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Review Article

Effect of Hybridization of Glass/kevlar Fiber on Mechanical Properties of Bast Reinforced Polymer Composites: A Review

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Abstract
Natural fibres are gaining more and more interest as reinforcing materials for polymer composite due to their environmental and economical benefits. Bast fibers is a prominent reinforcement for use in polymeric materials because of its low specific weight and cost, eco-friendly and abundantly available in nature. Several authors manifest the cellulosic fibers based polymeric composites as advantageously used in automobile industries and structural applications, but certain problems have been associated during usage of such fiber such as high water/mosture-uptake and low strength than inorganic fibers. These problems have been reduced to a major extent with enhancements in mechanical properties by the researchers through hybridization of these natural fiber based composites with synthetic fiber (glass/Kevlar). In the present article, we reviewed the effect of hybridization of glass/Kevlar synthetic fibers on mechanical properties of bast fiber (jute, hemp, kenaf, flax) reinforced polymer composites.

Keywords: Bast fiber; glass /kevlar fibre; hybrid composites; Mechanical properties
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1. Introduction

Bast fibers are defined as the outer cell layer of various plants and also have majority in plant fiber categories which has been utilized as reinforcement for making polymeric composies [1-2]. Various researchers have studied the mechanical properties of bast fibers reinforced polymer composites [3-8]. The polymer composites reinforced with bast fiber are characterized to be reasonable strong, economical, light in weight with less hazards and have potential to be used as structural materials. Bast fiber like hemp, jute, flax and kenaf are found increasingly important in composite production due to its better strength and stiffness as compared to other natural fibers. The mechanical properties of mostly used bast fiber that has been utilized are showed in Table 1. Despite of the above advantages they possess some limitations also, such as high water uptake capacity, and low strength as compared to inorganic fibers such as aramid, glass, carbon. These properties of bast fiber based composites can be improved by hybridization of such fiber with high strength synthetic fiber which emanates flexibility to the design engineer to tailor the properties of composites according to the requirements. Hybrid composites are termed as more advanced composites as compared to conventional FRP composites. Hybrids can accomodate more than one reinforcing phase and a single matrix phase or single reinforcing phase with multiple matrix phases or multiple reinforcing and multiple matrix phases [9-11]. Glass fiber is most commonly used synthetic fiber as reinforcing agents in both thermoplastics as well as thermoset polymers. They possess low cost, high dimensional stability, high tensile strength and chemical resistance and have excellent insulating properties; therefore various researchers have studied the behavior of combination of different bast fibers with glass and kevlar fibers in polymer composites.

Table1. Mechanical Properties of commonly used Bast fibers

Bast fibers	Young's Modulus (GPa)	Tensile Strength (MPa)	Elongation at break (%)
Flax [12]	27.6	345-1035	2.7-3.2
Jute [13]	30-60	400-800	1.8
Kenaf [14]	14-38	240-600	-
Hemp [15]	30-60	690	1.6

Hybrid composites contain two or more types of fiber, and therefore the benefits of one type of fiber could compliment with what are lacking in the other. In order to take the advantages of both bast fiber and glass as well as kevlar fiber, they have been added conjointly to the matrix so that superior, optimal and economical composite could be realised [16]. The motive of this paper is to review the mechanical properties of bast fiber (jute, hemp, kenaf, flax) in the context of fiber reinforced polymer composites and also the hybridization of such composites with the glass/kevlar fiber.

2. Mechanical Properties of bast-glass fibre based hybrid polymer composites

Since hybrid composites provides the valuable mechanical and tribological properties. The mechanical properties of hybrid composites depend on various factors like fiber length, orientation of fiber, interfacial bonding between fiber and matrix, layering pattern of both fibers etc [17]. In the recent day's hemp, flax and kenaf as natural fiber are conjoint with glass fiber to make hybrid composites for superior mechanical property. In this article, a review has been made on mechanical properties of such hybrid natural composites.

2.1 Jute-glass fiber and jute-kevlar based hybrid composites

Jute fiber reinforced plastics (JFRP) offer attractive proposition for cost-effective applications. Despite this, while using these fibers some problems such as low strength and modulus have been identified. Effective hybridization of JFRP with synthetic fiber (here glass and Kevlar) could be the possible real time solution to overcome these limitations. The compressive strength of jute-glass hybrid composites in longitudinal direction increases with increases the volume fraction of both jute and glass fiber [18]. Clark et al. [19] developed jute and glass fiber based hybrid composites, and observed that the toughness of such hybrid composites was maximized by sandwiching the jute fiber in between glass fiber layers. Ahmed et al. [20] studied the elastic properties and notch sensitivity of woven jute and jute-glass fiber reinforced composites (JGFRP), and revealed that the young's modulus and poission's ratio were decreased with the increase in weight percent of glass fiber. Moreover, they investigated out that the jute-glass fiber reinforced polymer composites (JGFRP) had lower notch sensitivity than JFRP. Rosa et.al [21] used the acoustic emission and pulse thermograph to develop jute/glass hybrid polyester laminate composites and revealed that the sandwich hybrids had better residual mechanical properties. Ramnath et al.[22] developed abaca-jute-glass fibre reinforced composites and foubd out that the tensile and shear strength of such composites were increased with the increase in weight. Akil et al. [23] produced hybrid composites composed of pultruded jute, kenaf with glass fiber. They revealed that the jute/glass fiber based composites revealed better flexural strength as compared to kenaf/glass fiber based composites. Recently such types of combination of fiber (sisal + glass, jute + glass, sisal + jute + glass) were prepared by researchers and it was observed that the tensile property of (jute + glass) hybrid fiber reinforced composites was much more superior as compared to the others. Flexural property of (sisal + jute + glass) based composite was higher, while the maximum impact strength was obtained with sisal-glass fibre based composites [24]. Superior mechanical properties of the composites were obtained when the sample was made up of higher abaca content for the case when the orientation of the fibers was at 45^{o} [25]. The best way to use hybridization (natural and synthetic) technique in the fabrication of composites is that the natural fiber should be sandwich between synthetic fibers, Dalbhera and Acharya [26] found out that the tensile and flexural properties of hybrid composites with two jute mat sandwich between glass fiber mats were higher than the normal composites.

Ahmed et al. [27] produced FRP with jute and jute-glass. They determined the tensile strength, flexural strength and inter-laminar shear strength (Fig.1.). They found out that the tensile strength of

JFRP composites was improved when incorporated with glass fiber as extreme glass plies. The hybrid laminate with two glasses plies on either side showed the optimum result with improved mechanical properties.

Similarly, Ramnath et al. [28] investigated the mechanical properties of jute-flax based glass fiber reinforced polymer composite (GFRP). The authors revealed that ultimate tensile strength and flexural strength (Fig. 2.a), hardness (Fig. 2.b) of jute-flax based GFRP were found more compared to mono jute-glass FRP composites, but mono-jute GFRP excelled well under impact loading and ultimate shear strength superior.

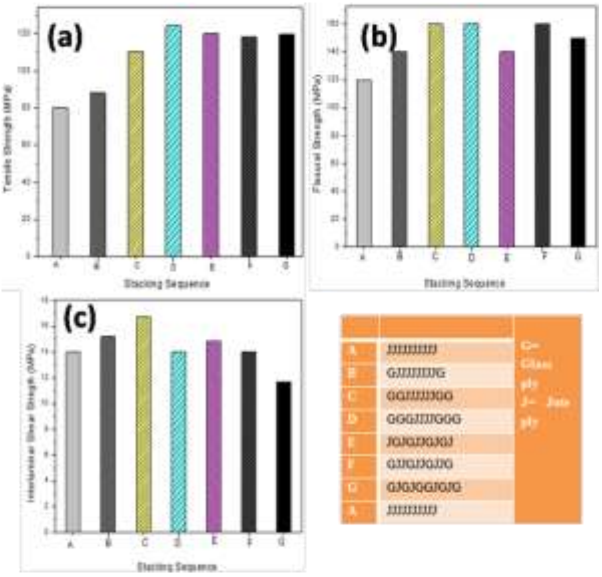


Fig.1 Variations of (a) Tensile Strength, (b) Flexural strength and (c) Inter-laminar Shear Strength with stacking sequence.

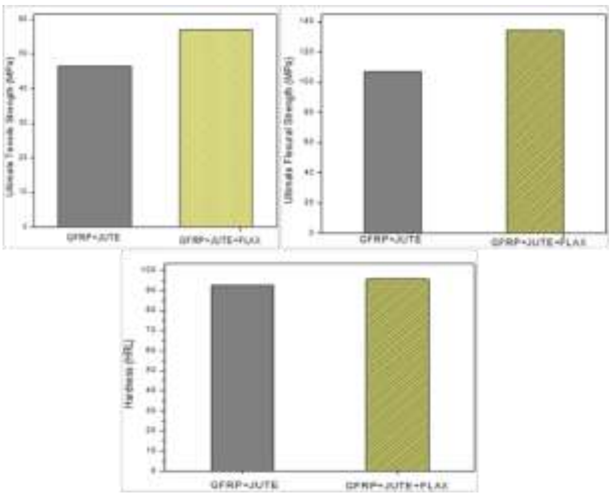


Fig.2 Variations of ultimate tensile strength, flexural strength and hardness of jute-flax based glass fiber reinforced polymer composite (GFRP).

2.2 Hemp-glass fiber and Kenaf-glass reinforced hybrid polymer composites

In the early nineteen century, the hemp fiber was recognized as the world's largest agricultural crop, but the interest in this material was overlooked with the advances of man-made/synthetic fibers. But due to environmental/ecological issues, high cost and limited availability of synthetic fibers, the motivation and interests to use such renewable fibers become the good deal [29]. The unfavorable hydrophilic nature, low strength of this organic fiber as compared to other synthetic fibers affects the mechanical properties of composites but this can be overcome by combining two fibers (glass and hemp) in FRP composites. Panthapulakkal and Sain [30] used glass and hemp based fiber composites and demonstrated that the moisture absorption capacity of mono-hemp (40 wt %) based propylene composites was highest which was improved significantly by 40% by incorporating the glass fiber with the hemp fibres. Same authors [31] also investigated the mechanical, water absorption, thermal properties of injection molded short hemp-glass fiber propylene composites. They found out that hybrid composites containing 25wt% hemp and 15wt% glass displayed better flexural strength, modulus, and notch impact strength. They also revealed that the thermal and water resistant properties of hybrid composites are superior as compared to mono hemp propylene composites.

Cicala et al. [32] investigated the properties and performance of hybrid composites with natural fiber/glass fiber for curved pipes. They observed that the tensile and flexural strength of natural fiber laminated based composites were lower as compared to glass fiber laminate polymer composites. To overcome this problem, they proposed a hybrid composites which showed low cost reduction of 20% and 23% weight saving, when hemp mats were used as compared to commercial pipes construction.

Due to the easily availability in nature and intermittent mechanical properties, kenaf fiber is used in many structural applications. The hybridization of cellulosic fiber especially kenaf fiber with synthetic fiber is a very good approach to enhance the mechanical and water resistance properties of the hybrid composites [33-34]. Atiqah et al. [35] examined the cellulosic kenaf-glass fiber based polyester hybrid composites by sheet molding process and also treated natural fiber with mercerization. The authors observed that tensile and flexural strength of surface modified hybrid composites was slightly better than untreated one. They also revealed that 15/15 wt % kenaf/glass hybrid material revealed superior mechanical properties as compared to other combinations of weight percentage. Mansor et al. [36] investigated the mechanical properties of kenaf/glass hybrid polymer composites by using rule of mixtures. They observed that hybrid composites had positive effects on stiffness of the composites. They also found out the stiffness of both short and randomly oriented composites was enhanced with the increase in the volume fraction of the fiber. Yaacob et al. [37] had found out the effect of hybridization of glass fiber composites with natural fiber on mechanical properties of composites. The authors revealed that high strength, low ductility, and low toughness were obtained when higher amount of glass fiber incorporated with low wt% of kenaf fiber.

2.3 Flax-glass fiber based hybrid composites

Flax fiber is most appropriate for reinforcement in polymeric composites due to its widespread availability in nature and good mechanical properties. The effects of modified flax fiber/matrix on mechanical properties of hybrid fiber reinforced plastics have been investigated by the researchers [38]. They reported that the stiffness of the untreated composites was decreased with increasing the flax fibers. They also found out that the modified hybrid composites have higher modulus as compared to none treated. Prabhakaran et al. [39] Performed experimental investigation on flexural properties of hybrid flax/glass epoxy composites. They revealed that flexural modulus of hybrid composites were consistently increased when flax fiber layer were replaced by glass fabric from the inner layer to outer layer. The proper arrangements of lamina and glass/flax ratio in composites enhanced the mechanical properties of hybrid composites [40].

Petrucci et al. [41] investigated the mechanical characteristics of hybrid composites with three combinations FHB (S1), GHB (S2), GFB (S3) (here F, G, H, B means flax, glass, hemp, and basalt lamina.) manufactured by vacuum infusion technique. The authors demonstrated that GFB hybrid composite revealed superior tensile, flexural and inter-laminar shear strength (Fig. 3) as compared to other combinations.

Zhang et al. [42] fabricated flax-glass fiber based hybrid polymer composites. They observed that inter-laminar shear strength (Fig. 4) of the hybrid composites was higher than the glass fiber reinforced polymeric material, and also the tensile failure strain and tensile modulus (Fig. 5) was enhanced with increase the vol % of glass fiber in hybrid composites.

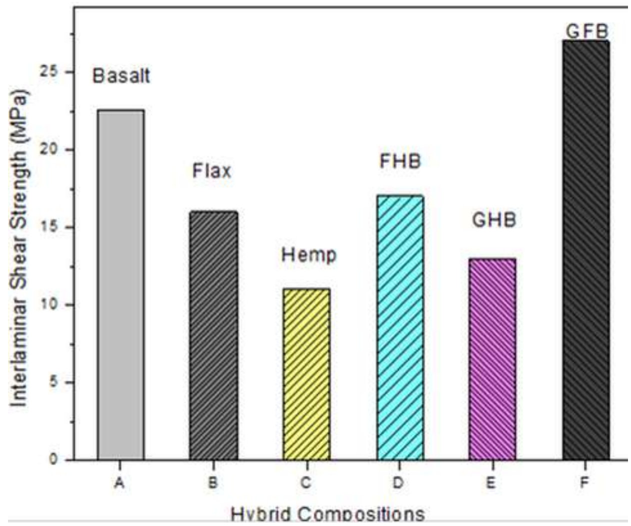


Fig.3 Variations of inter-laminar shear strength with hybrid composites.

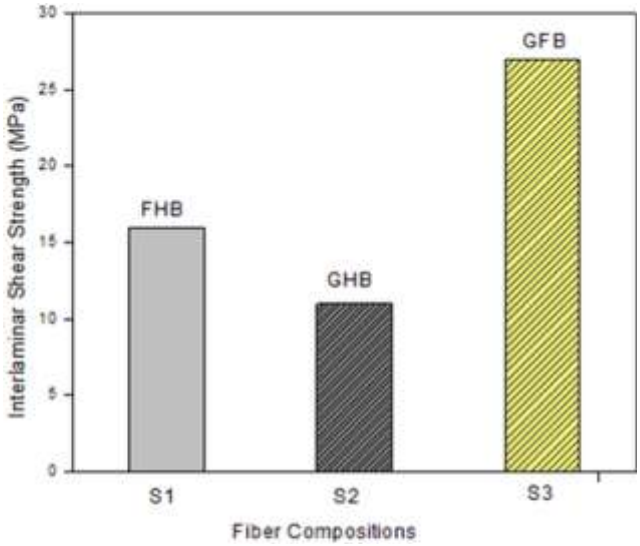


Fig.4 Variations of Inter-laminar shear strength with fiber compositions.

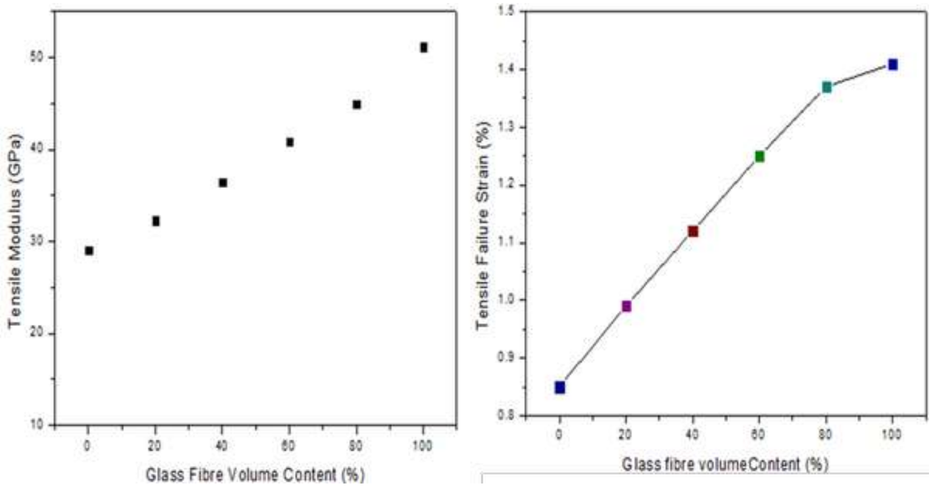


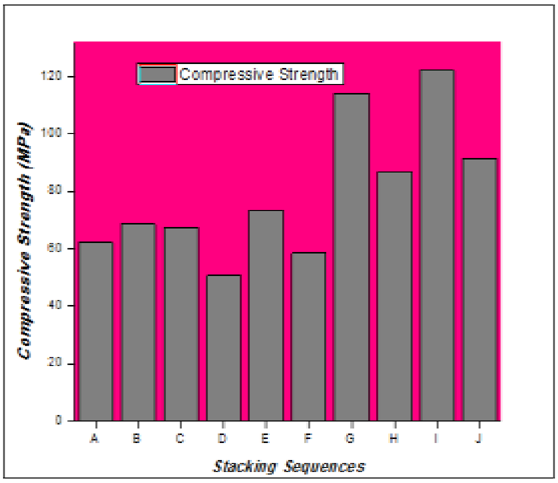
Fig.5 Variations of tensile modulus and tensile failure strain with glass fiber volume content percentage

3. Mechanical Properties of bast/Kevlar fiber based hybrid polymer composites

Kevlar has high fracture toughness, high tensile strength and high modulus of elasticity. In this section, we reviewed the effects of hybridization on mechanical properties of bast-kevlar hybrid polymer composites. Warbhe et al. [43] worked on Kevlar and jute as fiber reinforcement and epoxy as a matrix material. They found that the Kevlar to jute ratio increases the flexural strength, tensile strength, impact energy and strain energy and reduced the weight of specimen. Moreover Kevlar percentages lowers the epoxy percentage so, the cost of specimen is reduced. Sample K75J25 (Kevlar-18 wt%, Jute – 53 wt% and remaining epoxy matrix) delivers optimum results in tensile, flexural and impact energy properties. Ziminiewaska et al. [44] studied the natural fiber textile structures suitable for composite materials. They evaluated the mechanical properties such as tensile strength, tensile modulus, flexural strength, and flexural modulus. Results indicated that the specimen Kevlar1610 drex/flax, 310g/m^2 attained high tensile strength and modulus. It was possible due to reduction of hydrophilic nature of flax fiber by the hybridization with the synthetic fiber (Kevlar fiber).

The mechanical properties of kenaf fiber composites can be improved by hybridizing with another synthetic fiber or natural fiber [45]. Yahaya et al. [46] studied the effect of moisture absorption on mechanical properties of natural fiber hybrid composites. They prepared three samples with different volume percentage 18.64 vol% kenaf+ 0 vol% Kevlar, 8.27 vol% kenaf+21.30 vol% kevlar, and 12.96 vol% kenaf, 16.70 vol% Kevlar. They revealed that the tensile strength of hybrid kenaf/Kevlar composites was highly affected by water aging whereas the impact strength was not affected by water aging. Hyie et al. [47] investigated compressive properties of Kevlar/kenaf hybrid composites. The authors have revealed that the arrangement of kenaf fiber on the middle part sandwiched between Kevlar on the outer part gives the better compressive strength among all the specimens. Fig 6 shows the variations of compressive strength with different stacking sequences and

Fig 7 shows the variations of Hardness with different Kevlar wt%.



Composites	Stacking Sequences
A	5 KP
B	2KP+1kP+2KP
C	3KP+1kP+1KP
D	4KP+1kP
E	2KP+2kP+1KP
F	3KP+2kP
G	1KP+3kP+1KP
H	2KP+3kP
I	1KP+4kP
J	5kP

KP-Kevlar Plies, kP-Kenaf Plies

Fig. 6 Variations of compressive strength with different stacking sequences

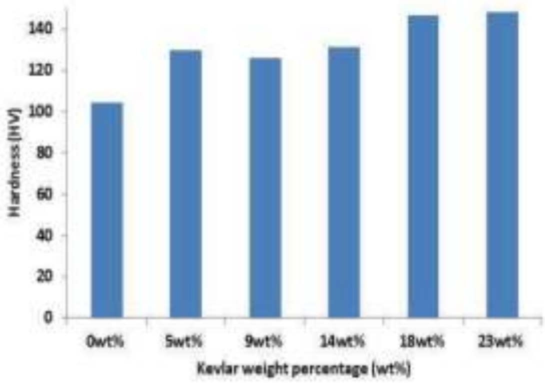


Fig. 7 Variations of Hardness with Kevlar wt%.

Naresh et al. [48] focused on the tensile response of natural fiber reinforced hybrid composites and also the stacking sequences and orientation on it. They revealed that the maximum tensile modulus was obtained for the stacking sequence of glass, hemp and jute reinforced composites where the orientation of jute was horizontal. Jani et al [49] observed the machinability of hybrid natural fiber composites with and without filler as reinforcement. They fabricated the composite material with 60 wt% hemp and 40 wt % Kevlar and observed that the hybrid composites with filler exhibited good surface finish without fiber delamination and pull out.

4. Conclusion

Natural fibers are gaining interest as reinforcement for polymer composite due to their environmental and economical benefits. However, some limitations must be overcome to exploit the full potential of such fibers used as reinforcement like lower strength and higher water-uptake capacity as compared to inorganic fibers. These properties can be easily enhanced by the combination of two or more fiber, one being the natural fiber and another as synthetic fiber. Hybrid composites with natural fiber sandwiched between glass/kevlar lamina shows the optimum mechanical properties. Furthermore, glass/kevlar fibers act as a barrier against the adverse environment to protect the degradation of natural fibers and also increase the strength of material. In this article, we reviewed hybridization effects on mechanical properties of bast-glass/kevlar fiber reinforced polymer composites and effective results have been found out to motivate use of such materials in various applications as compared to mono glass/kevlar fiber reinforced polymer composites. This work may provide incentive for researchers to use hybridization of jute, kenaf, hemp and flax with others synthetic fibers like carbon in order to achieve better mechanical strength.

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