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Developing Hybrid Bio-composites from Kenaf / coir natural fibers Reinforced Thermoset unsaturated polyester: Mechanical properties.

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ABSTRACT

Natural fibers reinforced polymer composites have widely attracted researchers and manufacturers because of the advantages of natural fibers, such as high toughness, high strength and stiffness with fibers low density, and biodegradability. Many techniques have been used and developed to manufacturing kenaf bio-composites, but still at the earlier stages especially with the thermoset polymers, due to the difficulties during the manufacturing processes with high temperatures for curing the polymers in a rapid time or to reach the mass products rate for complicated products having multi wall thickness. The purpose of this study was to develop Hybrid Bio-composites from Kenaf/Coir natural fibers Reinforced Thermoset unsaturated polyester using bulk molding compound manufacturing methods to produce multi wall thickness, complex shapes and to study the effect of hybridizing with Coir fibers on the mechanical properties. The tensile results showed that Kenaf /Coir % of weight (85/15) had the highest values from all formulations, and reached the maximum at 15.07 MPa of 25% mixed fibers /65% matrix measured by weight. Flexural results showed the same trends behavior as the tensile test and the maximum value was observed at (85 Kenaf weight % / 15 Coir weight %) of mixed fibers reinforced 65% weight of unsaturated polyester and reached 49.55 MPa among all formulations. Impact test values reached maximum values at 55% weight of unsaturated polyester, with highest impact performance (9.19 KJ/M^2) were recorded on 35% weight of mixed fibers (55 Kenaf weight % / 45 Coir weight %). The Coir fibers were significantly increased the impact values for all formulations.

INTRODUCTION

Kenaf (Hibiscus Cannabinus L.) is one of the Malvaceae family's members. Kenaf grows in warm regions like cotton and jute. The origin of Kenaf is believed to be Africa, specifically, western Sudan, where since 4000 B.C. (Sellers, 1999).

Kenaf fibers composites have a favorable tensile properties compared to the glass fiber composites and other natural fibers composites such as coir sisal hemp, while the impact properties is much lower(Aji, 2013and Paul, 2003).To increase the mechanical properties of thee natural fibers composites several methods have been used. Natural fibers chemical treatments such as treating natural fibers with silane were used to increase the interfacial shear stress between the fibers and the matrix (Xue Li *et al*., 2007), (Xie *et al*., 2010), (Kabir *et al*.

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2011) and(Akampumuza *et al*. 2013) (Venkateshwaran *et al*., 2013). The main aim of hybridization is to highlight the favorable properties of these involved materials and try to improve those properties; by hybridizing the natural fibers with other natural or synthetic fibers researchers try to increase the mechanical performance of these bio composites. For the thermoset polymers and specifically unsaturated polyester there were several attempts to reinforce it with hybrid fibers to increase its mechanical properties, by using Kapok/glass fibers (Venkata Reddy *et al*. 2008), Kapok/Sisal (Venkata Reddy *et al*. 2008) Sisal/Glass fibers (John and Naidu, 2004), Kenaf/Glass fibers (Atiqah *et al*., 2014), Banana/Kenaf fibers (Thiruchitrambalam*et al*., 2009) and Coir/Silk fibers (Noorunnisakhanam *et al*., 2010).
The needs of the mass production technologyfor a complicated shapes with malty wall thicknesses, accurate and dimensions stability, Specifically in thermoset composites manufacturing techniques, where a high temperatures eeds to complete the curing process of thermoset polymers in a short time, the researcher was motivated to develop and manufacture hybrid bio-composites by hybridizing kenaf reinforced unsaturated polyester with Coir fibers using Bulk Molding Compounds (BMC) technique in order to meet these needs.

MATERIALS AND METHOD

Fiber preparation:

The kenaf and Coir raw fibres were collected with a lot of dirt, stalks and impurities mixed with the ply, to purify the raw fibres, cleaning processes were conducted in which the raw fibres were handily cleaned and arranged into separated bundles of these fibers. These bundles of (kenaf and coir) were cut to (15mm) using cutting machine. This cutting machine was manufactured in a local company and the part of the machine is showed in Figure 1(A and B), using pneumaticactuator controller and magnetic sensors to control the sequences of the cutting process.

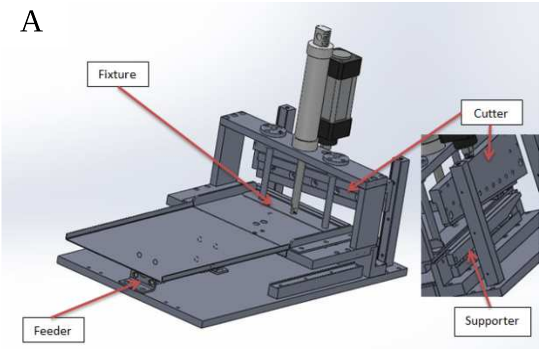

Fig. 1: Fibers Cutting Machine

After preparing the Kenaf and Coir fibers in (15mm) of length, the fibers were treated with 6% w\w concentration of silane (S. Sreenivasan *et al*., 2014). The kenaf and coir fibers were immersed separately in silane solutions for 24 hours, and subsequently washed with running water. The final process before manufacturing the samples is drying the kenaf and coir fibersat 85 °C for 24 hours using laboratory oven.

Matrix preparation:

The wet mixing compounds (resin, LP1 (Styrene monomers), PBQ (Para-Benzoquinone), Trig C (tert-Butyl peroxybenzoate), Trig 21-OP 50 (tert-Butyl peroxy-2-ethylhexanoate and SAk as releasing agent) have been supplied by local company (WAH MA CHEMICAL SDN. BHD), table 1 illustrates the name,weight percentage of these compounds, mixing the matrix components were carried out for 10 minutes using Shear Rotor Stator.

The mould is designed as a one open plate; plate thickness is (3mm). Plate was cut to form four square holes to give the square shape to the molded samples, the length and width (15 cm x 15 cm), respectively.

Table 1: Name and Weight Percentage of Matrix Compounds

Components	Weight %
Resin	66.3%
LPI	28.50%
PBQ	0.025%
Trig C	0.48%
Trig-21OP50	1,055%
SAK	3.64%

Mixing the hybrid bulk compounds and molding processs:

Treated two fibers (Kenaf, Coir) were mixed using industrial planetary mixerin three different weight percentage (85/15, 70/30 and 55/45 % of weight Kenaf/Coir), the mixing process were carried out for 15 minutes, while the total mass were fixed to be 90 gm for the mixed fibers for each mixing ratio.

The matrix were added after 15 minutes of fibers mixing process, mixed fibers weight were (15/75, 25/65, 35/55) to the matrix components weight (F/M) % and final step is adding the additives (5% of $Al(OH)_3$ and 5% of $CaCo_3$) measured by weight also, the additives were fixed as (5% of $Al(OH)_3$ and 5% of $CaCo_3$) measured by weight for all formulations. The adding process and mixing of matrix with mixed fibers and additives took 20 minutes. Table 2 illustratessamples names and weight ratio of fibers and matrix.

Using molding compression process, the samples were fabricated. All the mixed bulk compounds were preheated in the hot press machine for 1 minute and 30 seconds on 170 ^{0}C and then at the same temperature were pressed inside the square plate mold with 75 bar of pressure for 2 minutes then cold down cold plate of the press machine for 4 minutes.

Mechanical tests (Tensile, Flexural and IzodImpact):

All the samples were measured and cut regarding to the ASTM standards, table 3 show the dimensions of the samples and ASTM standards numbers. Five specimens were tested for each sample and results of the mean and the standard deviation error were calculated and plotted out in figures. Using a 5-kN Instron Universal testing machine (USA) to conduct the tensile and flexural test, for tensile and flexural tests, the cross-head displacement speed rate were fixed at 0.5 and 1.5 mm/min respectively.

The notch that leaves 10.16 +/- 0.05 mm of material was made for Izod impact test samples using notching machine.

Table 2: Names and Weight Ratio of Samples Compounds

Samples names	kenaf%/ Coir %	Mixed fiber%/ matrix%	mass of matrix gm
K55C45U55	55/45	35/55	142
K55C45U65	55/45	25/65	234
K55C45U75	55/45	15/75	450
K70C30U55	70/30	35/55	142
K70C30U65	70/30	25/65	234
K70C30U75	70/30	15/75	450
K85C15U55	85/15	35/55	142
K85C15U65	85/15	25/65	234
K85C15U75	85/15	15/75	450

Table 3: Dimensions of Samples and ASTM Standards Numbers

Tensile Test ASTM D 3039/3039M-00		
Length (mm)	Width(mm)	Thickness (mm)
150	21.5	3
Flexural Test ASTM ASTM D 790-00		
100	14	3
IzodImpact Test ASTM D 256		
65	12.5	3

Finally statistical analysis was implemented using Analysis of variance (ANOVA) of two factors (coir to kenaf fibers loading and fibers to matrix loading) with 5 replications. All the 5 specimens of each sample were included in the analysis for each mechanical test.

RESULTS AND DISCUSSION

Tensile Test:

Figure 2 shows the results of the maximum tensile stress and the elastic modulus of the 9 samples.

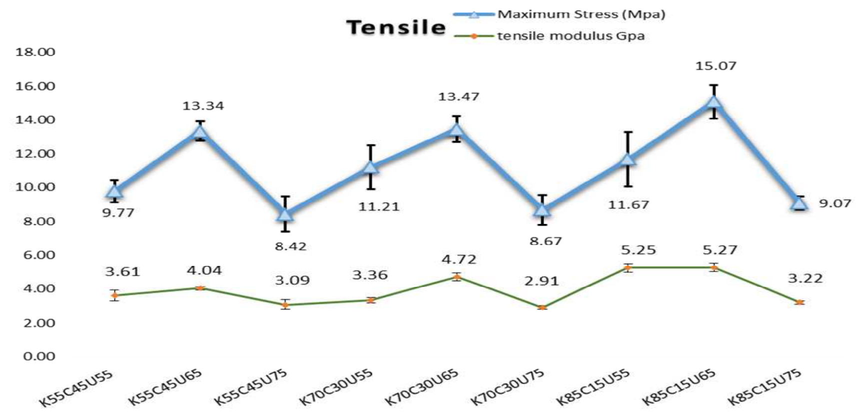

Fig. 2: Maximum tensile stress (Mpa) and tensile modulus (Gpa)

As shown in figure 2, the tensile stresses were increased by increasing the kenaffiber ratio to the coir fibers. However, fibers / matrix ratio had the significant effects on the tensile result compared to the kenaf/coir ratio, where the maximum values obtained with 25% of mixed fibers to 65% of matrix and reached the maximum (15.07 Mpa) between all formulations when the kenaf fibers to Coir fibers ratio where 85/15 % of weight. On the other hand, increasing the mixed fibers to the matrix ratio to 35/55 % of weight reduced the tensile stresses, because of the poor wetting of the fibers by the matrix leading to poor interaction between the fibers and the matrix during loading as a one system. When the mixed fibers reduced to the lowest values 15% of weight and the matrix increased to the highest values 75% of weight the tensile stresses were decreased and showed the lowest values between all formulations, thus due to the poorappearances of the reinforced mixed fibers in the hybrid composites leading to poor loads transfer from the matrix to the fibers and the system were unable to hold the stresses during loading (Thiruchitrambalam, 2009).

With similar stresses behavior, modulus behavior was observed as shown in figure 1. Where the highest values obtained from the formulations that contained 25% of mixed fibers to 65% of matrix and reached the maximum value (5.27Gpa) when kenaf/coir ratio was 85/15 % of weight. While, the formulations that contained 15% of mixed fibers to 75% of matrix showed the lowest modulus values. However ANOVA statistical analysis indicatedthere were no significant differences among the samples (Factor: kenaf / coir %), with a p-value of 0.19656, but there were significant differences when the matrix loading were increased (columns) with a p-value of 3.7134E-07, while there were no significant interactions between rows and columns as shown in figure 3. The changing of coir fibers to kenaf fibers ratio did not affect significantly on the tensile properties compared to the effects of increasing mixed fiber loading to matrix ratio.

SUMMARY	u55	u65	u75	Total
k55/C45				
Count	5	5	5	15
Sum	48.87103	66.68902	42.12427	157.6843
Average	9.774206	13.3378	8.424854	10.51229
Variance	2.143116	1.570864	5.298807	7.177113
K70/C30				
Count	5	5	5	15
Sum	56.03336	67.32971	43.36645	166.7295
Average	11.20667	13.46594	8.67329	11.1153
Variance	6.438004	2.775683	3.702051	7.796382
K85/C15				
Count	5	5	5	15
Sum	58.37495	75.3565	45.35374	179.0852
Average	11.67499	15.0713	9.070748	11.93901
Variance	12.97259	4.980389	0.790484	11.82237
Total				
Count	15	15	15	
Sum	163.2793	209.3752	130.8445	
Average	10.88529	13.95835	8.722964	
Variance	6.858711	3.331339	2.873344	

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sample	15.38834	2	7.694172	1.702586	0.19656	3.259446
Columns	207.643	2	103.8215	22.97388	3.71E-07	3.259446
Interaction	4.811214	4	1.202804	0.266159	0.897765948	2.633532
Within	162.688	36	4.51911			
Total	390.5305	44				

Fig. 3: ANOVA Analysis for Tensile Stresses

Australian Journal of Basic and Applied Sciences, 10(14) September 2016, Pages: 333-340

Flexural Test:

Figure 4 shows the results of the maximum flexural stress and the flexural modulus of the 9 samples.

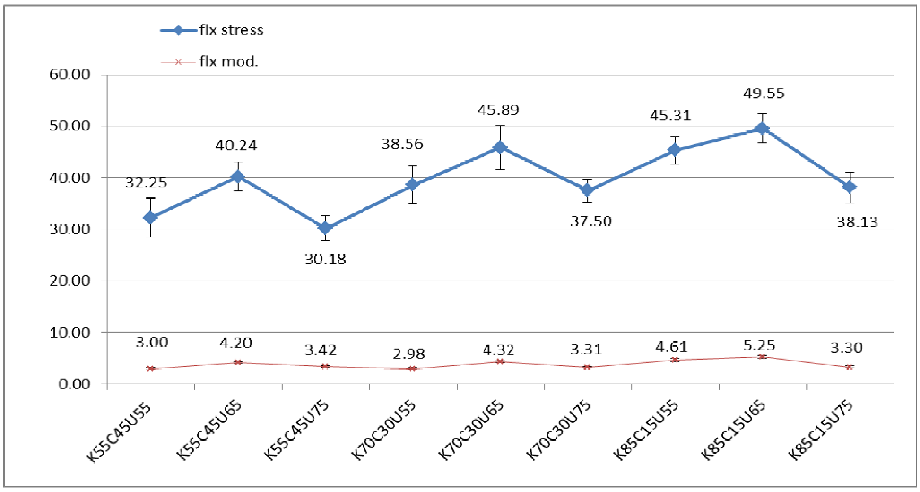

Fig. 4: Maximum Flexural stress (Mpa) and Flexural modulus (Gpa)

From figure 4 can be notice that the flexural stresses were increased by increasing kenaf fibers amounts to coir fibers in all samples. But the highest results reflected by the combinations of 25% mixed fibers/65% of matrix measured by weight, and reached the optimum result (49.55 Mpa) when the kenaf/coir ratio was 85/15. By decreasing the mixed fibers amount to 15% and increasing the matrix to 75% the flexural stresses were decreased noticeably, due to the absence of reinforcement fibers which led tofavorite the brittle nature of the matrix.However, increasing the mixed fibers/ matrix ratio to 35/55 also reduced the flexural stresses values, where the amount of matrix was insufficient to perform a good wettability on the mixed fibers which reduced the adhesion between the fibers and the matrix making the composite system weaker and the fibers were pulled out in a lower range of loading stresses.

The flexural modulus observed to have its maximum values when the mixed fibers/matrix ratio was 25/65 in similar scenario as flexural stress and reached the optimum of (5.25 Gpa)when kenaf/coir ratio was 85/15.

Figure 5 show ANOVA statistical analysis. The analysis indicated there were asignificant differences among the samples (Factor: kenaf / coir %), with a p-value of 0.0079667;there were significant differences when the matrix loading were increased (columns) with a p-value of 0.00056, while there were no significant interactions between rows and columns as shown in figure 5. Although the changing of coir fibers to kenaf fibers ratio had a significanteffect on the flexural stresses, but it was smaller compared to the effects of increasing mixed fiber loading to matrix ratio.

SUMMARY	u 55	u 65	u 75	Total
k55/C45				
Count	5	5	5	15
Sum	188.82	201.18	150.91	540.91
Average	37.764	40.236	30.182	36.06066667
Variance	40.66433	41.20533	29.20722	51.34106381
K70/C30				
Count	5	5	5	15
Sum	192.81	229.47	176.57	598.85
Average	38.562	45.894	35.314	39.92333333
Variance	67.76772	91.81438	25.57643	73.88388095
K85/C15				
Count	5	5	5	15
Sum	226.57	247.75	190.66	664.98
Average	45.314	49.55	38.132	44.332
Variance	37.54523	39.0829	44.27792	58.34167429
Total				
Count	15	15	15	
Sum	608.2	678.4	518.14	
Average	40.54667	45.22667	34.54267	
Variance	53.99694	64.90192	39.90819	

ANOVA

rce of Varia	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sample	513.8575	2	256.9287	5.543343834	0.0079667	3.259446
Columns	860.4914	2	430.2457	9.282728981	0.00056095	3.259446
Interactior	40.87547	4	10.21887	0.220476286	0.925262405	2.633532
Within	1668.566	36	46.34905			
Total	3083.79	44				

Fig. 5: ANOVA Analysis for Flexural Stresses

Australian Journal of Basic and Applied Sciences, 10(14) September 2016, Pages: 333-340

Izod Impact:

Figure 6 shows the results of the maximum flexural stress and the flexural modulus of the 9 samples.

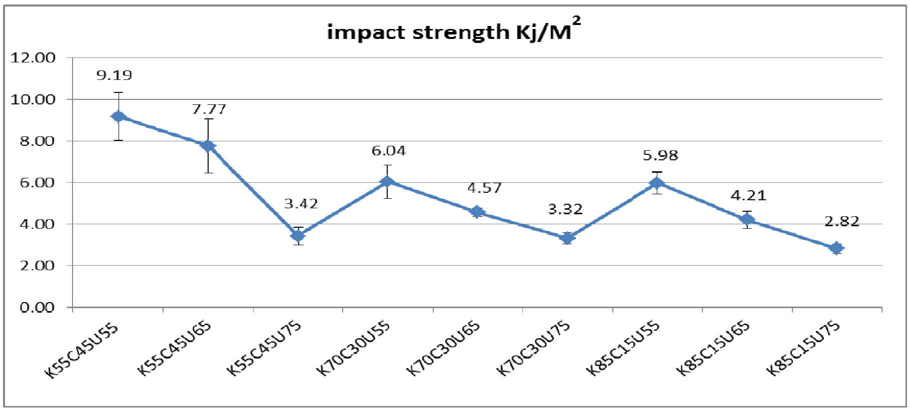

Fig. 6: Impact strength KJ/M^2

As can see, the impact results were increased by increasing the mixed fibers to the matrix ratio for all samples, and reached the maximum values (9.19, 6.04 and 5.98) KJ/M^2 at mixed fiber/matrix ratio of 35/55 % of weight and with kenaf/coir ratio (55/45, 70/30 and 85/15) % of weight respectively. Contrary, decreasing mixed fiber contents or coir fibers amount led to decreases in the impact properties of the hybrid composites, which is reflect a noticeable improving in the impact properties by hybridizing kenaf fibers with coir, where the coir fibers showed an impressive ability to resist the impact loads and absorb the impact energy compared to kenaf fibers. This was due to perfect fiber-to-fiber contact when which improve the load transferring from matrix to thefibers from the surface where the impact loads concentrate to the whole hybrid system, and the fibers pull out reaction to the impact loads were improved by the addition of coir, where most probably the coir fibers increased both the contacts between the mixed fibers and the matrix and also increased the required absorbed energy to weaken the hybrid composites(Beckermann, 2007) and(Aziz & Ansell 2004)1 and 2)., knowing that the coir fibers diameters (100-450) μm(Verma*et al*. 2013) were much higher than the kenaf fibers (17.7-21.9) μm(Idicula *et al*. 2006)and(Mohanty *et al*. 2005), that is what most likely the reason of better contact and better pull out resistance.

Figure 6 show ANOVA statistical analysis. The analysis indicated there were a significant differences among the samples (Factor: kenaf / coir %), with a p-value of 0.000117.

There were significant differences when the matrix loading were increased (columns) with a p-value of 2.38E-07, while there were no significant interactions between rows and columns as shown in figure 6. Although the changing of coir fibers to kenaf fibers ratio had a significant effect on the impactstrength, but it was smaller compared to the effects of increasing mixed fiber loading to matrix ratio.

SUMMARY	u 55	u 65	u 75	Total
K55/C45				
Count	5	5	5	15
Sum	45.93	38.82723	17.10677	101.864
Average	9.186	7.765447	3.421353	6.790933
Variance	6.57268	8.305833	0.973823	10.97213
K70/C30				
Count	5	5	5	15
Sum	30.21504	22.27898	16.58362	69.07765
Average	6.043008	4.455797	3.316725	4.605176
Variance	2.842094	0.281566	0.286215	2.313458
K85/C15				
Count	5	5	5	15
Sum	29.43694	21.04288	14.08693	64.56675
Average	5.887388	4.208575	2.817386	4.30445
Variance	0.721108	0.851378	0.301092	2.223252
Total				
Count	15	15	15	
Sum	105.582	82.14909	47.77732	
Average	7.038799	5.476606	3.185155	
Variance	5.370188	5.514203	0.520449	

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Sample	55.25284	2	27.62642	11.76383	0.000117	3.259446
Columns	112.7088	2	56.35441	23.99672	2.38E-07	3.259446
Interaction	19.87175	4	4.967937	2.115437	0.099007	2.633532
Within	84.54316	36	2.348421			
Total	272.3766	44				

Fig. 6: ANOVA Analysis for Impact strength

Conclusions:

- An innovative hybrid bulk molding compound has been developed successfully by hybridizing short kenaf fibers (15 mm length) with short coir fibers (15 mm length) to reinforce modified unsaturated polyester.
- Tensile and flexural strength were optimized at 25 mixed fibers/65 matrix % of weight, while the lowest results obtained when the mixed fibers amounts reduced to 15 % of weight.
- Impact strength increased by increasing mixed fibers amount and reached the maximum at 35 % of mixed fibers among other ratios. On the other hand, the impact properties were impressively increased by increasing Coir fibers amount.
- ANOVA analysis showed there were no significant interactions between samples (Factor: kenaf / coir %) and columns(Factor:matrix loading %) for all mechanical tests results. However, for the tensile stresses there were significant differences when the matrix loading were changed and no significant differences among the samples, for flexural and impact results there were significant differences in both factors (kenaf/coir % and matrix loading %).

REFERENCES

Aji, I., E. Zainudin, K. Abdan, S. Sapuan and M. Khairul, 2012. Mechanical properties and water absorption behavior of hybridized kenaf/pineapple leaf fibre-reinforced high-density polyethylene composite. Journal of Composite Materials, 47: 979-990.

Akampumuza, O., S. Peng and W. Li, 2013. Characterization and Analysis of Silane Treatment on the Morphological and Absorption Properties of Banana Fibers. AMR 821-822, 144-148.

Atiqah, A., M. Maleque, M. Jawaid and M. Iqbal, 2014. Development of kenaf-glass reinforced unsaturated polyester hybrid composite for structural applications. Composites Part B: Engineering, 56: 68-73.

Aziz, S. and M. Ansell, 2004. The effect of alkalization and fibre alignment on the mechanical and thermal properties of kenaf and hemp bastfibre composites: Part 1 – polyester resin matrix. Composites Science and Technology, 64: 1219-1230.

Aziz, S. and M. Ansell, 2004. The effect of alkalization and fibre alignment on the mechanical and thermal properties of kenaf and hemp bastfibre composites: part 2 – cashew nut shell liquid matrix. Composites Science and Technology, 64: 1231-1238.

Beckermann,G., 2007. Performance of hemp fiber reinforced polypropylenecomposite materials .A Thesis of PhD in Materials and Process Engineering.The University of WAIKATO.

Idicula, M., A. Boudenne, L. Uma Devi, L. Ibos, Y. Candau and S. Thomas, 2006. Thermophysical properties of natural fiber reinforced polyester composites, Composites Sciences and Technology, 66(15).

KABIR, M., H. WANG, T. ARAVINTHAN, F. CARDONA and K. LAU, 2011. EFFECTS OF NATURAL FIBRE SURFACE ON COMPOSITE PROPERTIES: A REVIEW, in: Energy, Environment And Sustainability. eddBE2011 Proceedings, Toowoomba, Australia, pp: 94-99.

Li, X., L. Tabil and S. Panigrahi, 2007. Chemical Treatments of Natural Fiber for Use in Natural Fiber-Reinforced Composites: A Review. Journal of Polymers and the Environment, 15: 25-33.

Mohanty, A., M. Misra and L. Drzal, 2005. Natural fibers, biopolymers, and biocomposites, CRC Press, New York.

Noorunnisa Khanam, P., G. Ramachandra Reddy, K. Raghu and S. Venkata Naidu, 2009. Tensile, Flexural, and Compressive Properties of Coir/Silk Fiber-reinforced Hybrid Composites. Journal of Reinforced Plastics and Composites, 29: 2124-2127.

Sellers, T. and N. Reichert, 1999. Kenaf properties, processing, and products. Mississippi State University, [Mississippi].

Sreenivasan, S., S. Ibraheem, S. Sulaiman, B. Baharudin, M. Ariffin and K. Abdan, 2014. Evaluation of Combined Treatments of Natural Fibers: Kenaf, Abaca and Oil Palm Fibers Using Micromechanical and SEM Methods. AMR 912-914, 1932-1939.

Thiruchitrambalam, M., A. Alavudeen, A. Athijayamani, N. Venkateshwaran and A. ElayaPerumal, 2009. IMPROVING MECHANICAL PROPERTIES OF BANANA/KENAF POLYESTER HYBRID COMPOSITES USING SODIUM LAULRYL SULFATE TREATMENT. Materials Physics and Mechanics, 8: 165-173.

Venkata Reddy, G., S. Venkata Naidu and T. Shobha Rani, 2008. A Study on Hardness and Flexural Properties of Kapok/Sisal Composites. Journal of Reinforced Plastics and Composites, 28: 2035-2044.

Venkata Reddy, G., S. Venkata Naidu and T. Shobha Rani, 2008. Kapok/Glass Polyester Hybrid Composites: Tensile and Hardness Properties. Journal of Reinforced Plastics and Composites, 27: 1775-1787.

Venkateshwaran, N., A. ElayaPerumal and D. Arunsundaranayagam, 2013. Fiber surface treatment and its effect on mechanical and visco-elastic behaviour of banana/epoxy composite. Materials & Design, 47: 151-159.

Verma, D., P. Gope, A. Shandilya, A. Gupta and M. Maheshwari, 2013. Coir Fibre Reinforcement and Application in Polymer Composites: A Review. Journal of Materials and Environmental Science, 4: 263-276.

Wambua, P., J. Ivens and I. Verpoest, 2003. Natural fibres: can they replace glass in fibre reinforced plastics?. Composites Science and Technology, 63: 1259-1264.

Xie, Y., C. Hill, Z. Xiao, H. Militz and C. Mai, 2010. Silane coupling agents used for natural fiber/polymer composites: A review. Composites Part A: Applied Science and Manufacturing, 41: 806-819.