The Sirindhorn International TGGS Thai-German Graduate School of Engineering

Industry-Oriented Graduate Education and Research in Thailand based on the RWTH Aachen Model

TGGS COLLOQUIUM FOR DOCTORAL STUDENT 2020

Wednesday; may 20, 2020 at 09.30–12.00

Via Cisco Webex Webseminar

PERFORMANCE ASSESSMENT OF HYBRID FIBERS REINFORCED COMPOSITES UNDER TRIBOLOGICAL CONDITIONS

Mr. Yashas Gowda Thyavihalli Girijappa

TGGS, KMUTNB, Thailand

ID:61-090939-6051-1

Advisor:Prof. Dr.-Ing. habil. Suchart Siengchin,President,KMUTNB

Co-advisor: Dr. Sanjay Mavinkere Rangappa

ACKNOWLEDGMENT

- ***Prof. Dr.-Ing. habil. Suchart Siengchin,President,KMUTNB.***

- ***Materials and Production Engineering (I-DMPE), Academic affairs Department & Board of Management, TGGS, KMUTNB.***

- ***Natural composites lab-Researchers ,members and faculties.***

BACKGROUND

- The recent research and development in the field of materials science and technology focuses attention towards the potential utilization of biodegradable materials in various applications.
- The development of ecofriendly materials of any kind is necessary for new demands.
- The development of composite materials utilized to solve technological problems is one of the most significant advances in the field of materials science.
- Today, composite materials appear to be the choice for many engineering applications.

SCOPE OF THE STUDY

- In the present work, natural and synthetic fibers are to be selected as reinforced fibers and then hybrid fiber composites are to be fabricated by different manufacturing techniques.
- The physical, mechanical and tribological performances of these hybrid fibers reinforced composites are to be systematically evaluated and studied.
- Furthermore, the effects of hybrid fibers on wear mechanism are to be studied based on the worn surfaces morphologies.

PURPOSE OF THE STUDY

- Over the past several years, many material scientists and formulation designers studied on the appropriate combination of reinforced fibers for tribological applications.

- The fundamental problem of incorporating and selecting the right combination of reinforced fibers tribological applications for has not yet been properly addressed, and which needs further research.

INTRODUCTION

- A **composite** is a structural material that consists of two or more combined constituents that are combined at a macroscopic level and are not soluble in each other. One constituent is called the **reinforcing phase** and the one in which it is embedded is called the **matrix.**

[Ref: Autar K. Kaw]

Reinforcement+ Matrix = Composite

CLASSIFICATION OF COMPOSITE MATERIALS

Based on the matrix materials

- Metal Matrix Composites (MMCs)

- Ceramic Matrix Composites (CMCs)

- **Polymer Matrix Composites (PMCs)**:

Generally, polymer can be classified into two classes, thermoplastics and thermosettings.

Based on the types of reinforcement, polymer can be classified as particulate reinforced polymer composite and fibre reinforced polymer composites (FRPCs).

- FRPCs are composed of natural and synthetic fibers which can be manufactured with or without the application of filler material.

- FRPCs are mainly categorized as natural fiber composites (NFCs) and synthetic fiber composites (SFCs).

Major drawbacks of synthetic fiber composites

- Though the composites made from synthetic fibers possess high strength, the field of application is restricted because of their higher cost of production and low biodegradability.

- Although SFCs have excellent mechanical properties but the process of disposal is very difficult due to severe environmental concern and process of recycling of these composites has been serious problems.

- Health problems during processing of composites like skin irritation, allergy, respiratory problems etc.

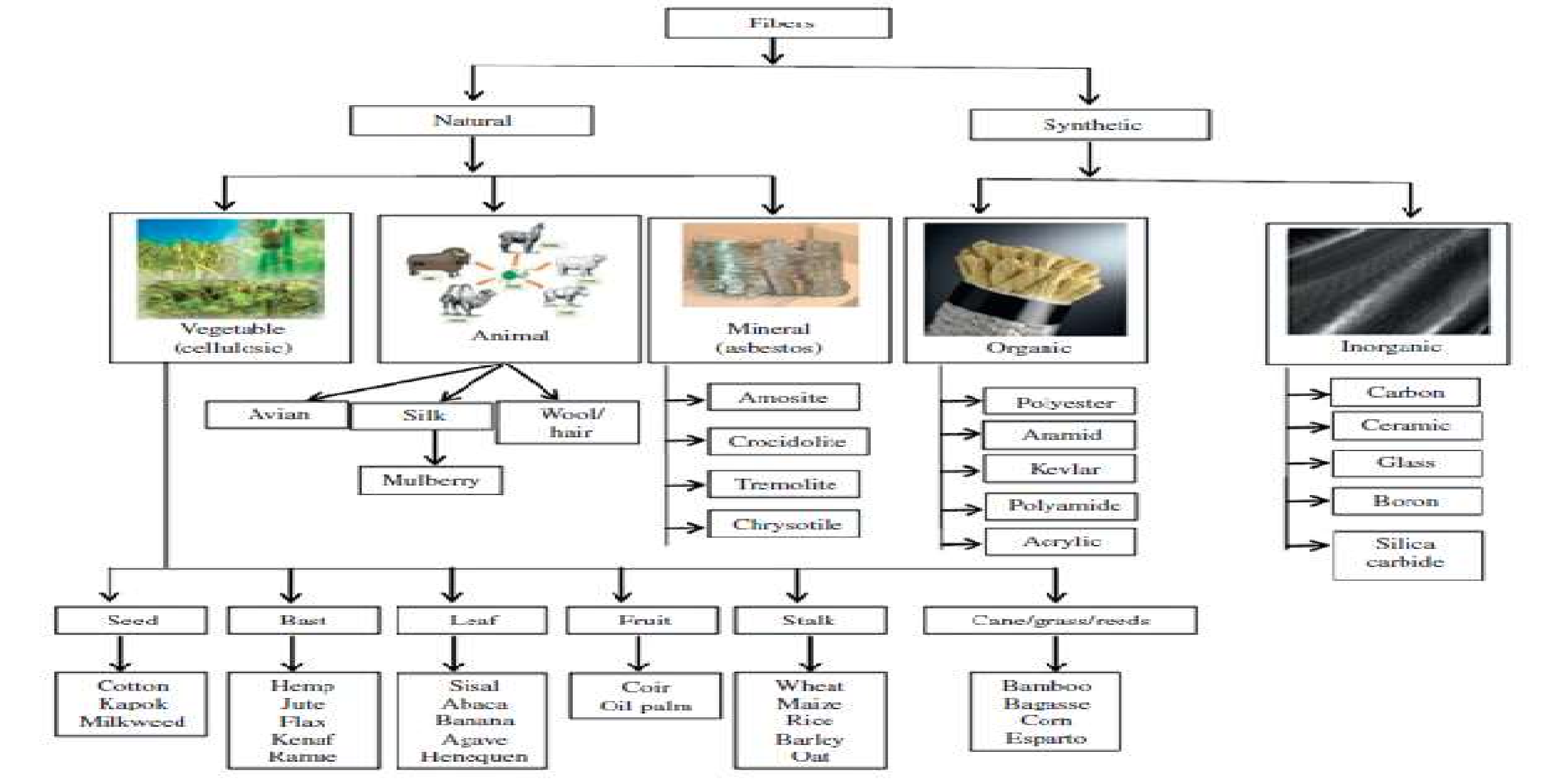
NATURAL FIBER COMPOSITES

- The increasing demand for green, environment friendly has resulted in new natural fiber based materials as replacements for non-degradable materials.

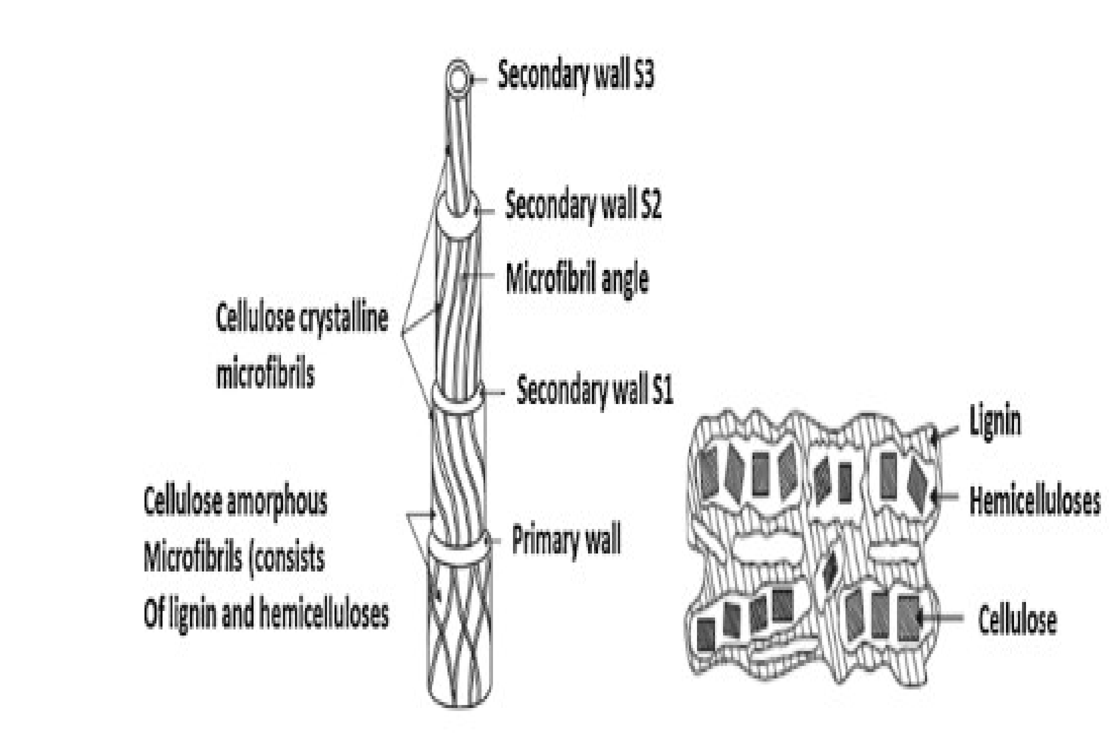
- Due to significant weight savings and low cost of raw materials the automobile industry begun to apply natural fiber composites in a variety of exterior and interior applications.

- The usage of natural fiber based composite materials is growing during recent years due to their specific properties, clearly positive environmental impact, economical production, processing and their safe handling and working conditions.

COMMONLY USED NATURAL FIBRES AND MATRICES FOR POLYMER COMPOSITES



Source: Sanjay M R "Potential of Natural/Synthetic Hybrid Composites for Aerospace Applications" In book. Sustainable Composites for Aerospace Applications. Woodhead Publishing UK (ELSEVIER, UK), 2018, pp. 315-351.



Advantages	Disadvantages
Low specific weight results in a higher specific strength and stiffness than glass	Lower strength, especially impact strength
Renewable resources, production require little energy and low CO_2 emission	Variable quality, influence by weather
Production with low investment at low cost	Poor moisture resistant which causes swelling of the fibers
Friendly processing, no wear of tools and no skin irritation	Restricted maximum processing temperature
High electrical resistant	Lower durability
Good thermal and acoustic insulating properties	Poor fire resistant
Biodegradable	Poor fiber/matrix adhesion
Thermal recycling is possible	Price fluctuation by harvest results or agricultural politics

Sanjay, M.R., Siengchin, S., Parameswaranpillai, J., Jawaid, M., Pruncu, C.I. and Khan, A., 2018. A comprehensive review of techniques for natural fibers as reinforcement in composites: Preparation, processing and characterization. Carbohydrate polymers.

CHEMICAL COMPOSITIONS OF SOME NATURAL FIBERS

Fiber	Cellulose (wt.%)	Hemicelluloses (wt.%)	Lignin (wt.%)	Wax (wt. %)	Moisture Content (%)	Ash (wt.%)
Prosopis juliflora	61.65	16.14	17.11	0.61	9.48	5.2
Acacia leucophloea	68.09	13.60	17.73	0.55	8.83	-
Sanseviera cylindrica	79.7	10.13	3.8	0.09	3.08	-
Agave	**68.42**	**4.85**	**4.85**	**0.26**	**7.69**	**-**
Areca	53.2	32.98	7.2%	-	-	-
Bamboo	33-45	30	20-25	-	-	-
Borassus	53.40	29.6	17.00	-	-	-
Banana	60-65	6-8	5-10	-	-	1.2
Jute	59-71	12-13	11.8-12.9	-	-	0.7
Sisal	60-67	10-15	8-12	-	-	0.14-0.87
Kenaf	31-72	20.3-21.5	8-19	-	-	-
Pineapple leaf	70-83	-	5-12.7	-	11.8	-
Century plant	71.65	22.24	6.09	-	-	-

MECHANICAL AND PHYSICAL PROPERTIES OF SOME FIBERS

Fiber	Density (g/cm^3)	Tensile strength (MPa)	Young's modulus (GPa)	Elongation at break (%)
Jute	1.23	325-770	37.5-55	2.5
Flax	**1.38**	**700-1000**	**60-70**	**2.3**
Hemp	1.35	530-1110	45	3
Ramie	1.44	915	23	3.7
Banana	1.35	721.5-910	29	2
Bagasse	1.2	290	17	1.1
Areca	**1-1.1**	**147- 322**	**3.5-5.7**	**10.1-13.2**
Pineapple	1.5	1020-1600	71	0.8
Kenaf	1.2	745-930	41	1.6
Coir	1.2	140.5-175	6	27.5
Sisal	1.2	460-855	15.5	8
Abaca	1.5	410-810	41	3.4
Cotton	1.21	250-500	6-10	7
Nettle	1.51	650	38	1.7

Yashas Gowda T.G.et,al (2019)

HYBRID COMPOSITES

- The word “hybrid” is derived from Greek- Latin origin and can be defined as the material composed of different mixture of matrices combined with two or more reinforcing and filler material.

- The important advantage of using hybrid composite is that, since it is made up of more than one fiber if any one fiber lacks certain characteristics it can be complemented by other fiber and also balance in cost and performance of this type of composite could be obtained by proper material design considerations.

- Better results could be obtained by hybrid composites depending upon various properties like individual fiber length, structure of fiber, fiber content and its orientation, fiber to matrix bonding, fibers arrangement and finally dependent on the failure strain of each fibers in composite.

System	Materials	Highlights	Advantages
Synthetic-natural fibres hybrids	– Glass-jute fibre hybrids	– Hybrid had higher mechanical properties when compared with non-hybrid jute reinforced composite – Reduction of degradation of jute fibres	– Balancing performance and cost – Reducing moisture absorption – Improved mechanical properties
	– Carbon-flax fibre hybrids	– Hybrid had increased mechanical properties when compared to non-hybrid woven flax reinforced composites	– Improved mechanical properties
	– Carbon-jute fibre hybrids	– Mechanical properties of hybrid material are higher than that of non-hybrid jute reinforced composites	– Improved mechanical properties – Hybrid can replace non hybrid carbon reinforced composite
Natural-natural fibre hybrids	– Kenaf-jute fibre hybrids – Kenaf-hemp fibre hybrids	– Hybrid composites absorbed less water in comparison to non-hybrid kenaf, jute and hemp reinforced composites – Hybrid composites had higher mechanical properties in comparison to non-hybrid kenaf, jute and hemp reinforced composites	– Low cost – Minimal improvement of mechanical and water resistance properties
	– Seaweed-sugar palm fibre hybrids	– Hybrid composites had slightly improved tensile and flexural strengths with lower impact resistance	– Low cost – Minimal improvement of mechanical and water resistance properties
Hybrid nanocomposites	– Oil palm fibres-clay hybrid	– Mechanical properties of hybrid showed significant increase when compared to non-hybrid oil palm fibre reinforced composites	– Low cost – Significant improvement of mechanical properties
	– Pine cone fibres-clay hybrid	– Tensile modulus of hybrid composite increase with increasing loading	– Low cost – Significant improvement of tensile modulus
	– Kenaf fibres- oil palm nanofiller – Kenaf- Montmorillonite (MMT) and organically modified montmorillonite (OMMT)	– Mechanical properties of hybrid showed significant increase when compared to non-hybrid kenaf fibre reinforced composites	– Low cost – Significant improvement of mechanical properties

Mochane, M.J., Mokhena, T.C., Mokhothu, T.H., Mtibe, A., Sadiku, E.R., Ray, S.S., Ibrahim, I.D. and Daramola, O.O., 2019. Recent progress on natural fiber hybrid composites for advanced applications: A review.

REVIEW ON MECHANICAL PROPERTIES OF NATURAL FIBER HYBRID COMPOSITES

Natural/Hybrid fiber	Matrix polymer	Fabrication Technique	Property Evaluated	References
Coir/glass fiber	Polyester	Close mold	Fiber alkali treatment, water absorption property	J. Rout et al.
Oil palm empty fruit bunch/ glass fiber	Phenol-formaldehyde(PF)	Hand layup	Tensile, flexural and impact properties, hardness, density and void formation	M.S. Sreekala et al.
Banana/glass fiber	Phenol-formaldehyde(PF)	Hand layup, Compression moulding	Adhesion between fibre and matrix, Tensile properties, Flexural behaviour, Impact behavior	S. Joseph et al.
Biofibre (pineapple leaf fibre/ sisal fibre)/ glass fibre	Unsaturated polyester	Hand layup	Tensile, Flexural and impact strength, fibre–matrix interaction, water absorption property	S. Mishra et al.
Banana/Hemp/glass fibers	Epoxy	Mold layup	Tensile, flexural and impact strength, SEM analysis	R. Bhoopathi et al.

Glass/natural fiber	Epoxy vinyl ester	Hand layup	Tensile strength, Flexural strength	G. Cicala et al.
Kenaf/glass fiber	Epoxy	Modified sheet molding compound (SMC)	Tensile, flexural, impact strength,	M.M. Davoodi et al.
Sisal/jute/GFRP	Epoxy	Hand layup	Tensile, flexural and impact properties, scanning electron microscopy (SEM) analysis	M. Ramesh et al.
Curaua/glass fiber	Orthophthalic polyester	Hot Compression moulding	Tensile, flexural and shear proper	J.H.S. Almeida Junior et al.
Sugar palm/ glass fiber	Unsaturated polyester	Hand layup	Tensile, flexural and impact strength, SEM analysis	S.M. Sapuan et al.
Flax/glass fiber	Phenolic resin	Compression moulding	Tensile and interfacial properties	Y. Zhang et al.

REVIEW ON MECHANICAL PROPERTIES OF NATURAL FIBER HYBRID COMPOSITES

Materials Science and Engineering: A
Volume 528, Issue 15, 15 June 2011, Pages 5190-5195

Woven hybrid composites: Tensile and flexural properties of oil palm-woven jute fibres based epoxy composites

M. Jawaid [a], H.P.S. Abdul Khalil [a], A. Abu Bakar [b]

Show more

https://doi.org/10.1016/j.msea.2011.03.047

Get rights and content

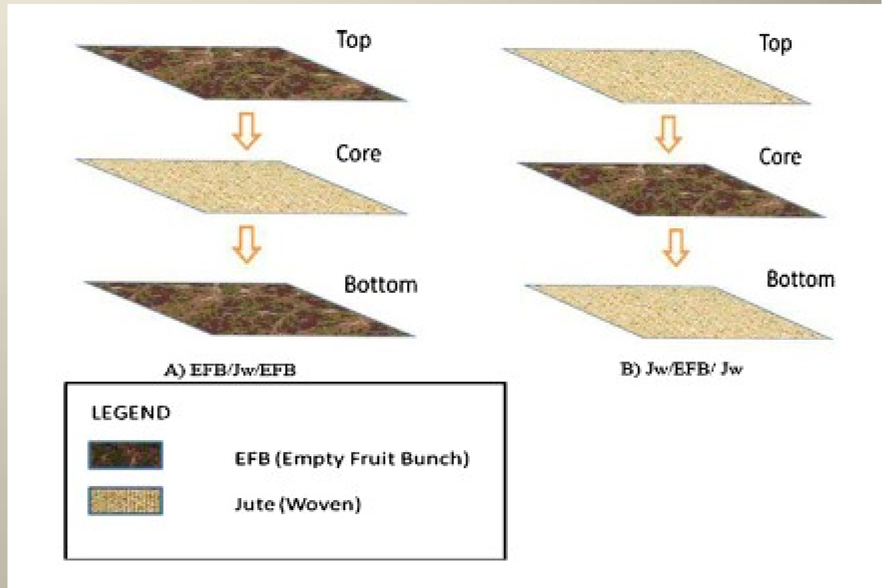
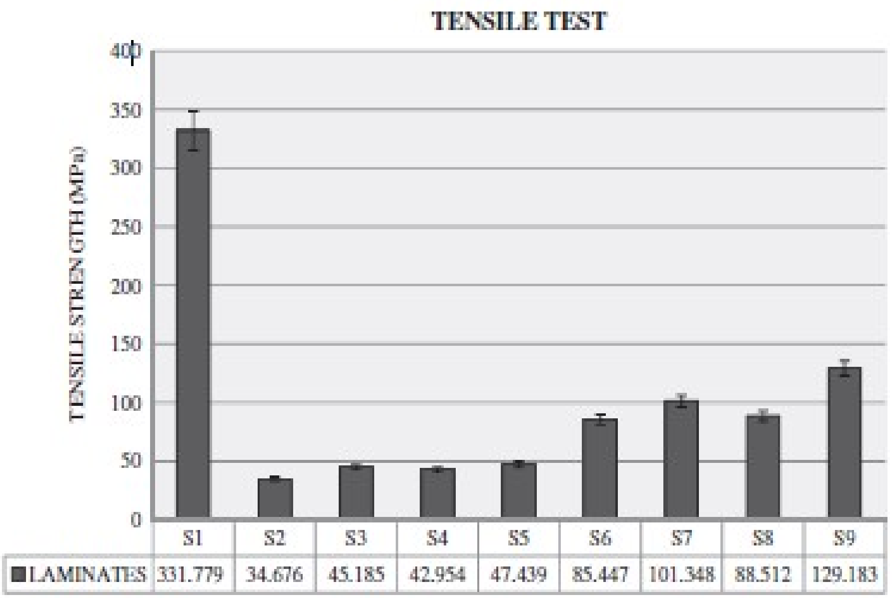


Fig. 1. Different layering pattern of hybrid composite (A) EFB/Jw/EFB, (B) Jw/EFB/Jw.

Mechanical behaviour of woven fabrics based composites depends on the type of weave, fabric weave is one of the important fundamental weaves. Textile bio composites can be tailored to satisfy the specific needs of mechanical performance as well as adequate structural integrity of composite structures at microstructure level



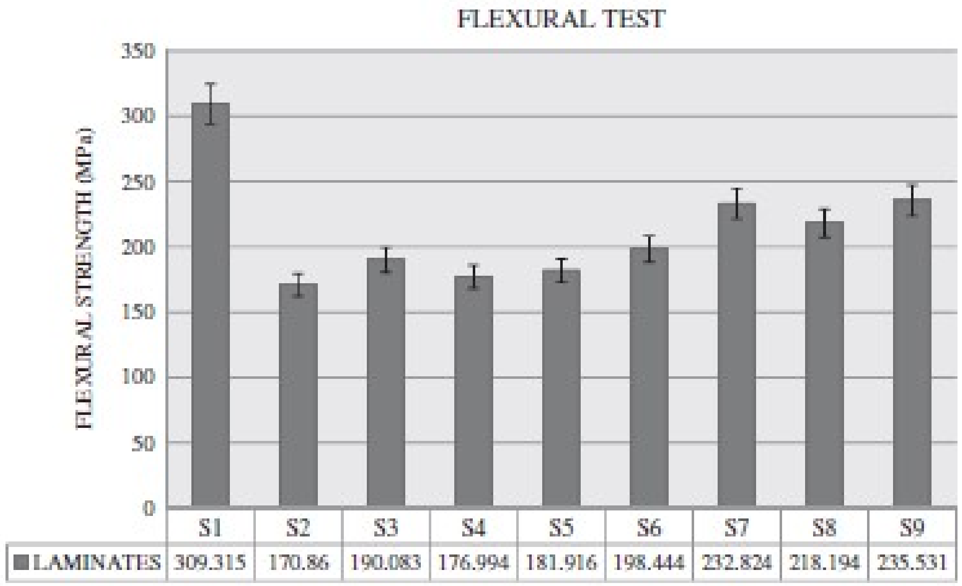
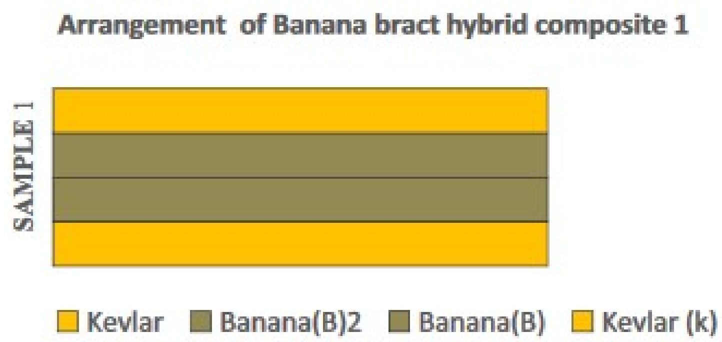


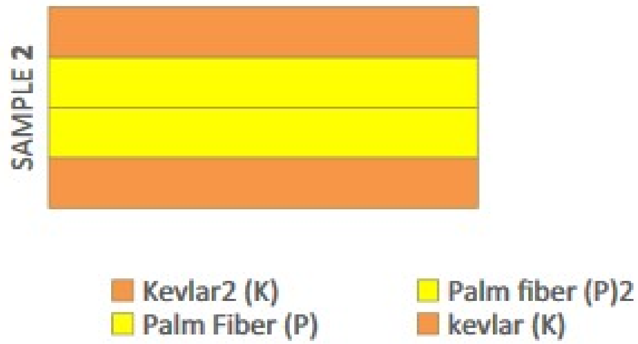
Table 2. Laminate stacking sequences.

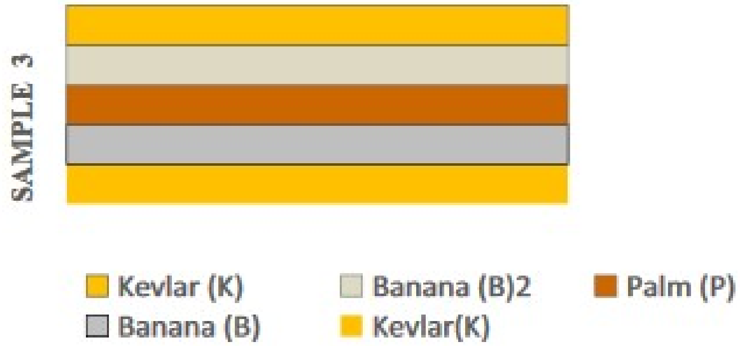
		Weight (g)				Weight fraction (%)				
		w_f				W_f				
Laminate	Stacking sequence	w_g	w_j	w_k	w_m	W_g	W_j	W_k	W_m	Volume fraction (%)
S1	G+G+G+G+G	180 ± 5	—	—	300 ± 10	37.5	—	—	62.5	20.56
S2	J+J+J+J+J	—	75 ± 3	—	200 ± 10	—	27.28	—	72.72	22.75
S3	K+K+K+K+K	—	—	75 ± 3	200 ± 10	—	—	27.28	72.72	22.75
S4	J+K+J+K+J	—	45 ± 2	30 ± 2	200 ± 10	—	16.36	10.90	72.74	23.30
S5	K+J+K+J+K	—	30 ± 2	45 ± 2	200 ± 10	—	10.90	16.36	72.74	23.65
S6	G+J+J+J+G	72 ± 3	45 ± 2	—	250 ± 10	19.62	12.26	—	68.12	20.10
S7	G+K+K+K+G	72 ± 3	—	45 ± 2	250 ± 10	19.62	—	12.26	68.12	20.86
S8	G+J+K+J+G	72 ± 3	30 ± 2	15 ± 1	250 ± 10	19.62	8.17	4.09	68.12	21.21
S9	G+K+J+K+G	72 ± 3	15 ± 1	30 ± 2	250 ± 10	19.62	4.09	8.17	68.12	21.45

Note: J: jute fabric; K: kenaf fabric; G: E-glass fabric; m: matrix.

Sanjay, M.R. and Yogesha, B., 2018. Studies on hybridization effect of jute/kenaf/E-glass woven fabric epoxy composites for potential applications: Effect of laminate stacking sequences. Journal of Industrial Textiles, 47(7), pp.1830-1848.







Sequences of Layer Arrangement	Tensile modulus (GPa)	Tensile strength (GPa)	Force (KN)	Thickness (mm)
(K + B + B + K)	60.3	53.3	4.74	5
(K + P + P + K)	42.65	40	4.02	5
(K + B + P + B + K)	35.42	33.5	3.8	5

Dinesh, S., Elanchezhian, C., Vijayaramnath, B., Sathiyanarayanan, K. and Adinarayanan, A., 2019. Experimental investigation of banana bract fiber and palm fiber reinforced with epoxy hybrid composites. Materials Today: Proceedings.

Table 4 Tensile properties of the composite laminates

Laminates	Peak load (N)	UTS (MPa)	Tensile modulus (GPa)
A1	6283.138	346.636	1.2837
A2	955.759	33.119	0.2014
A3	2301.632	108.224	0.5322
A4	3371.206	168.820	0.7216
A5	1024.174	31.853	0.2219

Table 5 Flexural properties of the composite laminates

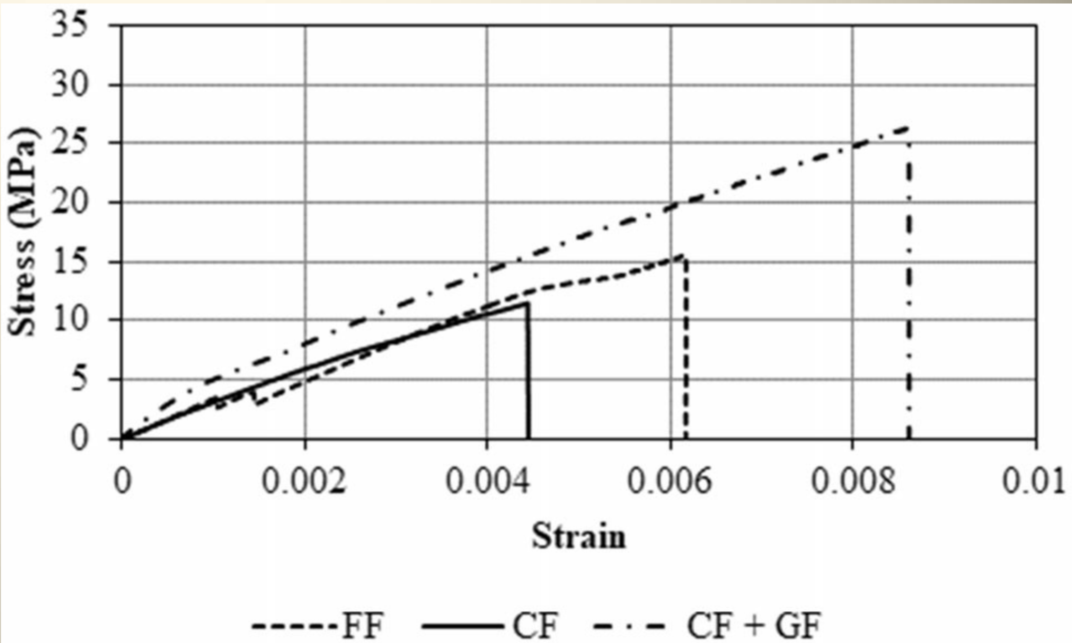
Laminates	Peak load (N)	Flexural strength (MPa)	Flexural modulus (GPa)
A1	170.812	318.753	20.831
A2	67.012	124.642	7.704
A3	110.647	205.643	12.720
A4	129.149	241.216	14.958
A5	90.536	168.396	10.430

Table 3 Laminate sequences and weight fraction of constituents

Laminates	Sequences	w (g)				W (%)			
		w_f			w_m	W_f			W_m
		w_g	w_s	w_{sc}		W_g	W_s	W_{sc}	
A1	G + G + G + G + G	180 ± 5	-	-	300 ± 10	37.5	-	-	62.5
A 2	S + S + S + S + S	-	75 ± 3	-	200 ± 10	-	27.28	-	72.72
A 3	G + S + S + S + G	72 ± 3	45 ± 2	-	250 ± 10	19.62	12.26	-	68.12
A 4	G + S + G + S + G	108 ± 4	30 ± 2	-	275 ± 10	26.15	7.26	-	66.59
A 5	S + S + S + S + S (With Filler)	-	75 ± 3	2	200 ± 10	-	27.07	0.722	72.208

Arpitha, G.R., Sanjay, M.R., Senthamaraikannan, P., Barile, C. and Yogesha, B., 2017. Hybridization effect of sisal/glass/epoxy/filler based woven fabric reinforced composites. Experimental Techniques, 41(6), pp.577-584.

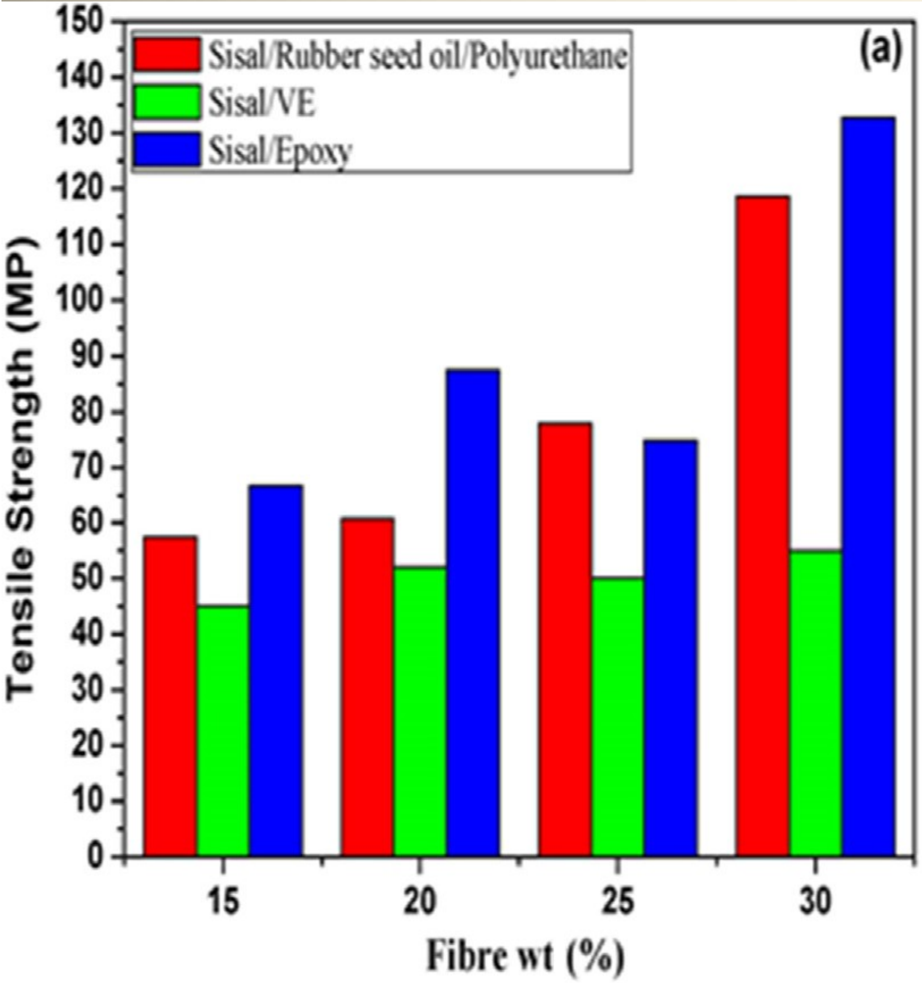
- Mechanical properties of composites made with coarse fibre and fine fibre have not changed significantly. Mechanical of coarse fibre sandwiched with glass fibre composites is more when compared to that of pure areca fibre composites

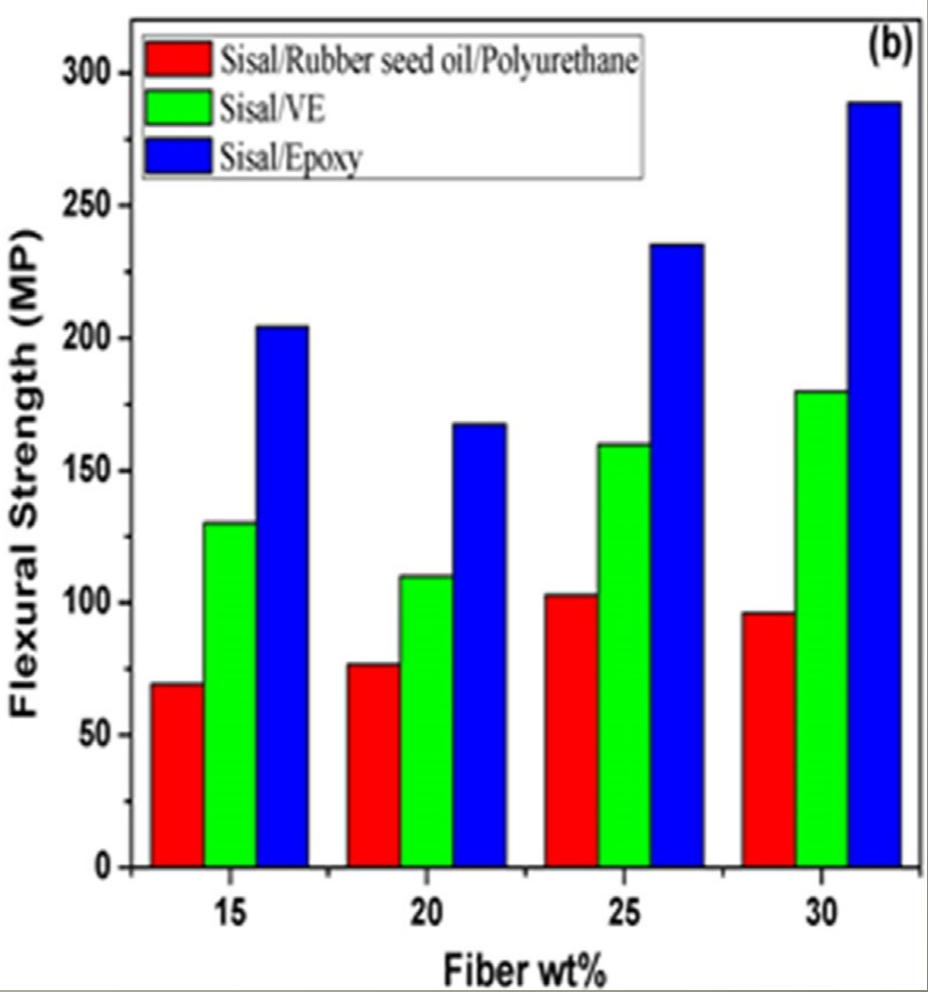


Stress–strain curves of composites made with fine fibre (FF),Coarse fibre (CF) and coarse fibre with glass fibre(CF+GF)

Muralidhar, N., Kaliveeran, V., Arumugam, V. and Reddy, I.S., 2019. A Study on Areca nut Husk Fibre Extraction, Composite Panel Preparation and Mechanical Characteristics of the Composites. Journal of The Institution of Engineers (India): Series D, pp.1-11.

Variation in tensile and flexural strength of sisal fibre reinforced composites with various matrices on varying fibre weight%





Senthilkumar, K., Saba, N., Rajini, N., Chandrasekar, M., Jawaid, M., Siengchin, S. and Alotman, O.Y., 2018. Mechanical properties evaluation of sisal fibre reinforced polymer composites: a review. Construction and Building Materials, 174, pp.713-729.

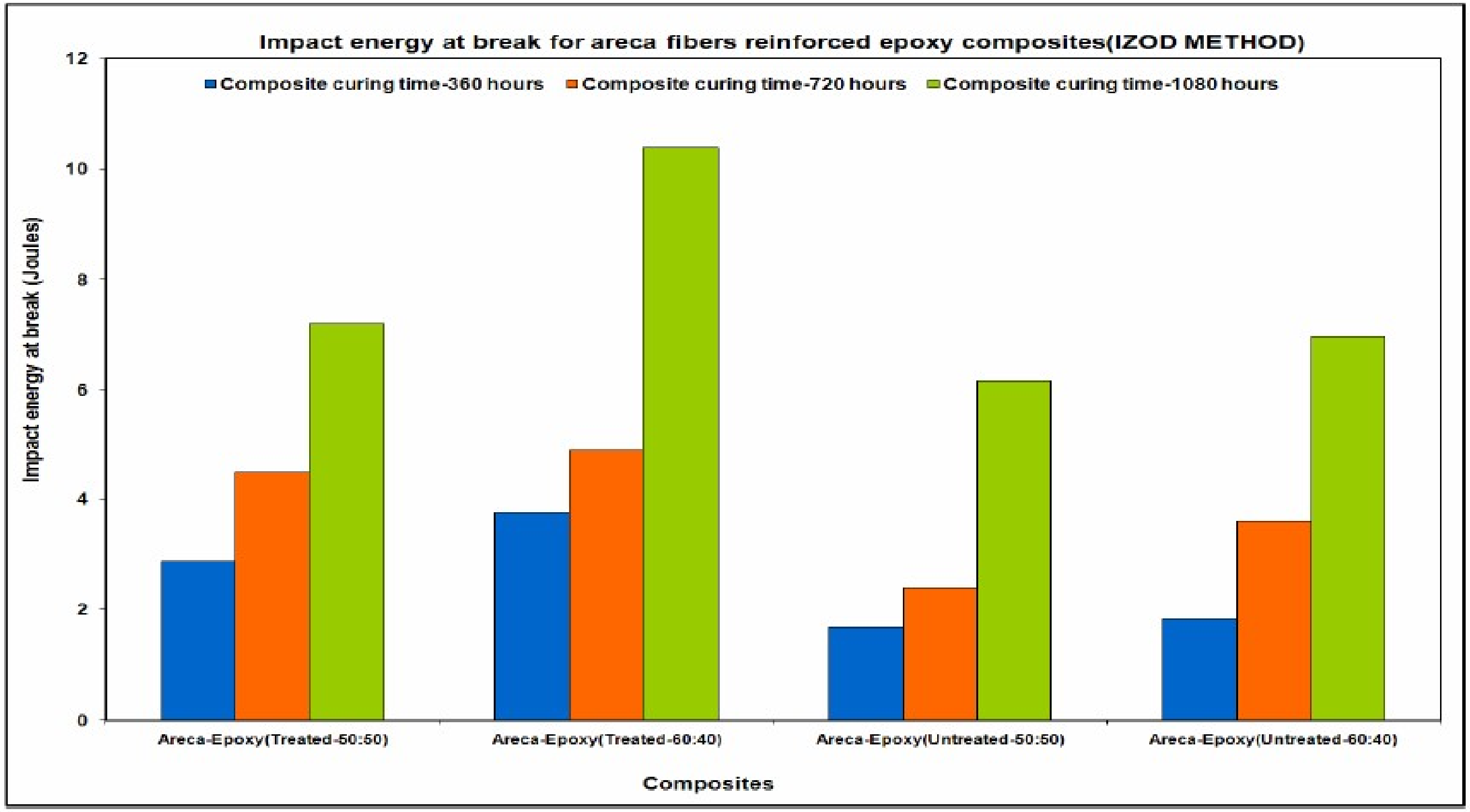
EPOXY

- **Effective strength.**
- **Good toughness.**
- **Appreciable resilience.**
- **Good resistance to moisture and chemical attack.**
- **Great electrical insulating properties and is devoid of volatile matter.**
- **They can be cured at ambient temperature without any pressure by using a curing agent or may be heat cured.**
- **They can be bonded to nearly all materials like wood, glass, natural fibers, and metal.**
- **They exhibit little or no shrinkage after curing.**

- Epoxy resin has excellent adhesion to a large number of materials and could be further strengthened with the addition of fibre.

Table 2
Properties of epoxy resin.

Appearance	A clear pale yellow liquid
Specific gravity at 25 °C (g/cm^3)	1.12
Solid content (%)	84
Tensile strength (MPa)	31
Flexural strength (MPa)	67
Impact strength (Kg/m^2)	9



The strength of areca fiber composites increases with increase in volume fraction of fibres in the composite and post composite curing time.

Srinivasa, C.V. and Bharath, K.N., 2011. Impact and hardness properties of areca fiber-epoxy reinforced composites. J Mater Environ Sci, 2(4), p.351e6

Table 7. Techniques for the composite preparation with the polymer.

Processing of natural fiber-thermosetting composites	**Processing of natural fiber-thermoplastic composites**
Hand lay-up and spraying	Extrusion
Compression	Injection molding
Transfer	Thermoforming
Resin transfer molding	Compression method
Injection molding	Cold pressing
Compression injection	Heating
Pressure bag molding	Direct long fiber reinforced thermoplastics
Pultrusion	Filament Winding
Vacuum assisted resin transfer molding	Foam molding
Casting Injection molding	Rotational molding, calendaring
Polyurethane foam molding	Co-extrusion

Saba, N., Tahir, P. and Jawaid, M., 2014. A review on potentiality of nano filler/natural fiber filled polymer hybrid composites. Polymers, 6(8), pp.2247-2273.

REVIEW ON APPLICATIONS OF NATURAL FIBER HYBRID COMPOSITES

Potential Application	Examples
Automobile, Transportation and Aviation	Door panels, seatbacks, headliners, dash boards, car door, pallets, trunk liners, decking, parcel shelves, spare tyre covers, other interior trim, spare-wheel pan, trim bin, automobile and railway coach interior, boat
Building and construction industry	Railing, bridge, siding profiles, panels for partition and false ceiling, partition boards, wall, floor, window and door frames, roof tiles, mobile or pre-fabricated buildings which can be used in times of natural calamities such as floods, cyclones, earthquakes, etc,.
House hold and utility products	Table, chair, fencing elements, door panels, interior panelling, Window frames, door-frame profiles, food tray, partition
Electronics appliances	Mobile cases, laptopscases
Sports & leisure goods	Tennis Racket, ball, bicycle, frames, snowboards
Storage devices	Post-boxes, grain-storage silos, bio-gas containers etc.,
Furniture	Chair, table, shower, bath units
Every day applications	Lampshades, suitcases, helmets

Puttegowda, M., Rangappa, S.M., Jawaid, M., Shivanna, P., Basavegowda, Y. and Saba, N., 2018. Potential of natural/synthetic hybrid composites for aerospace applications. In Sustainable Composites for Aerospace Applications (pp. 315-351). Woodhead Publishing.

OBSERVATIONS

- Plant based natural fiber composites have been demonstrated as an important alternative material for synthetic fiber reinforced polymer matrix composites due to their biodegradable nature.

- Increased utilization of natural fiber as reinforcement for composite materials can diminish the use of synthetic fibers and reduce greenhouse gas emissions.

- Hybridization with multiple natural and synthetic fiber reinforcements has been recognized as a potential technique to fabricate composites. Moreover, it can enhance certain mechanical properties.

- Incorporation of different natural fibre polymers with synthetic fibres leads to increase the applications and replace the non-renewable materials in the field of engineering and technology.

TRIBOLOGY

- Tribology is the greek word ‘tribo’ means rubbing and ‘logy’ means knowledge. Therefore tribology is the study of friction mechanism between two solid surfaces which have relative motion between them.

- There are clear economic and environmental incentives to aggressively pursue the development of the new materials that can reduce friction and wear.

- Friction and wear cost the economy a staggering amount of money ,energy and materials each year.

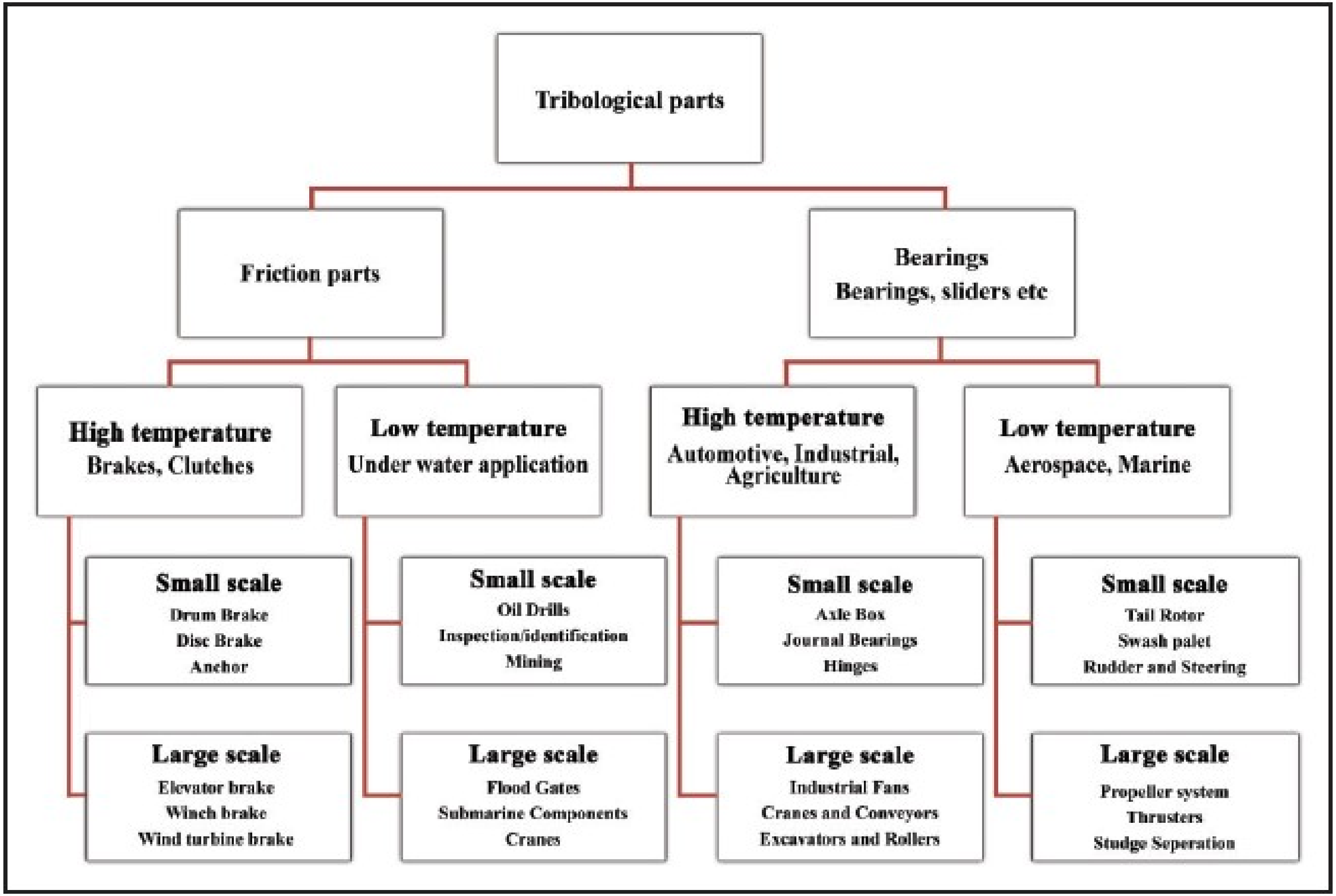
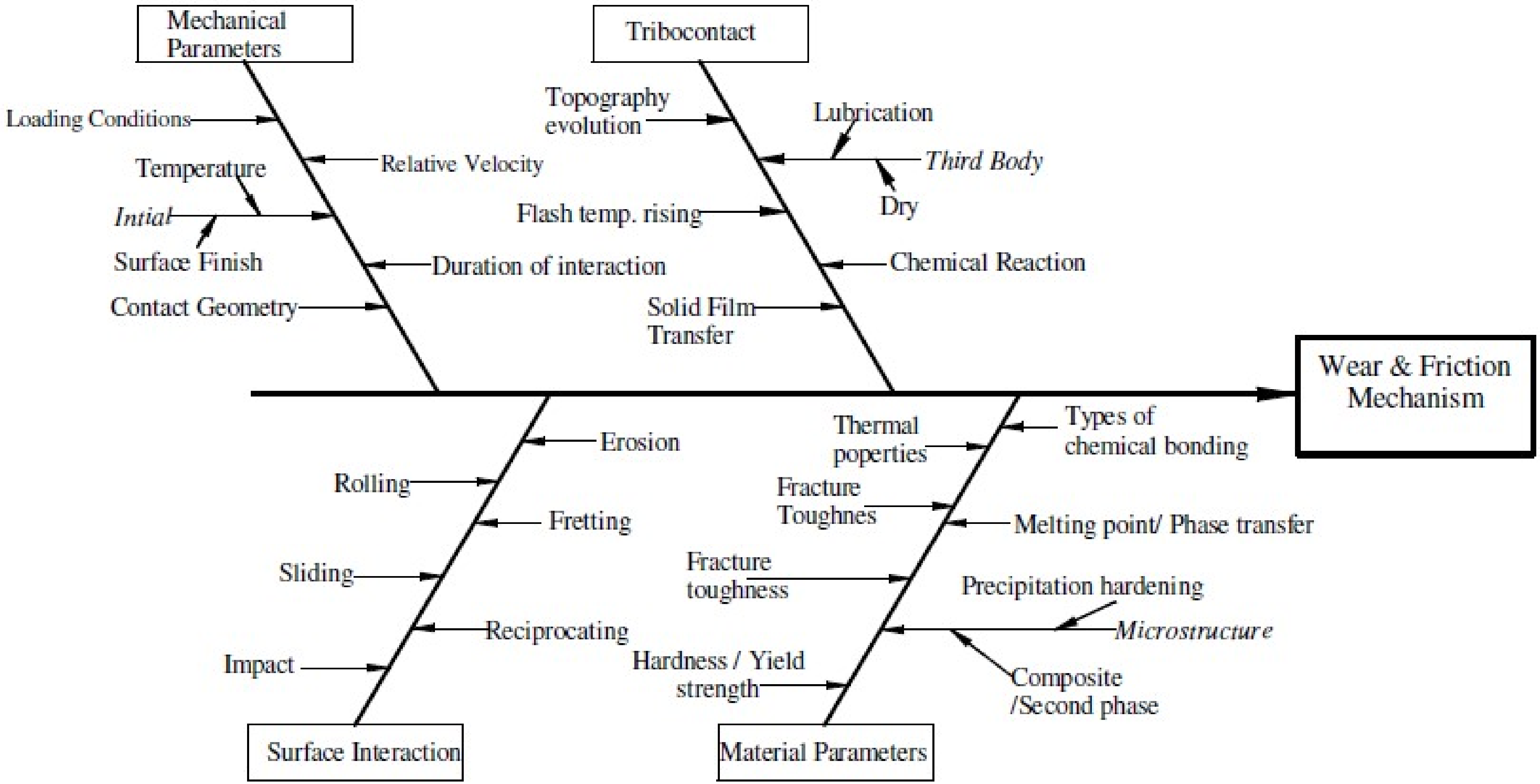

Tribological parts
Friction parts
Bearings
Bearings, sliders etc
High temperature
Brakes, Clutches
Low temperature
Under water application
High temperature
Automotive, Industrial, Agriculture
Low temperature
Aerospace, Marine
Small scale
Drum Brake
Disc Brake
Anchor
Large scale
Elevator brake
Winch brake
Wind turbine brake
Small scale
Oil Drills
Inspection/identification
Mining
Large scale
Flood Gates
Submarine Components
Cranes
Small scale
Axle Box
Journal Bearings
Hinges
Large scale
Industrial Fans
Cranes and Conveyors
Excavators and Rollers
Small scale
Tail Rotor
Swash palet
Rudder and Steering
Large scale
Propeller system
Thrusters
Studge Seperation

Table 3. List of measurement techniques related to friction and wear characteristics.

Parameter	Measurement device	Study	Ref.
Surface roughness	Optical interferometer	✓ Fiber diameter	101
	Atomic force microscope	✓ Uniform distribution of clay	102
Surface tension	Goniometer	✓ Contact angle	103
Testing of lubricants friction	Four-ball wear tester	✓ Effect of load	104
Friction and wear tests	Pin-on-disc	✓ Dry sliding friction	105
	Block-on-disk	✓ Dry / Wet contact	106
	Dry sand rubber wheel	✓ Three-body abrasive wear	107
	Pin-on-drum	✓ Abrasive wear test	108
	Linear tribo-machine	✓ Three-body abrasive wear	109
	Block-on-ring	✓ Dry sliding wear	110
	Universal micro-tribometer (ball-on-disk)	✓ High temperature tribo-test	111
Surface wettability	Contact angle system Water contact angle measurement	✓ Surface contact angle	112
Chemical analysis	X-ray photoelectron spectroscopy (XPS)	✓ Chemical changes	113
Imaging technique	Field-emission scanning electron microscopy	✓ Morphological changes	113
	Scanning electron microscopy	✓ Interface between fiber	113
Temperature monitoring	Iron-constantan thermocouple	✓ Temperature at edge of disc	114
	Infrared temperature measurement device	✓ Surface temperature	115
Vibration monitoring	Accelerometer	✓ Excitation magnitude of response	81
	Displacement transducers	✓ Deformation measurement	116

Karthikeyan, S., Rajini, N., Jawaid, M., Winowlin Jappes, J.T., Thariq, M.T.H., Siengchin, S. and Sukumaran, J., 2017. A review on tribological properties of natural fiber based sustainable hybrid composite. Proceedings of the Institution of Mechanical Engineers, Part J: Journal of Engineering Tribology, 231(12), pp.1616-1634.



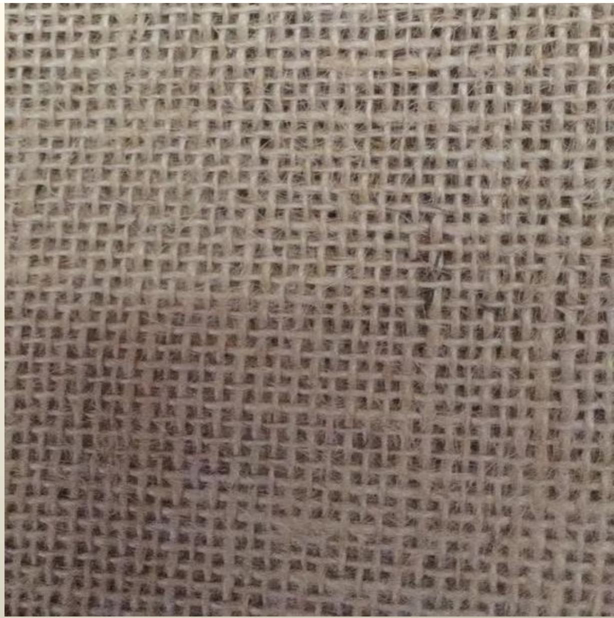
Cause and effect diagram of tributological properties.

Hemanth, K.T., Swamy, R.P. and Chandrashekar, T.K., 2011. Taguchi technique for the simultaneous optimization of tribological parameters in metal matrix composite. Journal of Minerals and Materials Characterization and Engineering, 10(12), p.179.

OBJECTIVES OF THE WORK

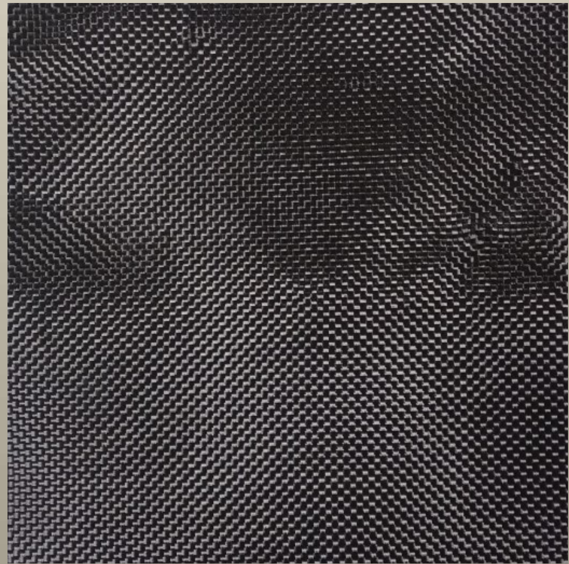
- To fabricate epoxy based hybrid composites reinforced with natural and synthetic fibers along with different laminate stacking sequences.
- To evaluate mechanical properties such as tensile, flexural, inter-laminar shear strength (ILSS), impact and micro-hardness characteristics of composites.
- To evaluate the physical properties such as density and void fraction of composites.
- To examine the interfacial properties of the fractured laminates using scanning electron microscopy (SEM).
- To apply design of experiments to understand Tribological behaviour of the composites.

Areca



Kenaf

Kevlar



Carbon

Kevlar- Carbon Hybrid

Flax - Carbon - Basalt

Sample No	Sequence/Layer				Matrix
	1	2	3	4	
1	F	F	F	F	BE
2	F	F	F	F	E
3	C	F	F	C	BE
4	C	F	F	C	E
5	B	F	F	B	BE
6	B	F	F	B	E

Areca - Carbon - Basalt

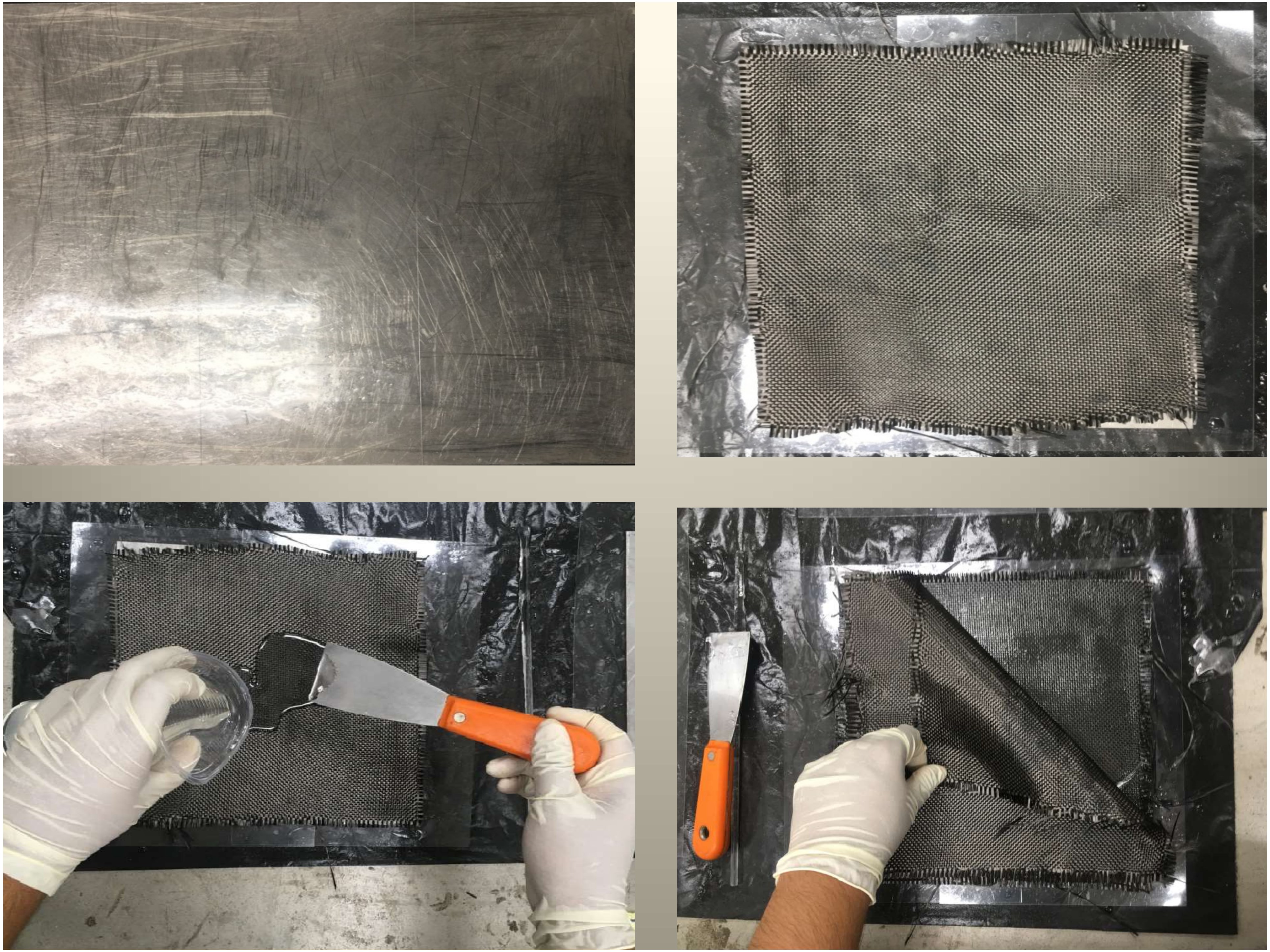
Sample No	Sequence/Layer				Resin
	1	2	3	4	
1	A	A	A	A	BE
2	A	A	A	A	E
3	C	A	A	C	BE
4	C	A	A	C	E
5	B	A	A	B	BE
6	B	A	A	B	E

Flax - Carbon - Kevlar - Hybrid CK

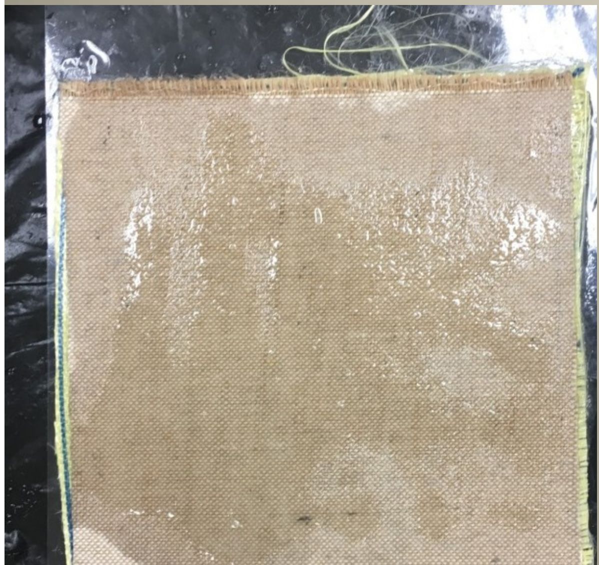
Sample No	Sequence/Layer				Resin
	1	2	3	4	
1	F	F	F	F	EPOXY
2	C	F	F	C	
3	K	F	F	K	
4	H	F	F	H	
5	C	C	C	C	
6	K	K	K	K	
7	H	H	H	H	

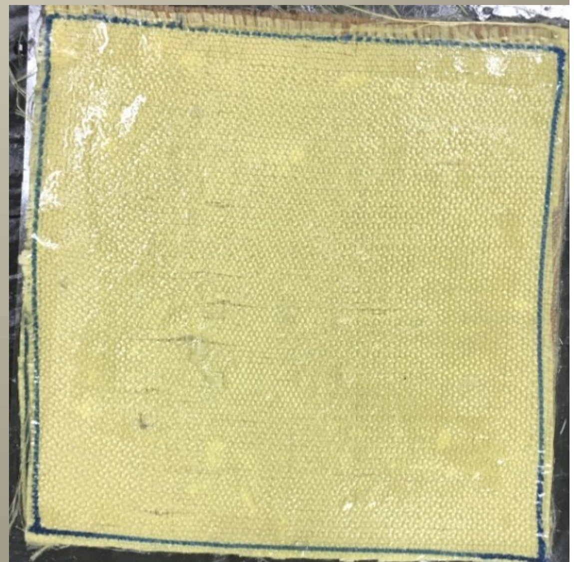
Areca- Carbon - Kevlar - Hybrid CK

Sample No	Sequence/Layer				Resin
	1	2	3	4	
1	F	F	F	F	EPOXY
2	C	F	F	C	
3	K	F	F	K	
4	H	F	F	H	
5	C	C	C	C	
6	K	K	K	K	
7	H	H	H	H	







CONCLUSION

- The hybrid composites developed with the combination of natural and synthetic fibres shows enhanced mechanical strength and finds application in higher loading tribological applications.

- The effect of layering sequence of hybrid composites also has its influence over the properties of the composites.

- It is found that only very little work has been done using natural fiber based hybrid composites in different matrix systems on tribological characteristics.

- Replacing existing synthetic materials from natural/bio based materials can reduce the impact on environmental issues .

PROGRESS OF THE WORK

- Literature review done and Based on the review one journal Paper and one book chapter is published.
- Selection of Materials and fabrication of the composites using synthetic and Natural fibres.
- Mechanical Characterization of the Prepared composites, SEM , TGA completed.

WORK TO BE DONE

- Design of Experiments for conducting Tribology tests.
- Analysing the results obtained and publishing paper.

JOURNALS

1. **T G Yashas Gowda**, Sanjay M R**,** Jyotishkumar Parameswaranpillai, Suchart Siengchin, **“Natural Fibers as Sustainable and Renewable Resource for Development of Eco-friendly Composites: A Comprehensive Review”** Frontiers in Materials, Polymeric and Composite Materials, 2019. DOI: 10.3389/fmats.2019.00226 **(IF: 2.689, SCI Indexed)** **(Published)**

2. K N Bharath, Madhu P, **Yashas Gowda T G**, Sanjay M R**,** Suchart Siengchin, Vinod Kushvaha, **“Extraction and Characterization of discarded waste of Moringa oleifera fruit fiber as a potential eco-friendly reinforcement for biocomposites”** SPRINGER, Journal of Polymers and the Environment **(Under Review).** **(SCI Indexed)**

3. K N Bharath, Madhu P, **Yashas Gowda T G**, Akarsh Verma, **Sanjay M R,** Suchart Siengchin, **“A novel approach for the development of bio-fiber based composites for printed circuit board application”** SAGE, Journal of Composite Materials **(Under Review).** **(SCI Indexed)**

4. K N Bharath, Madhu P, **Yashas Gowda T G**, Akarsh Verma, **Sanjay M R,** Suchart Siengchin, **“Mechanical and chemical properties evaluation of sheep wool fiber reinforced vinylester/polyester composites”** ASTM, Materials Performance and Characterization (Under Review). **(SCI Indexed)**

5. A Vinod, **Yashas Gowda T G**, R Vijay, D Lenin Singaravelu, **Sanjay M R,** Suchart Siengchin, Munish Kumar Gupta, Muhammad Jamil, **“Physiochemical, Thermomechanical, dynamic mechanical, water absorption and Morphological Analysis of surface tailored and characterized novel Muntingia Calabura bark fiber reinforced fully biobased bioepoxy marix composites”** ELSEVIER, Composites Part B (Under Review). **(SCOPUS Indexed)**

BOOK

1. Sanjay M R, Jyotishkumar P, **Yashas Gowda T G**, Suchart Siengchin, M.Özgür Seydibeyoğlu, "**Nano-Particles Based Polymer Composites**", Elsevier Inc. (In Progress)

BOOK CHAPTERS

1. P Madhu, **T G Yashas Gowda**, Sanjay M R**,** Jyotishkumar Parameswaranpillai, Suchart Siengchin, "**Effect of process engineering on the performance of hybrid fiber composites"** In book. Hybrid Fiber Composites. Materials, Manufacturing, Process Engineering. Wiley. (In Press). **(Scopus Indexed)**

2. **T.G Yashas Gowda**, Sanjay M R**,** Jyotishkumar Parameswaranpillai, Suchart Siengchin, Klaus Friedrich, **"Tribological Applications of Polymer Composites"** In Book. Tribology of Polymer Composites: Characterisation, Properties, and Applications, Elsevier Inc. (In Press). **(Scopus Indexed)**

3. **Yashas Gowda T G**, Vinod A, Madhu.P.Sanjay M R, Jyotishkumar Parameswaranpillai, Suchart Siengchin "**Plastics in automotive applications**", Encyclopedia of Materials: Plastics and Polymers.Elsvier **(In Progress)**

THANK YOU