

Properties of Kenaf Fibre Reinforced Natural Rubber Composites

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Kenaf has recently been seen as a competitive reinforcing material for conventional synthetic fibre, such as glass fibre in polymer composites. The usage of kenaf has increased due to its biodegradability and environmental compatibility. The cure characteristics and mechanical properties of kenaf bast fibre-reinforced natural rubber composites with and without bonding agent were investigated. Kenaf bast fibre composites were prepared by mixing kenaf with natural rubber (NR). The composites were vulcanised at 150°C according to their respective cure times. It was found that fibres with the smallest particle size exhibited the highest modulus at 100% (M_{100}), tensile strength, and elongation at break. The values were higher in the longitudinal direction than that of in the transverse direction of fibre orientation. Increasing the fibre loading resulted in a rise in the torque value, tensile strength and hardness of the composite. The mechanical properties were further enhanced when a dry bonding system comprising resorcinol, hexamethylene tetramine and silica was used as a bonding agent in the composites. Scanning electron microscopy (SEM) micrographs confirmed that the bonding agent helped to improve interfacial strength of the fibre composites. Vulcanisates containing kenaf bast fibre exhibit better mechanical properties compared to that containing kenaf core fibre.

Key words: kenaf bast fibre; mechanical properties; dry bonding system; composite; natural rubber

Modification of polymeric materials by incorporation of natural fibre is one of the more popular research activities in the composite industry. This has led to great interest in plant derived natural fibers as raw materials for the production of conventional and advanced polymer materials. The use of fibre as a filler offers several advantages over inorganic fillers with regards to their lower density, lesser abrasiveness to processing equipment, environmentally friendliness and lower cost. In addition, kenaf has been found

to be a new crop in Malaysia with a good potential for reinforcement in composites. Kenaf is an ancient crop and has a long history of being planted and used by human beings. The kenaf plant consists of two fibre types which are the outer bark or bast portion (40% of the plant) and the inner woody core material (60%)¹. Since the technology of separating kenaf core and bark has been developed, there is a possibility of using the entire kenaf plant or its separated parts. The bast fibres offer the advantage of renewability and biodegradability

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that is essential for making environmentally friendly products. Kenaf production is less costly and less time-consuming than other raw crops, given that it produces a high yield with minimal use of chemicals and fertilizers. Because of its biodegradability and environmental friendliness, the usage of kenaf has increased. Recently, kenaf has been seen as a competitive reinforcing material to conventional synthetic fibre, such as glass fibre in polymer composites². The matrix materials that are widely being used in natural fibre composites ranges from thermoplastic to thermoset and elastomers. However, the presence of the hydroxyl group in the fibre makes the fibre hydrophilic, which causes poor interfacial adhesion with hydrophobic polymer matrices and leads to poor compatibility. This had caused poor mechanical and physical properties to the fibre composites. Thus, the efficiency of the fibre as a reinforcement in rubber composites can be improved by selecting the proper components of the bonding agents.

The objective of this research is to study the effectiveness of kenaf fibre as a filler in

rubber compounding. The mechanical properties of kenaf fibre-filled vulcanisates at various filler loadings and fibre sizes will be determined. In addition, the bonding between the fibre and rubber matrix will be investigated.

EXPERIMENTAL

Materials

Natural rubber (NR) and kenaf bast fibre (KBF) were obtained from Malaysia Rubber Board. The bast fiber was ground using a hammer mill. The ground bast obtained from the mill has a size of about 500 μm . The ground kenaf bast was fractionated with sieves of pore sizes of 500 μm , 180 μm and 75 μm . All other chemicals used were of commercial grades.

Formulations

The formulation used to prepare the kenaf bast fibre filled NR compound is given in *Table 1* below:

TABLE 1. FORMULATION OF NR COMPOSITES

Formulation	Parts per Hundred rubber (p.h.r.)	
	SMR L	100
Zinc Oxide	5	5
Stearic Acid	2	2
Sulphur	2.5	2.5
^a CBS	1	1
^b Flectol TQ	1	1
^c Rhenogran Hexa 80	-	3.2
^d Rhenogran Resorcinol 80	-	5
Silica	-	5
Kenaf Bast Fiber	Varied (0,10,20,30, 40)	Varied (0,10,20,30,40)

^aN-Cyclohexyl-2-benzothiazole sulfenamide

^b2,2,4-Trimethyl-1,2-dihydroquinoline, polymer

^c80% Hexamethylene tetramine in elastomeric binder (Rhenogran HEXA-80)

^d80% Resorcinol in 20% Elastomeric Binder (Rhenogran Resorcinol 80)

Composite Preparation

Mixing was carried out on a laboratory size 12 inches \times 6 inches two-roll mill. Mixing was done in accordance with *ASTM D3184-80*. The nip gap, mill/roll speed ratio and number of passes were maintained for all mixes. The samples were milled for sufficient time to disperse the fibres. The fibres were incorporated at the final stage of mixing, taking care that the fibres are in the same direction. Cure characteristics of the mixes at 150°C were determined using a Monsanto Rheometer model MDR 2000. Compress moulded sheets were prepared and cured at their respective cure times.

Mechanical Properties

The tensile strength, elongation at break and modulus at 100% strain were measured in accordance with *ISO 37* using an Instron Universal Testing Machine with a crosshead speed of 500 mm/min. The IRHD hardness test was carried out according to *ASTM D2240* using the Durometer. A minimum of three samples were tested in each case and the results were averaged.

Scanning Electron Microscopy (SEM)

Cryogenically fractured samples were examined using JSM 5300/EDX scanning electron microscope. The fractured samples were sputter coated with gold using the SEM Coating Unit E5 100 Sputter Coater.

RESULTS AND DISCUSSION

Effect of Fibre Size on Mechanical Properties

Figure 1 shows the effect of fibre size and fibre orientation on the tensile strength of

kenaf bast fibre (KBF) composites with the fibre loadings kept at 30 p.h.r. It can be seen that the smaller particle size filler gives a higher tensile strength than that of the larger particle size. This may be due to the influence of the higher surface area of smaller particles which leads to more contact surface with the matrix leading to a higher strength³.

Figure 1 also shows the modulus at 100% elongation (M_{100}) of the KBF natural rubber composites. It is clear that the modulus decreases as the particle size increases. Based on this it can be deduced that fibres with smaller particle size are more compatible with the matrix than the larger ones. This is an indication that smaller particles have a better interaction with the matrix. Besides that, short fibres with smaller size also have more uniform dispersion in the polymer matrix.

To study the effect of fibre size and fibre orientation on the elongation at break, 30 p.h.r. of fibre containing composites were prepared. The incorporation of KBF in natural rubber shows that the elongation at break (*Figure 2*) of the smaller size composites compared with the large ones. This trend may be due to better filler dispersion of the smaller KBF in the matrix, which reduces the tendency of filler-filler interaction from taking place⁴.

All composites (*Figures 1 and 2*) show that the tensile strength (TS), elongation at break (EB) and M_{100} are all higher in the longitudinal direction than that of in the transverse direction. This observation is similar to the results with other fibres as reported by other researchers⁵. When the fibres are in the transverse direction, the fibres are less effective in restraining the matrix.

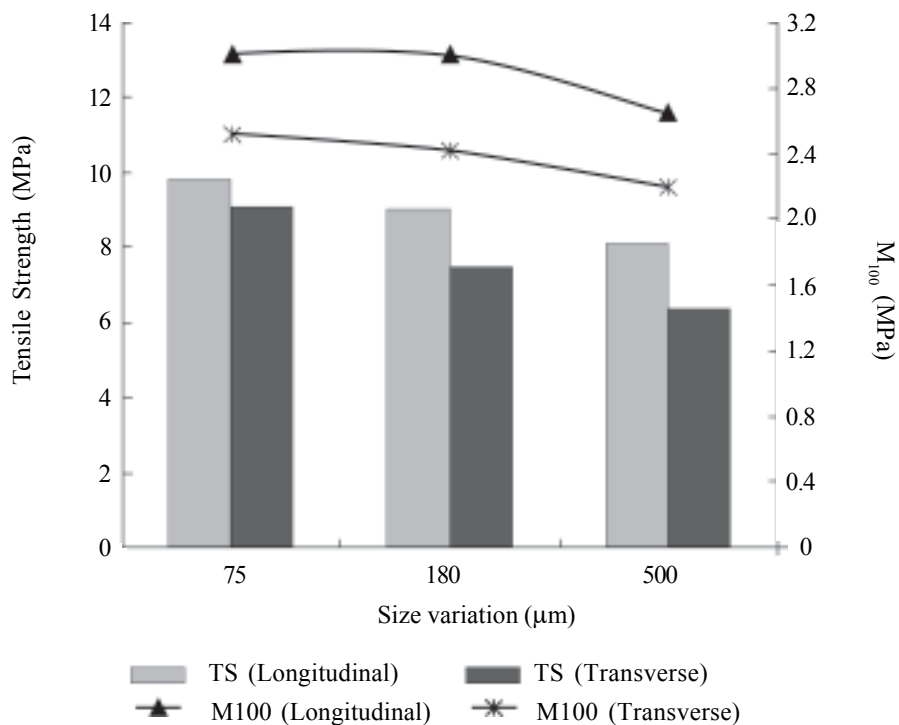


Figure 1. Effect of size variation on tensile strength and M_{100} .

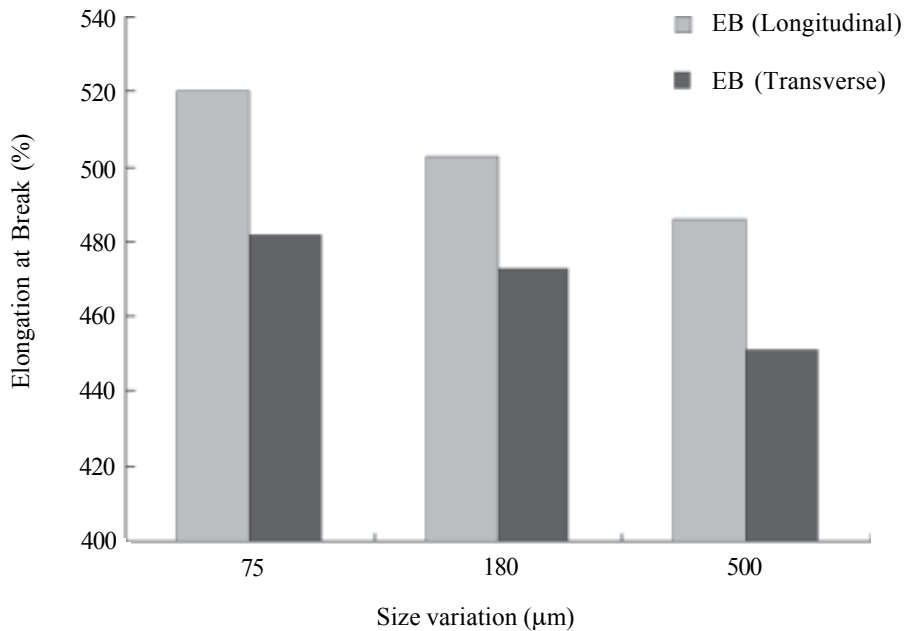


Figure 2. Effect of size variation and fibre orientation on elongation at break.

Effect of Fibre Loading and Bonding Agent

Curing Characteristics. Figure 3 shows that the presence of fibre generates an increase in torque of the mixes. The fibre size for the test was kept at 500 μm . The increase in maximum torque value as measured from the rheographs indicates that the processability of the composites is adversely affected by the introduction of fibre. The marked increase in maximum torque with increasing filler loadings indicates that the presence of fillers in the rubber matrix reduces the mobility of the rubber's macromolecular chains⁶. Figure 3 also shows maximum torque increases for composites with bonding agents. This may be due to the strong bonding at the fibre matrix interface and therefore the composite becomes harder, stiffer and stronger.

Effect of Loading and Bonding Agent on Tensile Strength

Figure 4 depicts the effect of KBF loading with the size of 500 μm on the tensile strength of the NR composites. It is apparent from Figure 4 that the tensile strength gradually decreases with increasing KBF loading. This trend can be associated with the fact that natural rubber possesses high strength due to strain induced crystallisation. Therefore, when fibres which are irregular in shape are incorporated into NR, the regular arrangement of the rubber molecules will be disturbed, which leads to loss of crystallisation ability⁷. This factor, together with poor adhesion between fibre and rubber leads to the deterioration of tensile strength with increasing fibre loading. However, with addition of HRS (hexa-resorcinol-silica) bonding agent the

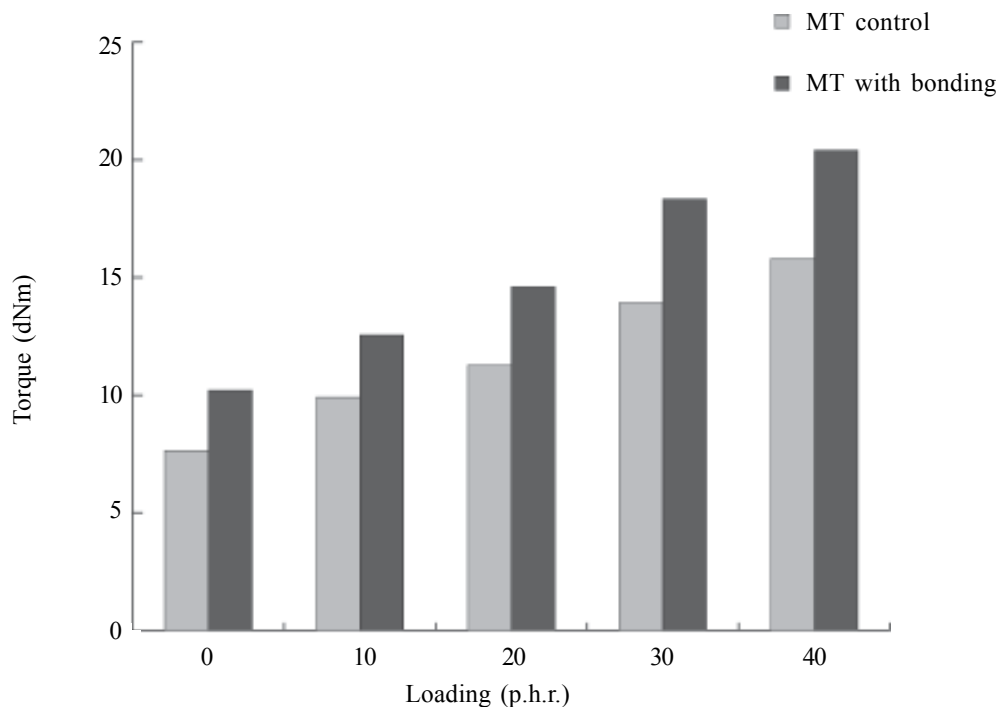


Figure 3. Effect of fibre loading and bonding agent on torque value (MT = Maximum torque).

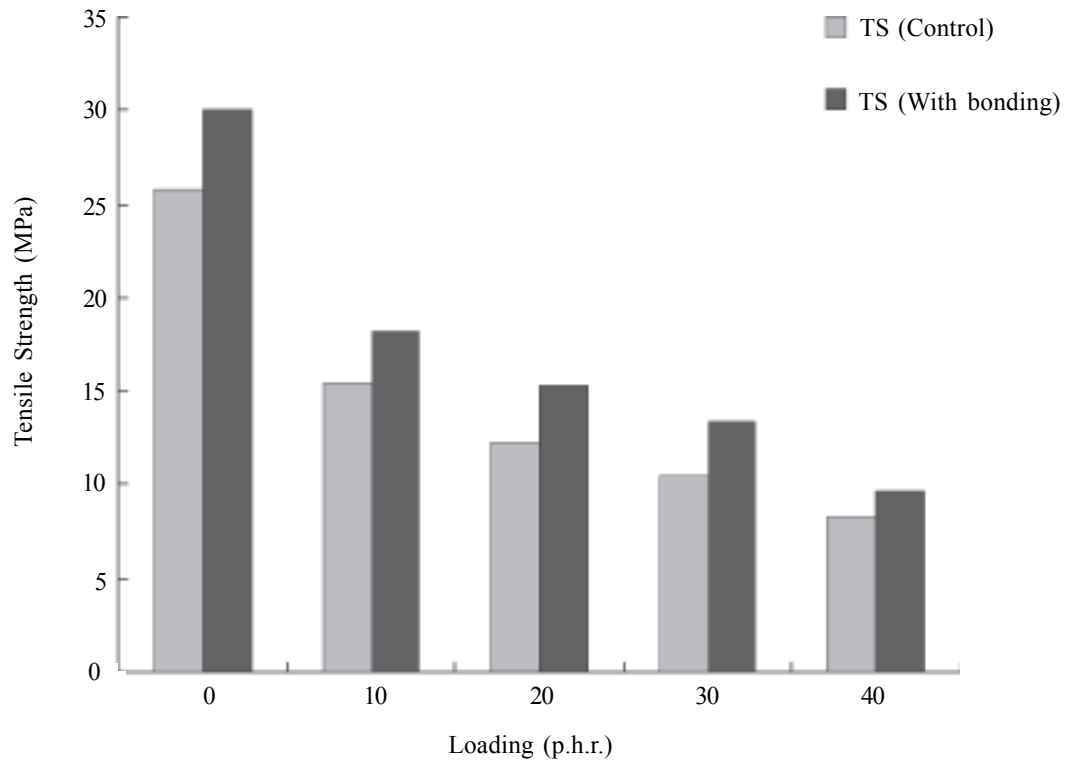


Figure 4. Effect of loading and bonding agent on tensile strength.

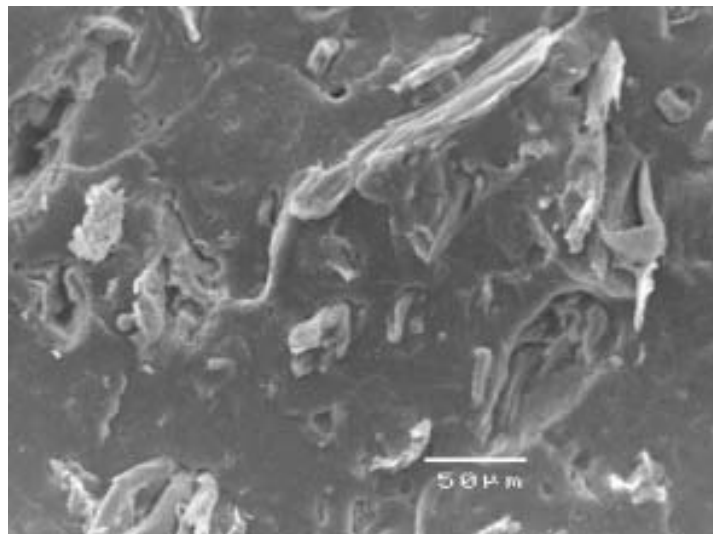


Figure 5. SEM micrograph of KBF composite with bonding agent.

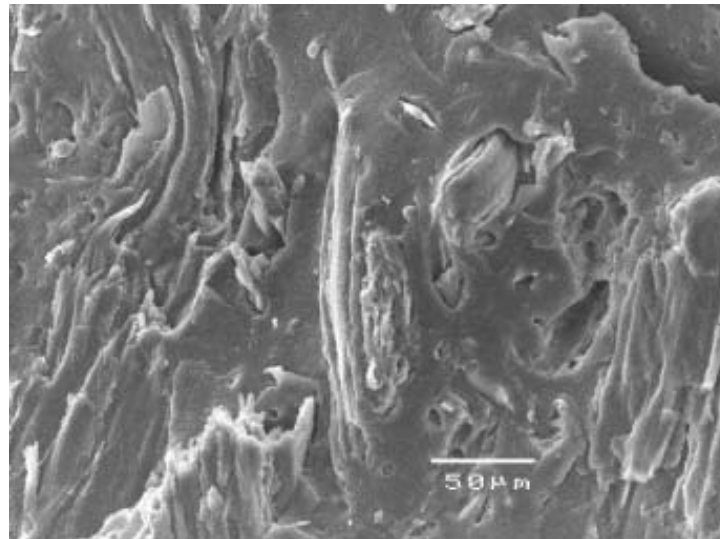


Figure 6. SEM micrograph of KBF composite without bonding agent.

natural rubber composites exhibit higher tensile strength. The improved fiber-matrix adhesion results in a stronger interfacial bond. It may therefore be anticipated that, more efficient stress transfer can occur between the fibers as the load is applied. This result is supported by the SEM micrograph. *Figure 5* shows the micrograph of KBF composite containing 30 p.h.r. of fibre with bonding agent and *Figure 6* shows a composite with 30 p.h.r. of KBF without the bonding agent. *Figure 5* shows fiber breakage rather than pull out which indicates better interfacial strength where else *Figure 6* shows holes that indicate the occurrence of fiber pull out. *Figure 6* also shows that the fibers are merely imbedded in the matrix without good adhesion or bonding at the interface. This may be due to insufficient adhesion between fiber and matrix.

Effect of Loading and Bonding Agent on Hardness

Figure 7 shows the dependence of the hardness on fibre loading and bonding agent

in NR. It is seen that the hardness of both composites (with and without bonding agent) increases on increasing the fibre loading. The presence of bonding agents further increased the hardness due to the increased adhesion between the fibre and matrix⁸.

Comparison Between Bast and Core Fibre Composites

The effect of different fibre compositions on tensile strength is illustrated in *Figure 8*. This figure indicates that the bast fibre provides higher tensile strength in all size variations. This is an indication that bast fibre naturally possesses better strength than the core which is the soft woody material. The bast fibre is more tough. The mechanical performance of the kenaf fibre is comparatively high in comparison with other fibres such as glass fibre⁹.

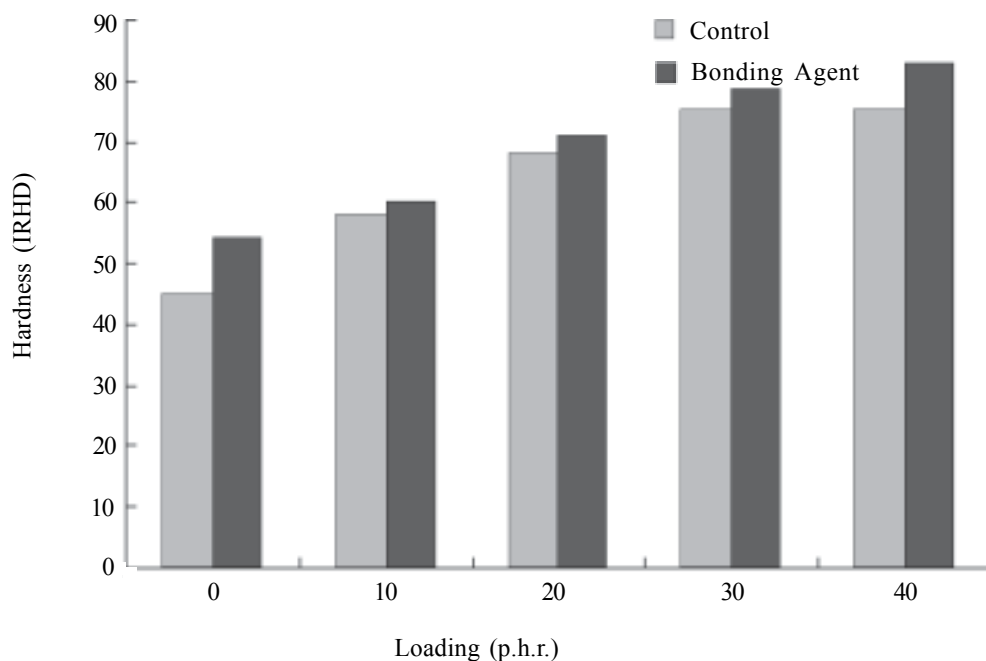


Figure 7. Effect of loading and bonding agent on hardness.

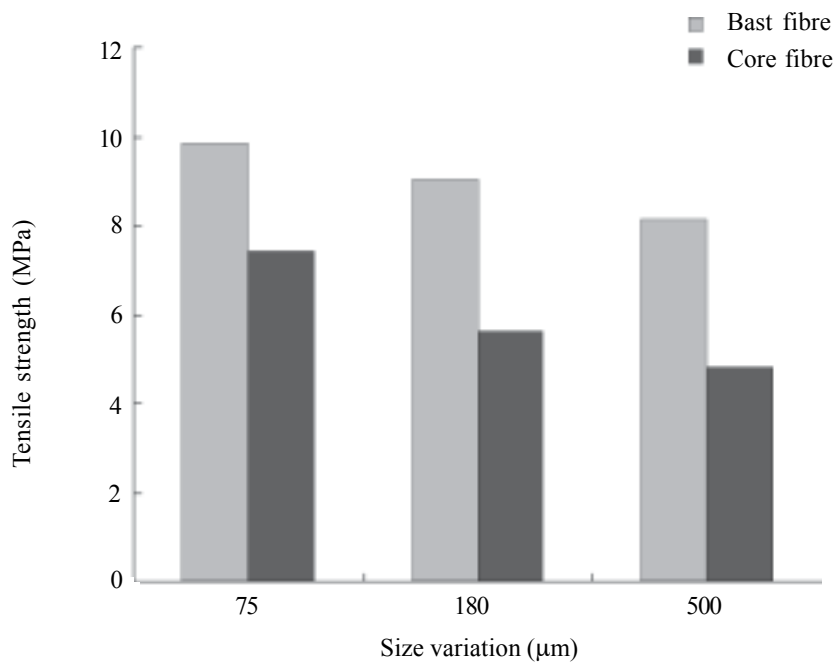


Figure 8. Effect of bast and core fibres composition on tensile strength.

CONCLUSION

The study on kenaf bast fibre composites revealed that fibres with the smallest particle size exhibited the highest modulus at 100% (M_{100}), tensile strength and elongation at break and the values were higher in the longitudinal than in the transverse direction of fibre orientation. It also showed that addition of bonding agents improved the fibre-matrix adhesion and this led to improved tensile properties.

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