



Review

Concise review on the mechanical characteristics of hybrid natural fibres with filler content

Timothy K. Mulenga, Albert U. Ude*, and Chinnasamy Vivekanandhan

Department of Mechanical, Energy and Industrial Engineering, Faculty of Engineering and Technology Botswana International University of Science and Technology, Palapye, Botswana

* **Correspondence:** Email: udea@biust.ac.bw, albertuche@yahoo.com; Tel: +(267)75957014.

Abstract: Characteristics and performance of natural fibre based composites can be altered through the incorporation of filler material in order to achieve acceptable properties for application in engineering. Academics working with the science of materials are currently exploring cellulose based fibres for use in extended applications due to their promising characteristics like low densities, acceptable mechanical characteristics, eco-friendliness and inexpensiveness. The property and performance enhancement of natural fibre composites is key to achieving acceptable properties similar to conventional fibres. Bulk literature has alluded to the addition of filler material in cellulose based fibre composites for enhancing the mechanical properties of the resulting composite. Filler materials in a form of nano-fillers or particulates are investigated to improve essential properties of composites such as hydrophilicity, mechanical and thermal properties. The current review studies the numerous filler material that exists and their effect on the mechanical characteristics of cellulose based fibre composites.

Keywords: fillers; natural fibres; matrix; hybrid composites; mechanical characteristics

1. Introduction

The demand for improved characteristics of composites with natural fibre as reinforcement material has largely increased due to rising ecological concerns caused by the conventional carbon and kevlar fibres due to their environmental safety, biodegradability and recyclability [1–3]. However, production and utilisation of natural fibre composites is significantly obstructed by the weak fibre-matrix interaction, hydrophilicity and low durability which adversely affects their

mechanical properties [4,5]. This has since led to a surge in research, development and process of schemes and approaches that aim to supplement these deficiencies and hence enable researchers to cope up with the global dispute. Researchers have provided evidence that two main techniques, namely, hybridization and addition of particulate fillers, prove effective in bypassing the deficiencies associated with natural fibre composites [6,7].

Santhosh et al. [8] defined a composite as the macroscopic level of fusing of two or more reinforcement and matrix materials with improved properties than the individual constituents. The characteristics of composites influence their selection while matrix type, fibre and filler particulate are generally used to categorize the composites. Due to improved properties like corrosion resistance, specific stiffness and specific strength, composite materials have had a wide usage in numerous industries like construction, aerospace, car manufacturing including military applications [8–10]. Recent ecological concerns have allowed manufacturers to incorporate natural and recycled materials in composites to which natural fibres have found attraction as reinforcement material. The continuous development of improved properties of natural fibre composites has evolved from single fibre reinforcement to the hybridisation of two or more fibres with filler material [10].

Natural fibres are gaining interest in academia and industry application over synthetic fibres due to their ease of availability, inexpensiveness, sustainability, low densities, desirable aspect ratio, reduced energy consumption, less health associated risks and moderate strength [1,11,12]. The current continuous increase in the number of reviews, journals, patents, and book publications on cellulose based fibre composites is a true testament to the unparalleled advantages offered by cellulose based fibres. The use of cellulose based fibres is attributed to the physical, mechanical, thermal and chemical characteristics. Numerous studies have shown that cellulose based fibres like sisal, kenaf, jute and hemp depict mechanical characteristics similar to important metals such as steel and aluminium [9,12]. In a bid to potentially replace synthetic fibres, single natural fibres that exhibit acceptable mechanical properties are combined to form hybrid composites resulting in composites with optimal characteristics. The characteristics of composites can be altered through the addition of filler material with the aim of enhancing some of the characteristics. Essentially, matrix material's physical and chemical characteristics can be modified through nano filler content addition with the aim of improving the product overall performance. Filler content is also attributed to the significant improvement in strength of the thermal and mechanical properties of the fibre based composites [8].

1.1. Matrix

The function of the matrix is to hold in place the reinforcement material in its set and essentially transfer the load between the reinforcements. The matrix influences the overall durability, surface finish and net shape of the resulting composite [13]. The matrix also serves an important purpose of protecting the fibre from damage due to the environmental effects or handling. The most prominent matrix is the polymer matrix which has been reported to exhibit good material properties like lower densities, acceptable thermal and electrical characteristics and inexpensiveness [8,14]. The current ecological concerns have also driven researchers to develop replacements to the petroleum-based matrices. There has since been a renaissance in the past decade on the use of renewable based plastic matrices. As a result, the development of renewable matrix material from recycled and natural resources have increased in recent years [11]. However, due to low properties exhibited by these bio based matrices, petrochemical based matrices continue to dominate the development of natural fibre

based composites. Thus, this review discusses the polymeric based matrices. The polymer matrices are categorised into thermoplastic and thermosetting polymers which is based on the effect of heat on their properties. Examples of thermoplastic matrices include polyvinyl chloride, polyethylene, polypropylene and polystyrene while polyester, epoxy resin, vinyl esters and phenol formaldehyde make up thermosetting matrices [10]. Studies have shown that thermosets are the mostly used matrix material for natural fibre based composites [13]. However these matrix materials sometimes exhibit poor properties that limit their functionality which include lower impact resistance, lower fracture toughness, limited resistance to crack initiation and propagation [15]. The incorporation of nano filler material has been established to certainly modify the properties of the polymer matrices with improved electrical, thermal and mechanical characteristics [15].

1.2. Reinforcement

The reinforcement material is categorised into fibre and particulate reinforced composite. The current review focuses on the emerging trend of combining both natural fibre and particulate as reinforcements in a single matrix.

1.2.1 Fibre reinforced composite

Fabrication of composite material through the process of embedding fibre into a matrix is termed fibre reinforced composite. The matrix here serves the purpose of holding the fibre in its set place and essentially transferring the load stress to the fibres [16]. Fibrous composites are categorised into continuous fibre and discontinuous fibre composites. Continuous fibre composites are further subdivided into unidirectional and bidirectional reinforcements which is based on their orientation [16]. Fibres in the unidirectional orientation are arranged in one direction and generally exhibit high strength in the longitudinal direction of the fibres but however also exhibit weakness in the perpendicular direction to fibre. To overcome this weakness, fibres can also be arranged in both directions termed bidirectional orientation which enables the resulting composite to possess equal strength in both directions [17]. Short fibre composites are termed discontinuous (short) fibre composite and properties of composite are attributed fibre length. The characteristics of short fibre composites are uniform in nature and the fabrication of this type of composite involves short fibres that are randomly arranged in liquid resin [16].

1.2.2 Particulate reinforced composite

Particulates can also be used as reinforcements to improve the matrix properties where the particles are non-fibrous and discontinuous. The properties of composites reinforced with particulate material are generally influenced by the dimensions of the particles and may be cubic, tetragonal and spherical in shape [17]. For particulate reinforced composites, limited load is transferred from the matrix to the particulates in comparison to the fibrous composite in exchange for improved stiffness while the overall strength is reduced. The particulates are used to enhance the characteristics of composites such as improved performance at high temperatures, thermal and electrical conductivity [17]. Economically, the particulate material lowers the overall cost of the composite while offering comparable mechanical characteristics such as wear and abrasion resistance, surface

hardness, machinability [16].

2. Filler content

Filler content consists of particulate material of nano-scale that is added to the matrix material in small quantities varying from 0.1 to 5 wt% which depends on the type of filler [5]. The addition of filler content into fibre reinforced composites forms a hybrid composite and serves the purpose of achieving reasonable fibre/matrix interfacial strength. The use of filler content in composites offers advantages of enhancing the mechanical characteristics of the resulting composite such as hardness, abrasion resistance and improved surface finish [5]. Generally, filler content material is cheap which makes the process of improving the mechanical characteristics more cost effective. Filler materials are categorised into conventional which include CaCO_3 , TiO_2 , Al_2O_3 , ZnO and SiC while the non-conventional fillers include cellulose nano-fibres, nano-clay, rice husk, saw dust and industrial waste such as fly ash [16]. The use of recycled and natural based materials is currently the most suitable and economical precursors for the fabrication of filler materials. The addition of fillers in hybrid composites has coined the term nanocomposites which are defined as materials that consist of multiple phases in which at least one or more of its phases has dimensions lower than 100 nm [18,19]. An ideal composite is achieved with good interaction between matrix and fibre because of the ease of load transfer between the interface [20]. The engineering behind the use of nano-fillers in composite materials is mainly to create an increased interfacial bonding between the reinforcing material and matrix material.

Since their inspection, nanocomposites materials have exhibited striking and acceptable characteristics for advanced applications in a wide range of engineering disciplines. The incorporation of nanoscale filler materials in different matrices enables engineers to match the demands of unique material characteristics for numerous engineering applications [18]. The unique characteristics offered by the incorporation of nanoparticles in composite materials include thermal, mechanical and electrical properties similar to the conventional composites like carbon and glass fibre composites which are attributed to the high aspect ratio, ideal dispersion and matrix filler fusion [10,19,21]. Higher matrix and filler with uniform dispersion of nanoparticles have been eluded to attain higher mechanical properties [6]. Generally, the mechanical characteristics of filler content filled composites are a function of parameters such as the interaction between the matrix and filler material, even the distribution and dispersion of fillers [1]. Numerous research groups have investigated the influence of filler material on the mechanical characteristics of hybrid natural fibre composites in a bid to investigate potential characteristics improvements and subsequently know the suitable applications.

3. Natural fibre composites

3.1 Natural fibres

Researches in science and engineering have described the current century as the cellulosic century due to the explosion in the discovery of increased number of resources from plants for the development of new materials [13]. Many researchers have studied different natural fibres while employing different testing methods, and different moisture conditions present which have led to

different characteristics of natural fibres varying among the referenced works. The natural fibres could belong to animals, plants or minerals which are established upon their origin. Among these natural fibres, mineral fibres are deemed the strongest natural fibres known due to their lower number of surface defects formed during formation [22]. Plants that are used to fabricate fibres are classified into primary and secondary plants which are usually on the basis of their specified usage. Primary plants are cultivated mainly for their fibres whereas the fibres are obtained from the waste product of the plants that make up the secondary plants. Plant cellulose fibres are categorised into; seed fibres, bast fibres, leaf fibres, fruit fibres, grass fibres and straw fibres [22] which are listed with examples in Table 1.

Table 1. Natural fibre types and natural particulates. Reprinted with permission from Ref. [23].

Type of fibre	Common name
Bast fibres	Flax fibre
	Kenaf fibre
	Roselle fibre
	Hemp fibre
	Ramie fibre
	Jute fibre
Leaf fibres	Rattan fibre
	Abaka
	Henequen
	Pineapple
Seed fibres	Banana fibre
	Kapok
Stalk fibres	Cotton
	Rice fibre
Fruit fibres	Bamboo fibre
	Coir fibre
Stem fibres	Tamarind
	Sisal fibre
Particulates	Crown
	Ground nut shell
	Sea shell
	Jack fruit

The inclusion of cellulose fibres in composite materials has however exhibited several drawbacks like lower mechanical characteristics, poor thermal stability, highly flammable and hydrophilicity [5,7] The combination of cellulose fibres into a single matrix is now a common practice to overcome these drawbacks. The selection of the combination of the natural fibres to form composites is based upon the considered application with the aim of or overcoming the limitation of the other natural fibre. Table 2 depicts some of the characteristics of the commonly studied natural fibres. From the table, flax, ramie and hemp and ramie fibres are seen to exhibit the highest tensile strengths and stiffness. The availability of the natural fibre is commonly dictated by the geography which is pivotal to the process of fibre selection. Studies have shown that improved performance is achieved in fibres with the highest cellulose content and having the fiber direction also in the same direction as the cellulose micro-fibrils, this characteristic is common with bast fibres [24]. Natural

fibre exhibits varying chemical and structural properties which are mainly influenced by the extraction methods, growing conditions, fibre treatment, harvesting time and the storage processes [25]. Studies have shown that embedding natural fibres in polymer based matrices improves the specific strength and stiffness of the resulting composite [16]. Generally the characteristics of cellulose based fibre composites are a function of the composition, fibre length, fiber diameter, orientation, shape and distribution coupled with the volume fraction [16,26].

Table 2. Mechanical characteristics of selected natural fibres [25].

Fibre	Density (g/cm ³)	Length (mm)	Failure strain (%)	Tensile strength (MPa)	Stiffness/Young's modulus (GPa)	Specific tensile strength (MPa/g cm ⁻³)	Specific Young's modulus (GPa/g cm ⁻³)
Ramie	1.5	900–1200	2.0–3.8	400–938	44–128	270–620	29–85
Flax	1.5	5–900	1.2–3.2	345–1830	27–80	230–1220	18–53
Hemp	1.5	5–55	1.6	550–1110	58–70	370–740	39–47
Jute	1.3–1.5	1.5–120	1.5–1.8	393–800	10–55	300–610	7.1–39
Harakeke	1.3	4–5	4.2–5.8	440–990	14–33	338–761	11–25
Sisal	1.3–1.5	900	2.0–2.5	507–855	9.4–28	362–610	6.7–20
Alfa	1.4	350	1.5–2.4	188–308	18–25	134–220	13–18
Cotton	1.5–1.6	10–60	3.0–10	287–800	5.5–13	190–530	3.7–8.4
Coir	1.2	20–150	15–30	131–220	4–6	110–180	3.3–5
Silk-	1.3	Continuous	15–60	100–1500	5–25	100–1500	4–20
Feather	0.9	10–30	6.9	100–203	3–10	112–226	3.3–11

Mittal et al. [27] studied the characteristics of cellulose based fibre composites embedded in a polymer matrix by analysing the effect of fibre loading. Based on their observations, the mechanical properties of natural fibre based composites in a polymer matrix can be improved by increasing the cellulose content. Biswas and Satapathy [28] studied the addition of red mud filler content on the mechanical properties of epoxy matrix composite reinforced with bamboo fibre and has since compared the resulting properties with those of glass/epoxy composites. However the strength of the bamboo fibre composite is less when compared to the epoxy matrix composite reinforced with glass fibre while the wear characteristics are improved. Benjamin et al. [29] studied the effect of lignin on the mechanical characteristics of epoxy matrix composite reinforced with hemp fibre. An improvement of 145% was obtained for the impact strength with the incorporation of 5% w/w lignin while the flexural modulus and elastic modulus increased with an increase in the weight of lignin up to 2.5% w/w. They have further observed that increasing the amount of lignin above 2.5% w/w decreased the flexural modulus and modulus of elasticity, which can be caused by unfavourable mixing due to elevated viscosity.

3.2 Hybrid natural fibre composites

A hybrid composite is the fusing of two or more varying fibres in a single matrix with the aim of overcoming the limitations of individual fibres [15]. Numerous researchers have fabricated hybrid composites by fusing different natural fibres together in different matrices including poly vinyl ester, epoxy, polyester, phenolic, and polyurethane resins [18]. Enhanced characteristics of hybrid natural fibre based composites can utilise the synergy between the use of natural fibres with nano-fillers as reinforcement material that can also lead to a positive environmental impact [18]. The distribution and dispersion of reinforcements, high aspect ratio of the reinforcements, large surface area, surface

modification, fibre dimension and orientation interfacial adhesion between polymer and reinforcements are key factors that influence the mechanical characteristics of natural fibre hybrid composites [7]. Hybrid composite products have three important parameters that have significant effect on the resulting properties. The matrix and reinforcement materials are the first parameters to be considered which are influenced by the considered application [7]. The fabrication process is the second parameter which often depends on the type reinforcement and matrix material being studied while the third parameter speaks to the interface between the reinforcement and matrix material.

3.2.1 Natural-natural fibre hybrid composite

Natural fibres can be fused together to form hybrid composites where the natural fibres act as reinforcement material that is embedded in a single matrix. This process is essential in enhancing the overall performance and characteristics of the resultant material while taking in account the current ecological concerns. The characteristics of natural-natural fibres reinforced hybrid composites from numerous research groups have been investigated extensively. Amongst these, Shireesha et al. [30] studied the combination of both jute and banana fibres in an epoxy matrix composite which revealed an enhancement in the characteristics up to 30% wt on loading and also noted that the mechanical characteristics of the individual fibres was improved in the resulting hybrid. Idicula et al. [31] in his research found out that improved fibre/matrix interface coupled with good stress transfer were discovered in a sample with a 3:1 relative volume fraction of banana and sisal, which showed the maximum flexural modulus, tensile strength and the lowest impact strength. Mochane et al. [7] observed that for natural-natural fibre hybrid composites, optimum tensile strength can be obtained when high strain is obtained. Srivastava [32] investigated the mechanical characteristics of sisal and jute fibres in an epoxy based matrix composite. Their results showed that temperature increase leads to substantial decrease in the storage modulus of the hybrid composites which is caused by the loss of stiffness of fibres. Furthermore, storage modulus value was seen to be directly proportional to the bonding interface between the fibres and matrix. Pappu et al. [33] reported the use of hemp and sisal by employing the melting and injection moulding processes to fabricate a hybrid fibre reinforced composite with polylactic acid (PLA). The results from their study have revealed water absorption capacity of $1.06 \pm 0.18\%$, density $1.14 \pm 0.07 \text{ g/cm}^3$ and elongation at break of $0.93 \pm 0.35\%$ of the hybrid composite. Compared to neat PLA, natural fibres embedded in PLA to form hybrid composites attained an enhanced mean specific tensile strength 38.86 MPa, specific flexural strength 79.76 MPa, flexural strength 94.83 MPa, Young's modulus 6.1 GPa, flexural modulus 6.04 GPa and tensile strength 46.25 MPa. They have since been able to conclude that the combination of hemp and sisal fibre with PLA significantly improved the impact strength of the resulting composite. The enhanced performance made them highly recommended for use as alternative renewable material in electronics, automotive, agricultural applications, interiors and packaging.

4. Mechanical characteristics of hybrid natural fibre composites with filler content

The incorporation of filler material into the composites is pivotal to altering the mechanical properties of the resulting composites that have been reviewed from the literature. Several parameters such as filler/matrix interface bonding, fibre dimension, matrix type and filler significantly influence the resulting characteristics of hybrid composites [19]. Uniform dispersion of

the reinforcing phase, relatively high aspect ratio, fibre orientation and good adhesion are also important parameters for substantial reinforcement and virtuous characteristics for any composite [18]. The mechanical characteristics of composite materials have been proven to be altered by the addition of a small amount of fillers with a considerable enhancement of properties in the resulting composite.

4.1 Natural fibre/filler hybrid composite

Filler materials can be added to natural fibre-matrix composites where the filler material is made up of particles of nano-meter or molecular level to develop a hybrid composite with the aim of improving the overall characteristics of the material. Mochane et al. [7] studied the mechanical characteristics of the addition of groundnut shell ash to woven banana fibre epoxy composite to form a hybrid. Their study has revealed that the addition of 3% groundnut ash to 15% banana with hybrid 82% attained enhanced mechanical characteristics such as tensile strength, hardness and compressive strength when compared to the non-filler composite, with an exception to the impact strength. The hybrid composite obtained 24.4 MPa of compressive strength, 12.02 MPa of tensile strength, 0.340 J/mm² of impact strength, 37.3 of hardness while with 85% epoxy and 15% banana 20.7 MPa of compressive strength, 35.6 of hardness, 10.21 MPa of tensile strength and 0.252 J/mm² of impact strength. The hybrid composite with groundnut shell ash added at 7.5% into an epoxy of 77.5% and 15% banana attained the maximum of 0.65 J/mm² in impact. N. Saba et al. [19] studied incorporation of nano-oil palm empty fruit bunch fillers in woven kenaf fibre with epoxy composite. In comparison to the kenaf/epoxy composite, results have shown that incorporation of nano oil palm empty fruit bunch filler in the composite enhances the tensile strength which is caused by the nano-filler minimized free spaces. Furthermore, an increase of 28.3% in the impact strength due to the addition of the nano filler was also observed in the hybrid composite.

Mochane et al. [7] studied the addition of three various nano-filler contents which include organically modified montmorillonite (OMMT), oil palm nano-filler (OPN) and montmorillonite (MMT) at 3 wt%, in the kenaf fibres to form nanocomposites. The incorporation of the nano filler content enhanced the tensile modulus, impact strength and tensile strength when compared to the non-filler kenaf/epoxy composite. The large surface area induces a link between the kenaf fibres and epoxy matrix through the addition of nano-scale materials which leads to an enhancement in the mechanical characteristics of hybrid nanocomposites. The addition of OPN however led to a decrease in tensile properties when compared to the addition of OMMT and MMT in hybrid nanocomposite. The addition of OMMT exhibited relatively high impact strength and tensile properties which is attributed to the strong reinforcing effect caused by the treatment. Arrakhiz et al. [34] observed the addition of clay content to hybridise pinecone fibres which caused an improvement in the stiffness of the composite while a continuous addition of clay filler content up to 30% led to an enhancement in the stiffness of the composite but the tensile strength remained unchanged. Malla Surya Teja et al. [35] observed the effect of incorporating Sic filler material on the thermal and mechanical characteristics of sisal fibre composites. They have since been able to report that an increase of 2.35 times in the tensile strength of composite with 10% SiC was obtained when compared to the non-filler composite. Satapathy & Kothapalli [28] prepared a hybrid composite through the incorporation of fly ash cenospheres (FACS) with recycled high-density polyethylene (RHDPE) reinforced with coir fibre to study variation in mechanical characteristics, water absorption, thermal stability and crystallization behavior. The scanning electron microscopy (SEM) analysis of

the fly ash cenosphere particles is shown in Figure 1 which reveals the uniformity of the particulates. Their results also revealed an increase in the flexural modulus, tensile modulus, hardness and flexural strength properties on the RHDPE with an increase in fibre loading from 10 to 30 wt%.

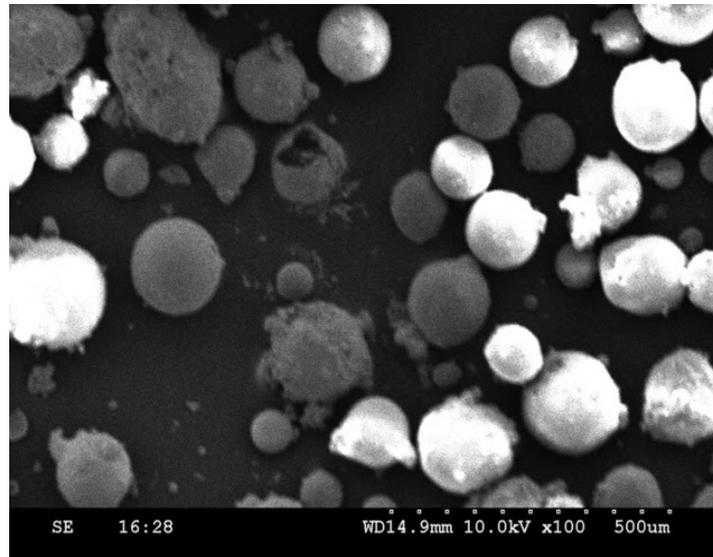


Figure 1. SEM micrograph of FACS particles. Reprinted with permission from Ref. [28].

Venkateshwar Reddy et al. [6] studied the effect of three different filler contents, Al_2O_3 , CaCO_3 and TiO_2 on the properties of prosopis juliflora fibre hybrid composite developed with constant weight proportion of filler content coupled with variation in fibre weight. SEM analysis carried out revealed the bonding interface between the reinforcements and matrix which was evenly distributed. Their results revealed an improvement in most of the mechanical characteristics due to the incorporation of filler content into the composite materials. Figure 2 depicts the tensile strength of the different composite materials which revealed an increase up to 20 wt% of the fibre while further increase in fibre wt% decreased the tensile strength. It is also clear that the highest tensile strength was obtained with Al_2O_3 filled composite samples at 20 wt% prosopis juliflora fibre. In overall an improvement of 6% in tensile strength, 10% in flexural strength and 36% impact strengths were obtained from the hybrid composite materials compared to non-filler composites. Akash et al. [36] studied the influence of incorporation silicon carbide powder in untreated dupion silk fibre/epoxy resin. The filler content was varied by percentage weight in a range of 0%, 2%, 4% and 6%. From their work, they observed a 41.4 MPa in tensile strength, 53 MPa in flexural strength and 88 RBHN value in hardness achieved at a 6% addition of silicon carbide with epoxy matrix composite reinforced with dupion silk fibre. The morphological characteristics of the composites were revealed through SEM micrographs which revealed the characteristics after the incorporation of silicon carbide into silk fibre/epoxy composite depicted in Figure 3 which reveal the randomly distributed SiC particles within the matrix.

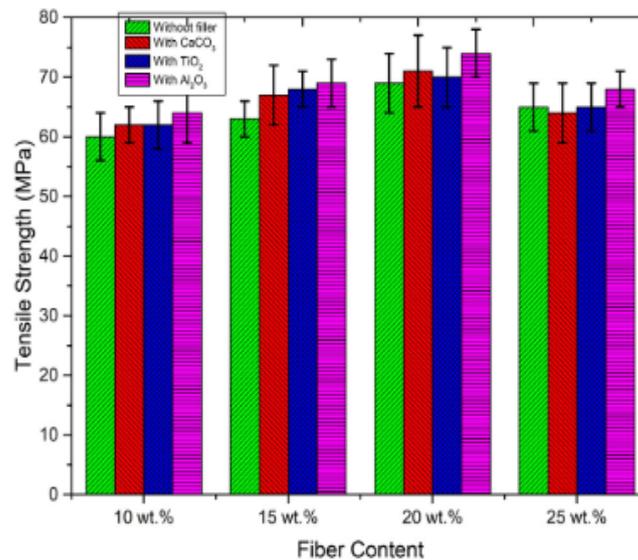


Figure 2. Influence of filler content on the tensile strength of sample composites. Reprinted with permission from Ref. [6].

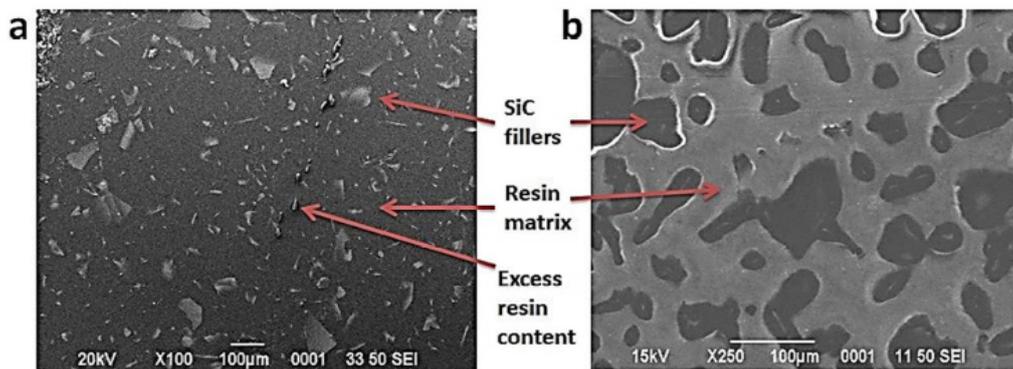


Figure 3. (a) 100× magnification of top surface of with 6% SiC sample, and (b) 50× magnification of top surface with 6% SiC sample. Reprinted with permission from Ref. [36].

Dhanola et al. [37] studied the addition of wood powder, rice husk and groundnut fillers prepared through the hand lay-up technique with varying wt% in polyester matrix reinforced with luffa fibre and investigated the physical, water absorption and mechanical properties of the composites. Based on their results, increasing the rice husk and wood powder filler material decreased the tensile strength of the composites whereas increasing in ground nut shell filler material increased the tensile strength. Results from the investigation revealed a maximum ultimate tensile strength of 31.5 MPa from the prepared test samples while an increase in the filler material increased the impact strength of the composites. However, an increase in the filler material led to a decrease in hardness of the composites while the incorporation of groundnut shell filler content increased the hardness.

4.2 Natural/natural fibre/filler hybrid composite

The use of filler material as reinforcements coupled with the use of more than one lingo cellulosic fibres embedded in a matrix is also initiated by some of the researchers. The combination of both has paved the way for a wide scope of research opportunities for the fabrication of a new variety of cellulose fibres and particulates in composite materials [26]. Islam et al. [38] investigated the surface morphology for tensile fracture due to the addition of montmorillonite (MMT) in kenaf/coir fibres with polypropylene to form a hybrid nanocomposite material through scanning electron microscopy as depicted in Figure 4. The SEM reveals rough surfaces with numerous traces of fibre pull-outs and micro-voids together with agglomeration of the fibres without the addition of filler content in Figure 4a,b. They have since indicated that these characteristics are an indication of the unfavourable distribution and bonding interface between polymer matrix and fibre. After hybridisation, a less indistinguishable result was also observed from the composites depicted in Figure 4c which indicates the unimproved interfacial interaction and adhesion. Figure 4d reveals the significantly enhanced interactions due to the addition of MMT filler content; hence there was a significant reduction in the fibre pull-outs and micro-fracture on the surfaces for nanocomposites materials. They have since concluded that the addition of MMT filler content leads to a smooth fractured surface which is an indication of favourable interaction and adhesion of the polymer matrix and the coir/kenaf fibres which enabled them to argue that the MMT filler content has the capability to enhance the interaction and compatibility between polymer matrix and the fibres. The mechanical characteristics were also enhanced as a result of the introduction of MMT filler content as proven by their tests results which depicted an increase in tensile strength from 9.82 to 10.7 MPa. Furthermore an increase from 345 to 368 MPa in the Young's modulus of the composites was observed after MMT filler content addition.

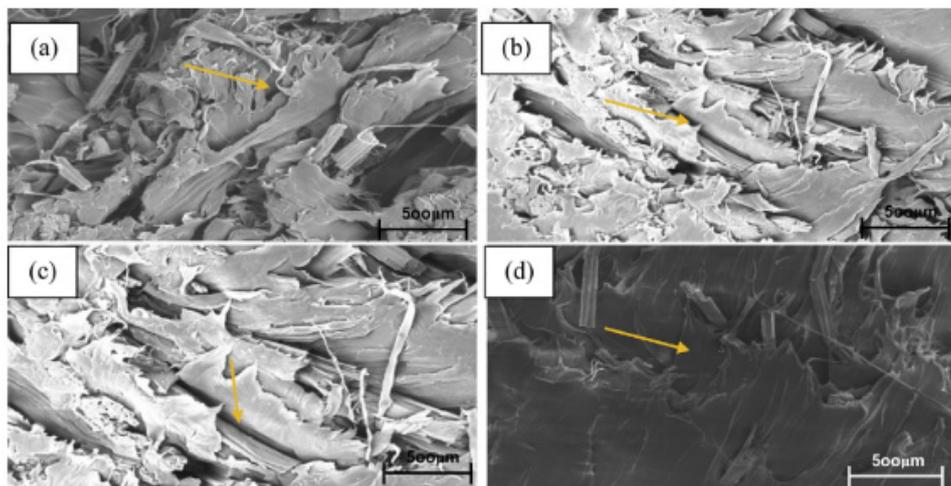


Figure 4. Cross-section surface based on SEM micrographs; (a) kenaf fibre and PP composite, (b) coir fibre and PP composite, (c) kenaf/coir fibre and PP hybrid composite, and (d) kenaf/coir fibre and PP/MMT hybrid nanocomposite at magnification of 200 (arrow shows matrix-fibre interfaces). Reprinted with permission from Ref. [38].

Sandeep K et al. [39] investigated the influence of incorporating rice husk filler content by

studying the mechanical and physical characteristics of Bauhinia-vahlia-weight (BVW) and Bauhinia-vahlia-weight/sisal fibres hybrid composites. Rice husk filler content was added varying loading of 0, 2, 4 and 6 wt% with 6 wt% BVW and mixed 6 wt% BVW-Sisal fibre/epoxy composites. From their results they have been able to conclude that the physical and mechanical characteristics like hardness, water absorption, tensile strength, impact energy and flexural strength were observed to be significantly affected by rice-husk filler material. Their results have shown the addition of rice husk filler material in BVW-Sisal fibre composites enhanced the tensile and flexural strength by up to 34.42% and 33% respectively while hardness obtained 7.1% increase when compared to non-filler composites. SEM was used to study the wear scars in order to understand the governing wear mechanisms which were found to have been improved due to the incorporation of rice husk filler content. Their research has been able to establish that the incorporation of rice husk filler content with optimum variation leads to enhancement in the wear and mechanical characteristics of epoxy matrix composites reinforced with natural fibres. Mohana Krishnu et al. [40] studied the effect of CaCO_3 as filler material on Dynamic Mechanical (DM) properties in different proportions of 0, 2 and 4% incorporated in coir/luffa cylindrical (C/L/C) hybrid epoxy composites. Samples with 2 g of CaCO_3 filler content were observed to exhibit high thermal and dynamic mechanical properties. Based on their results, they have also been able to conclude that composites 2 g CaCO_3 filler material can be applied for use in advanced engineering applications because of their enhanced dynamic mechanical characteristics.

5. Conclusion

Filler materials have been developed and used extensively to enhance the mechanical characteristics of cellulose fibre reinforced composites. Based on this review, natural fibres composites with filler content achieve acceptable mechanical characteristics with great potential to replace the synthetic fibres. Filler content proves prospective in overcoming numerous drawbacks associated with natural fibre composites like the poor adhesion between matrix and fibres, hydrophilicity and lower mechanical characteristics which adversely affects their industry application. Less literature has reported on the use of filler content with more than one natural fibre embedded in matrix to form hybrid composites. All the reported natural/natural fibre with filler hybrid composites displayed improved mechanical characteristics properties. Thus, further research is required to explore the full potential of filler material that remains to be attained in order to attain more improved renewable materials with great potential for new improved composites with a wide range of engineering applications.

Acknowledgements

The authors appreciate gracefully the support of Department of Mechanical, Energy and Industrial Engineering, Botswana International University of Science and Technology.

Conflict of interests

The authors will like to declare that this research has no any financial or work related competing interest.

References

1. Singh H, Singh T (2019) Effect of fillers of various sizes on mechanical characterization of natural fibre polymer hybrid composites: A review. *Mater Today Proc* 18: 5345–5350.
2. Vijayakumar S, Palanikumar K (2019) Mechanical property evaluation of hybrid reinforced epoxy composite. *Mater Today Proc* 16: 430–438.
3. Kerni L, Singh S, Patnaik A, et al. (2020) A review on natural fibre reinforced composites. *Mater Today Proc* 28: 1616–1621.
4. Amir N, Abidin KAZ, Shiri FBM (2017) Effects of fibre configuration on mechanical properties of banana fibre/PP/MAPP natural fibre reinforced polymer composite. *Procedia Eng* 184: 573–580.
5. Senthilkumar K, Saba N, Rajini N, et al. (2018) Mechanical properties evaluation of sisal fibre reinforced polymer composites: A review. *Constr Build Mater* 174: 713–729.
6. Reddy PV, Prasad PR, Krishnudu DM, et al. (2019) Influence of fillers on mechanical properties of prosopis juliflora fibre reinforced hybrid composites. *Mater Today Proc* 19: 384–387.
7. Mochane MJ, Mokhena TC, Mokhothu TH, et al. (2019) Recent progress on natural fibre hybrid composites for advanced applications: A review. *Express Polym Lett* 13: 159–198.
8. Santhosh S, Bhanuprakash N, Tech M (2017) A review on mechanical and thermal properties of natural fibre reinforced hybrid composites. *IRJET* 4: 3053–3057.
9. Elanchezhian C, Ramnath BV, Ramakrishnan G, et al. (2018) Review on mechanical properties of natural fibre composites. *Mater Today Proc* 5: 1785–1790.
10. Faruk O, Bledzki AK, Fink HP, et al. (2012) Biocomposites reinforced with natural fibres: 2000–2010. *Prog Polym Sci* 37: 1552–1596.
11. Mohankumara PB, Thakare SP, Guna V, et al. (2020) *Millettia pinnata*: a study on the extraction of fibres and reinforced composites. *BIOB* 2: 3–8.
12. Krishnudu DM, Sreeramulu D, Reddy PV (2020) A study of filler content influence on dynamic mechanical and thermal characteristics of coir and luffa cylindrica reinforced hybrid composites. *Constr Build Mater* 251: 119040.
13. Chollakup R, Smitthipong W, Kongtud W, et al. (2013) Polyethylene green composites reinforced with cellulose fibres (coir and palm fibres): Effect of fibre surface treatment and fibre content. *J Adhes Sci Technol* 27: 1290–1300.
14. Gu Y, Tan X, Yang Z, et al. (2014) Hot compaction and mechanical properties of ramie fabric/epoxy composite fabricated using vacuum assisted resin infusion molding. *Mater Design* 56: 852–861.
15. Saba N, Paridah, Abdan K, et al. (2016) Dynamic mechanical properties of oil palm nano filler/kenaf/epoxy hybrid nanocomposites. *Constr Build Mater* 124: 133–138.
16. Gohal H, Kumar V, Jena H (2020) Study of natural fibre composite material and its hybridization techniques. *Mater Today Proc* 26: 1368–1372.
17. Parbin S, Waghmare NK, Singh SK, et al. (2019) Mechanical properties of natural fibre reinforced epoxy composites: A review. *Procedia Comput Sci* 152: 375–379.
18. Saba N, Tahir PM, Jawaid M (2014) A review on potentiality of nano filler/natural fibre filled polymer hybrid composites. *Polymers* 6: 2247–2273.
19. Saba N, Paridah MT, Abdan K, et al. (2016) Effect of oil palm nano filler on mechanical and morphological properties of kenaf reinforced epoxy composites. *Constr Build Mater* 123: 15–26.

20. Ahmad F, Choi HS, Park MK (2015) A review: Natural fibre composites selection in view of mechanical, light weight, and economic properties. *Macromol Mater Eng* 300: 10–24.
21. Subasinghe A, Das R, Bhattacharyya D (2016) Study of thermal, flammability and mechanical properties of intumescent flame retardant PP/kenaf nanocomposites. *Int J Smart Nano Mater* 7: 202–220.
22. Ramu P, Jaya Kumar CV, Palanikumar K (2019) Mechanical characteristics and terminological behavior study on natural fibre nano reinforced polymer composite—A review. *Mater Today Proc* 16: 1287–1296.
23. Jeyapragash R, Srinivasan V, Sathiyamurthy S (2020) Mechanical properties of natural fibre/particulate reinforced epoxy composite—A review of the literature. *Mater Today Proc* 22: 1223–1227.
24. Rakesh P, Diwakar V, Venkatesh K, et al. (2020) A concise review on processing of hybrid composites produced by the combination of glass and natural fibres. *Mater Today Proc* 22: 2016–2024.
25. Pickering KL, Efendy MA, Le TM (2016) A review of recent developments in natural fibre composites and their mechanical performance. *Compos Part A-Appl S* 83: 98–112.
26. Mazzanti V, Pariante R, Bonanno A, et al. (2019) Reinforcing mechanisms of natural fibers in green composites: Role of fibers morphology in a PLA/hemp model system. *Compos Sci Technol* 180: 51–59
27. Mittal V, Saini R, Sinha S (2016) Natural fibre-mediated epoxy composites—A review. *Compos Part B-Eng* 99: 425–435.
28. Satapathy S, Kothapalli RVS (2015) Influence of fly ash cenospheres on performance of coir fibre-reinforced recycled high-density polyethylene biocomposites. *J Appl Polym Sci* 132: 1–14.
29. Shireesha Y, Nandipati G (2019) State of art review on natural fibres. *Mater Today Proc* 18: 15–24.
30. Shireesha Y, Suresh BV, Bahubalendruni MR, et al. (2019) Experimental investigation on mechanical properties of bi-directional hybrid natural fibre composite (HNFC). *Mater Today Proc* 18: 165–174.
31. Idicula M, Malhotra SK, Joseph K, et al. (2005) Dynamic mechanical analysis of randomly oriented intimately mixed short banana/sisal hybrid fibre reinforced polyester composites. *Compos Sci Technol* 65: 1077–1087.
32. Gupta MK, Srivastava RK (2015) Effect of sisal fibre loading on dynamic mechanical analysis and water absorption behaviour of jute fibre epoxy composite. *Mater Today Proc* 2: 2909–2917.
33. Pappu A, Pickering KL, Thakur VK (2019) Manufacturing and characterization of sustainable hybrid composites using sisal and hemp fibres as reinforcement of poly(lactic acid) via injection moulding. *Ind Crop Prod* 137: 260–269.
34. Arrakhiz FZ, Benmoussa K, Bouhfid R, et al. (2013) Pine cone fiber/clay hybrid composite: Mechanical and thermal properties. *Mater Des* 50: 376–381.
35. Teja MS, Ramana MV, Sriramulu D, et al. (2016) Experimental investigation of mechanical and thermal properties of sisal fibre reinforced composite and effect of sic filler material. *IOP Conf Ser Mater Sci Eng* 149: 012095.
36. Akash S, Avinash S, Ramachandra M (2018) A study on mechanical properties of silk fibre reinforced epoxy resin bio-composite with SiC as filler addition. *Mater Today Proc* 5: 3219–3228.

37. Dhanola A, Bisht AS, Kumar A, et al. (2018) Influence of natural fillers on physico-mechanical properties of luffa cylindrica/polyester composites. *Mater Today Proc* 5: 17021–17029.
38. Islam MS, Hasbullah NAB, Hasan M, et al. (2015) Physical, mechanical and biodegradable properties of kenaf/coir hybrid fibre reinforced polymer nanocomposites. *Mater Today Commun* 4: 69–76.
39. Sandeep K, Krishan KS, Brijesh G, et al. (2019) Synergy of rice-husk filler on physico-mechanical and tribological properties of hybrid Bauhinia-vahlii/sisal fiber reinforced epoxy composites. *J Mater Res Technol* 8: 2070–2082.
40. Krishnudu DM, Sreeramulu D, Reddy PV (2020) A study of filler content influence on dynamic mechanical and thermal characteristics of coir and luffa cylindrica reinforced hybrid composites. *Constr Build Mater* 251: 119040.



AIMS Press

© 2020 the Author(s), licensee AIMS Press. This is an open access article distributed under the terms of the Creative Commons Attribution License (<http://creativecommons.org/licenses/by/4.0>)