Enhanced dynamic mechanical properties of kenaf epoxy composites

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Abstract

Randomly distributed kenaf fibre with varying length (5-50mm) and weight fractions (25-40%) were used to reinforce epoxy resin to prepare environment friendly composites. Effect of fibre length with constant fibre loading on dynamic mechanical properties was studied and its effect on storage modulus, loss modulus and damping factor were investigated. Kenaf fibres were also subjected to alkali treatment to improve interaction with the epoxy resin. The mechanical properties of composites improved with the length and loading of fibres. Tensile strength, flexural strength and impact strength of composites at 40 wt% of fibre reinforcement improved by 46, 51 and 97% as compared to the composites containing 25 wt% of kenaf fibre. It was also observed that fibre folds developed during mixing became significant factor which limited the improvement in mechanical strength of kenaf epoxy composites. A few important predictive models namely rule of mixture, Haplin-Tsai, Nielson Chen and Manera models were compared with the experimental values obtained in this present study. Manera model predicted the experimental data most accurately. Alkali treatment improved the interface and its outcome reflected in the improved modulus that increased 21.76% in samples having 10mm length of kenaf fibre. Copyright © 2017 VBRI Press.

Keywords: Kenaf fibre-epoxy composite, mechanical properties, dynamic mechanical analysis, micro-mechanical models, SEM.

Introduction

Environmental concern and cost of synthetic fibres have led the foundation of using natural fibre as reinforcement in polymeric composites. There is an increasing trend in the application of natural fibres in various manufacturing sectors of industry. Natural fibres have several advantages such as high specific strength and modulus [**1**], low cost, low density [**2**], relative non-abrasiveness, renewable nature [**3**], biodegradability, no health hazards, no CO_2 emission in production [**4**]. Natural fibres can easily be recycled thermally causing less impact on the environment as compared to artificial fibres. Many natural fibres such as hemp, flax, jute, sisal, coir, pineapple provide a probable substitute to the synthetic fibres. Kenaf fibre has many advantages over other fibres due to short plantation cycle, adaptable to environmental conditions and requirement of fewer amounts of pesticides and insecticides [**5**]. Researchers found that mechanical and thermal properties of kenaf fibre composites were superior to other natural fibre composites, making them suitable for high-performance natural fibre composites [**6**]. Kenaf fibre is extracted from the bast of plant genus hibiscus, the family of Malvaceae and the species of H. cannibinus. Its composition is cellulose (44-57%), hemi- cellulose (22-23%), lignin (15-19%), ash (2-5%). It requires less water to grow because kenaf fibre has growing cycle of 150 to 180 days with an average yield of 1700kg/ha [**7**]. Kenaf fibre has been investigated as a promising reinforcing fibre for the composites using thermoplastics (polypropylene [**12**], PLA [**13**]) and thermosetting (epoxy [**8, 9, 10**], polyester [**11**]) polymers as matrix materials. The tensile strength of unidirectionally reinforced kenaf fibre epoxy composites increased from 60 MPa to 100 MPa on increasing the fibre volume from 15 to 45% [**8**]. Yousif and Shalwan [**9**] investigated that reinforcement of epoxy with treated kenaf fibres increased the flexural strength of the composite by about 36%, while untreated showed 20% improvement, with 80mm of fibre length and fibre loading range of 38-41% .Chin and Yousif [**10**] investigated the tribological properties of kenaf fibre epoxy composite. The tensile strength of kenaf fibre unsaturated polyester composite was found 24.7% higher than bamboo polyester composite and 21.3% higher than jute polyester composite at 13% fibre loading [**11**]. The specific tensile strength and flexural strength of alkali-silane treated kenaf polypropylene composites with 30% fibre loading matches with glass fibre composites [**12**]. Increase in fibre volume of unidirectional kenaf fibre PLA composite resulted in an increase of tensile strength and modulus of elasticity [**13**]. Improvement in mechanical properties of kenaf fibre has been reported after alkali treatment [**1**]. Fiore et al. [**14**] investigated that the storage and the loss moduli are influenced by the alkali treatment of kenaf fibre. Rezaei et al. [**15**] investigated the effect of fibre length on thermomechanical properties of short carbon fibre reinforced polypropylene composites.

The available literature on kenaf fibre polymer composites suggests a need of systematic study of kenaf-epoxy composites to determine the influence of length and its role on mechanical performance of composites. The mechanical properties like tensile, flexural and impact were investigated for the composite having various fibre lengths of kenaf fibre and different fibre loadings. Fibres were treated with NAOH solution and effect of treatment was also investigated. The effect of fibre length at constant fibre loading on dynamic mechanical properties of kenaf epoxy composites was studied. Micromechanical models available in the literature for the short fibre reinforced composites were used to predict Young's modulus of these newly developed composites and the experimental values were compared to theoretical values.

Experimental

Materials

The raw kenaf fibres were obtained from the Institute of Jute Technology (West Bengal, India). Fibres were in raw form with an average length of 2m. Kenaf fibres were cleaned by putting the raw fibres in water for 2 days and then were combed to remove the bast. Then fibres were washed properly in running water and were dried at 80°C in an air circulation oven. Epoxy resin (Bondtite Part A) and hardener (Bondtite Part B) were supplied by Resinova Chemie Limited, Kanpur (INDIA).

Fibre treatment

Portion of the cleaned fibres were treated with 6% NaOH solution. In the NaOH treatment process, the fibres were soaked in 6% NaOH solution for 24 h, then washed properly in running water and dried at 80°C for 8 h.

Fabrication of composite plate

The composition of composites prepared under this study is given in **Table 1.** The compression moulding technique was used to fabricate kenaf fibre reinforced epoxy composites. Kenaf fibres were carefully cut to desired lengths (5, 10, 30 and 50mm) and were weighed according to the fibre loading (25, 30, 35 and 40%). Epoxy and hardener were weighed according to the composition required and were mixed properly in the ratio 5:4. Fibres were mixed thoroughly with the resin for 20 minutes for proper coating of the fibres. The mixture was uniformly spread over the wax coated mold surface. The mold was separated from the base plate using Teflon sheet for ease of removal. The mold was secured to the base plate using C-clamps. Through plunger, the mold was compressed in the hydraulic press. The composite plate was removed from the mold after 24 hours. The plates were post cured at 120°C for 4h in air circulated oven.

Table 1. The composition of kenaf fibre reinforced epoxy composites.

Sample designation	Length of fibre (mm)	Composition	
		Epoxy resin wt. %	Kenaf fibre wt. %
EK0525	5	75	25
EK1025	10	75	25
EK3025	30	75	25
EK5025	50	75	25
TEK0525	5	75	25
TEK1025	10	75	25
TEK1030	10	70	30
TEK1035	10	65	35
TEK1040	10	60	40

E- Epoxy, K- kenaf, T- Treated

Mechanical Test

Tensile tests were carried out according to ASTM D 3039 standards using INSTRON Universal Testing Machine model 8801 with cross head speed of 2mm/min. For each composition at least three samples were tested. Three point bending tests were carried out according to ASTM D 790 using TINIUS OLSEN Universal Testing Machine model H25KT with span to thickness ratio of 16:1 and span length of 50mm and cross head speed of 10mm/min. Impact test was conducted on CEAST impact testing machine. Initial notch was machined according to the ASTM D 256 standards on all impact specimens by a CEAST razor blade notch generating machine according to the ASTM D 256 standards.

Scanning electron microscopy (SEM)

The fractured surfaces of specimen after tensile test were studied using JOEL JSM-5600 scanning electron microscope. The fractured specimens were coated with gold. Images of the fractured specimens were taken by subjected them to a voltage of 5kV – 10kV.

Dynamic mechanical analysis (DMA)

Dynamic mechanical analysis was carried out using EXSTAR 6100 DMS machine. Three point bending mode was used. The heating rate used was 2 °C/min and the frequency was 1 Hz for the temperature range from 30 °C to 150 °C. The sample dimensions were a span length of 40 mm, width 10 mm and thickness 2 mm.

Results and discussions

Fig. 1 shows the variation of tensile strength and modulus of the composite with the change of fibre length at constant 25% loading of kenaf fibre. In general, the tensile strength of the composite improved with fibre length. The improvement is most noticeable with 28.57% increase in tensile strength for composites having fibre length 5 to 10 mm.

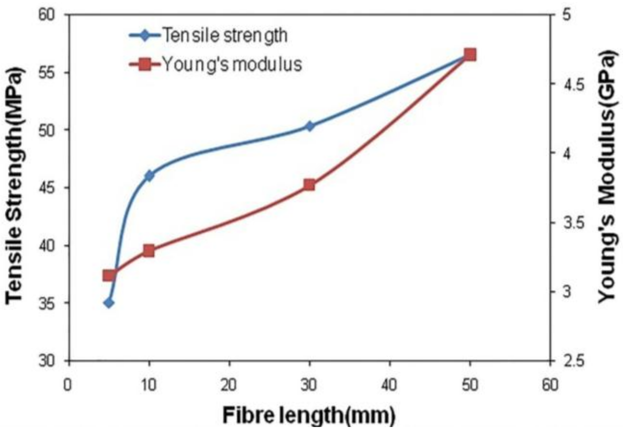

Fig. 1. Effect of fibre length on tensile properties of composite having 25% fibre concentration.

From 10 to 50mm length, the tensile strength of composites increased almost linearly. The trend suggests that strength can further be increased by increasing the fibre length. In epoxy kenaf composites, the load is mainly taken by the kenaf fibre through the interface between fibre and epoxy matrix. Increased value of tensile strength indicated a good adhesion and bonding between fibre and matrix which increases further with the length of kenaf fibre. The increased tensile strength with the increased length may be attributed to reduced number of stress concentration points which invariably occur at the end of the fibres. Tensile modulus also increased with increased fibre length in the composite at fixed weight % of kenaf fibre. Tensile modulus increased from 3.11 GPa to 4.71 GPa with fibre length. Contrary to tensile strength the change in tensile modulus was almost linear with increased length of kenaf fibre. The inclusion of longer fibres might have offered higher resistance to short-range deformation that resulted in increased modulus. Change in modulus is generally attributed to packing density, geometry of reinforcing material, its own modulus, interaction and bonding with the matrix. The increase in length changes the aspect ratio of fibre that might be the major cause of improvement.

Fig. 2 shows the variation of tensile strength and modulus of the composite with the change of fibre concentration. Tensile strength increased with the increase of fibre concentration. This figure clearly depicts the influence of reinforcing kenaf fibre that contributes in increasing tensile strength. The higher weight fraction of kenaf fibres takes the maximum load as the load is applied to composites. Tensile strength increased from 53 MPa to 77.33 MPa with fibre loading. The tensile modulus of the composites showed an increasing trend with the increase of fibre loading. The maximum modulus is obtained for 40% fibre loading with 24.38% improvement over the composite with 35% fibre loading. Increase in fibre loading results in increased packing density of fibres in the composites thus increases modulus.

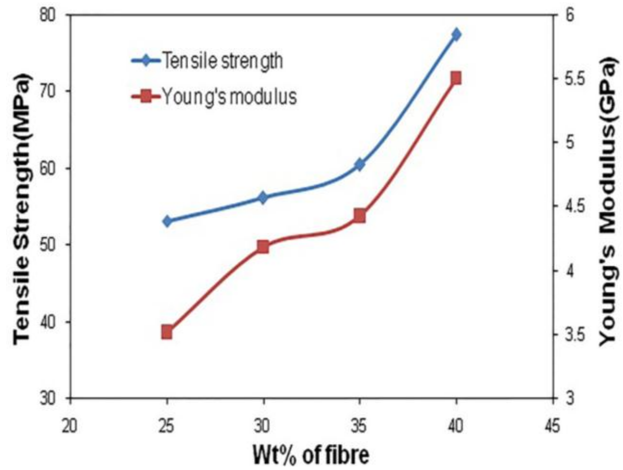

Fig. 2. Effect of fibre loading on tensile properties of composite having 10mm fibre length.

Fig. 3 shows the effect of NaOH treatment on the tensile strength. The composite with 6% NaOH treated kenaf fibre showed improvement in tensile strength as compared to untreated kenaf fibre composite. The composite with 5mm length kenaf fibre showed an improvement of 36.2% as compared to untreated kenaf fibre composite. NaOH Treatment results in surface modification of fibres that improved the fibre- matrix interaction. Better interaction results in better transfer of load from the matrix to fibre thereby result in improvement of tensile strength of the composite.

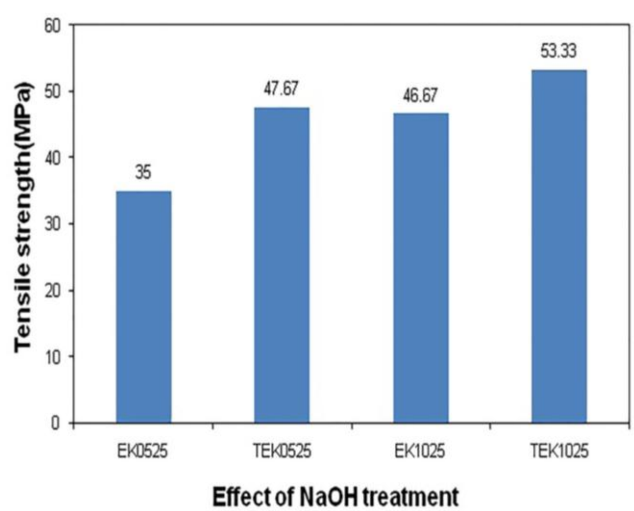

Fig. 3. Effect of NaOH treatment on tensile strength of composites having 5mm and 10 mm fibre length at 25% fibre loading.

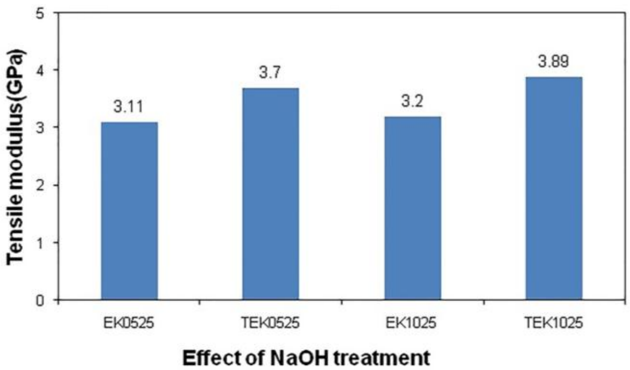

Fig. 4. Effect of NaOH treatment on tensile modulus of composites having 5mm and 10 mm fibre length at 25% fibre loading.

Fig. 4 shows the effect of NaOH treatment on the tensile modulus. The composite reinforced with 6% NaOH treated kenaf fibre showed improvement in tensile modulus as compared to untreated kenaf fibre composites. Composite with 10mm length treated kenaf fibre showed an improvement of 21.76% over the composites having untreated fibres. NaOH treatment results in better interaction between fibre and matrix that increases the modulus of treated kenaf fibre composite as compared to untreated fibre composite.

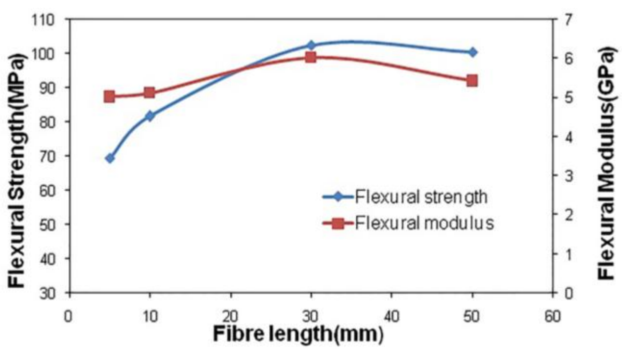

Fig. 5. Effect of fibre length on flexural properties of composite having 25% fibre concentration.

Fig. 5 shows the variation of flexural strength and modulus of the composite with the change of fibre length. The flexural strength of the composite showed an increasing trend with the increase in length of fibre and reaches a maximum flexural strength of 102.4 MPa with 30 mm fibre length then starts decreasing. The flexural modulus of the composite increased with increasing length of kenaf fibre and obtained a maximum value of 6009.33 MPa at 30mm.

Fig. 6 shows the variation of flexural strength and modulus of the composite with the change of fibre loading. The effect of change of fibre loading showed a similar trend with the effect of change of fibre length on flexural strength. A maximum flexural strength of 102.77MPa was achieved at 35% fibre loading then starts decreasing. The trend observed was, that the flexural modulus increased with increasing fibre loading, reaches a maximum value of 5999.33 MPa at 35% fibre loading.

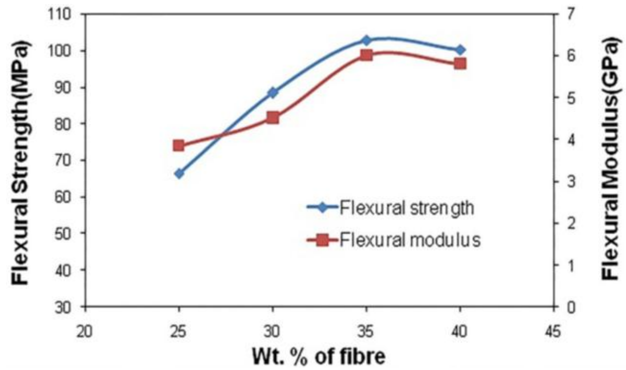

Fig.6. Effect of fibre loading on flexural properties of composite having 10mm fibre length.

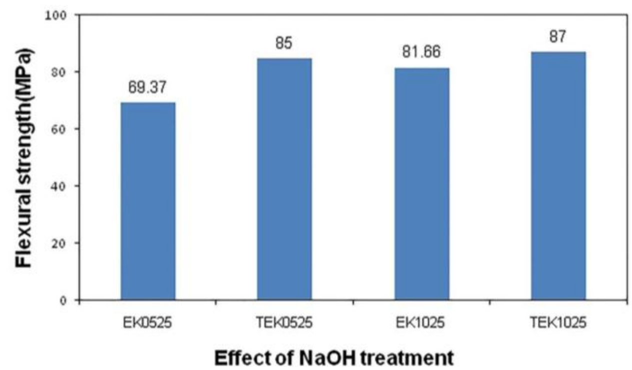

Fig. 7. Effect of NaOH treatment on flexural strength of composites having 5mm and 10 mm fibre length at 25% fibre loading.

Fig. 7 shows the effect of NaOH treatment on the flexural strength. The composite reinforced with 6% NaOH treated kenaf fibre showed improvement in flexural strength as compared to untreated kenaf fibre composites. Effect of NaOH treatment on flexural strength showed a similar trend as tensile strength. The composite with 5mm length treated kenaf fibre showed an improvement of 22.53% as compared to untreated kenaf fibre composite.

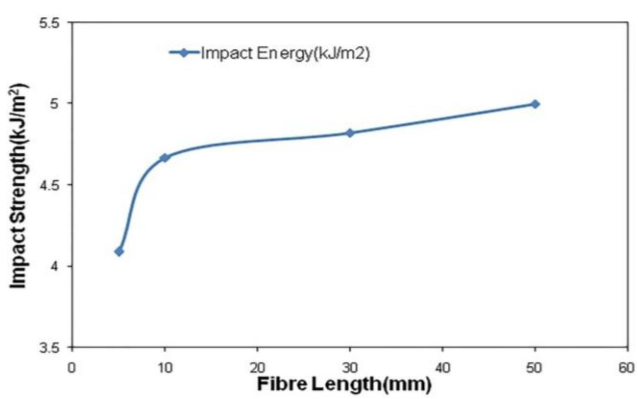

Fig. 8. Effect of fibre length on impact strength at 25% fibre loading.

Fig. 8 shows the variation of impact strength of composite with the change of fibre length. The increase in

Impact strength of the composites was observed by increasing the length of kenaf fibres. By changing the fibre length from 5 to 10mm, impact strength increased by 14.14%. After that, it increased with a constant rate of 3.5%. The maximum impact strength of 5kJ/m^2 was found in composite with 50mm fibre length. The low impact strength of shorter fibres composites may be due to the presence of too many fibre ends within the composites, which could induce crack initiation because of stress concentration points at the region around fibre ends.

Fig. 9 shows the variation of impact strength of composite with the change of fibre loading. Composite with 40% fibre loading showed the highest impact energy of 7.53 kJ/m^2. Impact energy increased with the increase in fibre loading percentage in the composite. This trend may be due to the elimination of voids in the composites and applied stress was transferred efficiently due to effective interfacial bonding strength.

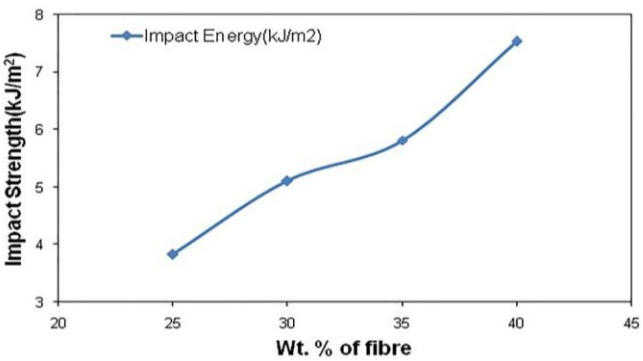

Fig. 9. Effect of fibre loading on impact strength of composite having 10mm fibre length.

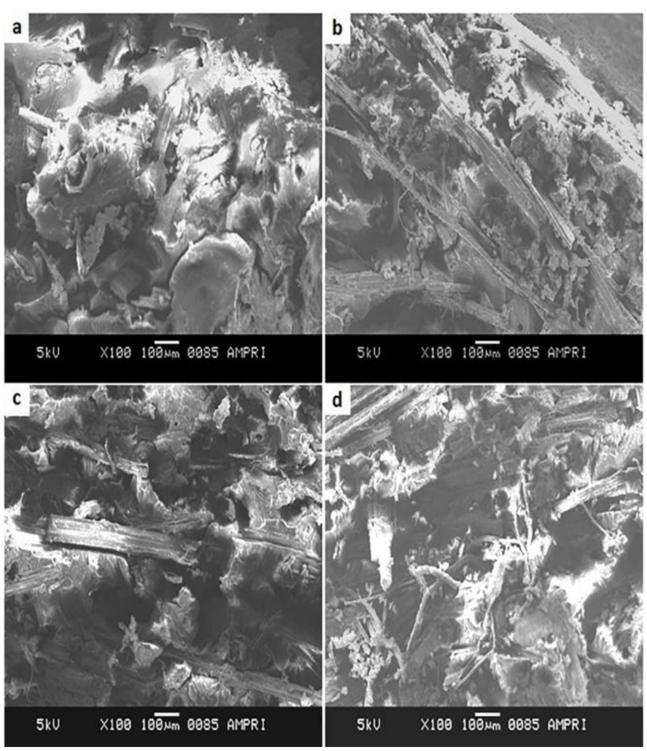

Fig. 10. SEM micrographs of tensile fractured surfaces of kenaf fibre epoxy composite with different fibre loading (25, 30, 35 and 40wt %).

Scanning electron micrographs (SEM) of tensile fractured alkali treated kenaf fibre reinforced epoxy composites are shown in **Fig. 10** for different fibre loadings a) 25, b) 30, c) 35 and d) 40wt %, number of fractured fibres could be observed with the increased loading of fibres in the matrix. Fibres are distributed randomly and therefore longitudinal surface, cross sectional views etc. can be easily observed in each of the fractograph. The fractographs show fibre-matrix interface, fibre pull out, splitting of fibre ends and debonding etc in the different specimen. It is observed that adhesion between the fibre and matrix is strong. In **Fig. 10(a)** cracks were observed in the matrix for composite having 25wt % fibre loading. Fractographs of the samples having higher concentration of kenaf fibres exhibits the higher amount of fractured fibres that indicates excellent bonding between the reinforcement and matrix due to which stresses were transferred to fibres causing improved mechanical properties namely tensile, flexural as well as impact strength of composites.

SEM micrographs of tensile fractured kenaf fibre reinforced epoxy composites are shown in **Fig. 11** for different fibre lengths (5, 10, 30 and 50 mm). **Fig. 11(a)** represents the composite having 5 mm fibre length mostly straight fibres were observed depicting less influence to the fibres caused by process parameter particularly the mixing of fibres with resin. **Fig. 11(b)** represents composite having 10 mm fibre length, some straight fibres were observed as in **Fig. 11(a)** but there was splitting as well as folding in some of the fibres. **Fig. 11(c)** and **Fig. 11(d)** represent composites having fibre lengths of 30 and 50 mm. The Longer fibres were found folded at many places that happened during mixing and compression process. In **Fig. 11(d)** splitting of fibre into fine fibrils was also observed. The mechanical properties of the composite having longer fibres were found better than those of shorter length fibre reinforced composites.

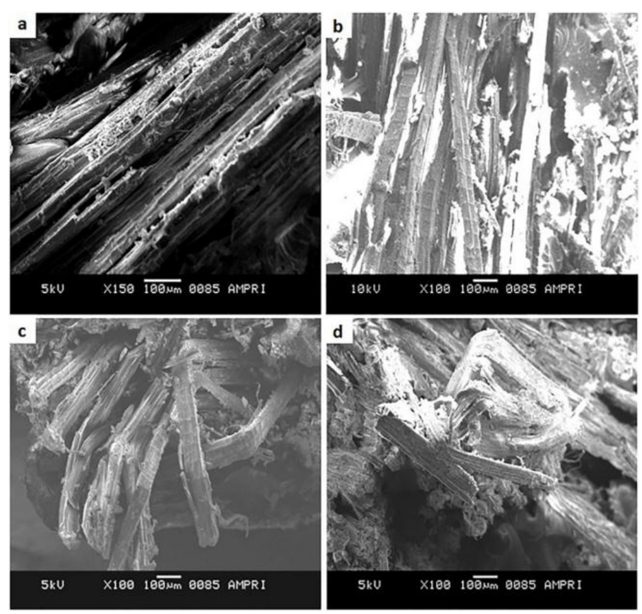

Fig. 11. SEM micrographs of tensile fractured surfaces of kenaf fibre epoxy composite with different fibre lengths (5, 10, 30 and 50 mm).

Significant increase in mechanical properties was observed while changing the length of fibre from 5 to 10 mm that may be attributed to a smaller number of stress concentration points those occurred at fibre ends. The similar improvement was not observed in the specimen having 30 or 50 mm length because of another factor, particularly the limitation of processing parameter, due to which fibres could not remain straight and folds were observed. Moreover, the composites having shorter fibres as compared to longer fibres shall have better dispersion and homogeneity that may also affect the mechanical properties of composites. Due to such inhomogeneity and folds, there might be many stress concentration points which nullifying the effect of longer fibres.

Fig. 12 represents scanning electron micrographs of tensile fractured surfaces of untreated kenaf fibre and treated kenaf fibre composites. **Fig. 12 (a)** shows that fibres are clean and have little traces of epoxy resin on them whereas **Fig. 12 (b)** clearly shows that fibre having traces of epoxy resin on them representing better bonding between fibres and matrix due to better physical locking and chemical bonding. Better bonding results in better load transfer from matrix to fibres, thus resulting superior mechanical properties in case of treated kenaf fibre composites.

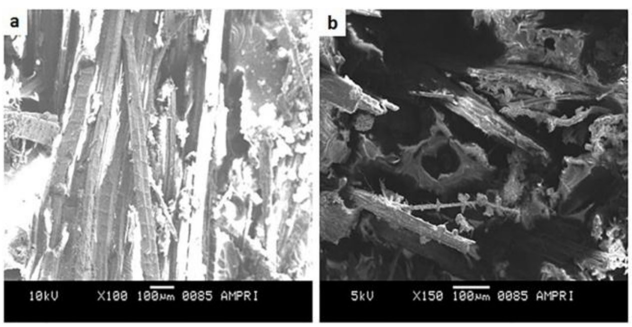

Fig. 12. SEM micrographs of tensile fractured surfaces of untreated and treated kenaf fibre epoxy composites.

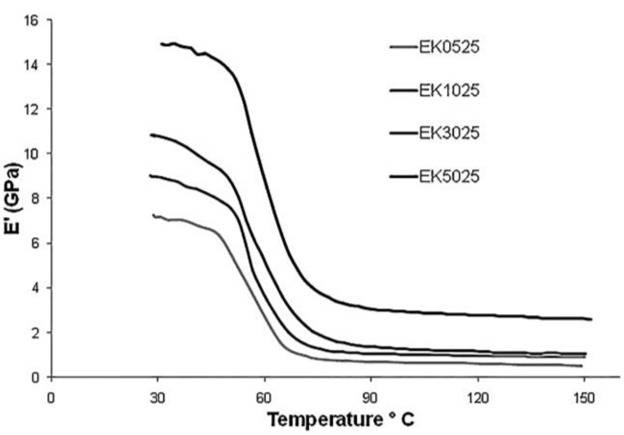

Fig. 13. Effect of varying fibre length on storage modulus with temperature of kenaf epoxy composite.

Fig. 13 shows the variation of storage modulus E' with temperature of kenaf-epoxy composite with the change of fibre length (5- 50 mm) at constant 25wt % loading of fibres. Storage modulus is a measure of stiffness and load bearing capability of a composite material. On comparing different composites higher E' values were found for longer fibres at low temperature. At higher temperature the storage modulus drops due to loss in stiffness of the matrix. A sharp decrease in E' value was being observed in the vicinity of the glass transition temperature (T_g) indicating material is going through glass/rubbery transition stage. E' value is directly proportional to the interface bonding [**16**]. The results show better interface bonding with the increasing fibre length in the composite due to effective stress transfer between fibre and matrix. The E' at 150 °C of EK5025 was found to be about 2.62 GPa higher than EK0525 (0.521 GPa).

Fig. 14 shows the variation of loss modulus E" with temperature of composites with the change of fibre length (5- 50 mm) at constant 25wt % loading of fibres. Loss modulus E" represents the viscous response of the material, its ability to dissipate energy in the form of heat or molecular rearrangements during deformation. Loss modulus E" increased in the plastic region, and then started decreasing with increasing temperature in the rubbery region. Loss modulus E" also showed similar trends as in case of storage modulus E', highest value of E" max observed for EK5025 and lowest for EK0525. The T_g obtained from E" curve is shown in the **Table 2**. The T_g value obtained from E" showed an increasing trend with the increase of length of fibres in the composite, showing better ability of composite to dissipate energy during the deformations.

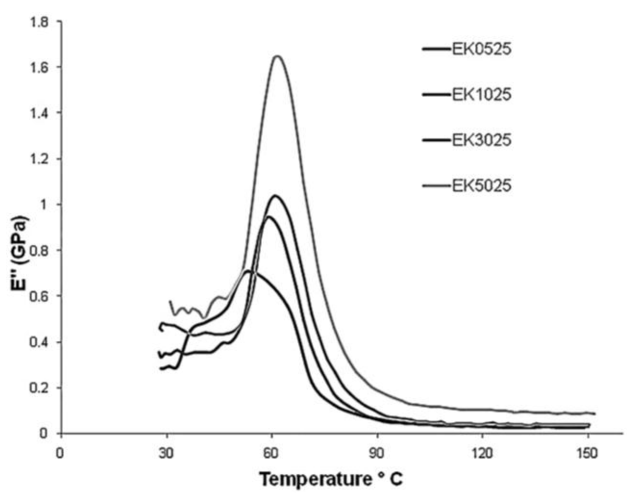

Fig. 14. Effect of varying fibre length on loss modulus with temperature of kenaf epoxy composite.

Damping factor (Tan δ) is the ratio of loss modulus E" and storage modulus E'. Tan δ depends on the fibre-matrix adhesion; higher Tan δ value indicates weaker fibre-matrix adhesion. Lower Tan δ value indicates higher load bearing capacity of the composite [**17**]. Better fibre-matrix interface bonding reduces the mobility of the molecular chain at the interface thus a reduced damping factor is obtained.

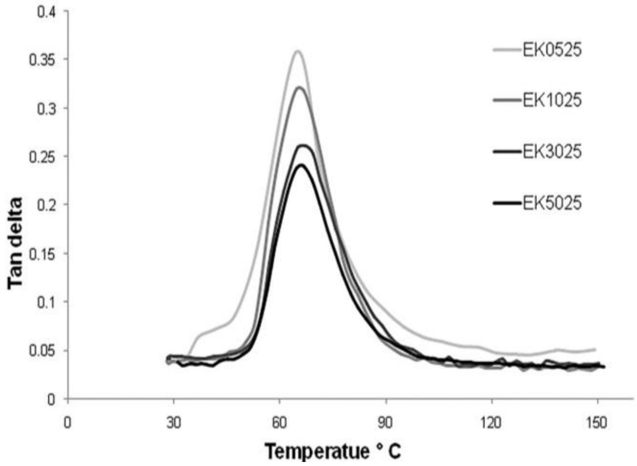

Fig. 15. Effect of varying fibre length on damping factor with temperature of kenaf epoxy composite.

Fig. 15 shows the variation of Tan δ value with temperature of composites with the change of fibre length (5- 50 mm) at constant 25wt % loading of fibres. The Tan δ peak height decreased with the increase of the fibre length indicating lower damping and better fibre-matrix adhesion. The T_g obtained from Tan δ max. is shown in the **Table 2**. The value of T_g from Tan δ max. of composite also showed an increasing trend with the increase of fibre length in the composites, T_g for EK0525 was found to be 64.49 °C whereas for EK5025 it was 68.98 °C.

Table 2. Tan δ_{max} (T_g) and E"$_{max}$ (T_g) of kenaf fibre reinforced epoxy composites.

Composite	Temperature (°C)	
	T_g from Tan δ_{max}	T_g from E"$_{max}$
EK0525	64.49	53.27
EK1025	64.68	58.57
EK3025	67.17	61.03
EK5025	68.43	62.47

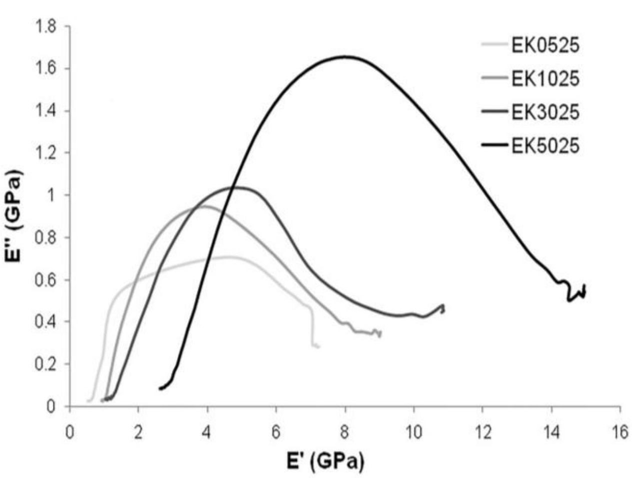

Fig. 16. Cole-Cole plots of kenaf epoxy composites.

Fig. 16 shows the Cole-Cole plots where loss modulus E" data are plotted as function of storage modulus E' for composites having different fibre lengths (5- 50 mm) at constant 25wt % loading of fibres. Cole-Cole plots are reported to be indicative of homogeneity of the system [**18**]. A semi- circular diagram shows homogeneous polymeric system [**19**].

The elastic properties of natural fibre reinforced composites can be estimated from various micromechanical models. Properties such as Young's modulus (E), Poisson's ratio (ν) and volume fraction of both fibre and matrix are used to predict the properties of the composite material. In this paper following models were tested to predict the Young's modulus of the studied material.

Rule of mixtures (ROM): Rule of mixture [**20**] predicts elastic properties of the composite material. The young's modulus E_1 of composite is given by equation -

$$E_1 = E_F V_F + E_M V_M \quad (1)$$

E_F, E_M, V_F and V_M are Young's moduli and volume fractions of the fibre and matrix materials.

Halpin – Tsai Equations: The Halpin-Tsai model [**21, 22**] was proposed by Halpin and Kardos, which was originally based on the Hill micromechanical model. This model is used to predict the elastic properties of the composite materials as per following relations-

$$P/P_m = \frac{1+\xi\eta V_r}{1-\eta V_r} \quad (2)$$

$$\eta = \frac{(P_r/P_m)-1}{(P_r/P_m)+\xi} \quad (3)$$

P = composite properties (E_{11}, E_{22}, G12,G23), P_r= Reinforcement properties (E_r,G_r), P_m= Matrix properties (E_m, G_m), ξ = A measure of reinforcement geometry, packing geometry and loading conditions, V_r=Reinforcement volume fraction, ξ Factor is obtained by comparing the Halpin-Tsai equations with numerical solution of Micromechanics equations.

$$\xi = 2\, l/t + 40\, V_r^{10} \text{ for } E_{11} \approx \xi = 2(l/d) \quad (4)$$

$40\, V_r^{10}$ is a very small value.

For circular fibre- $l = l_f$ and $t = w = d_f$

Nielson-Chen Model: Nielson-Chen model [**23**] predicts the elastic properties of random fibre reinforced composites. The equation is expressed as follows.

$$E_c = 3/8 E_1 + 5/8 E_2 \quad (5)$$

$$E_1 = E_f V_f + E_m [1 - V_f] \quad (6)$$

$$E_2 = \frac{E_f E_m}{E_f[1-V_f] + V_f E_m} \quad (7)$$

$V_f -$ Fibre volume fraction
$E_m, E_f -$ Modulus of matrix and fibre
$E_C -$ Modulus of composite

Approximation Model by Manera: Another model proposed by Manera [**24**] predicts the elastic properties of randomly oriented short glass-fibre composites. The invariant properties of composites defined by Tsai and Pagano were used along with Puck's micromechanics formulation. Manera simplified Puck invariants equations and the approximate equations can be expressed as follows.

$$E_C = V_f(16/45E_f + 2E_m) + 8/9E_m \quad (8)$$

V_f − Fibre volume fraction

E_m, E_f − Modulus of matrix and fibre

E_C − Modulus of composite

Young's moduli of composites with different fibre loading (25 to 40%) obtained by experimental method were compared with the predicted values derived from different micro-mechanical models as shown in **Fig. 17** and average relative error between them was calculated. Rule of mixture (ROM) showed the maximum deviation from the experimental data with an average relative error of 34.60%. Modulus predicted by ROM was higher than the experimental modulus. Halpin-Tsai model showed an average relative error of 20.56%. The error was found minimum for 35% fibre loading then started deviating as the volume fraction increased. Nielson-Chen model showed an average relative error of 17.65% from the experimental values. This method also showed the same trend as Halpin-Tsai method that the relative error becomes higher after 35% fibre loading. Approximation model by Manera was found to be most accurate among all the models with only 7.79% average relative error. The relative error of 0.589% was found for 35% fibre loading composite almost equivalent to the experimental value.

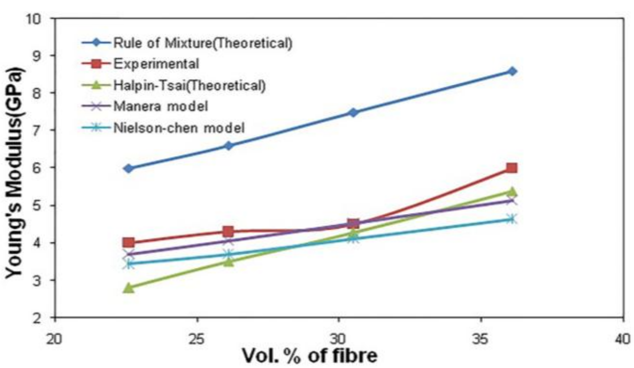

Fig. 17. Comparison between experimental results vs. micro-mechanical models results.

Conclusions

Kenaf fibre reinforced epoxy composites were developed using compression molding method. Mechanical test results showed that increase of fibre length in the composite resulted in better tensile, flexural and impact properties. The maximum length of kenaf fibre used in the present study was 50 mm at 25% fibre loading, the tensile, flexural and impact strength was found as 56.54 MPa, 100.4 MPa and 5 kJ/m^2 respectively. The increase in fibre loading also showed the same trend, the mechanical properties increased with the increase in fibre concentration. 40% fibre concentration was found optimum, results showed that increasing concentration further will result in the decrease of flexural properties and there was no proper wetting of fibres. The alkali treatment with 6% solution showed better results with improvement up to 36.2% in tensile strength. The storage moduli increased with increase in fibre lengths, showing effective stress transfer between fibres/matrix and better interface bonding. An increasing trend in loss modulus upon increasing the fibre length was observed. Tan δ peak height lowered with increasing fibre length showing lower damping and good fibre/matrix adhesion in it. Different micromechanical models which have been used to predict properties of synthetic fibre composites were applied to kenaf fibre epoxy composites. Approximation model by Manera was found very accurate in predicting the elastic properties, suggesting that analytical methods can be successfully used to predict properties of natural fibre composites reducing costly and time-consuming experiments.

Reinforcement of the future

Kenaf fibre reinforced epoxy composite has excellent tensile strength combined with superior flexural strength concluded by several mechanical testing and micro-mechanical models enabling it to utilize in various applications such as automobile industry, light weight constructional applications, building materials. Comparable modulus and strength of kenaf epoxy composite with glass fibre composite shows potential of kenaf fibre as an alternative medium to replace conventional materials and synthetic fibres as reinforcement in composites. Low water requirement with growing cycle of 150 to days can helps farmers to use kenaf as a cash crop with many ecological advantages. Dynamic mechanical analysis showed improvement in T_g values of composites indicating its potential for high temperature materials and future research scopes. Light weight, low cost and ecological considerations make kenaf fibre composites as a great alternative composite material especially in building and construction industry. Metal wired bound kenaf epoxy composite pressure vessels and pipes could replace conventional metal and synthetic fibre materials. The future work would be synthesizing of composite materials and nano- composite from kenaf fibre along with biodegradable resin with superior mechanical properties.

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