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A SYSTEMATIC REVIEW ON FABRICATION METHODS AND PROPERTIES OF NATURAL FIBRE REINFORCED EPOXY COMPOSITES

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ABSTRACT

Fibre reinforced epoxy composites has wide range of applications. Natural fibre reinforced bio epoxy composites are gaining popularity over synthetic/glass fibre reinforced composites to reduce the environmental degradation and to provide a sustainable product. This has oriented many researchers towards the study of natural reinforced fibre composite. The current article reviews the work carried out by the investigators in the area of bio epoxy composites reinforced with natural fibres. The review process was carried out in a systematic procedure and bibliographic data was used to analyse and scrutinize the articles from the database. From the shortlisted articles of natural fibre reinforced epoxy composite, various influencing parameters of mechanical and durability properties such as strength, water absorption, thermal stability and fibre characteristics viz., size, geometry, content and surface treatment are presented in this review article. From the review process conducted, it can be concluded that the composites with properly treated and oriented fibres have strength and durability in comparable to normal epoxy composite.

Keywords: Epoxy, Bio-composite, natural fibre, eco-friendly, sustainability;

INTRODUCTION

Fibre reinforced composite find its applications in all major industries like automobile, packaging, construction sector as building components etc. The term “Bio epoxy composite” is a term coined to denote the epoxy composite reinforced with natural materials. Natural fibre reinforced composites are gaining momentum due to increase in awareness towards the ecofriendly and sustainable technology. The advantages such as less weight, equivalent strength, low carbon footprint during fabrication/disposal, economical, reduced feedstock, dampness and low abrasiveness [1] attracts the industrialists and researchers towards natural fibre reinforced composite for different industrial applications. In addition to these, it also possesses good fatigue performance, corrosion resistance, low thermal expansion and non-magnetic properties [2,5]. This increased awareness towards the natural fibre reinforced composite for environment sustainability should also meet the engineering requirements. A few disadvantages or difficulties of using natural fibres in epoxy composite includes less interfacial bonding, high water absorption, less adhesion and poor wettability. To overcome this minimal drawback and for effective utilization of natural fibres in epoxy to make it bio-composite, a thorough study about the different parameters of fibre and the composite should be made. The current article reviews the work carried out by the investigators in the area of bio epoxy composites reinforced with natural fibres by conducting systematic literature review through Scopus database. Various influencing parameters of mechanical and durability properties such as strength, water absorption, thermal stability and fibre characteristics viz., size, geometry, content and surface treatment are presented in this article.

SYSTEMATIC REVIEW OF BIO EPOXY COMPOSITES

For the conduct of systematic literature review, ‘Scopus’ database was assessed with few keywords to refine the results related to natural fibre reinforced epoxy composites. A keyword

“natural fibre epoxy composite” [TITLE-ABS-KEY (natural AND fibre AND reinforced AND epoxy AND composite) was given and found 1923 documents. In order to refine the results in particular only about natural fibre reinforced composite, the keyword was recoined as "natural fibre" epoxy AND composite which have shown results of 1875 documents. From the search conducted, it was evident that use of fibres in epoxy composite have evolved during the year

1972 [3] and natural fibre reinforced epoxy composite was first reported in the year 1986 [4].

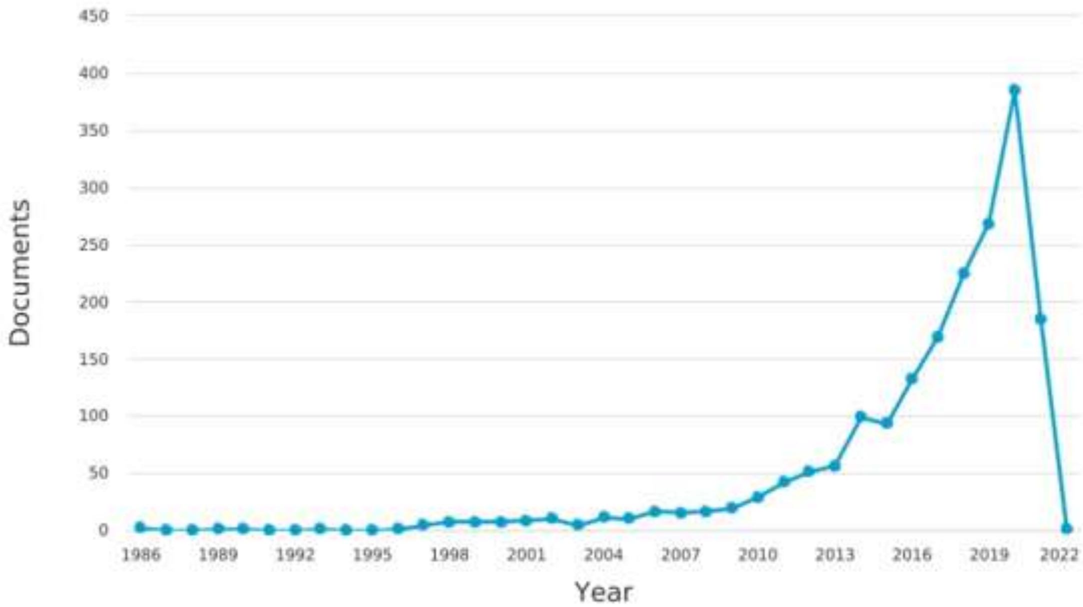

Fig 1. Year wise number of publications related to natural fibre reinforced epoxy composite

Fig. 1 shows the number of documents published year wise from the year 1986 to 2022 as on 12/08/2021. Further, the results were refined by choosing few criteria such as year, subject area, document type, source type and language to get a final result of 830 documents. The obtained documents were used for analysing the authors with maximum number of publications, top 10 countries and institutes, source and subject of publication as shown figures 2 – 6.

For a review article, it is mandatory to review the authors who have more contribution towards the topic. Figure 2 shows the authors bearing maximum number of publications with respect to epoxy composite reinforced with natural fibres. From the figure 2, it is evident that Sergio Neves Monteiro from Military Institute of Engineering, Brazil is holding 25 indexed journals to his credit in the area of natural fibre reinforced epoxy composite followed by Jawaid M.

from Universiti Putra, Malaysia with more than 10 publications.

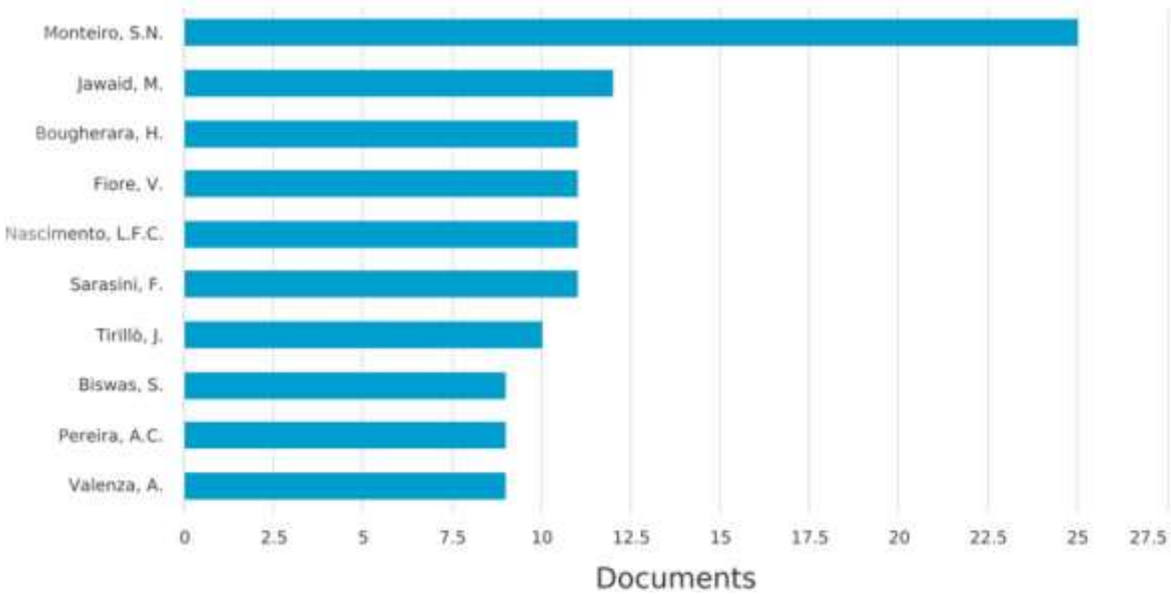

Fig 2. Authors with maximum number of publications related to natural fibre reinforced epoxy composite

Figure 3 and Figure 4 shows the top 10 countries and top 10 institutions carried out research in the proposed area. From figure 3, it is evident that India is holding more than 350 publications compared to Malaysia with more than 100 publications. The other countries like Brazil, Italy, US, France, China, Canada and UK have less than 50 publications. It is apparent that India is conducting more research towards the use of natural fibres in epoxy composites. In India, authors affiliating to Anna University Chennai have done more than 25 publications followed by Universiti Putra, Malaysia as shown in figure 4.

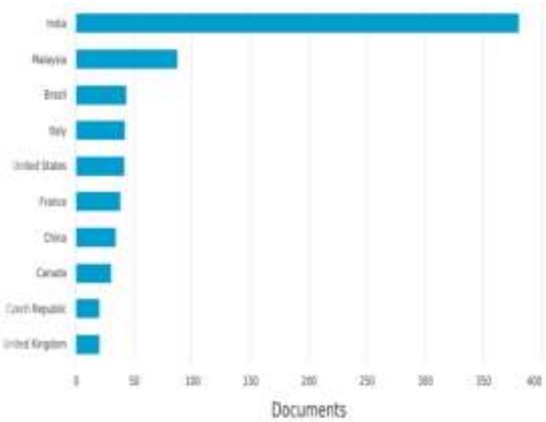

Fig 3. Top 10 countries with publications related to natural fibre reinforced epoxy composite

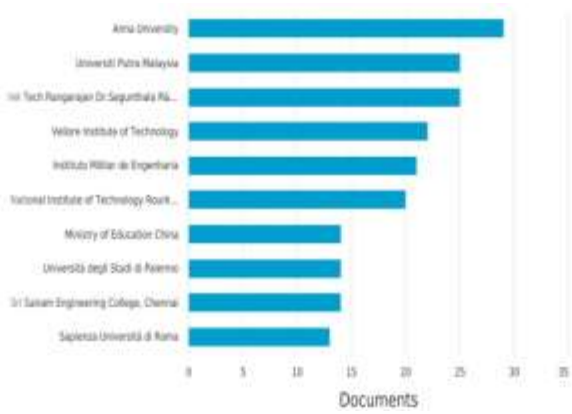

Fig 4. Top 10 institutions with publications related to natural fibre reinforced epoxy composite

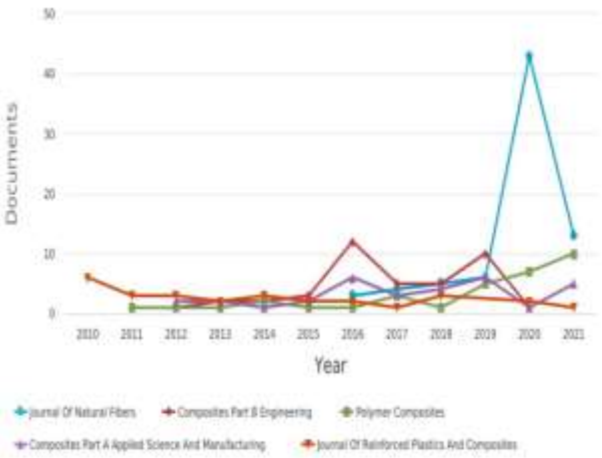

Fig 5. Top 5 journals with publications related to natural fibre reinforced epoxy composite

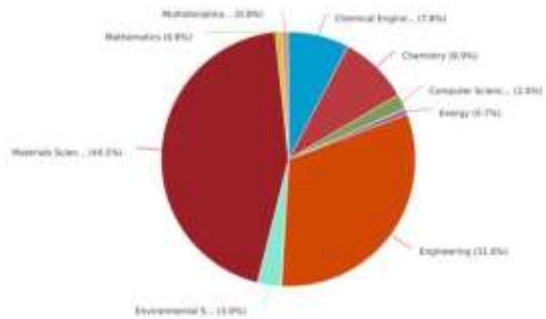

Fig 6. Subject wise publications related to natural fibre reinforced epoxy composite

The journals which have published maximum number of articles in the past few years (2010-2021), in relation to bio epoxy composite is shown in figure 5. "Journal of Reinforced Plastics and Composites" have consistent publications from the year 2010 to 2021. The journals like "Polymer Composites", "Composites Part A: Engineering", "Composites Part B: Engineering" have their publications after 2011. "Journal of Natural Fibres" having maximum number of publications compared to other journals have started its publication from the year 2016. The natural fibre reinforced epoxy composite articles published in different journal falls under the subject area as shown in figure 6. It is obvious that the articles largely fall under the category Material Science (44.5%) followed by Engineering (31.6%). Few articles have publication in other areas such as Chemical engineering, Chemistry, Environmental Science with less than 10% contribution.

NATURAL FIBRES AS REINFORCEMENT FOR EPOXY COMPOSITES

Monteiro et. al [6-11] have utilized Mallow fibre from malvaceous plant, Piassava fibre from Brazil palm tree, Kenaf fibre from Hibiscus plant, tucum fibre extracted from the leaves of the Amazon Astrocaryum vulgare palm tree, Curaua fiber from the leaves of the Amazonian curaua plant, ramie fiber from Boehmeria nivea plant, carnauba fiber from Copernicia prunifera palm tree, PALF from pineapple leaves and guaruman fiber from guaruman plant as reinforcement in epoxy composite for various applications such as Multilayered Ballistic armor, hard armor system etc.,. In order to test the suitability of natural fibre epoxy composite for armor system ballistic test was conducted along with tensile test, impact test and pull-out test. All the abovementioned fibres provided comparable ballistic performance to that of Kevlar composite except PALF fibre for which extensive study has to done to check its suitability.

Sumesh et. al. [12-14] investigated epoxy composites with different combinations of hybrid natural fibres such as sisal/coir, sisal/banana, banana/coir, pineapple/flax for mechanical properties (tensile, flexural, impact), thermal stability, water absorption, machinability of composites through conventional and Abrasive water jet machining. The authors have used the hybrid fibres along with different filler materials such as alumino nano powder, peanut oil cake, bio fly ash such as bagasse, banana and coir. The findings reveal that the hybrid fibres along with filler materials improve the mechanical properties and also the machinability characteristics. Table 1 and Table 2 shows the summary of literature review conducted and the key findings.

Nagamadhu et. al. [15] investigated sisal fibre reinforced epoxy composite for drilling characteristics. 60% weight fraction of sisal fabrics was used to prepare composite through compression moulding. Drilling parameter such as spindle speed, feed rate, drill diameter was chosen. The optimum parameters finalized are 2700 rpm speed, 60 mm/min feed rate and 8 mm drill diameter.

Table 1 Different types of natural fibre utilized and their percentage of utilization

Authors	**Journal**	**Title**	**Type of Fibre**	**% of usage**	**Reference**
Lucio Fa´ Bio Cassiano Nascimento, Luis Henrique Leme Louro, Sergio Neves Monteiro, E´ Dio Pereira Lima Jr., and Fernanda Santosda Luz	The Minerals, Metals & Materials Society	Mallow FiberReinforced Epoxy Composites in Multilayered Armor for Personal Ballistic Protection	Mallow fibre from malvaceous plant	30 vol.%	[6]
Fabio Da Costa Garcia Filho and Sergio Neves Monteiro	The Minerals, Metals & Materials Society	Piassava Fiber as an Epoxy Matrix Composite Reinforcement for Ballistic Armor Applications FABIO	Piassava fibre from Brazil palm tree	10 vol.%, 20 vol.%, 30 vol.%, 40 vol.%, and 50 vol.%	[7]
Ulisses Oliveira Costa , Lucio Fabio Cassiano Nascimento, Julianna Magalhães Garcia, Sergio Neves Monteiro, Fernanda Santos da Luz, Wagner Anacleto Pinheiro and Fabio da Costa Garcia Filho	Polymers	Effect of Graphene Oxide Coating on Natural Fiber Composite for Multilayered Ballistic Armor	Curaua fiber from the leaves of the Amazonian curaua plant	30 vol%	[8]

Michelle Souza Oliveira, Fernanda Santos da Luz, Andressa Teixeira Souza, Luana Cristyne da Cruz Demosthenes, Artur Camposo Pereira, Fabio da Costa Garcia Filho, Fábio de Oliveira Braga, André Ben-Hur da Silva Figueiredo and Sergio Neves Monteiro	Polymers	Tucum Fiber from Amazon Astrocaryum vulgare Palm Tree: Novel Reinforcement for Polymer Composites Michelle	tucum fibre extracted from the leaves of the Amazon Astrocaryu m vulgare palm tree	20 and 40 vol%	[9]
Raí Felipe Pereira Junio, Lucio Fabio Cassiano Nascimento, Lucas de Mendonça Neuba,	Polymers	Copernicia Prunifera Leaf Fiber: A Promising New Reinforcement	carnauba fiber from Copernicia prunifera palm tree	40 vol%	[10]

Andressa Teixeira Souza , João Victor Barbosa Moura, Fábio da Costa Garcia Filho and Sergio Neves Monteiro		for Epoxy Composites			
Fernanda Santos da Luz, Fabio da Costa Garcia Filho, Michelle Souza Oliveira, Lucio Fabio Cassiano Nascimento and Sergio Neves Monteiro	Polymers	Composites with Natural Fibers and Conventional Materials Applied in a Hard Armor: A Comparison	PALF from pineapple leaves	30 vol %	[11]
K. R. Sumesh1 · K. Kanthavel1	Journal of Polymers and the Environm ent	Green Synthesis of Aluminium Oxide Nanoparticles and its Applications in Mechanical and Thermal Stability of Hybrid Natural Composites	sisal/coir, sisal/banan a, banana/coir	35 wt%	[12]

KR Sumesh, V Kavimani, G Rajeshkumar, S Indran and Anish Khan	Journal of industrial textiles	Mechanical, water absorption and wear characteristics of novel polymeric composites: Impact of hybrid natural fibers and oil cake filler addition	pineapple/f lax	20–40 wt.%	[13]
K R Sumesh and K Kanthavel	Material Research Express	Abrasive water jet machining of Sisal/Pineapple epoxy hybrid composites with the addition of various fly ash fille	Sisal/Pinea pple	30 wt%	[14]
Sen Yang,1 Vijaya Chalivendra ,1 Essien Benjamin,1 Yong Kim	Polymer Composite s	Electrical Response of Novel Carbon Nanotubes Embedded and Carbon Fiber Z-	Jute fibre	500, 1000, 1500, and 2000 fibres/m m2	[15]
		Axis Reinforced Jute/ Epoxy Laminated Composites			
Sen Yang, Vijaya Chalivendra & Yong Kim	Journal of Natural Fibers	Electro-fracture Studies of Natural Fiber Composites Sen	Jute fibre	2000 fibres/m m^2	[16]

Vijaya Chalivendra et. al. [16-19] fabricated jute fibre laminated epoxy composites by embedding Carbon nanotubes CNT and reinforcing with short carbon fibres between the laminates. The jute fibres were placed in different flock density (500, 1000, 1500, and 2000 fibers/mm^2) and found that orientation of jute fibres laminates did not have much consequences on the electrical resistivity. The maximum increase of initial fracture toughness was achieved for carbn fibre length of 350 m with fibre density 2000 fibres/mm^2.

Pickering et. al. [20] manufactured basalt/PALF fibre mat composite through hand lay up technique and compression moulding with a pressure of 0.1 MPa. The stiffness and damping properties of the composite can be controlled by position and angle of fibre placed which is evident from the high storage modulus for all fibre orientations. Hafsa Jamshaid [21] developed bio epoxy composite using jute, sisal, coconut/coir, and sugarcane/bagasse as reinforcement to study the mechanical characteristics such as tensile, impact, flexure and modulus. The results revealed that lignocellulosic fibers can used as an environment friendly material for different applications including electrical appliances. Bagasse composites exhibit superior flexural response due to low density. The coir/ bagasse composite has better electrical resistivity due to low crystallinity of fibres.

Rajeshkumar et. al. [21] investigated jute fibre reinforced epoxy composite with rosewood and Padauk wood dust fillers. Through the conduct of mechanical and thermal studies, it was inferred that the properties got improved with the addition of wood dust particles. Mylsamy et. al. [22] experimented with wear characteristics of Agave fibres of different length such as 3, 5 and 7 mm.

From the study, it was concluded that, 3 mm chopped length produced good results compared to other length and the same was confirmed from the SEM images.

Table 2 Summary of key findings on the strength development of micro structure in bio epoxy composite

Reference	Fabrication process	Study Conducted	outcome
[6]	Hand lay-up technique and a pressure of 3 MPa was applied during the composite cure	ballistic tests	mallow composite provides same ballistic performance and lightness similar to Kevlar composite at much lower cast
[7]	Hand lay-up Process and a pressure of 3 Mpa was applied during the composite cure	ballistic tests	composite reinforced with 50 vol.% exhibited superior characteristics during the ballistic impact test. Kinetic energy absorption was similar to Kevlar composite.
[8]	hydraulic press by applying a load of 5 tons for 24 h	ballistic tests, Pullout test	Comparable ballistic performance to that of Kevlar composite, pullout test on graphene oxide coated curaua fibre epoxy composite shows 50% higher interfacial shear strength
[9]	Hand lay-up technique with compression process with a load of 3 Mpa	Tensile test, Izod impact tests, ballistic impact energy absorption using	40 vol% tucum fibre epoxy composites increased the tensile strength by 104% and the absorbed Izod impact energy by 157% in comparison to the plain epoxy, while the ballistic performance of the 20 vol% tucum fibre composites increased 150%
[10]	hand lay-up and a pressure of 3 Mpa was applied for 24 h	Tensile test, Izod impact tests, thermogravimetric analysis	Exhibits higher impact resistance and thermal behaviour compared to glass epoxy composite
[11]	Hand lay-up and compression molding	Ballistic tests	Exhibited a BFS depth of 26.6 mm meeting the standard of NIJ. Further research is required to validate the fibre efficiency
[12]	compression molding process	Characterization Testing (XRD, SEM, EDX), Mechanical testing (tensile, flexure, Impact,	Mechanical properties and thermal degradation of fibre reinforced composite with nano alumina have shown improvement for all hybrid combinations. The fibre breakage was less and the voids were filled up with alumino nano powder as depicted from the SEM images.
[13]	hand layup cum compression moulding	Tensile test, Flexural test, Impact test, wear characteristics	Mechanical properties showed enhanced strength for 20 wt.% of hybrid fibres with 2 wt.% of peanut oil cake. The wear rate was optimized for 20 wt.% of fibres, 2 wt.% of peanut oil cake, load of 5 N and 1500 m SD

[14]	compression molding process	Mechanical testing (Tensile, flexural, impact, hardness and density) and Abrasive Water Jet Machining (AWJM)	Mechanical properties were improved for hybrid fibre epoxy composite with the addition of 3% flyash fillers. Treated fibres show good machining characteristics with decreased surface roughness and also filler material increases the material removal rate

CONCLUSION

The summary of systematic literature review conducted on bio epoxy composite is stated below.

- Scopus Database was accessed to conduct systematic literature review on natural fibre reinforced epoxy composite with keywords and restraints to shortlist the articles based on author, journals, country etc.,
- Fibres were used in the composite as a single reinforcement/hybrid reinforcement/along with filler materials.
- As the natural fibres have high water absorption, it must be alkaline treated before its application as fibre in the epoxy composite to improve its thermal characteristics and inter facial bonding.
- Addition of natural fibres to the epoxy composite proves to be an cost-effective eco-friendly strategy for achieving sustainability in various industries.
- Further, the durability studies on bio composite need to be done extensively done to find the suitability of natural fibre on a long run.

REFERENCES

1) Tataru, G. et al. (2020) 'Modification of flax fiber fabrics by radiation grafting : Application to epoxy thermosets and potentialities for silicone-natural fibers composites', Radiation Physics and Chemistry. Elsevier Ltd, 170 (November 2019), p. 108663. doi: 10.1016/j.radphyschem.2019.108663.

2) Mittal, V., Saini, R. and Sinha, S. (2016) 'Natural fi ber-mediated epoxy composites e A review', Composites Part B. Elsevier Ltd, 99, pp. 425–435. doi: 10.1016/j.compositesb.2016.06.051.

3) Peretz, D. & DiBenedetto, A.T. 1972, "Crack propagation in polymeric composites", Engineering Fracture Mechanics, vol. 4, no. 4, pp. 979-984, IN51-IN52,985-990.

4) Giridhar, J., Kishore & Rao, R.M.V.G.K. 1986, "Moisture Absorption Characteristics of Natural Fibre Composites.", Journal of Reinforced Plastics and Composites, vol. 5, no. 2, pp. 141-150.

5) Ramasamy, M. et al. (2021) 'Materials Today: Proceedings Characterization of natural – Synthetic fiber reinforced epoxy based composite – Hybridization of kenaf fiber and kevlar fiber', Materials Today: Proceedings. Elsevier Ltd., 37, pp. 1699–1705. doi: 10.1016/j.matpr.2020.07.243.

6) Nascimento, L. F. C. et al. (2017) 'Mallow Fiber-Reinforced Epoxy Composites in Multilayered Armor for Personal Ballistic Protection', Jom, 69(10), pp. 2052–2056. doi: 10.1007/s11837-017-2495-3.

7) Garcia Filho, F. D. C. and Monteiro, S. N. (2019) 'Piassava Fiber as an Epoxy Matrix Composite Reinforcement for Ballistic Armor Applications', Jom. Springer US, 71(2), pp. 801–808. doi: 10.1007/s11837-018-3148-x.

8) Costa, U. O. et al. (2019) 'Effect of graphene oxide coating on natural fiber composite for multilayered ballistic armor', Polymers, 11(8). doi: 10.3390/polym11081356.

9) Oliveira, M. S. et al. (2020) 'Tucum fiber from amazon astrocaryum vulgare palm tree: Novel reinforcement for polymer composites', Polymers, 12(10), pp. 1–17. doi: 10.3390/polym12102259.

10) Junio, R. F. P. et al. (2020) 'Copernicia Prunifera leaf fiber: A promising new reinforcement for epoxy composites', Polymers, 12(9). doi: 10.3390/POLYM12092090.

11) da Luz, F. S. et al. (2020) 'Composites with natural fibers and conventional materials applied in a hard armor: A comparison', Polymers, 12(9), pp. 1–13. doi: 10.3390/POLYM12091920.

12) Sumesh, K. R. and Kanthavel, K. (2019) 'Green Synthesis of Aluminium Oxide Nanoparticles and its Applications in Mechanical and Thermal Stability of Hybrid Natural Composites', Journal of Polymers and the Environment. Springer US, 27(10), pp. 2189– 2200. doi: 10.1007/s10924-019-01506-y.

13) Sumesh, K. R. et al. (2020) 'Mechanical, water absorption and wear characteristics of novel polymeric composites: Impact of hybrid natural fibers and oil cake filler addition', Journal of Industrial Textiles, pp. 1–28. doi: 10.1177/1528083720971344.

14) Sumesh, K. R. and Kanthavel, K. (2020) 'Abrasive water jet machining of Sisal/Pineapple epoxy hybrid composites with the addition of various fly ash filler', Materials Research Express. IOP Publishing, 7(3). doi: 10.1088/2053-1591/ab7865.

15) Yang, S. et al. (2018) 'Electrical Response of Novel Carbon Nanotubes Embedded and Carbon Fiber Z-Axis Reinforced Jute / Epoxy Laminated Composites'. doi: 10.1002/pc.24935.

16) Yang, S., Chalivendra, V. and Kim, Y. (2021) 'Electro-fracture Studies of Natural Fiber Composites', Journal of Natural Fibers. Taylor & Francis, 18(7), pp. 1044–1053. doi: 10.1080/15440478.2019.1685425.

17) Yang, S. et al. (2020) 'Electro-bending behavior of curved natural fiber laminated composites', Composite Structures. Elsevier, 238(August 2019), p. 112004. doi: 10.1016/j.compstruct.2020.112004.

18) Meninno, C., Chalivendra, V. and Kim, Y. (2021) 'Electro-flexure response of multifunctional natural fiber hybrid composites', Journal of Reinforced Plastics and Composites, 40(5–6), pp. 220–234. doi: 10.1177/0731684420957396.

19) Karthikeyan, K., Nagamadhu, M. and Jaiprakash, M. (2020) 'ScienceDirect Effect of drilling parameters on natural fiber reinforced with chaired epoxy poly urethane foam composites using grey relational analysis .', Materials Today: Proceedings. Elsevier Ltd., 24, pp. 2193–2203. doi: 10.1016/j.matpr.2020.03.677.

20) Pickering, K. L. and Le, T. M. (2016) 'High performance aligned short natural fibre - Epoxy composites', Composites Part B: Engineering. Elsevier Ltd, 85, pp. 123–129. doi: 10.1016/j.compositesb.2015.09.046.

21) Jamshaid, H. et al. (2020) 'Lignocellulosic Natural Fiber Reinforced Bisphenol F Epoxy Based Bio-composites: Characterization of Mechanical Electrical Performance', Journal of Natural Fibers. Taylor & Francis, 00(00), pp. 1–16. doi: 10.1080/15440478.2020.1843586.

22) Rajeshkumar, G. et al. (2021) 'Influence of Sodium Hydroxide (NaOH) Treatment on Mechanical Properties and Morphological Behaviour of Phoenix sp. Fiber/Epoxy Composites', Journal of Polymers and the Environment. Springer US, 29(3), pp. 765–774. doi: 10.1007/s10924-020-01921-6.