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Mechanical Characterisation of the Kenaf Fiber Reinforced Epoxy Composite for Ankle Foot Orthosis

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Abstract: Kenaf fiber epoxy composites were fabricated for ankle foot orthosis, testing five volume fractions (0%, 10%, 20%, 30%, 40%). Results showed increasing voids with fiber content. 40% kenaf had highest tensile strength (89 MPa). Flexural strength peaked at 30% (148 MPa). MOORA optimization ranked 40% best for physical and mechanical properties

INTRODUCTION

1.1 Introduction to composites

Composites are multiphase materials with a matrix (binder) and reinforcement, offering high strength-to-weight ratio, toughness, corrosion resistance, and ease of fabrication. Common in aerospace, automotive, marine, medical, and construction industries, their properties depend on constituent materials, amounts, and reinforcement geometry. Natural examples include bones and wood.

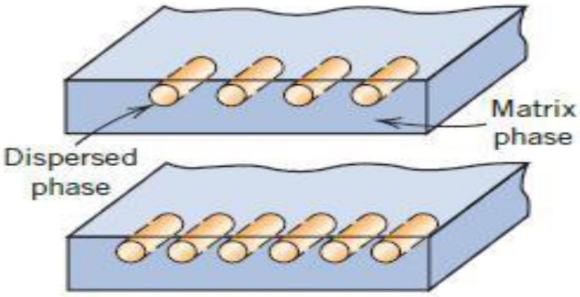

Fig 1.1: Composite materials

1.2 Classification of composites

Composites are broadly classified in two ways:-

1. Type of reinforcement
2. Type of matrix

According to the type of reinforcement, composites are further classified in two types as shown in figure 1.2.

i. Particulate reinforced composite
ii. Fiber reinforced composite

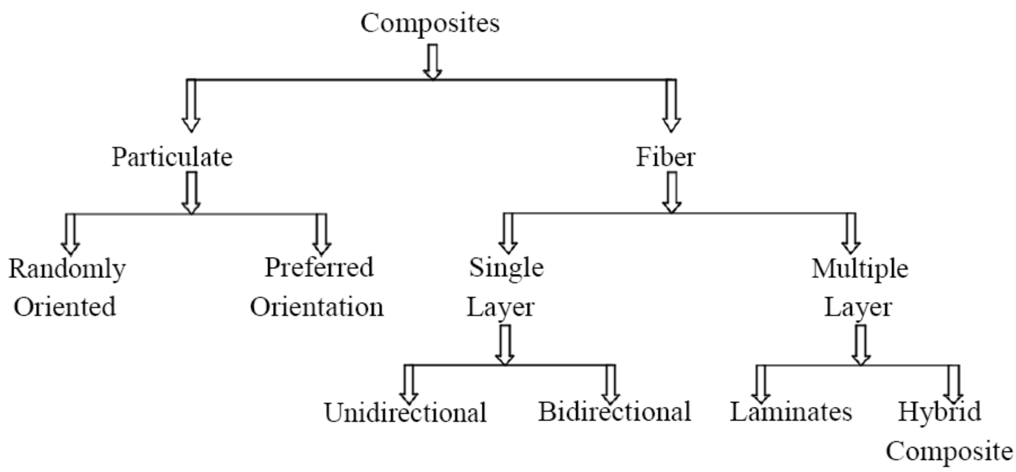

Fig 1.2: Classification of composite on the basis of reinforcement

1.3 Orthosis

Composites are multiphase materials with a matrix (binder) and reinforcement, offering high strength-to-weight ratio, toughness, corrosion resistance, and ease of fabrication. Common in aerospace, automotive, marine, medical, and construction industries, their properties depend on constituent materials, amounts, and reinforcement geometry. Natural examples include bones and wood.

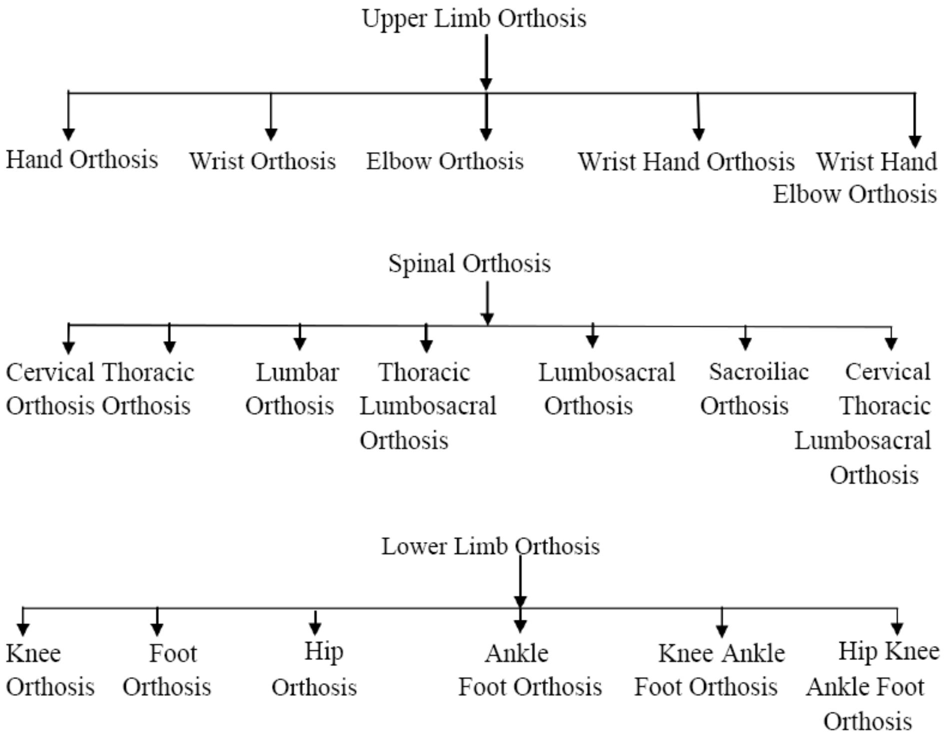

Fig 1.3: Classification of orthosis devices.

1.4 Ankle foot orthosis (AFO)

Ankle Foot Orthosis (AFO) is a device used to support and correct ankle deformities, improving gait. AFOs are classified into passive, semi-active, and active types. Passive AFOs are rigid and inexpensive, while semi-active and active AFOs incorporate actuators and sensors for flexibility, control, and improved gait but are bulkier and costlier.

(a)

(b)

Fig.1.4 Type of AFOs (a) Passive AFO and (b) Active or articulate AF

LITERATURE REVIEW

2.1 Effect of materials and fabrication techniques on the performance of ankle foot orthosis (AFO)

Ankle foot orthosis is assistive device which is used to correct lower limb deformities. AFOs serve different purposes such that support the limb, improve gait of patients, resists unwanted movement of joints in fracture, etc. Currently different type of materials such polymers, metals and carbon fibers are used for fabrication of AFO. Fabrication techniques such as 3D printing, pre-preg technique, and thermoforming used in AFO fabrication. Fabrication technique and materials greatly affect the performance of AFO which is shown in table 2.1.

Table 2.1: Overview of materials and techniques used for ankle foot orthosis (AFOs)

S. No.	Objective	Body Part	Materials	Fabrication Method	Results	Reference
1	Design and built AFO with 3D printing technique.	Ankle foot	Thermoplastic polyurethane	3D-printing	AFO results in increase in gait speed.	10
2	Computer integrated design approach to built an AFO.	Ankle foot	Side bar & foot plate aluminium alloy 6061-T6 Calf part- PLA	Rapid prototyping	AFO is light weight. AFO is comfortable & easy to use.	11
3	Establish a novel methodology for quantification of AFO moment during walking.	Ankle foot	Polypropylene	Thermoforming polymer sheets.	Method provided is used to determine load and strain carried by AFO during walking.	12
4	Using finite element analysis predict the mechanical behaviour of AFOs.	Ankle foot	Three AFOs. Two made up of carbon fiber and one made up of thermoforming material.	Thermoforming polymer sheets. Pre-preg carbon fiber sheet with resin.	FEA model used to predict mechanical behaviour.	13
5	Manufacture a custom made orthosis using a low cost 3D scanning & printing tool.	Ankle foot	Acrylonitrile butadiene styrene.	3D printing	3D printing method results in a higher arch index (AHI) than shod condition.	14
6	Methodological study of foot orthosis using rapid manufacturing.	Foot	Acrylonitrile butadiene styrene. Polylactic acid.	Fused deposition modelling.	Practice is less invasive. Reduction in waste material.	15
7	Build & design a new AFO which provide more normal ankle joint movement.	Ankle foot	NiTi alloy for hinged spring	Thermoforming polymer sheets.	Higher ankle moment and normal walking due to use of NiTi spring.	16
8	Establish a standard procedure to perform the skin strain analysis	Ankle foot	Nylon 12PA	3D printing	Skin strain analysis LoNES improve & optimise the	17

	and to calculate lines of non-extensions.				wearable device. Reduction in friction between skin and device.	
9	Design and build a spring orthosis for children with plantorflexor weakness.	Ankle foot	Carbon fiber composite	Autoclave technique	Positive ankle work increases. Ankle power absorption and generation increases.	18
10	Design & produce an AFO using alternate method which is laser sintered as shaping technology and compare with traditional method.	Ankle foot	Calf & foot part Polyamide 12 Two carbon fiber rod	Laser sintering	Less time required for patient fitting compare to tradition method.	19
11	Create & validate a standardized framework for the evaluation of ankle stiffness of 3D printed AFOs.	Ankle foot	Rods-CFRP Foot & calf part-polyamide 12	3D printing	Result revealed a better indication of AFO stress distribution and stiffness.	20
12	Manufacturing of ankle foot orthosis by SLS technique.	Ankle foot	Dura form PA Dura form GF Rilsan D80	Selective laser sintering	Better mechanical damping. High energy dissipation.	21
13	Investigate the feasibility of AFO fabrication by additive manufacturing.	Ankle foot	Polyamide 12	3D printing	AFOs are light in weight have good mechanical property. Improvement in gait of patient.	22
14	Build a knee ankle foot orthosis using carbon fiber composite and compare mechanical property with polypropylene AFO.	Ankle foot	Bars- stainless steel. Carbon fiber with corthocryl laminated resin as matrix.	Pre-preg carbon fiber sheet	Carbon fiber AFO has superior mechanical properties than polypropylene.	23
15	Present a new method for 3D printed AFOs that customises the fit and also allows variable stiffness of ankle joint	Ankle foot	Carbon fiber pre-impregnated with an epoxy matrix.	3D printing	Automation can be easily achieved for 3D printed segment which reduce the labour cost.	24

2.2. Natural fiber reinforced composite material as an alternate material for ankle foot orthosis.

Natural fibers like kenaf, jute, and flax are lightweight, eco-friendly, and cost-effective alternatives to carbon and glass fibers. Treatments and hybridization enhance their properties, making them ideal for ankle foot orthoses.

Table 2.2: Overview of mechanical properties of kenaf fiber reinforced composites.

Fiber/Matrix	Fabrication method	Fiber orientation /Fiber weight %	Tensile Strength (MPa)	Flexural Strength (MPa)	Impact Strength	Reference
Sisal/kenaf/Polyster	Compression molding	Randomly orientated/40 %	91.33	150.3	22.3 KJ/m^2	27
Kenaf/Epoxy	Hand-lay up	Unidirectional/38-41%	-	300-350	-	28
Kenaf/Epoxy	Compression molding	Random mat/ 50%	45	260	-	29
Kenaf/Polylactic acid	Hot press molding	Random/60%	8	28	70 J/m	30
Kenaf/Polylactic acid	Hot press molding	Unidirection/ 30%	130.5	155	-	31
Kenaf/Epoxy	Hand-lay up with cold compression	Unidirectional/40%	100.53	-	-	32
Kenaf/Magnesium hydroxide/ Epoxy	Hand-lay up	Nonwoven mat/40%	39.36	88	24 J/m	33
Kenaf/Epoxy	Hand-lay up	Unidirectional/40%	164	-	-	34
Kenaf/Polypropylene	Hand-lay up with hot compression	Laminates/20 %	44	-	-	35
Kenaf/Epoxy	Vaccum bagging	Unidirectional/48.6%	106	177.6	-	36
Kenaf/High density polyethylene	Compression molding	Random/20%	13.68	73.21	-	37
Kenaf/Epoxy	Vaccum Infusion	Random mat/50%	-	45.7	-	38
Kenaf/Polypropylene	Injection molding	Short fiber mesh/40%	25.186	46.14	-	39
Kenaf/ABS	Hand-lay up	-	279.2	-	3.1 Kj/m^2	40
Kenaf/Thermoplastic polyurethane	Compression molding	Mesh form/30%	33	25	2.75 Kj/m^2	41

MATERIALS AND METHODOLOGY

3.1 Properties of Selected Materials

Literature shows high potential for kenaf fiber-epoxy composites as sustainable alternatives to carbon or polymer-based materials for ankle foot orthoses.

3.1.1 Matrix material

Matrix material used in the study was epoxy resin (Lapox L-12) with chemical name Bisphenol diglycidly ether and K-6 was used as hardener. This Epoxy resin and K-6 hardener were purchased from AES, Bengaluru.

Table 3.1: Physical and mechanical properties of epoxy resin Lapox L- 12 [Atul Ltd data sheet]

Properties	Values
Viscosity (MPa s)	9000 - 12000
Density (g/cc)	1.1 - 1.2
Tensile strength (MPa)	70-80
Flexural strength (MPa)	140 - 150
Impact strength (KJ/m^2)	18-20
Elastic modulus (GPa)	4-4.8
Elongation at break (%)	2.5-5

3.1.2 Reinforcement material

Kenaf fiber, derived from the bast of *Hibiscus* plants in the Malvaceae family, is a cost-effective, commercially available natural fiber. Sourced from Gogreen Products, it grows 2.5–4.0 m tall in tropical and subtropical Asia and Africa.

Fig 3.1: Raw kenaf fiber

Table 3.2: Physical and mechanical properties of kenaf fiber.

Properties	Values
Density (g/cc)	1.2 1.4
Cellulose (%)	51 52
Hemicellulose (%)	20.3 21.5
Lignin (%)	17
Tensile strength (MPa)	223 - 930
Young’s modulus (GPa)	20
Elongation at break (%)	9.3 12.3
Moisture absorption (%)	12 14

3.2 Chemical treatment of fiber

Kenaf fibers exhibit poor matrix compatibility, improved by chemical treatments. In this study, raw kenaf fibers (1–2 m bundles) were treated with 6% NaOH solution for 24 hours, rinsed with distilled water, and sun-dried for 48 hours to enhance adhesion between fiber and matrix.

Fig 3.2: Treated kenaf fiber

3.3 Fabrication technique

Kenaf fiber reinforced composites were fabricated with 0%, 10%, 20%, 30%, and 40% fiber weight fractions using the hand lay-up technique. Treated fibers were cut to 200 mm, weighed, and layered unidirectionally in a steel mold (200 mm × 200 mm × 3 mm). A polyethylene sheet and silicone-based release spray ensured easy demolding. Fibers were immersed in Lapox L-12 epoxy resin and K-6 hardener (10:1 ratio), and a steel roller removed air bubbles. Dead weights flattened the surface during curing. Samples were demolded after 24 hours, cut to ASTM standards, and tested for mechanical properties. Steps were repeated per fraction.

3.4 Physical and mechanical characterisation

3.4.1 Void contents

Voids in composites arise from air entrapment or reinforcement clustering during fabrication. They can be minimized using proper placement and rolling. Void content is calculated using a theoretical formula based on material densities.

$$\text{Void contents} = \frac{\text{Theoretical Density-Experimental Density}}{\text{Theoretical Density}} \quad (3.1)$$

Theoretical density of a composite is calculated by formula given below:-

$$\text{Theoretical density} = \frac{1}{\frac{\text{Weight Fraction of kenaf fiber}}{\text{Density of kenaf fiber}} + \frac{\text{Weight fraction of epoxy}}{\text{Density of epoxy}}} \quad (3.2)$$

3.4.2 Tensile Test

Tensile strength measures a material's resistance to breaking under tension, expressed in Pascals (N/m^2). Ultimate tensile strength is the ratio of maximum load to original cross-sectional area. Tensile tests were conducted according to ASTM D638 standard, using specimens (165 mm × 19 mm × 3 mm) on a universal testing machine (UTM) with 100 KN capacity.

Fig 3.3: Tensile specimens

Fig.3.4: Tensile test set up on UTM at NER workshop.

3.4.3 Flexural test

Flexural strength is a material property which is defined as the maximum bending stress that can be applied to that material before it yields. Flexural strength is also known as bend strength or modulus of rapture. 3 point bending test has been performed as per ASTM D790 standard. Sizes of specimens were 127 mm × 12.7 mm × 3 mm (Fig 3.5). Flexural test of composite performed at NER Workshop on universal testing machine equipped with maximum load capacity of 100 KN (figure 3.6). The flexural strength also can be determined by equation 3.3.

$$\text{Flexural strength} = 3PL/2wt^2$$

Where, P denotes maximum load, width of specimen is w, thickness of specimen is t and L denotes span length of the sample.

Fig 3.5: Flexural test specimens

Fig.3.6: Flexural test set up on UTM at NER workshop

SUMMARY AND CONCLUSION

Summary and Conclusion of research work

In this research work kenaf epoxy composite has been presented as an alternate material for orthosis especially ankle foot orthosis. The overall conclusion from this research work is summarized as follows:-

1. The kenaf fiber epoxy composite has been fabricated using hand lay-up technique with Lapox L-12 as matrix material and kenaf fiber as reinforcing material.

2. Composite has been fabricated for different volume fractions of kenaf fibers i.e. 0%, 10%, 20%, 30% and 40%. Fibers placed in unidirectional manner in the epoxy matrix and compressed with dead weight.

3. In present research work different physical and mechanical properties such as void content, ultimate tensile strength and flexural strength were determined by experimental set up for varying fiber volume fractions (0%, 10%, 20%, 30% and 40%). of kenaf epoxy composite.

4. Void contents have been increased with increase in fiber volume fraction. Void content increases from 0.434 % for 0 % kenaf fiber volume fraction to 1.323 % for 40 % kenaf fiber volume fraction.

5. It has been observed that ultimate tensile strength increases from 43 MPa for 0% kenaf fiber volume fraction to 89 MPa for 40% kenaf fiber volume fraction. Flexural strength increases from 76 MPa for 10% kenaf fiber volume fraction to 148 MPa for 30 % kenaf fiber volume fraction. Futher increase in fiber volume fraction to 40 % results in decrease of flexural strength to 143 MPa.

6. Finally, MOORA technique has been used to find optimal result for the combination of physical and mechanical properties of fabricated kenaf fiber reinforced epoxy composite. It has been found that 40 % fiber volume fraction composite is the best alternative among four different volume factions. The sequence obtained from MOORA technique is 40% > 30% > 20% > 0% > 10% of kenaf fiber volume fraction.

7. Mechanical and physical properties obtained by various mechanical tests have been compared with previously used materials by different researchers for ankle foot orthosis.

REFRENCES

[1] J.P. Agarawal, composite materials, Popular Science and Technology Series, 1990.
[2] W.D. Callister, Material Science and Engineering- an Introduction, John Willey & Sons. Inc. 2007.
[3] P.M. Mohite, Composite Materials, Aerospace Engineering, IIT Kanpur.
[4] J. Ramkumar, Manufacturing of Composites, NPTEL Course, IIT Kanpur, 2017.
[5] A.K. Kaw, Mechanics of Composite Material, Taylor & Francis Group, LLC, 2006.
[6] F.S. Shahar, M.T.H. Sultan, S.H. Lee, M. Jawaid, A.U.M. shah, S.N.A. Safri,
[7] P.N. Sivasankaran, A Review on Orthotic and Prosthetics and the Potential of
[8] Kenaf Composite as Alternative Material for Ankle Foot Orthosis, Mechanical Behavior of Biomedical Materials, vol. 99, 2019, pp. 169-185.
[9] R.K. Chen, Y. Jin, J. Wensman, A. shih, Additive Manufacturing of Orthoses and

Prostheses-A Review. Additive Manufacturing, 2016, vol. 12, pp. 77-89.

[10] O. Ulkir, G. Akgun, E. Kaplanoglu, Mechanical Design and Analysis of a Pneumatic Ankle Foot Orthosis. IEEE, 2018.

[11] T. Kobayashi, M.S. Orendurff, et al., An Articulate Ankle Foot Orthosis with

[12] Adjustable Planterflexion Resistance, Doriflexion Resistance and Alingment: A

[13] Pilot Study on Mechanical Properties and Efforts on Stroke Hempaertic Gait.

[14] Mechanical Engineering & Physics, 2017, pp. 1-8.

[15] Y.H. Cha., K.H. Lee., et al., 2017. Ankle foot orthosis made by 3D printing technique and automated design software. Applied Bionics and Biomechanics, vol. 2017.

[16] M. Alam., I.A. Chaudhary., A.B. Mamat., Custom aided design and fabrication of a custom articulated ankle foot orthosis.Mechanics In Medicine and Biology, vol.15, no.4, 2015.

[17] E. Papi., J. Maclean., R.J. Bower., et al., Determination of loads carried by polypropylene ankle-foot orthoses: a preliminary study. Proceedings of the

[18] Institution of Mechanical Engineers, Part H: Journal of Engineering in Medicine, pp. 40 51.

[19] D. Zou., T. He., M. Dailey., et al., Experimental and computational analysis of composite ankle foot orthosis. J. Rehabil. Res. Dev. 51, pp. 1525 1536.

[20] C.E. Dombroski., M.E. Balsdon., A. Froats., The use of a low cost 3D scanning and printing tool in the manufacture of custom made foot orthoses : a preliminary study. BMC Research Notes, 2014.

[21] M. Fantini., F.D. Crescenzio., et al., Design and rapid manufacturing of a customized foot orthoses: a first methodological study. Advanced On

[22] Mechanics, Design Engineering And Manufacturing, Lecture Notes In Mechanical Engineering, Springer Internation Publishing, 2017.

[23] A. Amerinatanzi., H. Zamanian., et al., On the advantages of superelastic NiTi in ankle foot orthoses. Conference on Smart Material, Adaptive Structures And

[24] Intelligent System, Proceedings of ASME. 2016.