The Effect of Orientation and Fibre Combination Ratio of Sisal/Jute Hybrid Polymer Composite Tensile Property Using Unsaturated Polyester and Bisphenol A Resin

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Abstract : *Present in this research work is the Effect of orientation and fibres combination ratio of sisal/Jute hybrid polymer composite tensile property using unsaturated polyester and Bisphenol A resins. The produced samples have been subjected to tensile test to determine the effect on orientation and fibre ratio combination of Sisal/Jute hybrid fibres reinforced in Bisphenol A (Epoxy group) resin, which demonstrated a highest tensile strength of 38.3MPa on sample SJ/T1/45/55/2:1/B laid at* $90^0/45^0$ *orientation. Sisal/Jute hybrid fires reinforced in unsaturated polyester resin demonstrated a highest tensile strength of 31.7MPa on sample SJ/T3/75/2:1 laid at* $90^0/45^0$ *orientation.*

Keywords *: Sisal, Jute, Hybrid, Tensile Stength, Unsaturated Polyester and Bisphenol A.*

INTRODUCTION

There is a growing urgency to convert agricultural by products and surpluses of the crops into new, profitable products. The need to develop technology allied with environmental preservation has created a renewed interest in the scientific world to study the viability of using natural fibres as reinforcement agents in biopolymer matrices. Such fibre based composites normally show good mechanical properties and reduce the dependence on materials obtained from non renewable source (fossil-based), leading to both economic and environmental benefits. The advantages of natural fibres over synthetic or man-made fibres such as glass or carbon are low cost, low density, acceptable specific strength properties, ease of separation, carbon dioxide sequestration and biodegradability.

A study by U.S.Bongarde, V.D.Shinde (2014) on review on natural fiber reinforcement polymer composites using Coir fiber reinforced polypropylene composite was tested. Flexural properties of coir fiber pp composite were satisfied in between 40 to 60 wt%. Further increment of coir fiber content the flexural strength decreases. The main reasons for lower flexural strength were insufficient matrix to cover all the surface of the coir fiber. Optimal composite panel formulation for automotive interior applications was mixture of 60 wt% coir fiber, 37 wt% PP powder and 3 wt% MAPP. Jute fiber reinforced epoxy composites were analyzed with effect of fiber orientation. The fiber orientations were 0/90°, 15°/-75°, 30°/-60° and 45°/-45°. The higher strength and stiffness were found at 0/90° fiber orientation. Compressive test of jute composite were tested and it found higher strength as compared to bamboo fiber reinforced epoxy composites. The effects of hybridization of coir-jute, sisal-jute and coir-sisal fiber with polyester resins were analyzed. The result shows hybridization play important role for improving mechanical properties of composites.

Another innovative approach to hybrid composites is the incorporation of two natural fibres in a matrix system. Recently, Jacob et al., studied the mechanical properties of sisal fibre-oil palm hybrid fibre reinforced natural rubber bio composites with special reference to fibre length, loading and sisal – oil palm ratio. The optimum length for sisal and oil palm fibres were found to be 10 and 6 mm respectively. The optimum fibre loading was found to be 30 phr. Superior mechanical properties were obtained at higher sisal fibre loadings, especially when sisal and oil palm fibres are in the ratio of 70 and 30 respectively.

Several studies have been reported on the use of sisal/jute fibers as reinforcements in polymer matrices. Parandaman P. and Joyaraman M. (2015) Investigated the mechanical properties of Jute/Sisal/Glass and Jute/Banana/Glass Hybrid composite materials on Epoxy resin, the study in an attempt to analyze the effect of hybridization of natural fibres with glass fibres on the mechanical behavior of the composites conducting test to evaluate their tensile, hardness, impact strengths, the results of the hybrid composite samples shown: for Jute/Sisal/Glass (JSG), Tensile modulus of 23.29MPa, Flexural strength of 59.8MPa, Impact strength of 15.01KJ/m^2, compared to that of Jute/Banana/Glass (JBG) which shows maximum Tensile modulus of 42.24MPa, maximum flexural strength of 72.93MPa, maximum impact strength of 26.35KJ/m^2.

Soma D. and Acharya (2014) experimentally investigated the effect of stacking sequence of tensile, flexural and inter laminar shear properties of untreated woven jute and glass fabric reinforced epoxy hybrid composite. The result showed the properties of Jute-Eglass-Epoxy and its composites to have considerably improved by the incorporation of glass fibre as extreme glass piles.

Ravi R et al (2013) Investigated on the Mechanical Characterization of Banana/Sisal Fibre Reinforced Poly Lactic Acid PLA Hybrid Composites for Structural Application, The test results obtained evident that the tensile strength properties of the treated banana/sisal fibre reinforced PLA biocomposites materials were significantly higher than those of untreated banana/sisal fibre reinforced PLA biocomposites. The treated fibers with NaOH were having the best mechanical properties than pure PLA and untreated fibre bio-composites. The chemical treatment also improved fiber matrix interaction by removal of lignin and hemicellulose, which led to the better incorporation of fiber with the matrix.

Hemachardral R. et al (2013) evaluated mechanical properties such as tensile and flexural properties of hybrid glass fibre-Sisal/Jute reinforced epoxy composite. It was observed that the incorporation of Sisal fibre with Glass Fibre Reinforced Polymer (GFRP) exhibited superior performance rather than the Jute Fibre Reinforced GFRP composites for tensile properties and in contrast Jute fibre reinforced GFRP composite perform better for flexural properties.

Shokrick and Omidi (2011) examined the strain rate effects on transverse tensile and compressive properties of unidirectional glass fiber reinforced polymeric composites. The characteristic results for the transverse properties suggest that damage evaluation is strain-rate-dependent empirical material model associated with different regression constants have been proposed from experimental results obtained which used to characterize the rate dependent behavior of Glass/Epoxy composite material.

There are remarkable developments towards the replacement of established materials by several types of natural and wood fibers embedded in plastic matrices. The automotive industry is using flax, hemp, jute, sisal, kenaf, wood and grain based products as reinforcement, Rudd (2001) and Dúbravčík (2013. Mazda is working with many institutes and agencies among which is the Kinki University, School of Engineering Japan which has focused their efforts on developing a need nucleating agent for crystallization and a compound to raise strength and heat resistance of the new plastic, dramatically increasing the amount of applications for automobile manufacturing.

Natural reinforced fibre polymer composite could be applied in the production of the following automobile parts: Bumper, Seat back, side and back door panel, boot lining, hat rack, spare tire lining, various damping and insulation parts, C-pillar trim, centre console and trim, business table, rear storage shelf and panel, windshields/dashboard.

Figure 1. Picture of Sisal Plant.

Figure 2: Jute plant.

MATERIALS AND METHOD

Sisal/Jute Hybrid Polymer composite at 1:1, 1:2, 2:1 mixture ratio, 0.25, 0.35 and 0.45 volume fraction mixture using Bisphenol A resin, Methyl methacrylate (Catalyst) , Dimethyl Benzene amine (accelerator), using unsaturated polyester resin, Methylethylketone (Catalyst) ,Cobalt (accelerator), Vaseline (releasing agent) bought from Pascal Scientific Laboratory, Akure, Ondo State, Nigeria. Sisal plant was purchased from Ineni , Anambra State, Nigeria while Jute plant was purchased from Owode, Ogun State, Nigeria. Sisal and Jute plant were retted to obtain fibres. Fibres strands were reinforced with Bisphenol A resin. chemically belonging to the epoxy family is used as the matrix material. Its common name is Bisphenol, the low temperature curing resin and corresponding harder Methyl Methacrylate and the accelerator – Dimethyl Benzen amine mixed in the ratio of 5:4:1 by weight as recommended. The unsaturated polyester low temperature curing resin and corresponding harder Methylethylketone hardener and Cobalt accelerator at a ratio of 10:1:0.5 by weight as recommended. The different composites are fabricated for tensile test. Each composites are loaded in 0.25, 0.35 and 0.45 fibre loading - resin fraction, arranged in the orientation of (90, 45, -45, 90,), (0, -45, 45, 0), (30, 60, -60, 30) and in fibres combination ratio, sisal to jute of 1:1, 2:1, 1:2, sisal alone, jute alone with reference to a control sample of nil fibre (resin alone). The casting of each composite was consolidated with a roller load weight of 50g and allowed to cured under room temperature for 4hrs before sample are removed from the mould. Then, specimens are cured in the air for another 12hrs after removing from the mould. Test specimens were subjected to various mechanical test as per ASTM standards using Instron 3369 Universal testing machine located at Obafemi Awolowo University, Ife, Center for Energy and Research - The tensile test – ASTM D638, Tensile sample dimensions: Gauge Length =50mm, Thickness =5mm, Width =12mm, Grip Length =17mm.

Fig.3. Isron Universal Testing Machine

Fig.4 Extracted sisal fibre

Fig.5. Extracted Jute fibre

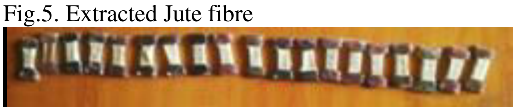

Fig. 6 Samples prepared with Bisphenol A for Tensile Test

Fig. 7. Samples prepared with Unsaturated Polyester for Tensile Test

Results

Table : 1. Summary of Samples' maximum obtained values using Sisal, Jute and Unsaturated Polyester resin, Methylethyllketone Peroxide and Cobalt.

SAMPLE CODE	VOLUME FRACTION (FIBIRE VOLUME)/(RESIN VOLUME + FIBRE VOLUME)	HYBRID FIBRE RATIO COMBINATION (SISAL=S JUTE=J (S:J)	FIBRE ORIENTATION	MAXIMUNM VALUE
TENSILE TEST				(MPa)
CPT		NILL FIBRE	CONTROL	8.01695
S/T1/45/55	0.45	SISAL ALONE	$90^0,45^0,-45^0,90^0$	13.23517
J/T1/45/55	0.45	JUTE ALONE	$90^0,45^0,-45^0,90^0$	5.32992
SJ/T1/45/55/1:1 ($90^0/45^0$)	0.45	1:1	$90^0,45^0,-45^0,90^0$	16.62321
SJ/T1/45/55/2:1	0.45	2:1	$90^0,45^0,-45^0,90^0$	5.78090
SJ/T1/45/55/1:2	0.45	1:2	$90^0,45^0,-45^0,90^0$	3.29199
SJ/T1 /45/55/1:1/($0^0/45^0$)	0.45	1:1	$0^0,45^0,-45^0,0^0$	13.01148
SJ/T1 /45/55/1:1/($30^0/60^0$)	0.45	1:1	$30^0,60^0,-60^0,30^0$	23.95157
S/T2/35/65	0.35	SISAL ALONE	$90^0,45^0,-45^0,90^0$	12.98744
J/T2/35/65	0.35	JUTE ALONE	$90^0,45^0,-45^0,90^0$	28.33942
SJ/T2/35/65/1:1	0.35	1:1	$90^0,45^0,-45^0,90^0$	8.64767
SJ/T2/35/65/2:1	0.35	2:1	$90^0,45^0,-45^0,90^0$	4.16632
SJ/T2/35/65/1:2	0.35	1:2	$90^0,45^0,-45^0,90^0$	8.78325
S/T3/25/75	0.25	SISAL ALONE	$90^0,45^0,-45^0,90^0$	20.30426
J/T3/25/75	0.25	JUTE ALONE	$90^0,45^0,-45^0,90^0$	12.10546
SJ/T3/25/75/1:1	0.25	1:1	$90^0,45^0,-45^0,90^0$	4.90922
SJ/T3/25/75/2:1	0.25	2:1	$90^0,45^0,-45^0,90^0$	31.65459
SJ/T3/25/75/1:2	0.25	1:2	$90^0,45^0,-45^0,90^0$	9.42133

TABLE 2: Summary of samples' maximum obtained values using Sisal, Jute and Bisphenol resin, Methyl methacrylate and Dimenethyl benzen amid

SAMPLE CODE	VOLUME FRACTION (FIBIRE VOLUME)/(RESIN VOLUME + FIBRE VOLUME)	HYBRID FIBRE RATIO COMBINATION (SISAL=S JUTE=J (S:J)	FIBRE ORIENTATION	MAXIMUNM VALUE
TENSILE TEST				(MPa)
CPT/B		NILL FIBRE	CONTROL	6.60625
S/T1/45/55/B	0.45	SISAL ALONE	$90^0,45^0,-45^0,90^0$	31.22853
J/T1/45/55/B	0.45	JUTE ALONE	$90^0,45^0,-45^0,90^0$	19.29944
SJ/T1/45/55/1:1/B	0.45	1:1	$90^0,45^0,-45^0,90^0$	33.19270
SJ/T1/45/55/2:1/B	0.45	2:1	$90^0,45^0,-45^0,90^0$	38.26735
SJ/T1/45/55/1:2B	0.45	1:2	$90^0,45^0,-45^0,90^0$	10.66825
SJ/T1 /45/55/1:1/($0^0/45^0$)/B	0.45	1:1	$0^0,45^0,-45^0,0^0$	11.93156
SJ/T1 /45/55/1:1/($30^0/60^0$)/B	0.45	1:1	$30^0,60^0,-60^0,30^0$	20.85426
S/T2/35/65/B	0.35	SISAL ALONE	$90^0,45^0,-45^0,90^0$	39.49904
J/T2/35/65/B	0.35	JUTE ALONE	$90^0,45^0,-45^0,90^0$	23.50592
SJ/T2/35/65/1:1/B	0.35	1:1	$90^0,45^0,-45^0,90^0$	30.37900
SJ/T2/35/65/2:1/B	0.35	2:1	$90^0,45^0,-45^0,90^0$	3.65627
SJ/T2/35/65/1:2/B	0.35	1:2	$90^0,45^0,-45^0,90^0$	4.64193
S/T3/25/75/B	0.25	SISAL ALONE	$90^0,45^0,-45^0,90^0$	2.63931
J/T3/25/75/B	0.25	JUTE ALONE	$90^0,45^0,-45^0,90^0$	9.90068
SJ/T3/25/75/1:1/B	0.25	1:1	$90^0,45^0,-45^0,90^0$	2.99069
SJ/T3/25/75/2:1/B	0.25	2:1	$90^0,45^0,-45^0,90^0$	2.25661
SJ/T3/25/75/1:2/B	0.25	1:2	$90^0,45^0,-45^0,90^0$	1.82109

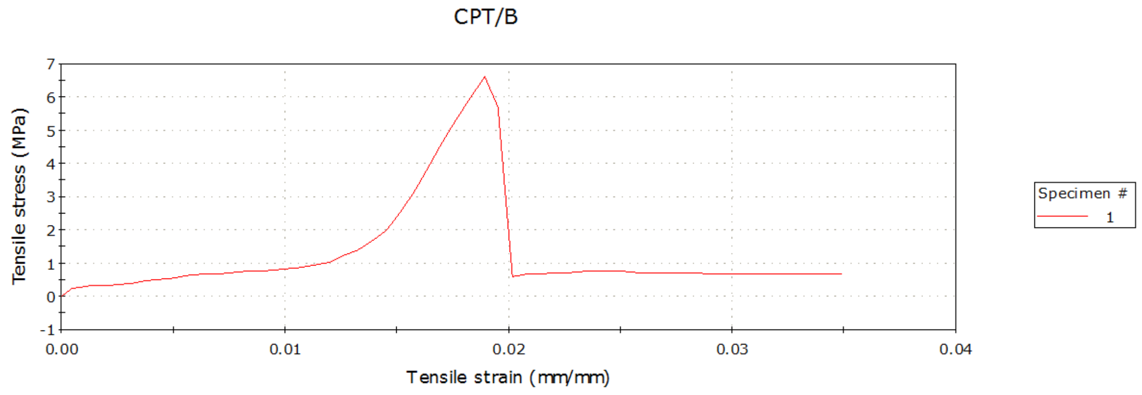

Fig. 8. Graph of Tensile test on CPB/B (CONTROL SAMPLE) prepared with Bisphenol A resin.

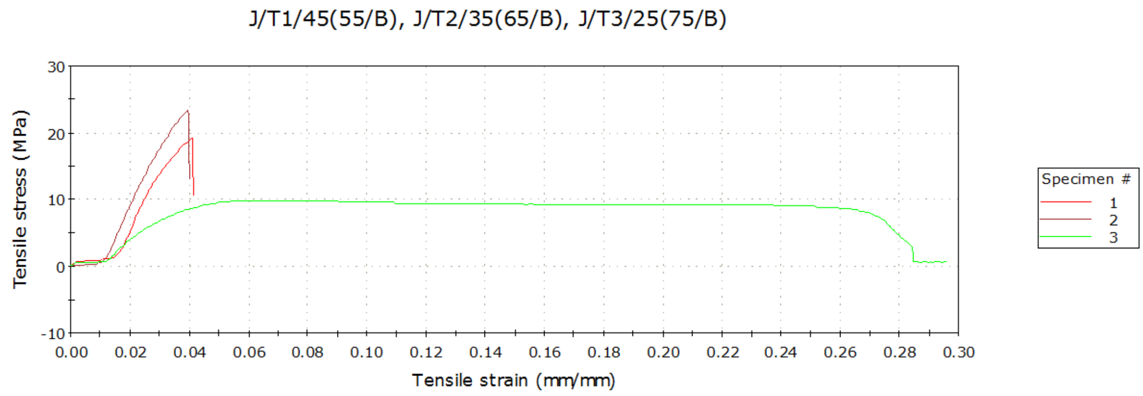

Fig. 9 Graph of Tensile test on Sample J/T1/45/55/B, J/T2/35/65/B, J/T3/25/75/B prepared with Bisphenol A resin.

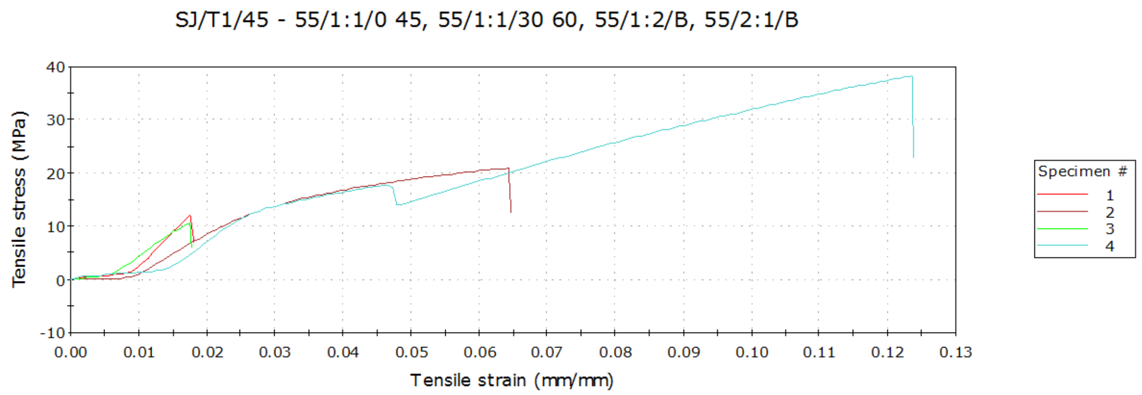

Fig. 10. Graph of Tensile test on Sample SJ/T1/45/55/1:1(0/45^0)/B, SJ/45/55/1:1(30/60^0), SJ/T1/45/55/1:2(0/45/90^0)/B, SJ/T1/45/55/2:1(0/45/90^0)/B prepared with Bisphenol A resin.

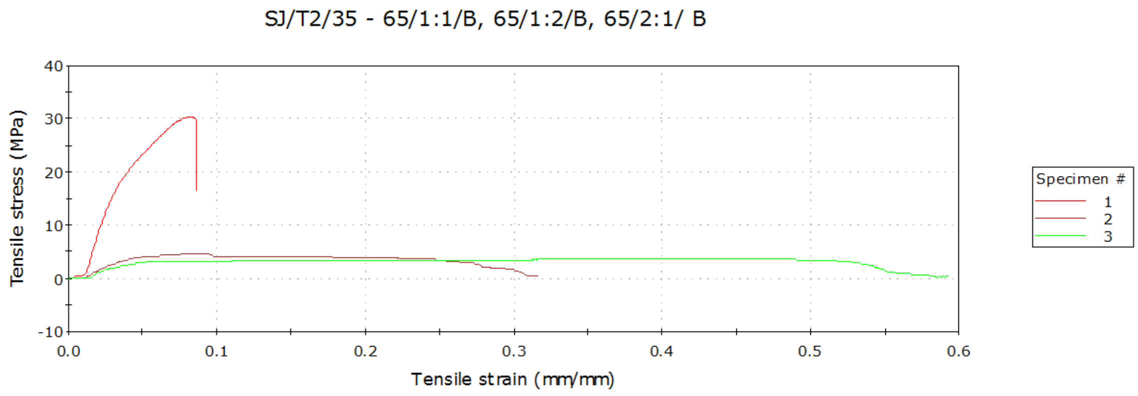

Fig. 11. Graph of Tensile test on Sample SJ/T2/35/65/1:1/B, SJ/T2/35/65/1:2/B, SJ/T2/35/65/2:1/B prepared with Bisphenol A resin.

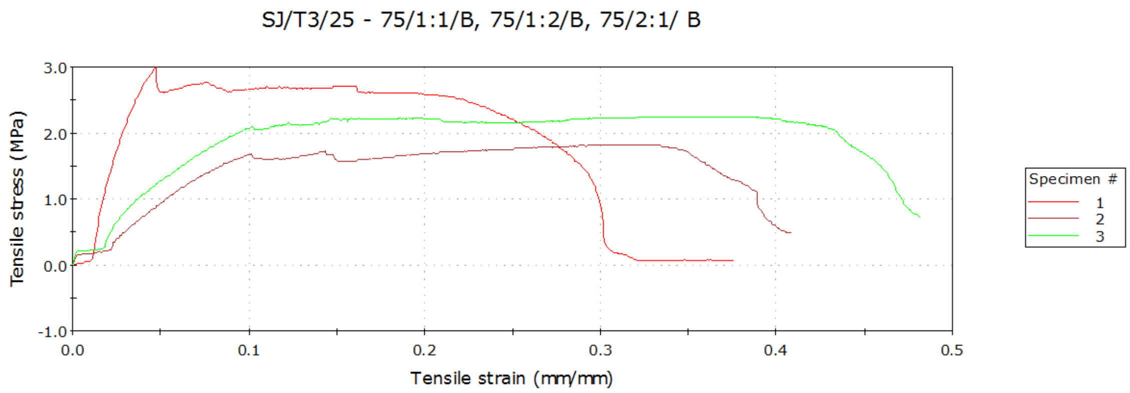

Fig. 12. Graph of Tensile test on Sample SJ/T3/25/75/1:1/B, SJ/T3/25/75/1:2/B, SJ/T3/25/75/2:1/B prepared with Bisphenol A resin.

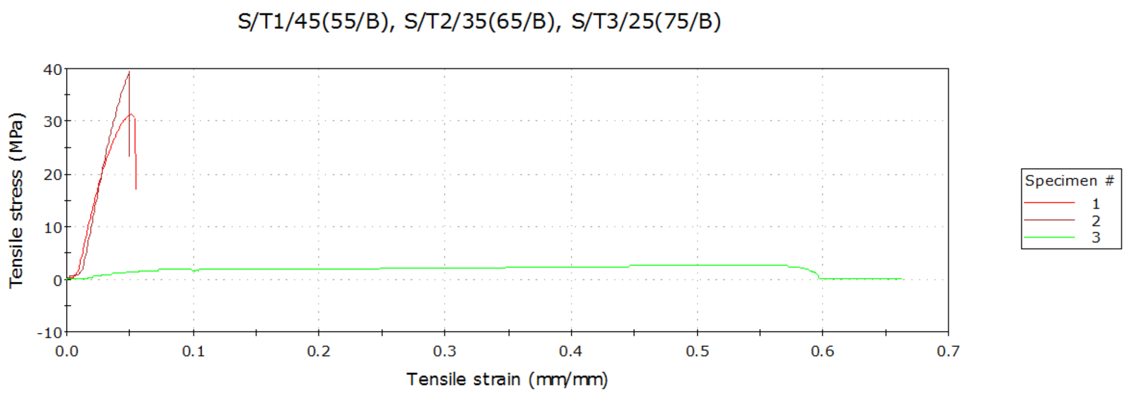

Fig. 13. Graph of Tensile test on Sisal Hybrid Polymer composite Sample S/T1/45/55/B, S/T2/35/65/B, S/T3/25/75/B prepared with Bisphenol A resin.

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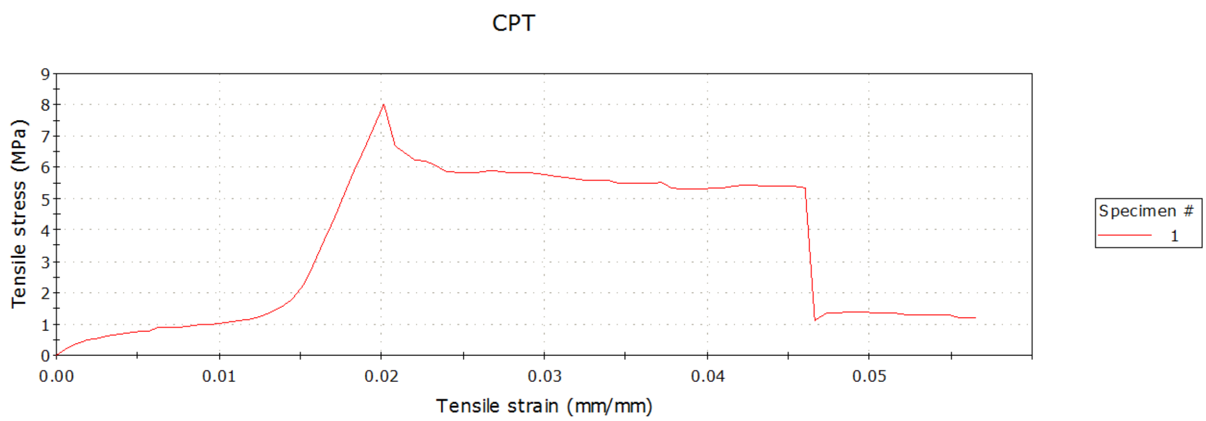

Fig. 14 Graph of Sample CPT (Control Sample) without Fibres prepared with Unsaturated Polyester resin.

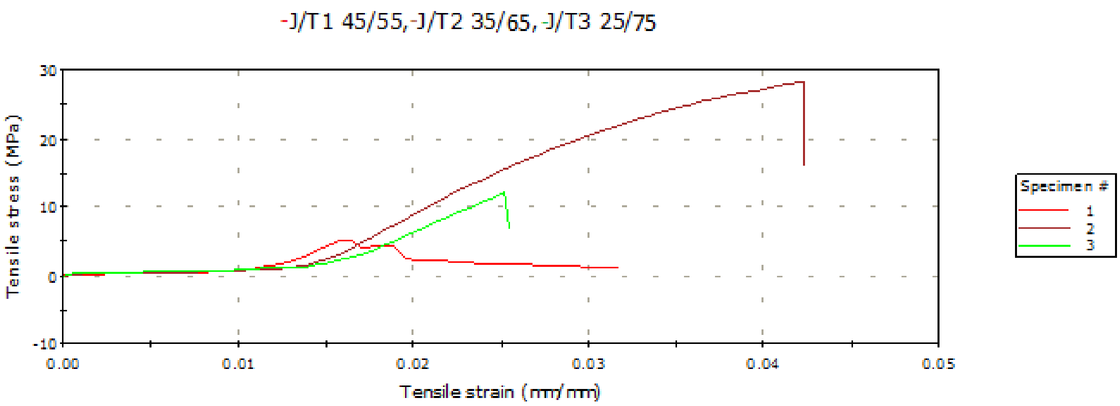

Fig. 15 Graph of Tensile Test on Sisal/Jute Polymer Composite (Samples J/T1/45/55, J/T2/35/65, and J/T3/25/75 prepared with Unsaturated Polyester)

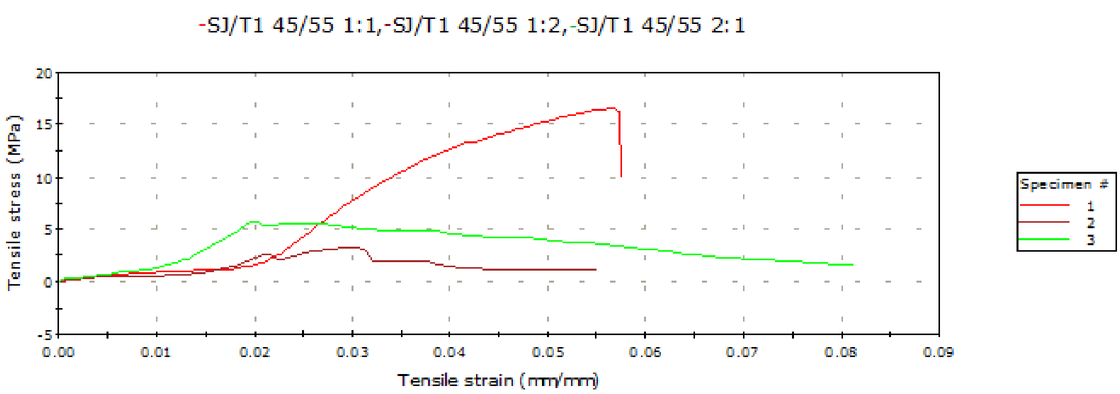

Fig.16. Graph of Tensile Test on Sisal/Jute Polymer Composite (Samples SJ/T1/45/55/1:1, SJ/T1/45/55/1:2 and SJ/T1/45/55/2:1 prepared with Unsaturated Polyester)

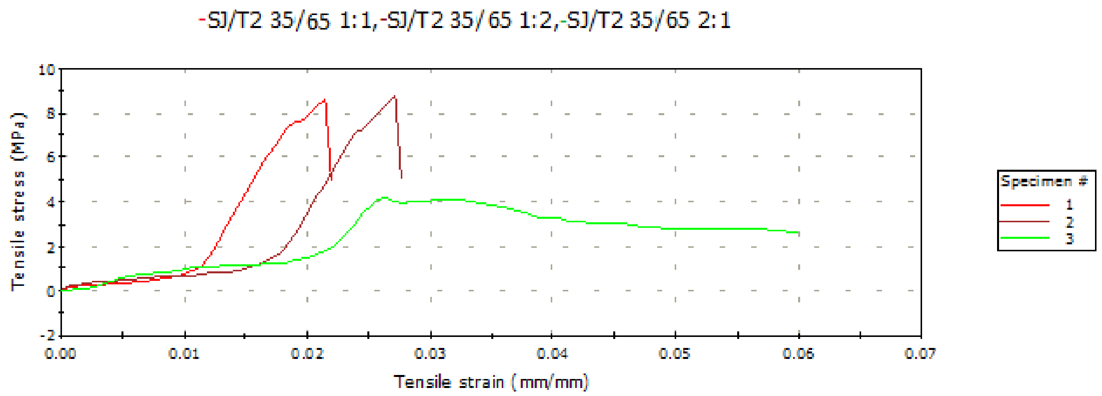

Fig 17. Graph of Tensile Test on Sisal/Jute Polymer Composite (Sample SJ/T2/35/65/1:1, SJ/T2/35/65/1:2 and SJ/T2/35/65/2:1 prepared with Unsaturated Polyester)

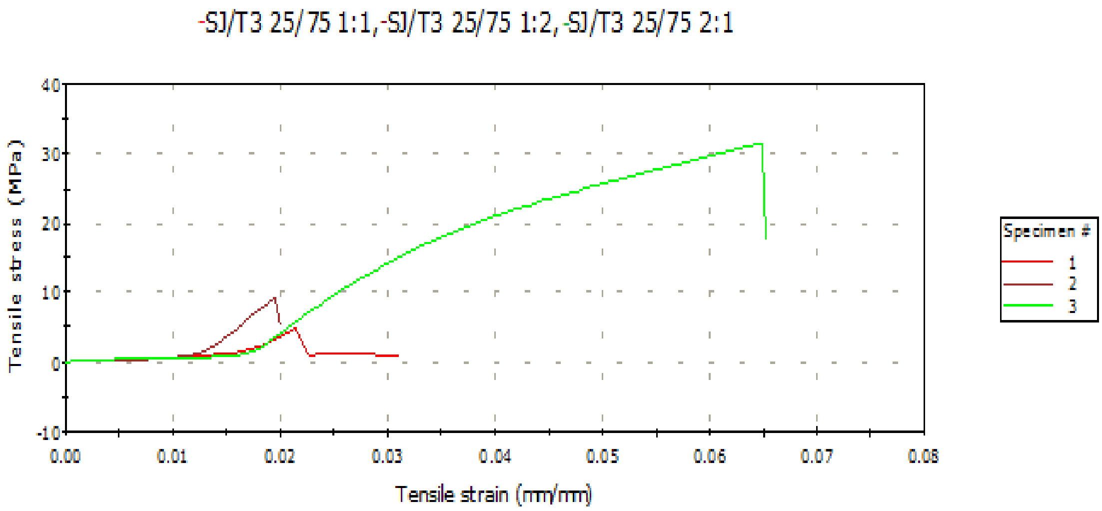

Fig. 18. Graph of Tensile Test on Sisal/Jute Polymer Composite (Samples SJ/T3/25/75/1:1, SJ/T3/25/75/1:2, and SJ/T3/25/75/2:1 prepared with Unsaturated Polyester).

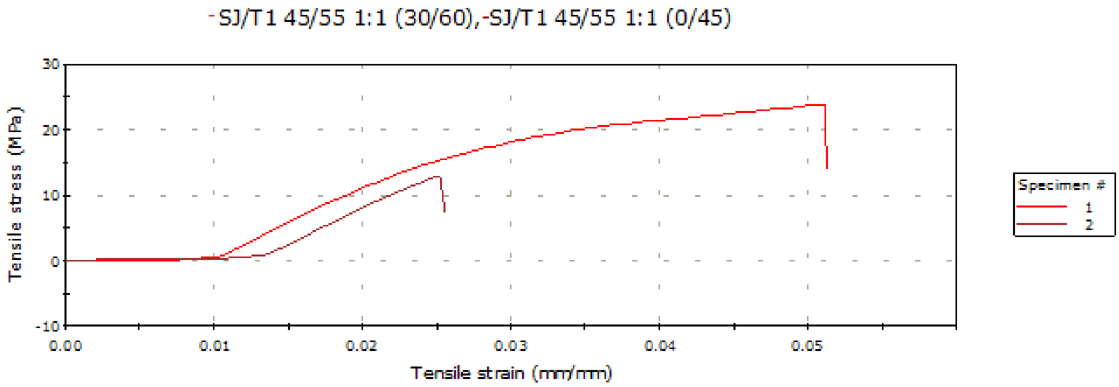

Fig. 19. Graph of Tensile Test on Sisal/Jute Polymer Composite (Samples SJ/T1/45/55/1:1(30/60^0), and SJ/T1/45/55/1:1(0/45^0) prepared with Unsaturated Polyester).

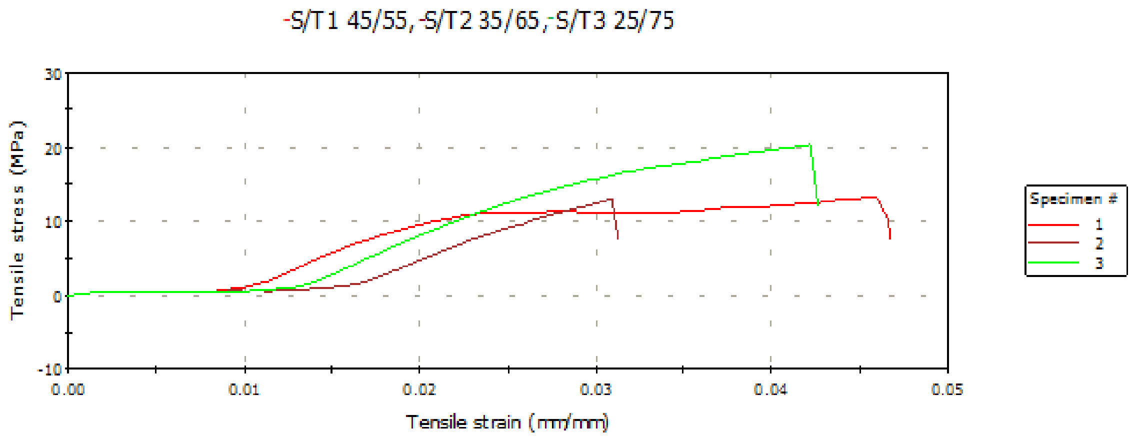

Fig. 20. Graph of Tensile Test on Sisal/Jute Polymer Composite Samples S/T1/45/55, S/T2/35/65, S/T3/25/75 prepared with Unsaturated Polyester)

DISCUSSION OF RESULTS.

Comparing the reported samples below at 0.45 volume fraction produced with unsaturated polyester resin shows significant influence of orientation and sisal/jute fibre combination ratio. Sample coded SJ/T1/45/55/1:1(90^0/45^0) laid at (90^0, 45^0, -45^0, 90^0.) orientation in the combination ratio of 1:1 sisal to jute displayed a maximum tensile strength of 16.6MPa. Sample coded SJ/T1/45/55/2:1(90^0/45^0) laid at (90^0, 45^0, -45^0, 90^0.) orientation in the combination ratio of 1:1 sisal to jute displayed a maximum tensile strength of 5.8MPa. Sample coded SJ/T1/45/55/1:1(0^0/45^0) laid at (0^0, 45^0, -45^0, 0^0.) orientation in the combination ratio of 1:1 sisal to jute displayed a maximum tensile strength of 13MPa. Sample coded SJ/T1/45/55/1:1(30^0/60^0) laid at (30^0, 60^0, -60^0, 30^0.) orientation in the combination ratio of 1:1 sisal to jute displayed a maximum tensile strength of 24MPa. Comparing the reported samples below at 0.45 volume fraction produced with Bisphenol A resin shows significant influence of orientation and sisal/jute fibre combination ratio. Sample coded SJ/T1/45/55/1:1(90^0/45^0)/B laid at (90^0, 45^0, -45^0, 90^0.) orientation in the combination ratio of 1:1 sisal to jute displayed a maximum tensile strength of 33.2MPa.Sample coded SJ/T1/45/55/2:1(90^0/45^0)/B laid at (90^0, 45^0, -45^0, 90^0.) orientation in the combination ratio of 2:1 sisal to jute displayed a maximum tensile strength of 38.3MPa. Sample coded SJ/T1/45/55/2:1(90^0/45^0)/B laid at (90^0, 45^0, -45^0, 90^0.) orientation in the combination ratio of 1:2 sisal to jute displayed a maximum tensile strength of 10.7MPa. Sample coded SJ/T1/45/55/2:1(0^0/45^0)/B laid at (0^0, 45^0, -45^0, 0^0.) orientation in the combination ratio of 1:1 sisal to jute displayed a maximum tensile strength of 11.9MPa. Sample coded

SJ/T1/45/55/1:1($30^0/60^0$)/B laid at (30^0, 60^0, -60^0, 30^0) orientation in the combination ratio of 1:1 sisal to jute displayed a maximum tensile strength of 20.9MPa.

CONCLUSION

From the successful analysis of different orientation and fibre ratio produced, different results were observed and different fibre ratio combination produce different results. The highest result on orientation was at ($90^0/45^0$)/B and at fibre ratio of 2:1 sisal to jute for Bisphenol A resin demonstrating a maximum tensile strength of 38MPa while Sisal/Jute hybrid fires reinforced in unsaturated polyester resin, demonstrated a highest tensile strength of 31.7MPa on sample SJ/T3/75/2:1 laid at $90^0/45^0$ orientation.

REFERENCES

[1] Agunsoye, J.O, Aigbodion, V. S. (2013). Bagasse Filled Recycled Polyethylene Bio-composites; morphological and mechanical properties study, Result in Physics 3, 187-194

[2] Alsina O.L.S. , Carvalho L.H.D., Filho F.G.R.Filho, Almeida J.R.M.D. (2005) Polym. Test. 24 1 81

[3] Arib, R.M, Sapuan S.M (2006) Mechanical Properties of pineapple leaf fibre reinforced Polypropylene composites, Mater. Des 27, 291-396

[4] Atuanya C. U., Ibhadode A. O. A., Igboanugo A. C. (May 2011) Potential of using recycled low-density polyethylene in wood composites board, *African Journal of Environmental Science and Technology Vol. 5(5), pp*. 389-396,

[5] Berghezan, A.Nucleus; 8(5), 1966, (Nucleus A Editeur, 1, rhe,Chalgrin,Paris, 16(e).

[6] Bledzki , A. K., Sperber, V. E., and Faruk, O., (2002). Textbook of Natural and Wood Fibre Reinforcement in Polymers, *Rapra Technology Ltd, UK, 13, 8.*

[7] Blicblau AS, Coutta RSP, Sims A. J Mater Sci Letter. 1997; 16-1417.

[8] Budrun N. , Mahbubur R.B, Humayun K. (2014), Study of Mechanical and Physical Properties of Palm Fiber Reinforced Acrylonitrile Butadiene Styrene Composite, *Journal of Materials Science and Application, 2014, 5, 39-45*

[9] Burguen˜o R., Quagliata M.J., Mohanty A.K., Mehta G., Drzal L.T., Misra M (2005) Composites: Part A 36 581

[10] Ciaraldi SW, Alkire JD and Huntoon GG. 1992. Fiberglass firewater systems for offshore platforms. Paper OTC 6926.In: *Offshore technology conference. Houston.*

[11] Chandramohan D., Bharanichandar J. (2013) Natural Fiber Reinforced Polymer Composites for Automobile Accessories**,** *American Journal of Environmental Sciences* Volume 9, Issue 6 Pages 494-504

[12] Chandramohan D ., K. Marimuthu K. (2011) A Review on Natural Fibers, IJRRAS 8 (2) www.arpapress.com/Volumes/Vol8Issue2/IJRRAS_8_2_09 August 2011

[13] Campbell F.C. (2010) "Structural Composite Materials" Copyright © 2010, ASM International, www.asminternational.org

[14] Cook J. G., Handbook of Textile Fibre and Natural Fibres, 4th Ed.,Morrow Publishing, England, 1968

[15] Dalbera, Soma and S.K. Acherya, 2014, Study on mechanical properties of natural fiber reinforced woven jute-glass hyrid epoxy composites, *Advances in Polymer Science Technology*, 4(1): 1-6

[16] Edelugo S. O. (2010), ― The Behaviour of Polymer Composite Plates During and After Cure and Consequent Immersion in Water. *Journal of Advanced Materials*, JAM, SAMPE Pub, (USA). Vol. 42, 3, pp 25-30.

[17] Edelugo S. O. (2004), ―Effect of Reinforcements Combination on the Mechanical strength of Glass Reinforced Plastic (GRP)Handlay-up Laminates with Regards to Increased Temperature Conditions. *Nigerian Journal of Technology. Vol. 23. No. 1. pp 39 – 47*

[18] Filho, R.D.D.T., F. de Andrade Silva, E.M.R. Fairbairn and J. de Almeida Melo Filho, 2009. Durability of compression molded sisal fiber reinforced mortar laminates. Construct. Build. Mat., 23: 2409-2420

[19] GRAM, H.E. (1983) Durability of Natural Fibres in Concrete, Swedish Cement and Concrete Research Institute, v.1, n.83, p.225,.

[20] Hapuarachchi TD, Ren G, Fan M, Hogg PJ, Pejis T. *App Compos Mater. 2007; 14-251.*

[21] Harriëtte L.B (2004). "The potential of flax fibres as reinforcement for composite materials "– Eindhoven : *Technische Universiteit Eindhoven, 2004.Proefschrift. – ISBN 90-386-3005-0*

[22] Ishaya M.D, Joseph O. (2014) Property Evaluation of Hybrid OPEBF/Banana/Glass Fiber Reinforced Unsaturated Polyester Composites. *American Journal of Materials Science and Engineering, 2014, Vol. 2, No.4, 45-53.*

[23] Jartiz, A.E.; *Design* (1965), p.18.

[24] Jones F.R.(1994), Handbook of Polymer Composites, *Longman Scientific andTechnical*

[25] Kelly A.; The Nature of Composite Materials, *scientific American Magazine* 217, (B), (1967): p. 161.

[26] Lu, Y., Weng, L., & Cao, X. (2006).Morphological, thermal and mechanical properties of ramie crystallites—

reinforced plasticized starch biocomposites. Carbohydrate Polymers 63 (2006) 198–204

[27] Lu, Y., Weng, L., & Cao, X. (2005). Biocomposites from plasticized starch and cellulose crystallites from cottonseed Linter. Macromolecular Bioscience.

[28] Lu, Y., Weng, L., & Zhang, L. (2004). Morphology and properties of soy protein isolate thermoplastics reinforced with chitin whiskers. Biomacromolecules, 5, 1046–1051.

[29] Merlin Barschke .(2009) "Finite Element Modeling of Composite Materials using Kinematic Constraints", Ingeniería y Ciencia, ISSN 1794–9165Volumen 5, número 10, diciembre de 2009, páginas 133–153

[30] Mohanty, A. K., Misra, M., & Drzal, L. T. (2002). Sustainable bio-composites from renewable resources: opportunities and challenges in the green materials world. *Journal of Polymer and Environment, 10, 19–26*

[31]Mohanty A.K., Drzal L.T. Misra M. (2002) J. Adhesion Sci. Technol. 16 999

[32] Mohmood, M., Shokrick and Majamal O., (2011), Investigating the transverse behavior of Glass-Epoxy Composites under intermediate strain rates, composite structure, 93: 690-696

[33] Mustafa Akay (2012), Introduction to polymer science and Technology, ISBN 978-87-403-0087-1

[34] Parandaman P. and Jayaraman M., (2015), Experimental Investigation on the mechanical properties of Jute/Sisal/Glass and Jute/Banana/Glass Hybrid composite materials., *European Journal of Applied Sciences 7(3): 138-144, 2015.*

[35] Ramesh, M., Palanikumar and Hemachandra K. R, (2013), Comparative Evaluation on Properties of Hybrid Glass Fiber-Sisal/Jute Reinforced Epoxy Composites, *Procedia Engineering, 51: 745 – 750.*

[36] Ravi R., Bajpai P.K amd Tyagi R.K (2013), Mechanical Characterization of Banana/Sisal Fibre Reinforced PLA Hybrid Composites for Structural Application, *ABC Journal of Engineering International, Volume 1, No. 1 (2013)*

[37] Ravi K.N, Ranga R.C (2014) Mechanical properties of Vakka Fiber Reinforced Polypropylene Composites, 2014 *International Conference on Innovations in Engineering and Technology (ICIET'14).*

[38] Richard Wood "Car Bodywork in Glass Reinforced Plastics" *Published 1980 by Pentech Presss Limited, Estover road, Plymouth Devon, ISBN 0 7273 0304 X*

[39] Salazar, V.L.P., A.L. Leao, D.S. Rosa, J.G.C. Gomez and R.C.P. Alli, 2011. Biodegradation of coir and sisal applied in the automotive industry. *J. Polym. Environ*., 19: 677-688.

[40] Sanjay M.R., Arpitha G.R., Yogesha B., *Mater. Today: Procee.* 2 (2015) 2967.

[41] Sapuan,V., and Maleque, M. A.(2003). "Mechanical properties of epoxy/coconut shell filler particle composites*," Arabian Journal for Science and Engineering, vol. 28,no. 2B, pp. 171–181, 2003.*

[42] Sapuan, S. M., Leenie, A., Harimi, M. and Beng, Y.K. (2006). "Mechanical properties of woven banana fiber reinforced, epoxy composites". *Materials and Design* **27**(8):689–93.

[43] Sastra, H.Y., Siregar, J.P., Sapuan, S.M., Leman, Z. & Hamdan, M.M. (2005). Flexural properties of Arenga pinnata fibre reinforced epoxy composites. *American Journal of Applied Sciences.* (Special Issue): 21-24.

[44] Scheibel T. 2004; http://www.microbialcellfactories.com/content/3/1/14.

[45] Singh, B., Gupta, M., Verma, A.(2003). Polyester moulding compounds of natural fibres and wollastonite. Composites: Part A, 34, pp.1035–1043.

[46] Soma Dalbehera, S. and Acharya, K. (2014). Study on mechanical properties of natural fiber reinforced woven jute-glass hybrid epoxy composites. Advances in Polymer Science and Technology, **4** (1): 1 – 6. *American Journal of Materials Science and Engineering* 53.

[47] Sreekala M.S., George J., Kumaran M.G., Thomas S. (2002) Comp. Sci. Technol.62 339

[48] Sumaila M., et. al.(2013). Effects of fiber length on the physical and mechanical properties Of random oriented, nonwoven short banana (Musa Balbisiana) fiber / epoxy composite, *Asian Journal of Natural and Applied Sciences*, 2,1: 39, (2013).

[49] Swanson, S.R. (1997). "Introduction to Design and Analysis with Advance Composite Materials," *Department of Mechanical Engineering, University of Utah, Salt Lake,* Prentice Hall, Ed., pp. 29 – 101.

[50] Thatayaone P, Chongwen Y., Josphat I., Nobert M., Zheng F. L, 2012. Production and Characterization of Kenyan Sisal. *Asian Journal of Textile, 2: 17-25.*

[51] Thatoi, H.N., Panda, S.K. Rath, P.K. and Dutta, S.K. (2008).Antimicrobial activity and ethnomedicinal uses of some medicinal plants from similipal biosphere reserve, Orissa. Asian J. Plant Sci., 7: pp.260-267.

[52] Thwe M.M., Liao K. (2003) Comp. Sci. Tech,, 63 ,375

[53] Thiruchitrambalam, M., Alavudeen, A., Athijayamani, A., Venkateshwaran, N. and Elayaperumal, A. "Improving mechanical properties of banana/kenaf polyester hybrid composites using sodium lauryl sulfate treatment" *Materials Physics and Mechanics 8 (2009) 165 – 173*

[54] Venkateshwaran N., Elaya P. A., Arunsundaranayagam D.,(2013) "Fiber surface treatment and its effect on mechanical and visco-elastic behaviour of banana/epoxy composite," *Materials & Design, vol. 47, pp. 151–159, 2013.*

[55]Venkateshwaran, N. and Elaya Perumal, A. (2010). "Banana fiber reinforced polymer composites – A review", *J. Reinf. Plast. Compos.* 29: 2387–2396.

[56] Venkateshwaran, N., ElayaPerumal, A. and Alavudeen, M. (2011). Thiruchitrambalam "Mechanical and water absorption behaviour of banana/sisal

reinforced hybrid composites" *Materials and Design* 32: 4017–4021.

[57] Venkateshwaran, N., Elayaperumal, A. and Sathiya, G.K. (2012). Prediction of tensile properties of hybrid-natural fiber composites, Composites: Part B, 43:793 – 796.

[58] Wang W, Sain M, Cooper PA. Polym Degrad Stab. 2005; 90:540-545.

[59] Wang, B., Panigrahi, S., Tabil, L., and Crerar, W. (2007). Pretreatment of flax fibres for use in rotationally molded biocomposites. Reinforced Plastics and Composites, 26(5), 447-463.

[60] Weindling, L 1947, Long Vegetable Fibers, 311 Pp, illus. New York.

[61] White, D.W. and Puckett, P.M., "Resin Systems and Applications for Resin Transfer Molding" *The Dow Chemical company U.S.A, Freeport, Texas,* pp. 1 – 5.

[62] Wollerdorfer, M. & Bader, H. (1998). Influence of natural fibres on the mechanical properties of biodegradable polymers. *Industrial Crops and Products*, 8: 105 – 112.

[63] Wood, R. (1980). Car body work in glass reinforced plastics Pentech press limited Plymouth Devon London pp.1-2). (Erhard, G. 2006. Design with plasticstrans. Martin Thompson. Munich: Hanser publisher).

[64] Yyoti P.D (2013) Processing and Properties of Natural Fiber-Reinforced Polymer Composite, *Hindawi Journal of Materials,Volume 2013 (2013), Article ID 297213, 6 pag*es.