



A Review on Application of Natural fibre in Structural Reinforcement: Challenges of Properties Adaptation

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ABSTRACT: The foray of natural fibre reinforced composite in structural application is not new and researchers are currently considering different approaches of maximizing its performance. In many published works, natural fibres have enjoyed reasonable patronage in cooling applications and in cementitious structural materials. The moisture affinity of these fibres is another challenge that have dominated literature for ages. Moreover, modification of natural fibre in structural application is a herculean tasks that have not been established in many published works. In this work, properties and characteristics variation of natural fibre in structural reinforcement are discussed. Substantial part of this work is also dedicated to main properties inherent in natural fibre inimical to structural applications. It is expected that this work will assist researchers to formulate new compatible matrix materials suitable for further research works.

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The application of natural fibres in reinforcement of composite have been reported in many past works (Adekomaya et al., 2017b, Santamouris, 2016) with improvement and shortcomings depending on the application of the resulting composites. Environmental concerns and sustainability of convectional materials are stimulating research into natural fibres. Natural fibres seem to be applicable in all facet of life in view of their availability and recyclability (Novais *et al.*, 2016). Natural fibres have been a popular reinforcement in furniture, polymer matrix, and automotive industries. Part of their attractive tendencies in automotive component formations is their lightness and energy efficiency in these vehicles (Vigneault et al., 2009). Natural fibre are majorly sourced from plant-based derivatives and they are lignocellulosic in nature with components usually of cellulose, hemicelluloses, lignin, pectin and waxy substances. It is also noted in many published works that the embedded structural composition and chemical composition of these fibres made them suitable for variety of application as depicted in Figure 1 and Table 1. The different cross-sectional shapes of natural fibres are shown in Figure 2 confirms irregular and varying shape of natural fiber. Figure 3 is a reflection of schematic structure of a natural fibre and

in the work of Kabir *et al.*, 2012, cellulose is considered the major framework embedded in the fibre structure.

Part of the advantages of lignocellulosic content in the natural fibres over synthetic materials are their mechanical properties, low thermal conductivities values, non-abrasivity, enhanced energy recovery and biodegradability (Abdellaoui et al., 2015). The main disadvantages of natural fibres in the reinforcing of matrix is their moisture affinity, which brings about dimensional instability in the lignocellulosic based fibres. Abiola and his co-workers discussed in their work that for a natural fibre to effectively perform optimally in a matrix based composite, the interfacial structure and stress transferability of resulting composite and natural fibre must be sustainable. The stress transferability plays a key role in sustaining the mechanical properties of the resulting composite (Dong et al., 2014). The moisture affinity of natural fibre is a major drawback in the reinforced composite (Kabir et al., 2012, Szolnoki et al., 2015). Although, natural fibres have been treated in many experimental works and the resulting composites have shown reasonable improvement in their adhesion to matrix materials (Ramesh, 2016). In other

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works(Mechraoui *et al.*, 2007, Nayak *et al.*, 2012), most natural fibres have shown low degradation temperatures (~200 °C), which make them highly vulnerable to structural application compared with thermosets with high curing temperatures. This tendency tends to limit the scope of exploration of natural fibre composites to relatively low temperature applications. There are numerous other challenges as reported in the large variability of their mechanical properties, lower tensile strength as compared with synthetic fibre, and variation in mechanical properties when exposed to moisture(Ramamoorthy *et al.*, 2015).

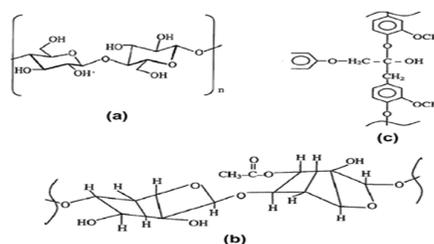


Fig. 1. Chemical compositional structure of (a) cellulose (b) hemicelluloses and (c) lignin (Bledzki and Gassan, 1999).

Table 1: Structural composition of specific natural fibres (Fakirov, 2007, Abiola *et al.*, 2014)

Name of the fibres	Cellulose (wt.%)	Lignin (wt.%)	Hemicellulose (wt.%)	Pectin (wt.%)	Wax (wt.%)	Micro-fibrillar/spiral	Moisture content (wt.%)
Bast fibres							
Jute	61–71.5	12–13	13.6–20.4	0.2	0.5	8.0	12.6
Flax	71	2.2	18.6–20.6	2.3	1.7	10.0	10.0
Hemp	70.2–74.4	3.7–5.7	17.9–22.4	0.9	0.8	6.2	10.8
Ramie	68.6–76.2	0.6–0.7	13.1–16.7	1.9	0.3	7.5	8.0
Leaf fibres							
Sisal	67–78	8.0–11.0	10.0–14.2	10.0	2.0	20.0	11.0
Pineapple leaf fibre	70–82	5–12	–	–	–	14.0	11.8
Seed fibres							
Cotton	82.7	0.7–1.6	5.7	–	0.6	–	33–34

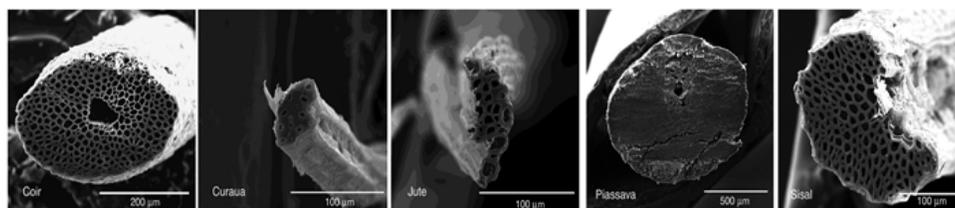


Fig. 2. SEM images of different natural fibres(Fidelis *et al.*, 2013).

The interface in the fibre–matrix composite is the reaction zone where the individual fibre and matrix are chemically and physically bonded. This on its own, already confer major disadvantages on composite as per hydrophilicity. In most cases where the resulting composite display poor adhesion across the phase boundary, this further propagate weak dispersion of force across the composite boundaries, resulting in poor performance of the composite. The threat of the moisture attack is mostly predominant at the interfacial boundaries as a result of the presence of hydrophilic hydroxyl groups on the fibre surface(Ayrilmis *et al.*, 2011). Lately, the emergence of modifiers and coupling agents have largely reduced the interfacial bonding gap between the fibre and matrix(Pérez-Pacheco *et al.*, 2013, Adekomaya *et al.*, 2016). In most cases, the natural fibres are modified with different chemical additives and coupling agents. As a result of this intervention, significant improvements have been recorded in the mechanical properties of the natural fibre reinforced composites. Table 2 showcases the mechanical properties of natural fibres as an illustrative

background for structural application. It can be observed in this Table that the tensile strength of these fibers appear to have been enhanced as a result of chemical modifiers used in the treatment of these fibers. This may not be the same for moisture contents level of these fibers as the level are still relatively high compare with the synthetic fibers.

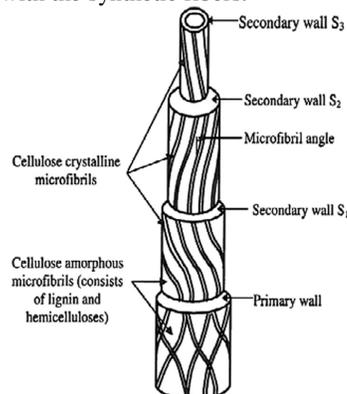


Fig 3: Structural components of natural fibre (Kabir *et al.*, 2012)

Table 2: Natural fibre properties(Ramamoorthy et al., 2015, Väisänen et al., 2016)

Natural fibre	Tensile strength (MPa)	Young's modulus (GPa)	Density (kg m ⁻³)	Moisture content ((%)
Cotton	300–700	6–10	1550	8.5
Kapok	93.3	4	311–384	10.9
Bamboo	575	27	1500	–
Flax	500–900	50–70	1400–1500	12
Hemp	310–750	30–60	1400–1500	12
Jute	200–450	20–55	1300–1500	12
Kenaf	295–	22–60	1220–1400	17
Ramie	915	23	1550	8.5
Abaca	12	41	1500	14
Banana	529–914	27–32	1300–1350	–
Pineapp	413–	60–82	1440–1560	–
Sisal	80–840	9–22	1300–1500	11
Coir	106–175	6	1150–1250	13

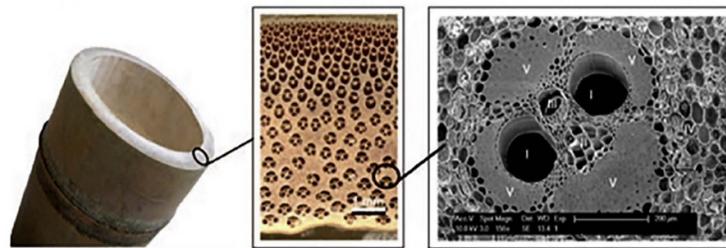


Fig 4. Bamboo culm (a); Cross section of bamboo culm (Lau et al., 2018)

Part of the work of Lau et al. (2018), discussed the enormous prospect of bamboo fibre in structural application with other natural fibres. Although, the authors highlighted key of their advantages to include low density, low cost, high mechanical strength and high growth rate as part of their comparative advantages over other natural fibres. Some other published works(Yao and Li, 2003, Deshpande et al., 2000) also reported that bamboo fibre possess the ability of producing oxygen and absorbing carbon dioxide in about approximately three times when compared with other plants fibre, thereby reducing carbon emission and greenhouse gas effect to a limit. In another observation(Mitch et al., 2010), some tiny holes are cited on bamboo as revealed by SEM Micrograph (Fig. 4). In a similar paper(Zakikhani et al., 2014), bamboo fibre is reported to be porous in nature, with high moisture content, and sometimes difficult to extract fine and continuous fibre from their parent fibers. Their thermal degradation is also noted as a major setback especially during their manufacturing process. This further reduces the prospect of bamboo in structural reinforcement.

Properties Adaptation of Natural fibers: Exploring the properties of natural fibres in engineering applications is a great task that have not been resolved in many past works. Some of the issues raised is the high level of moisture absorption (5–10%), bonding tendency of fiber and matrix which appear to be the most pressing disadvantage of adapting natural fibre in real life. In automotive industry, natural fiber is gaining space and the global market has accorded natural fibre the much needed recognition it deserves. Cost and weight saving properties of natural fibers is a tool that had saved reasonable quantity of fossil fuel demand in cold chain(Adekomaya et al., 2017a). Car manufacturers are currently utilizing natural fibre composites as an alternative for glass fiber and aluminum sheet. In structural applications, it has been observed that cementitious based materials is formed from tension-susceptible materials, thereby propagate micro-cracks easily from the surface or at the interface between cement phase and aggregate after the hydration process. For concrete formations, cement is a basic material to bond all aggregates substances

(sand, fine and small large stones) together to form resultant structures with reasonable compressive strength. Dispersion of this fiber in cementitious components is a recurrent issue in many past works. Some researchers (Ho et al., 2012, El-Sabbagh, 2014) have once concluded that if large quantity of natural fibres agglomerates together, it would largely reduce the ultimate strength of the structures (Fig.5). This has further enhanced the treatment of natural fibre with NaOH or $AlCl_3$, H_2SO_4 or $Ca(OH)_2$ thereby making them to resist harsh weather and temperature. In light of the above, natural fibre reinforced cement composites are often used in residential housing for exterior applications only i.e siding and roofing.

In another work, Sain et al. (2004) explored the flammability of natural fiber with polypropylene and sawdust/rice husk filled polypropylene composites by using horizontal burning rate and oxygen index tests. These authors went further to study the effect of flame-retardants on zinc borate in combination with magnesium hydroxide. It was noted in their findings that magnesium hydroxide can only reduce the flammability of natural fibre filled polypropylene composites by about 50%. Their works also showed little effect when magnesium hydroxide was used to reduce the flammability of natural fiber. Although, natural fibres find usefulness in major application as a result of their product cost, their flammability still raise a lot of concern which may not exclude structural application.



Fig 5: Pellitised extrudates of PA6 + 10% kenaf +20% FR (left) and PA6 + 22.5% kenaf and 20% FR (right) (Elsabbagh et al., 2017)

In a similar paper, Szolnoki et al. (2015) used phosphorus to reduce the flammability of hemp fibre reinforced polymer composites. The authors applied fire retardant onto the surface of fabrics by immersing pre-heated dry fabric into a cold phosphoric acid solution. The result showed that the mechanical properties of the composite was slightly affected which may not reduce the flammability of natural fibre composite. Elsabbagh et al. (2017) also established the possibility of reducing the melting temperature and thermal stability of natural fibre reinforced composite.

The authors only used flame retardant which could not significantly produce substantial improvement. Part of the process employed was to mix Jute, flax and kenaf with Polyamide 6 (PA6) in a pellet form as shown in Figure 5. Figure 6 further shows that the heat release rate (HRR) of natural fibres reinforced composite tend to decrease with higher content of flame retardant substance. In a case of composite with 22.5% flax fibre and 20 wt % flame retardants, the heat release rate is noticed to decline by 50%.

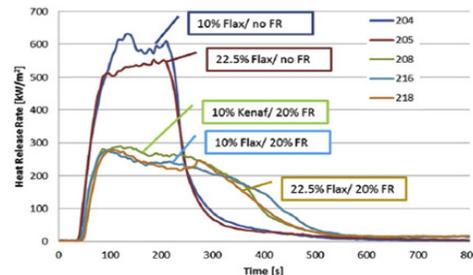


Fig 6. Heat release rate of PA 6 reinforced by different content of natural fibre and FR (Elsabbagh et al., 2017).

Conclusion: Application of natural fibres is growing and will continue to dominate market environment for years to come. The reasons may not be unconnected with its abundance in nature, and environmental friendliness. Automobile industries will find this material useful for ages in terms of weight saving of component part and energy reduction. In real life, natural fibre will continue to be new materials for reinforced polymer composites for different structural applications. However, as their manufacturing process remain unsynthesized with no specific methodology, hence their mechanical and material properties will remain unresolved for sometimes. The drawback to natural fibre application as highlighted has not been resolved and no substantial progress has been published in this regard. Existing mathematical and numerical models developed to predict the properties of natural fibre reinforced composites are sometime not accurate due to the difficulty of having reliable input data. In another vein, modelling of natural fibre is difficult by either traditional cylinder or shear-lag model as a result of varying diameter of the natural fibre along its length. The enormity of research along this problem is huge as many issues raised in past works are yet to be solved. Re-designing natural fibre reinforced composites with properties alignment toward structural application will no doubt enhance the market base of natural fibre.

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