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REVIEW ON HEAT TREATMENT OF NATURAL FIBRES FOR USE AS REINFORCEMENT IN COMPOSITES

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Abstract: Heat treatment of natural fibres is important for their use as reinforcements in composites. Heat treatment of natural fibres has been reported to reduce moisture and improve mechanical properties both in the fibre and in the manufactured composites. Therefore such factors as the specimen gauge length, number of specimens tested, average diameter of each specimen taken at various points along the gauge length and mode of fracture of the specimen after heat treatment should be fully reported as they affect the outcome of the mechanical properties of heat treated fibres. Others include the type of oven (vacuum or air oven), pre and post processing as well as storage conditions of the fibres after heat treatment prior to testing should be taken care of. These factors and their implications with respect to heat treatments were addressed with a view of improving the mechanical properties of natural fibres for use in composites for advanced applications.
Keywords: heat treatment, natural fibres, reinforcement, properties

INTRODUCTION

A classification for natural fibres is displayed in Figure 1 showing that such fibres are derived from natural resources such as mineral, plants animal. Mineral–based fibres are often associated with extractive and manufacturing industries whilst plants and animal–based fibres are associated with agriculture.

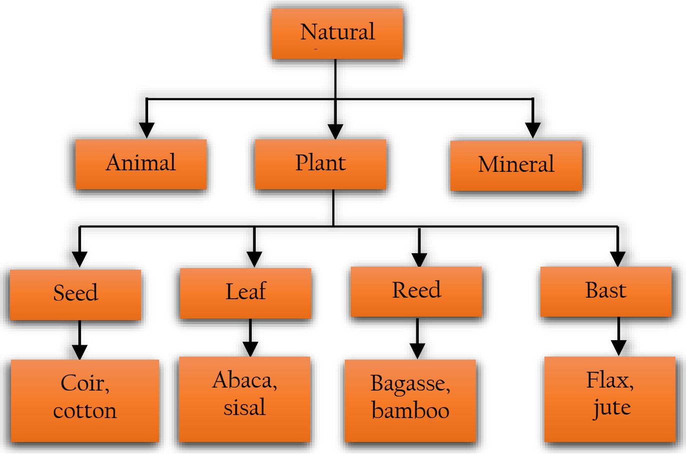

Figure 1. Basic classifications of natural fibres

Several approaches have been sought in other to reduce the use of conventional synthetic fibres such as glass and carbon via the use of natural fibres as reinforcements in composites. Apart from sustainability factor, natural fibres possess several relevant properties and advantages as shown in Tables 1 and 2. Biofibres from plants and other natural materials have been exploited for use as reinforcements in composites (Rao, Rao and Prasad, 2010; Agunsoye et al., 2015; Edoziuno et al., 2020). Unlike synthetic fibres, bio fibres are not dependent on petroleum based precursors. In addition, utilization of natural fibres as composites reinforcements promotes the use of local natural resources and subsequently adds to the socioeconomic development, local content and sustainability of those products (Araújo and Godoy, 2018). They are abundantly available (Jawaid and Khalil, 2015) and require much less energy to produce than synthetic fibres (Joshi et al., 2004).

Table1. Advantages and limitations of natural fibre

Advantages of natural fibre	– Low–cost – Relatively low density – Non–toxic – Sustainable – Renewability – Environmentally–friendly
Limitations of natural fibre	– Poor resistance to moisture ingress – Variability in fibre length and diameter – Relatively high porosity – Significantly lower mechanical properties when compared to synthetic fibres – Low degradation temperatures limit the options for selecting the matrix

(N Mahato", 1995; Fujiura et al., 2010; Gourier et al., 2014).

Table 2. Relevant properties of coir fibre in comparison with other natural fibres and with E–glass fibre

Fibre	Tensile Strength (MPa)	Tensile Modulus (GPa)	Elongation at break (%)	Density (kg/m^3)
Coir	131–175	4–6	30.0–45.0	1150
Sisal	468–640	9.4–22	2.0–2.5	1450
Jute	393– 1316	13– 91.9	1.3–1.8	1300
Hemp	514 –2140	24.8 –143.2	1.6 –1.8	1480
E–Glass	400	1.0	2.5	1900–2500

Sources: (Carl and Brook, 1985; Ticoalu, Aravinthan and Cardona, 1997; Gassan and Bledzki, 1999; Alves Fidelis et al., 2013; Latif et al., 2019; Park 2006; ; Ferreira, Cruz and Fangueiro, 2018; Brígida et al., 2010b; Sanjay, Arpitha and Yogesha, 2015)

HEAT TREATMENT OF NATURAL FIBRES

Natural fibres are made up of different chemical constituents; as a result, heat treatment at increased temperature can give rise to varying degrees of changes in the fibre. Such changes include change in colour and appearance, weight, fibre orientation, decomposition of the chemicals that make up the fibres. Natural fibres have showed different decomposition temperatures and different levels of changes in physical properties.

Investigations from many researchers confirm that natural fibres undergo thermal degradation in two stages:

(a) at lower temperatures (150–300°C) and

(b) at higher temperatures (300–400°C).

(a) has been linked with the degradation of cellulose and includes hydrolysis, oxidation, dehydration among others while (b) has been mainly associated with degradation of both cellulose and lignin with formation of charred product (Varma, Varma and Varma, 1986; Silva et al., 1999; Dam et al., 2006).

In one study, coir fibres were subjected to heat treatment in an air–circulating oven at a temperature of 150°C for 10 minutes; a drop in tensile strength by 0.58% and increase in Young's modulus by 20% were recorded, however, at 200°C for the same duration, a drop in the tensile strength and increase in modulus by 40% and 20% respectively were recorded (Ezekiel et al., 2011), however, the storage conditions after the treatment prior to tensile testing was not revealed.

In a similar way, at heat treatment temperatures of 100, 140 and 180°C, a drop in the tensile strength by 14, 24 and 29% and a drop in the value of the degree of polymerization by 5, 12 and 19% respectively were observed (Khan, Alam and Terano, 2012). An improvement in dimensional stability has been recorded for heat treated fibres. At 170°C and duration of 2 hours for Eucalypt wood, a 60% anti shrinkage efficiency in radial direction was recorded (Esteves, Domingos and Pereira, 2007).

Esteves, Domingos and Pereira, (2007) carried out an oven heat treatment on eucalypt wood in the presence of oxygen at 170–200°C for 2 to 24 hours and observed an increase in the dimensional stability whereas the bending strength decreased and a mass loss of 9.5% was observed at 190°C. After heat treatment of hemp and bamboo fibres, a 60% decrease in the tensile strength was recorded for both fibres (Ochi, Takagi and Niki, 2002), the gauge length and strain rate were not mentioned, besides only 10 specimens were tested. (Shahzad, 2013) subjected hemp fibres to oven temperatures for 30, 100, 150 and 200°C, however it was not specified if it was a vacuum or air oven.

Cao, Sakamoto and Goda, (2007) subjected kenaf fibres to vacuum heat treatment at temperatures of 130°C, 140°C and 160°C and observed maximum increase in strength at 140°C but the diameter, stiffness and elongation were not mentioned (Varma, Varma and Varma, 1986) subjected coir fibres to air oven heat treatment temperatures of 150, 200 and 250 for 1 hour, however, the number of fibres, fibre origin and specie as well as gauge length used were not stated.

Kenaf and bamboo fibres were subjected to an oven heat treatment temperature of 140°C, an increase in tensile strength, fracture strain, crystallinity index and in the length to width ratio were observed (Y. Cao, Sakamoto and Goda, 2007; Yun et al., 2016).

Dixit and Verma, (2012) recorded a reduction in moisture content, increase in crystallinity index, increase in elastic modulus and increase in fracture strain at 140–150°C for 4 hours of oven heat treatment.

Gassan and Bledzki, (1999) subjected jute and flax fibres to a maximum temperature of 170°C and observed a change in the mechanical properties.

The tensile properties of untreated sisal fibres were evaluated by Luz et al., (2017) for varying gauge lengths but at a constant strain rate, no effect on the tensile strength was observed rather a 35% decrease in Weibull modulus was observed with increase in gauge length.

DISCUSSIONS

The Issues with heat treatment of natural fibres in preparation for use in composites are that several factors were not reported by the authors in other to validate their findings. For example, in the case of coir fibres, the number of fibres used were either not mentioned or below the minimum number stipulated for natural fibres in order to achieve meaningful result.

Several other factors such as gauge length, diameter of the fibre, fibre specie and origin, strain rate, method of extraction, age, specie and origin of the fibres, porosity and pore size distribution were missing in the literature. These factors have been identified among other factors to influence the tensile strength of natural fibres and their applications in composites. Besides, several authors have used different diameters for the same type of natural fiber such as coir resulting in significant inconsistency in the tensile properties. The failure traces and changes in failure pattern of heat treated fibres were not discussed.

Investigations into the tensile properties coir fibres of different varieties and different ages but of Philippine origin and extracted manually were carried out (van Dam et al., 2006). It was discovered that the tensile strength of the Indian retted coir fibre was 248 MPa while the strongest fibre of all the species of the manually extracted Philippine coir fibre was 114 MPa. Therefore, information such as fibre origin, specie and maturity ought to be provided.

For lignocellulosic fibres such as natural fibers, an inverse relationship between the tensile strength and the fibre diameter has been reported by several authors (Mukherjee and Satyanarayana, 1984; Tomczak, Sydenstricker and Satyanarayana, 2007; Fiore et al., 2016).

The gauge length used for tensile testing has been reported by Mukherjee and Satyanarayana, (1984); Defoirdt et al., (2010); Fidelis et al., (2013) and Mathura and Cree, (2016) to significantly influence the results of such tests, see Figures 2 and 3.

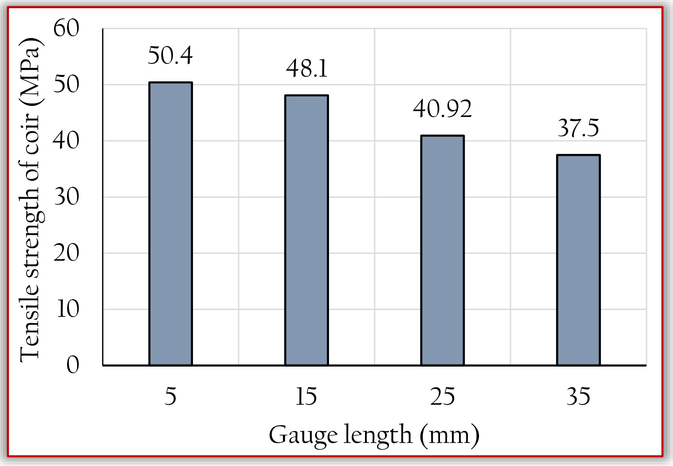

Figure 2. Effect of gauge length on tensile strength of coir fibre adapted from (Mir et al., 2012)

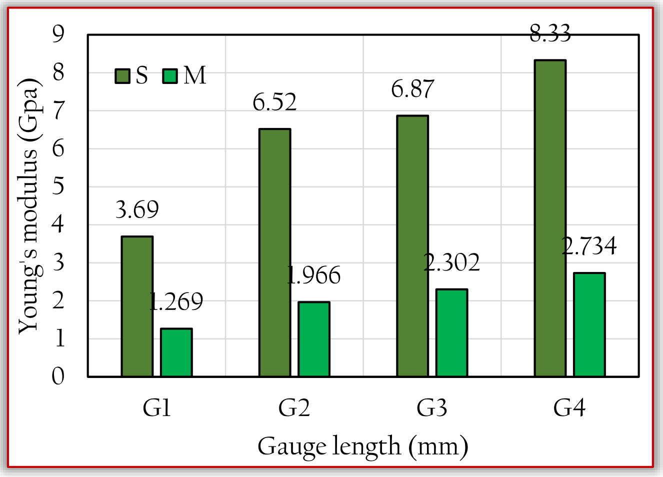

Figure 3. Effect of gauge length on the Young's modulus of coir fibre adapted from (Tomczak, Sydenstricker and Satyanarayana, 2007; Mir et al., 2012) {T for: G1=5; G2=10; G3=20;G4= 25. M for: G1=5; G2=15;G3=25;G4=35}

Mukherjee and Satyanarayana, (1984) observed that increase in the test length of coir fibres from15–65mm brought about decrease in UTS and elongation at break while Young's modulus increased, moreover, increase in strain rate from 1 to 50mm/minute led to increase in the UTS signifying tearing of the cell wall.

The Young's modulus of raw treated coir fiber increased with increase in span length, while the tensile strength and strain to failure of the same decreased with increase in span length (Mir et al., 2012). (Defoirdt et al., 2010) reported that strain to failure depends on the specimen gauge length and that this value varies with a factor of 1.62 for coir fibres.

The longer the gauge length, the lower the strength and vice versa. This can be attributed to the increase in the degree of flaws for natural fibres or as a result of the number of defects and so the weak links present in the fibre.

The incremental change in strength $d\sigma$ of the fibre with a corresponding change in gauge length dL according to Mukherjee and Satyanarayana, (1984) is represented by Equation [1];

$$d\sigma = \propto \frac{dL}{L} \quad [1]$$

- σ represents the fibre strength
- $\propto$ represents a measure of the frequency of occurrence of weak links; and
- L represents the gauge length of the fibre.
- The change in strength with respect to change in gauge length is obtained by integrating Equation [1];
- The strength of the fibre of length L is represented by σ_o

$$\sigma_L = \sigma_o + \alpha \ln \frac{L}{L_0} \quad [2]$$

The properties of natural fibres have been reported to depend on the type of fibre, specie, age or maturity and method of extraction (van Dam et al., 2006; Tomczak, Sydenstricker and Satyanarayana, 2007; Mathura and Cree, 2016; Dhaliwal, 2019). Therefore these information ought to be provided for a better characterization of the effects of heat treatment of natural fibres for their use in composites.

CONCLUSION

Heat treatment of natural fibres is important for composite applications. Therefore such factors as the specimen gauge length, number of specimens tested after heat treatment, average diameter of each specimen taken from various points along the gauge length before and after heat treatment and mode of fracture of the specimen should be fully reported. Others include the type of oven (vacuum or air oven) pre and post processing as well as storage conditions of the fibres after heat treatment prior to testing.

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