (V50) and energy concentration.	All the composites were made using the method of hand layout, followed by static load compression.	Increased depth and areal density of the composite proportionally increased energy consumption (14, 46% to 41, 30%) and V50 (5.5% to 8, 44%).	The advantages of naturally occurring fibres had great potential in applying ballistic resistance, such as spall lines.

Author(s) / Year / Ref No.	Grouping Identifier (Approach)/Variables/ Concepts	Summary	Methodology	Conclusion	Comments
Asavavisithchai *et al.*, (2018) [32]	The element of bouncing rubbery strengthened with wire mesh, besides Aluminium film been studied for ballistic armour system.	The rubber composite provides low density, high specific strength, high specific modulus, and decent anti-eroding efficiency on bullets and kinetic energy projectiles.	Composite layers were used to support an NIJ-Type III threats test layer with a ballistic test standard NIJ 0108.01, as illustrated in **Figure 17.**	Due to the high fracture resistance, a composite layer successfully reduces the projectile's speed by strengthening the compounds' steel wirework layers.	For vehicles to maintain high mobility, but to provide low cost and biodegradable, the lightweight safety system's improvement is needed.
Dawood *et al.*, (2018) [33]	The mechanical properties of Kevlar/ phenolic hybrid composites were investigated by durian skin fibre.	Durian skin fibre may reinforce the need for higher fracture stiffness in improving hybrid compound products, as shown in Figure 24.	This research shows that 0 to 30 % of Durian Skin Fibre loading in KDSPHC corresponds to DSF reinforcement.	The Durian Skin Fibre (DSF) content of Kevlar Durian Phenolic Skin Hybrid Composites (KDSPHC) decreased the tensile and bending strength up to approximately 40%, compared to 0% DSF load, as illustrated in **Figure 18.**	SEM found the DSF-Kevlar fibre interface decent, which adds to the compound properties difference by the diverse polarity between Kevlar and durian skin.
Braga *et al.*, (2017) [34]	To analyse the characteristics of curaua, subjected to ballistic energy from full metal jacket bullet.	The stand-alone ballistic testing explains either testing will go on without the front ceramic any fabric.	The ballistic impact shown in **Figure 19** in terms of mixtures reinforced with 10, 20, and 30 vol. % of curaua fibres.	The neat polyester resin demonstrated the highest energy absorption and showed a high energy absorption in the 30 vol. % curaua fibre.	Curaua fibre reinforced compounds potentially replaced as a substitutional layer in multilayer armour structures.
Risby *et al.*, (2008) [35]	The potential use of a Twaron-style CT716-fortified coconut shell (COEX) board as hard shield material and fracture characteristics at a particular risk level when ballistic trials are carried out (NIJ Standard 0101.08), as shown in **Table 11.**	Ballistic reinforcements have improved their abilities by using COEX by 170 %.	To create the COEX tile configuration panel, 12 COEX tiles to produce a flat armour panel.	The COEX / Twaron test panels have been developed to withstand the impact of 9 mm FMJ bullet corresponding to NIJ Level IIIA but have an effect of 7.62 mm FMJ, as shown in Figure 27, at NIJ Level III.	The COEX compound has the potential as a lightweight and low-cost hard armour part.

Front face Rear face

Figure 1. Shooting effect at opposition face [14].

Table 2. Configuration and properties of woven bamboo and fibreglass [14].

Types of the layer arrangement	Dimension in mm (length*width*height)
Woven bamboo / E-glass	300*300*18
E-glass / Woven bamboo / E-glass	300*300*18

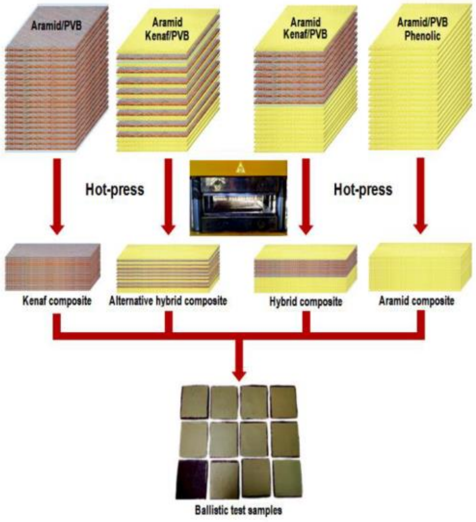


Figure 2. Kenaf/Aramid/PVB composite specimen prepared using hot press [15].

Table 3. Kenaf/Aramid/PVB composite ballistic testing results [15].

Specimens descriptions	Sample depth (mm)	Fibre volume fraction (%)		Bullets speed using 9 mm FMJ (m/s)
		Aramid	Kenaf	
19 Aramid	8.8	61.94	0	426 ±15
17 Aramid/2 kenaf	10.1	48.42	11.6	426 ±15
16 Aramid/3 kenaf	10.6	43.56	16.7	426 ±15
15 Aramid/4 kenaf	11.1	39.14	21.3	426 ±15
13 Aramid/6 kenaf	12.3	31.29	29.5	358 ±15
11 Aramid/8 kenaf	13.1	24.55	36.4	358 ±15
9 Aramid/10 kenaf	14.3	18.75	42.5	358 ±15
19 Kenaf	17	0	62	Does not fulfil the requirement

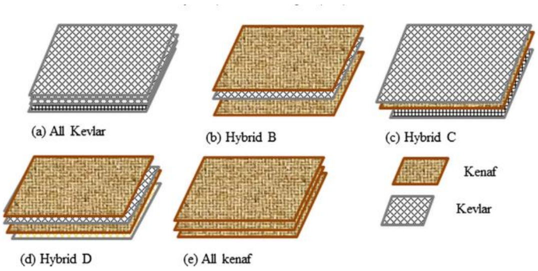


Figure 3. Configuration of Kevlar and Kenaf layer [16]

Table 4. Layering sequence, energy absorption and a maximum load of kenaf [16].

Specimens	Layering sequence	Energy absorption (J)	Maximum force (N)
A	All Kevlar layers	73.3	9260
B	Kenaf at the outermost layers	90	13,275
C	Kenaf at the innermost layers	131	17,440
D	Kenaf and Kevlar are at the alternate layers	88.1	16,440
E	All kenaf layers	4.8	790

Table 5. Ballistic testing result using gas gun [17].

No.	Composites Sample	Speed before (m/s)	Speed after (m/s)	Energy absorb (J)
1	Kevlar (0/100) -8L	303	210	119.3
2	Kevlar (0/100) -12L	342	184	207.8
3	Kenaf/Kevlar (30/70)-8L	305	235	94.5
4	Kenaf/Kevlar (30/70)-12L	318	204	148.8
5	Kenaf/Kevlar (50/50)- 8L	310	261	69.9
6	Kenaf/Kevlar (50/50)-12L	317	243	103.6
7	Kenaf/Kevlar (70/30)- 8L	308	281	39.8
8	Kenaf/Kevlar (70/30)-12L	315	264	73.8
9	Kenaf (100/0)-8L	300	288	17.6
10	Kenaf (100/0)-12L	310	285	37.2

Figure 5. Side view of sandwich armour plate with Kenaf foam [18].

Table 6. Result of Quasi Static compression testing of Polyurethane foam [18].

% of kenaf	Young's Modulus (MPa)	Energy absorption (J)	Specific Energy Absorption (J/g)
0	3,072,806	186,075	0.9908
10	7,627,439	947,684	50,895
20	13,895,624	1,195,915	63,009
30	5,671,304	570,756	29,978

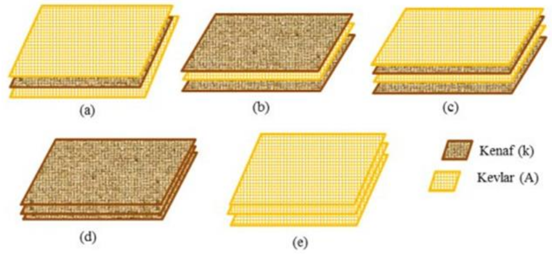


Figure 6. Composite configuration between Kenaf and Kevlar [19].


Carbon fabric
Aramid fabric
Intraply hybrid fabric

Figure 7. Schematic of the twill woven fabrics [20].

Figure 8: VHDPE Ballistic panel [22].

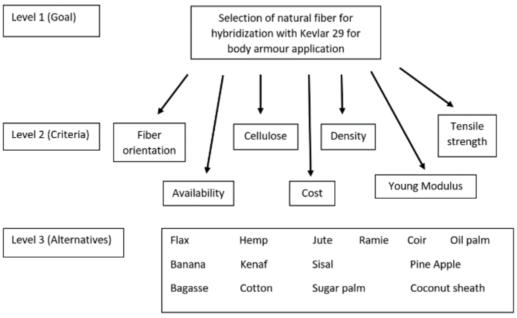


Figure 9. Hierarchical framework for the natural fibre selection [23].

Table 7. Characteristic of reinforced HDPE samples for biocomposite armours [21].

Bio-composite specimens	Chonta palm wood micro-particles / (wt. %)	Tensile strength /MPa	Strain, Ɛ %	Young's Modulus /MPa
HDPE 1	0	14.91± 1.77	5.38±1.12	496.8±21.2
Ch10	10	16.16± 1.15	5.45±1.57	724.7±17.4
Ch20	20	16.47± 1.05	6.00±1.36	742.2±13.2
Ch25	30	16.53± 0.27	4.89±1.47	798.9±17.3
Ch30	40	15.19± 0.83	5.13±1.48	730.2±12.1

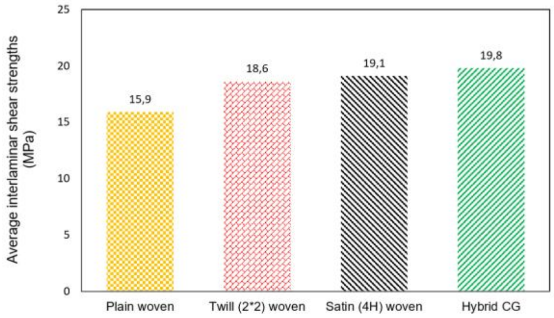


Figure 10. Plot of average interlaminar shear strength versus laminate constructions [24].

Table 8. Velocity and energy absorption for ballistic impact test [24].

Laminate type	Projectile weight (g)	$V_{initial}$ (m/s)	$V_{residual}$ (m/s)	ΔV (m/s)	$KE_{Initial}$ (N-m)	$KE_{Residual}$ (N-m)	Energy absorbed (N-m)	Energy absorbed (%)
Plain woven	6.53	141.11	76.97	64.14	64.96	19.33	45.63	70.25
Twill (2×2) woven	6.37	149.41	88.60	60.81	71.04	24.98	46.06	64.84
Satin (4H) woven	6.48	146.54	74.71	71.83	69.52	18.07	51.45	74.01
Hybrid CG	6.44	146.54	81.94	64.60	69.09	21.60	47.49	68.73

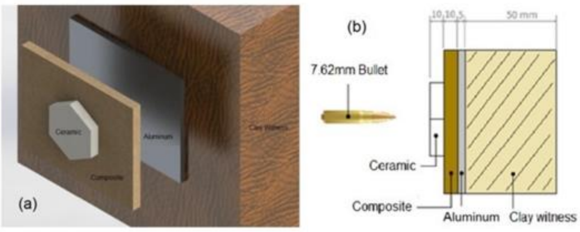


Figure 11. (a) Schematic of a Multilayer Armour system (b) Thickness layers [25].

Table 9. Possessions of aramid fibre, mallow fibre, jute fibre and epoxy resin [25].

Materials	Density (g/cm3)	Tensile resistance (MPa)	Young's modules (GPa)	Specific resistance (MPa)	Specific modules (GPa)
Aramid	1.4	3,000–3,150	63–67	2,143–2,250	45–48
Mallow	1.4	160	17.4	116	13
Jute	1.3–1.4	393–800	13–27	271–615	9.3–21
Epoxy	1.1–1.3	60–80	2–4	46–73	1.5–3.6

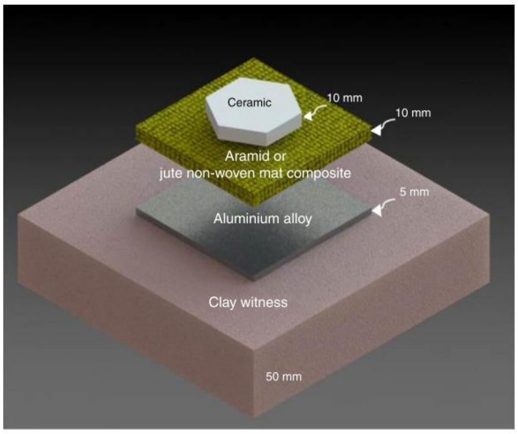


Figure 12. Schematic of a Multilayer Armour system with thickness layers [26].

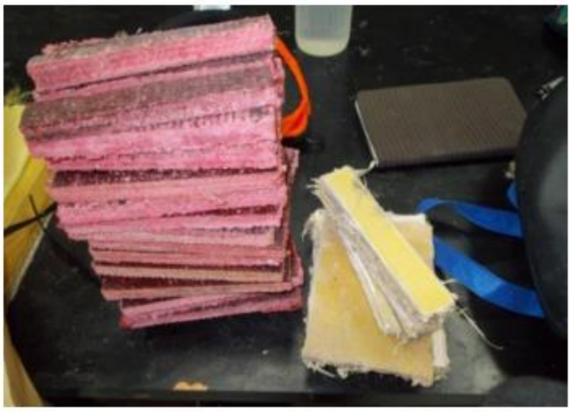
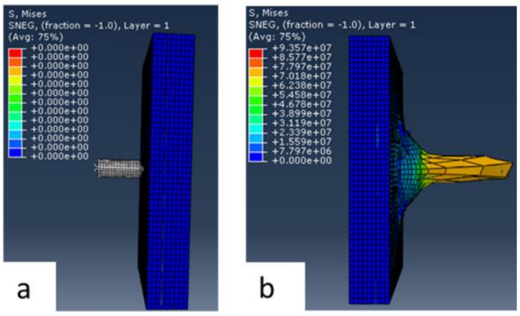


Figure 13. Specimen of hybrid Kenaf-Kevlar composite for drop test [27].



a) Time=0. 00s

b) Time=3. 000E-04s

Figure 14. The damage of Jute Reinforced Epoxy plate in simulation ballistic test [28].

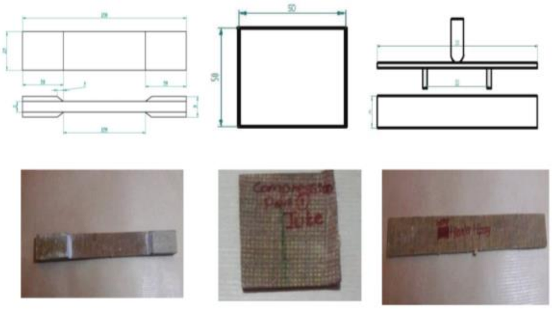


Figure 15. Geometry and dimension of Jute/Kevlar/Epoxy composite specimens for tensile, compression, and flexural test [29].

Table 10. Dissipated energy in different MAS constituents and velocities [30].

MAS constituents	V_i (m/s)	V_r (m/s)	E (kJ)	ΔEd (%)
Al2O3 ceramic	848 ± 6	567 ± 43	1.93 ± 0.310	71.75
10 vol% jute fabric polyester composite	838 ± 3	805 ± 7	0.26 ± 0.004	9.67
20 vol% jute fabric polyester composite	837 ± 4	807 ± 5	0.24 ± 0.006	8.92
30 vol% jute fabric polyester composite	837 ± 8	812 ± 8	0.20 ± 0.008	7.44
Kevlar™	848 ± 6	841 ± 7	0.06 ± 0.001	2.23

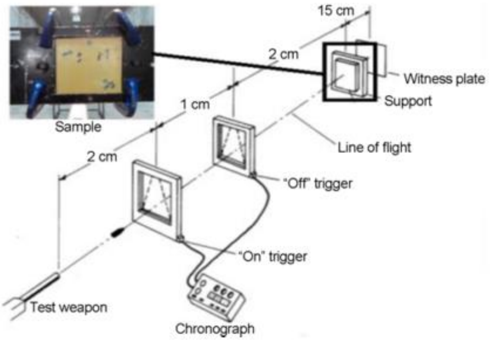


Figure 16. Ballistic experiment setup constructed on NIJ standard [31].

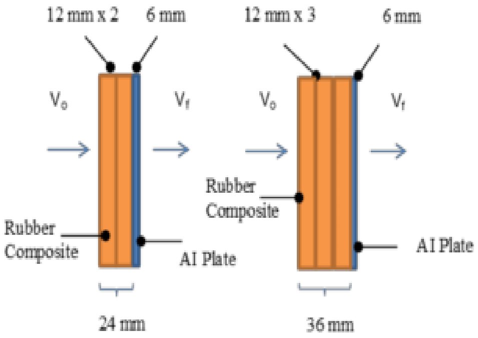


Figure 17. Arrangement of Rubber Composite and Aluminium with different thickness [32].

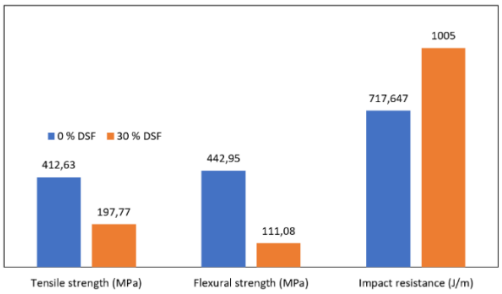


Figure 18. Bar chart of Kevlar Durian Phenolic Skin Hybrid Composites properties based on an average of five specimens [33].

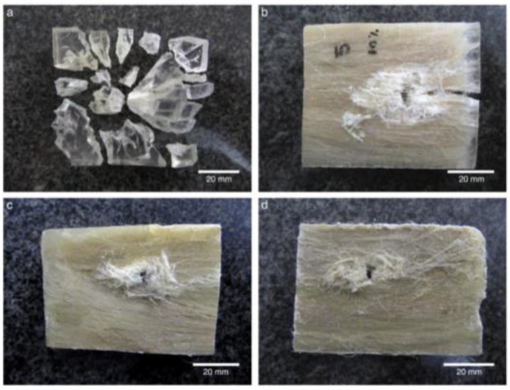


Figure 19. Samples subjected ballistic impact. (a) 0%C (b) 10%C (c) 20%C (d) 30%C [34].

Table 11. Comparison of tested Twaron panel and manufacture's specification [35].

NIJ level	Teijin Twaron recommendation for Twaron CT716 for body armour fabrication	Tested/lowest complete penetration velocity of Twaron CT716 using 9 mm FMJ bullets
I	7 layers (322 m/s)	5 layers (279 m/s)
IIA	14 layers (341 m/s)	15 layers (360 m/s)
II	20 layers (367 m/s)	15 layers (360 m/s)
IIIA	23 layers (420m/s)	N/A

4. CONCLUSION

The latest approaches in materials and panel developments for creating a body shield framework have invigorated scholars to study more on this matter. It is pertinent to say the reasons leading the plan and development of the body shield product. Likewise, the body armour system's flexibility, manufacturing cost and bio sustainability must also be taken into consideration to achieve user-friendly systems. The utilisation of natural fibre as strengthening in polymer mixtures was reviewed based on the condition's perspective and natural fibres' requirements for enhancements in the polymer composite based. This also provides a means for economic development in rural areas, owing to raw materials in different industrial applications and manufacturing activities. This list complies with the Malaysian government's concern on diversifying local woodland-based products besides craft and furniture industries. The result of this review suggests that the properties of reinforced polyester hybrid natural fibres with synthetic fibres embedded with polymers may be improved. But only some investigations were carried out on the potential of woven natural reinforcement hybrid with synthetic fibres. There are apparent strength enhancements between the yarns of fibres in the frame of various weaving patterns. The bonding structure upon intraply between fibre yarns and the inter-ply between laminar is still understudied by previous research.

The literature revealed only a few data on the investigation process to ascertain lamination properties on woven natural fibres with synthetic composite. An effective hybrid with the betterment of stacking series will have optimal weight and cost reduction applications in the ballistic resistance. This leads to upgrades over the mechanical characteristic of woven natural fibres with human-made fibre strengthened compounds by consuming Quasi-static experiment techniques, thus validating the results through finite element simulation and statistical analysis. The advancements of kinetic, strain, and friction energy constituents, proportion to composite mass and angle of obliquity, need further studied for the improved ballistic fortification of typical weaving style compared to other weaving patterns. This analysis shows that structural architecture and composite lamination for the entire projectile protection of inter-ply approaches are still not explored. Exploring effect disruption and high-strength flexibility fibre structure has turned them into favourable constituents not only for army services but also for domestic protecting uses, such as personal armour outfit, head covering, and auto parts. Equally, for bio sustainability, the long-term effect makes the composite biodegradable and practically used for.

CONFLICTS OF INTEREST

The authors declare no conflicts of interest.

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