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A Review on Tensile and Flexural Properties of Fiber-Reinforced Polymer Composites

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Abstract: *Fiber-reinforced polymer composites have large applications in different important sectors like aerospace engineering biomedical engineering, constructions because of their light-weight and high strength. Tensile and flexural properties are the two ultimate factors for measuring the strength of materials. The role of fiber content, length, and their orientations on these two properties are explored in this study. Different chemical modifications to improve the surface property of fiber/matrix and hence improve the tensile and flexural properties of polymer composites are also reviewed in this paper.*
Key Word*: Fiber-reinforced polymer composites; Tensile property; Flexural property; Chemical Modifications; Fiber arrangement.*

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I. Introduction

Fiber-reinforced polymer composites can be defined as polymer matrix imbedded in with fibers of high mechanical properties to achieve high strength to weight and stiffness to weight ratio[1]. The constituents of a composite can be divided into two parts: a continuous phase is known as matrix and a discontinuous phase known as reinforcement. The first commercial production of polymer composites can be dated back to the 1950s when natural fibers were reinforced in different types of thermoset plastics[2]. Polymer composites have a wide range of applications in biomedical engineering especially in dental and tissue engineering[3], aerospace industries[4], automotive sector[2][5], civil construction[6][7]. The matrix material of polymer composites can be classified into thermoplastic and thermoset polymers. Polyethylene, polypropylene, polystyrene, polyvinyl chloride, etc. are some thermoplastics used in polymer composites preparation, whereas epoxy, polyester, phenolics are widely used thermoset plastics for composite preparation[8]. Apart from these, different biopolymers are also used as composite matrix due to their biodegradability[9]. Fibers used for composite preparation can be categorized into two types: Synthetic fibers and natural fibers. Synthetic or man-made fibers such as glass fibers, carbon fiber, acrylic fibers are used for their tensile strength and modulus[10]. In recent years, researchers are trying to replace conventional synthetic fibers with different natural fibers due to low cost, flexibility, satisfactory mechanical properties, biodegradability, and environmental concerns [11]. Different types of natural fibers such as jute fiber[12][13], hemp[14][15][16], sisal fiber[17][18], kenaf[19][20], coir fiber[21][22], Banana[18], palm[22], cotton fiber[23] etc. are used as reinforcement to different thermoset and thermoplastic polymers. Both synthetic and natural fiber reinforcements had reported improving the mechanical properties such as tensile strength, flexural strength, the impact resistance of polymers materials [24][25][26][27][28][29].

The tensile and flexural properties of polymer composites are dependent on fiber content, fiber length, fiber orientation, and the matrix-fiber adhesive property[30][31][32]. It is very difficult to find a definite combination for all fibers for desired properties. The optimum value of fiber content, fiber length, and fiber orientations vary from material to material, so researchers are working for decades to develop suitable composite materials for the application.

For the last few years, researchers are trying to replace the synthetic fibers with naturally available fiber materials due to environmental concerns. Unfortunately, the natural fibers could not replace the synthetic fibers due to some drawbacks. Natural fibers constitute of cellulose, Hemicellulose, Lignin, Pectin, Moisture[33]. The presence of a high quantity of hydroxyl group makes the natural fibers polar and strongly hydrophilic, whereas the polymer matrix materials are hydrophobic in nature [33][34]. These differences in properties make the interfacial attraction between the natural fibers and synthetic polymers vulnerable to environmental conditions i.e. lower the resistance to moisture adsorption. Consequently, swelling of fibers at the matrix interface occurs and hence the mechanical properties of polymer composites deteriorate. Another sever problem rise from this characteristic different is poor dispersion of polymer fibers in the matrix. At present researches is going on to improve the interfacial adhesion between the matrix and fibers. Different

types of chemical modifications such as alkali treatment, Acetylation, Silane treatment, Benzoylation Treatment, Permanganate Treatment are done on the fiber surface to improve the mechanical properties of polymer composites by increasing the surface roughness of fibers, decreasing the hydroxyl group in fibers, decreasing the adsorption of water by fibers [35][36][37][38].
This paper aims to review the effect of fiber length, content, and orientations of both synthetic and natural fibers on the tensile and flexural properties of polymer composites. This works also study the effect of different chemical modifications of fiber on the mechanical properties of Fiber-reinforced polymer composites.

II. Tensile Property of fiber-reinforced polymer composites

Tensile strength is defined as the resistance of a material to an applied force [39]. There are different ASTM methods for testing the tensile strength of polymer samples. ASTM D638 is recommended for testing discontinuous, randomly arranged polymer composites, whereas ASTM D3039 is applied for well-oriented, highly tensile modulus polymer composites, ASTM D882 is used to determine the tensile strength of thin plastic sheets [40].

2.1. Effect of fiber length and content on the tensile property of Composites

Incorporation of fibers to polymer has reported improving the tensile property of polymer materials as they often have higher tensile strength than pure polymer materials. Table 1 and Table 2 show the tensile strength of some widely used fiber and Polymers for composite preparation respectively. It can be seen that the tensile property of the fibers is much higher than the pure polymers.

Table 1: Mechanical and Physical Properties of Reinforcement fibers

Fiber	Density(g/cm^3)	Tensile strength (MPa)	Elastic modulus (GPa)	Reference
E-Glass fiber	2.55	1956	78.51	[41]
S-Glass fiber	2.65-2.8	3000-4840	93-110	[42]
Carbon fiber	1.77	3950	238	[41]
Aramid (Std.)	1.4	3000-3150	63-67	[43]
Jute	1.46	385-850	9-31	[38]
Bagasse	1.5	170-350	5.1-6.2	[44]
Banana	1.35	355	33.8	[45]
Cotton	1.51	400	12	[45]
Sisal	1.33	600-700	38	[45]
Kenaf	0.749	223	14.5	[46]

Table 2: Mechanical and Physical Properties of Polymers

Polymer	Density(g/cm^3)	Tensile strength (MPa)	Elastic modulus (GPa)	Reference
Unsaturated polyester	1.35	90	3.23	[24]
Polypropylene	0.903	31.6	1.30	[41]
Low density Polyethylene	0.910-0.925	40-78	0.055-0.38	[27]
High density Polyethylene	0.94-0.96	14.5-38	0.4-1.5	[27]
Polystyrene	10.4-1.06	25-69	4-5	[27]
Epoxy	1.1-1.4	35-100	3-6	[27]

Fu et. al. prepared polypropylene (PP) composites with short-glass-fiber (SGF) and short-carbon-fiber (SCF) as reinforcement using a twin-screw extruder and injection molding technique. They observed that SCF/PP has more tensile strength than both SGF/PP and pure PP, however, it was also more brittle than the other materials [41]. Researchers found that volume/weight fraction and the length of the fibers has a noticeable effect on the tensile property and ductility of the composites. Thomason and Vlug studied the effect of glass fiber (GF) reinforcement of various length and weight fraction on the tensile property of composites and found that the tensile modulus of composite increases remarkably up to a 40weight percentage and the change is not significant after that. However, the fiber length above 0.5mm had very little effect on the tensile property [47]. Wazery et. al. investigated the tensile property of Glass fiber/polyester composites with varying the fiber percentage and found that the tensile strength increases about 300% from zero fiber percentage to 60 fiber percentage[24]. It was further noticed that the yield strength increased from 0 to 45 wt.% but it drastically decreases at 60 wt.%. Davis et. al. incorporated carbon nanotube functionalized with fluorine into epoxy and studied the tensile property for different weight fractions. They noticed that the tensile strength and tensile modulus increases with the increase in weight percentage of reinforcement(illustrated in fig. 1)[48]. However, a different kind of observations was made by Li[49]. He studied the tensile properties of Wood and High-Density Polyethylene(HDPE) composite and observed that with the increase in the weight percentage of fiber, the tensile strength of the subject materials decreases drastically[49]. A similar kind of observation was made by Zaini et. al. for oil palm wood-flour fillers[50]. Fig. 2(a) and (b) show the effect of the weight percentage of fiber loading on the tensile strength for some experimental cases.

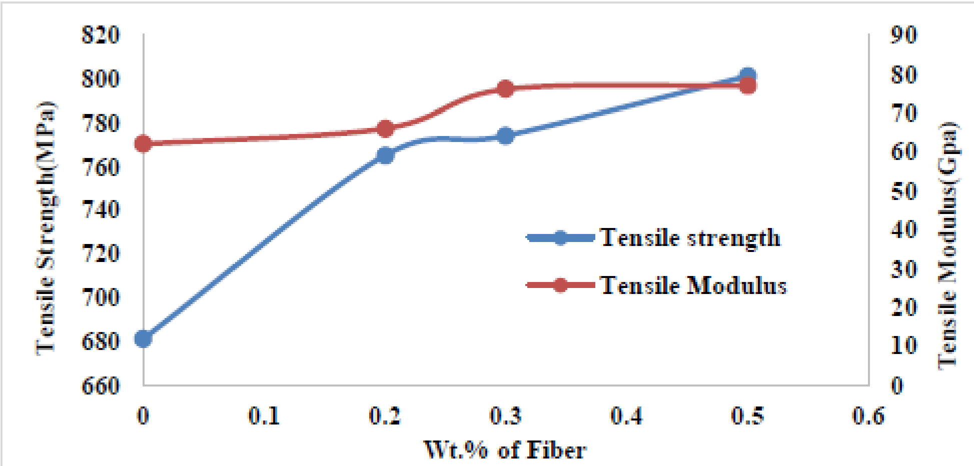


Fig. 1: Tensile strength and tensile modulus of Fluorine functionalized carbon nanotubes and Epoxy resin (adapted from [48]).

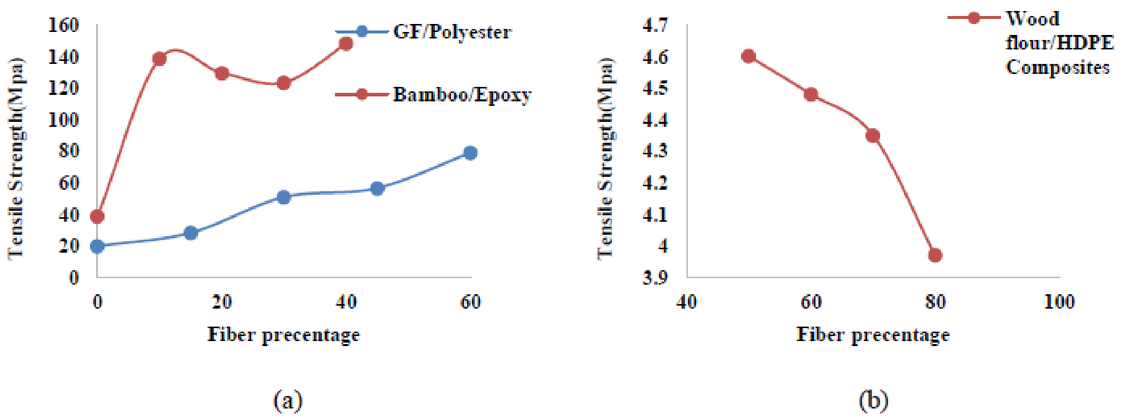


Fig. 2: a. Tensile strength of GF/Polyester and Bamboo/Epoxy composites(adapted from[24][51]) b. Tensile strength of Wood flour/HDPE composites (adapted from [49]).

2.2. Influence of fiber orientation on the tensile property of Polymer composites

Fiber orientation plays a vital role in the tensile property of polymer composites[52]. However, the effect varies from material to material. Tanwer experimented to determine the effect of uni-direction and bi-directional orientation of Gf on epoxy composite and found that the uni-directional orientations had superior tensile properties compared to the other arrangement [53]. Yong et. al. studied the tensile property for Kenaf/Polyester composites at different fiber orientations (Perpendicular, anisotropic and isotropic) and found that the anisotropic arrangement had the highest tensile properties (tensile strength and tensile modulus), however, the elongation at break (%) significantly decreases after fiber reinforcement [54]. Bakir and Hashem observed that with the increase of the degree of orientation of GF, the tensile strength of epoxy resin composites increases which is illustrated in figure 02 [55]. Lasikun et. al. studied the effect of fiber orientation on the tensile property for a Zalacca Midrib Fiber(ZMF)- HDPE Composites and concluded that with the increase in the orientation of the fiber, the tensile strength of the composites declines [56].

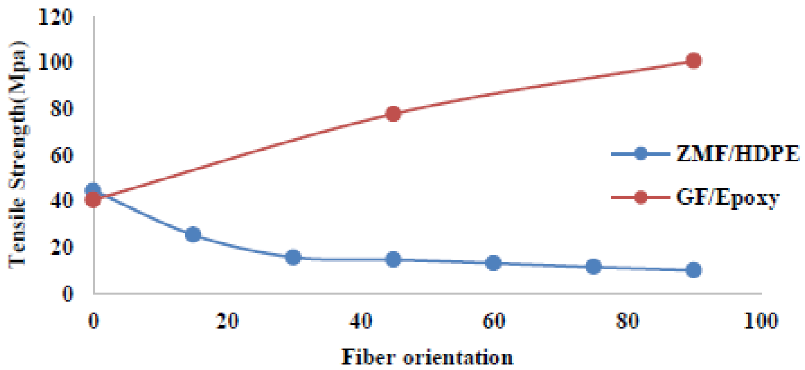


Fig. 3: Effect of fiber orientations on Zalacca Midrib Fiber(ZMF)/HDPE and GF/Epoxy composites (adapted from[56][55]).

2.3. Chemical modification to improve the tensile property of Polymer Composites

The surface of Fibers is modified to improve the tensile property of polymer composites. Mobarakeh et. al. improved the tensile property of short glass fiber/Polyamide 6,6 composites by incorporating ionic groups to short glass fibers[57]. Jing et. al. modified the surface of glass fiber by graphene oxides and a silane coupling agent, and found that silane treated fiber had superior tensile properties [58] However, a completely different kind of observation was made for Chlorine treated Aramid fibers and Epoxy polymer. Tarantili and Andreopoulos observed that after chlorine treatment the tensile properties of the composite decrease [59].

For the last few decades, researchers are focusing on natural fibers for their biodegradability, however, the tensile properties of natural fibers are poor compared to the synthetic ones. Table 1 shows a comparison of tensile properties among different natural and synthetic fibers used to polymer composites. To improve the mechanical properties of Natural fiber reinforced Polymer (NFRP), researchers are performing different types of chemical modifications on Natural fibers and polymer matrix. Alkaline treatment of fibers known as mercerization is one of the most applied chemical modifications performed to promote the adhesiveness of fiber surface[60]. Another widely used chemical modification is bleaching, done mainly to remove physical impurities present in the fiber. Carvalho et. al. done both alkaline (sodium hydroxide solution) and bleaching on green coconut fibers to improve the fiber surface and prepared composites with Polystyrene (PS). They later studied the tensile properties of the prepared composites and the tensile modulus of 30% reinforced composite was found to significantly increased, on the contrary, the chemical treatment could not improve the surface interaction [61]. Danyuo et. al. studied the effect of different degrees of Alkaline treatment on Banana fiber/Poly-Dimethyl-Siloxane-Based composites and found the optimum treatment condition at 8% NaOH concentration[62]. Fig. 4 illustrates the effect of NaOH concentrations on the discussed composite system.

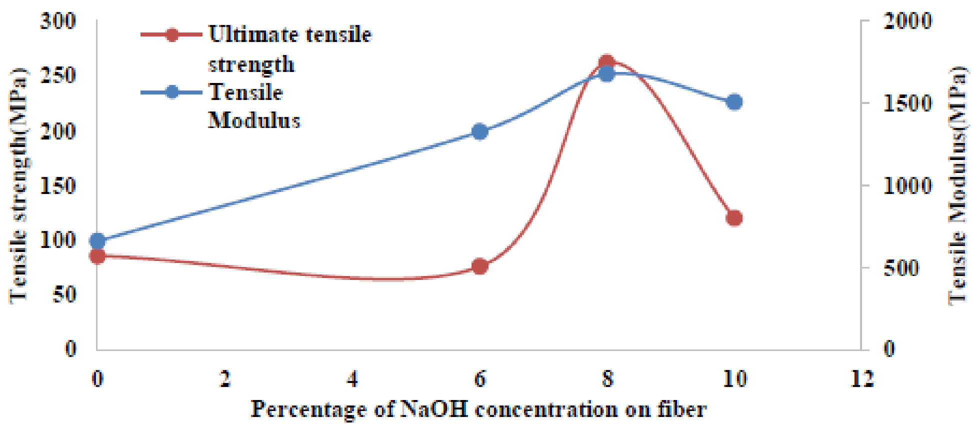


Fig. 4: Effect of different degree of Alkaline treatment on the tensile strength and tensile modulus for Banana fiber/Poly-Dimethyl-Siloxane-Based composites [62].

In another study, the tensile properties of Flax fiber/PP composites were improved by enhancing the interaction property of Fiber/Matrix by treating the Flax fiber with maleic anhydride, maleic anhydride-polypropylene copolymer(MAPP), and vinyl trimethoxy silane[63]. Xue et. al. improved the surface adhesion of Aspen fiber/PP composites by treating the fiber with the MAPP coupling agent and consequently improved the mechanical properties of the composite[64]. Besides this many different chemicals are used to treat the fiber for improving the tensile properties of composites, some of the treatments are given in table 03.

Table 3: Effect of chemical modifications of fibers on tensile properties for different composites.

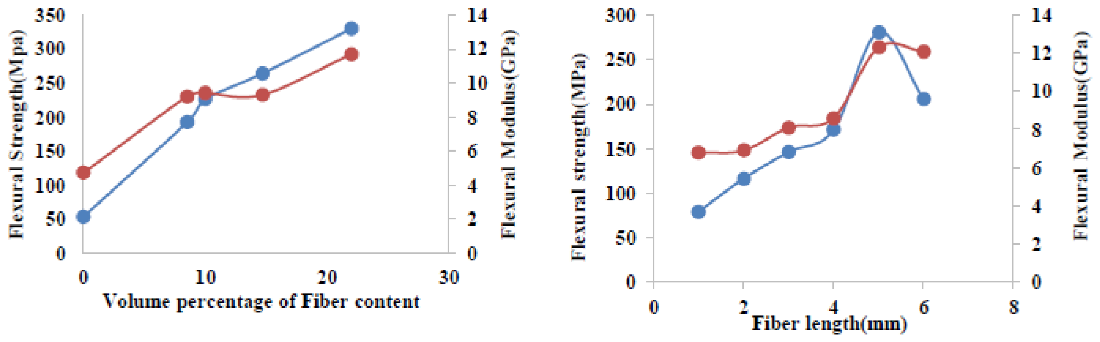
Fiber/Polymer Composites	Chemical modifications for fiber treatment	Effect on tensile property	Reference
Feldspar/PP	3-(aminopropyl) triethoxy silane (3-APE) coupling agent	Tensile property/Flexural strength improved	[65]
Henequen fiber/HDPE	Sodium hydroxide (NaOH)	No significant improvement	[66]
Henequen fiber/HDPE	Silane coupling agent	Up to 19% improvement in tensile strength	[66]
Sisal/PP	Potassium permanganate ($KMnO_4$)	Tensile strength increases; Tensile modulus decreases	[67]
Sisal/PP	Maleic Anhydride	Tensile strength increases; Tensile modulus decreases	[67]
Sisal/PP	Alkali treated	Tensile strength increases; Tensile modulus decreases	[67]
Jute fiber/Epoxy	Alkali and acid treatment	The tensile property of treated fiber-reinforced composites improves compared to untreated fiber	[68]
Flax fiber/Polyurethane	2% Sodium hydroxide	Tensile strength is higher than untreated Fiber and tensile modulus decreases	[69]
Flax fiber/Polyurethane	Silane	Tensile strength is higher than untreated Fiber and tensile modulus decreases	[69]
Flax fiber/Polyurethane	Benzoyl Peroxide	Tensile strength is higher than untreated Fiber and tensile modulus decreases	[69]
Flax fiber/Polyurethane	Permanganate	Tensile strength is higher than untreated Fiber and tensile modulus decreases	[69]
GF/PP	Silane grafted PP coupling agent	The tensile strength and modulus increased by 148% and 33% respectively after treatment	[70]
GF/Polyester	Polyalkenyl-poly-maleicanhydride-ester	No significant change	[71]
GF/Polyester	Polyalkenyl-poly-maleicanhydride-ester	Tensile strength decreases	[71]
GF/Polyester	Polyalkenyl-poly-maleicanhydride-amide	No significant change	[71]
GF/Polyester	Polyalkenyl-poly-maleicanhydride-ester-amide	Tensile strength increases	[71]
GF/Polyester	Polyalkenyl-poly-maleicanhydride-ester-amide	Tensile strength increases	[71]

III. Flexural testing of fiber-reinforced polymer composites

Flexural testing is used to determine the stiffness of materials by measuring the force required to bend a material[72]. There are mainly two different standard methods for determining the flexural strength of polymer composites-ASTM D790-03 and ASTM D 7264/D 7264M – 07[73]. ASTM D790-03 is mainly used for reinforced and unreinforced polymer composites of lower strength, however, ASTM D 7264/D 7264M – 07 is used for polymer composited reinforced with continuous fibers and having high modulus.

3.1. Effect of fiber length and content on the Flexural property of Composites

Similar to the tensile strength, flexural properties are also largely effected by fiber length and the fiber content of the reinforcements[74]. Ramesh et. al. prepared Banana Fiber/ Epoxy resin composites with three different volume fractions and tested the flexural property by the ASTM D790 method. They observed that the highest flexural strength was 76.53 MPa at a 50/50 ratio of banana fiber and epoxy resin [75]. The study of flexural property for GF/PMMA composites at different fiber lengths and content revealed that fiber length of 5mm at fiber content volume of 22% at dry condition has superior flexural properties (fig. 5)[32]. In another study, flexural strength for Kenaf and Bagasse reinforced biodegradable polymers were measured for different volume fractions and length of the fiber. In both cases, with up to 60% of fiber content, the flexural strength increases with the addition of more fibers, and up to 2.8 mm kenaf and 3.2 mm bagasse fiber length the flexural strength decreases[46]. Zuraida et. al. studied the effect of increasing fiber length on flexural strength of coir fiber/Cement/Albumen biopolymer and observed that at a fiber length of 5mm maximum flexural strength is achieved, afterward with the increase of length, strength also decreases as illustrated in figure 06 [76].



(a) (b)

Fig. 5: Effect of (a) fiber content (b) fiber length on the flexural strength and flexural modulus for GF/PMMA composites [32].

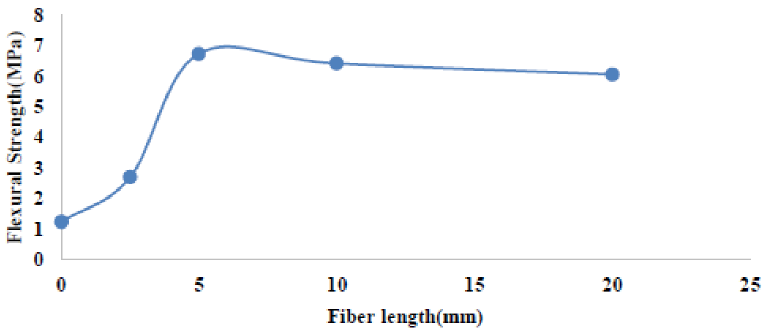


Figure 06:[76]

Fig. 6: Effect of fiber length on the flexural strength for coir fiber/Cement/Albumen biopolymer.

3.2. Effect of fiber orientation on the flexural property of composites

The flexural strength of polymers is influenced by the arrangement of the fibers in the composites. Numerous researchers had tried to find an optimum arrangement for enhanced mechanical properties. Biswas et. al. studied the flexural strength of GF/Epoxy composites for four different degrees of fiber orientations at various fiber contents and found that at 20% fiber loading and 30°arrangement, the optimum flexural strength was obtained. Figure 07 illustrates the effect of the degree of fiber orientations at different amounts of loading. [77]. For sisal fiber/epoxy composites the maximum flexural strength was obtained at 90°fiber orientation as shown in figure 08 [78]. Yong et. al. also studied the flexural modulus of Kenaf/Polyester composites for three different arrangements (Perpendicular, anisotropic, and isotropic) and obtained the highest value at the anisotropic arrangement[54].

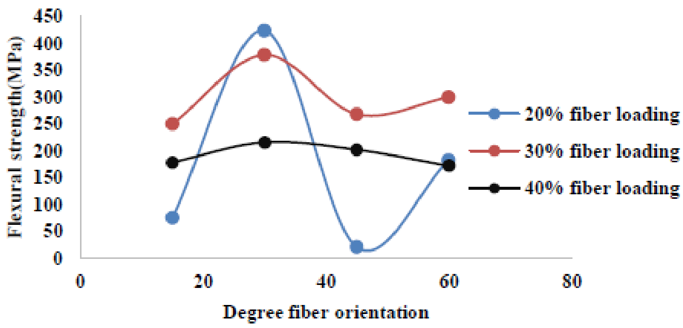


Fig. 7: Effect on flexural strength at different degrees of fiber orientations at 20%, 30%, and 40% fiber loading for GF/Epoxy composites(adapted from [77]).

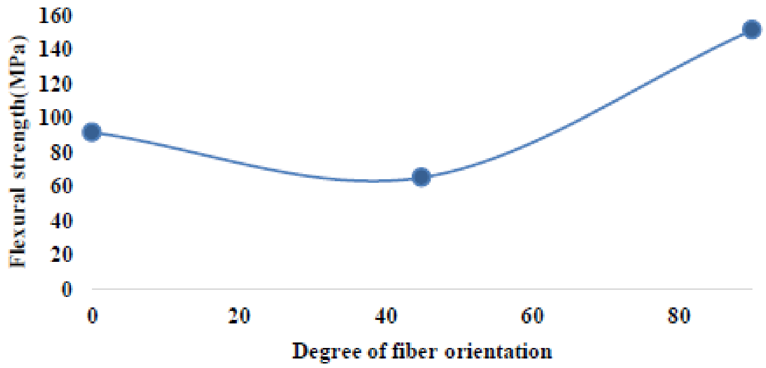


Fig. 8: Effect on flexural strength at different degree of fiber orientations for sisal fiber/epoxy composites (adapted from [78]).

3.3. Chemical modifications of fiber to improve the Flexural property of Polymer Composites

Enhancement of the flexural property by chemically modifying the surface/interface interaction is done on both synthetic and natural fibers. Cao et. al. modified the surface of GF with silica particles and used the modified fiber to prepare GF/Epoxy composites. They also prestressed the silica modified GF and clean GF before composite preparation to study the flexural property and observed that prestressed the silica modified GF showed superior property[79]. In another study, the flexural properties of GF/PP composites were improved using silane grafted Polypropylene (Vinyltrimethoxysilane modified PP (PP-g-Si)). The effect of the coupling agent on the flexural properties of GF/PP composites is shown in figure 09[70]. Table 04 enlists some other chemical modifications of fiber for improving the flexural strength of composites.

Table 4: Effect of chemical modifications of fibers on flexural properties for different composites.

Fiber/Polymer Composites	Chemical modifications for fiber treatment	Effect on flexural property	Reference
Aramid fibers/Epoxy	Chlorine treated	Flexural strength and modulus improved	[59]
GF/Poly (phenylene Sulfide)	RC-2 Silane and Styryl Silane	Flexural strength increased	[80]
GF/Dilulin (Biopolymer)	Silane coupling agent	Flexural strength increased	[81]
Banana fiber/Polypropylene	5% Sodium hydroxide (NaOH)	Flexural strength and modulus increased for all three fiber weight percent (10%,20% and 30%)	[82]
Sugar Palm fiber/Polystyrene	4% NaOH	Flexural strength and modulus increased by 2.5% and 15% respectively	[83]
Sugar Palm fiber/Polystyrene	6% NaOH	Flexural strength and modulus increased by 12% and 19% respectively	[83]
Sisal fiber/ recycled HDPE	NaOH+ Maleic Anhydride (MA)	Flexural strength higher at 7.5% fiber content than NaOH+MA+BP treated fiber	[84]
Sisal fiber/ recycled HDPE	NaOH+ (MA)+ Benzoyl peroxide (BP)	Flexural strength higher at 30% fiber content than NaOH+MA treated fiber	[84]
Alfa fiber//Polyester	NaOH at three different concentrations (1%,5%,10%) for three treatment time (0, 24, 48 hours)	Flexural properties show highest rise for 10% NaOH, treated for 24-hour period.	[85]

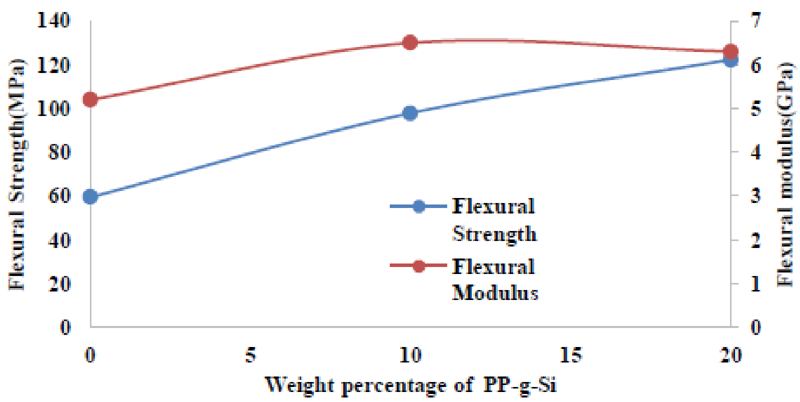
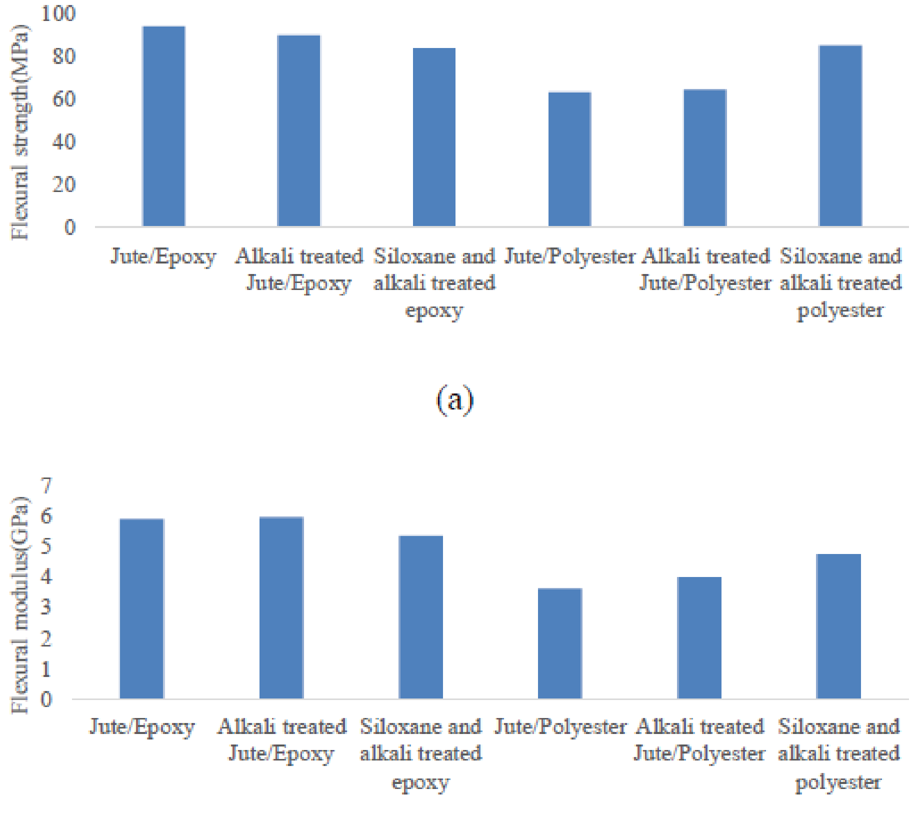


Fig. 9: Effect on flexural strength and modulus for GF/PP at different weight percentages of PP grafted Silane coupling [70].

Different types of chemical modifications are also performed on natural fibers to enhance the flexural properties of polymer composites. Strength is improved by increasing the roughness of the fiber materials, enhancing the interfacial adhesion. The flexural properties of jute reinforced epoxy/polyester were augmented by treating the fibers with Alkali and Oligomeric Siloxane[86]. The effect of different treatments on the flexural strength and flexural modulus is illustrated in figure 10(a) and (b) respectively. Yousif et. al. treated the kenaf fiber with a 6% NaOH solution and the treated Kenaf/epoxy composites showed 16% higher flexural strength than the untreated one[34]. Vinayagamoorthy treated the Vetiveria zizanioides fibers with three different chemicals (Sodium hydroxide, Peroxide, and benzoyl chloride) and prepared polyester composites. He found that hydrogen peroxide treated fiber composites has the highest flexural strength and the raw fiber composite had the lowest strength. Some other chemical modifications on natural fibers are listed in table 4.



(b)

Fig. 10: Effect on (a) flexural strength and (b) flexural modulus for different types of chemical modifications jute fibers for Jute/Epoxy/Polyester composites [86].

IV. Conclusion

The tensile and flexural properties of different synthetic and natural fiber composites are explored. It was found that these properties of polymer composites are largely influenced by fiber length, content, and orientations. The tensile and flexural properties are often found to increase with the fiber length and content and after an optimum point, they decline. Researchers are trying to find optimum parameters for gaining maximum mechanical properties. The mechanical properties of natural fibers are not satisfactory compared to synthetic fibers due to the hydroxyl group present in the cellulose of natural fibers. Numerous chemical treatments such as silane coupling, bleaching, Mercerization, etc. are done on the fiber surface to improve the abrasion of the surface and improve the fiber/matrix interface.

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