The 27th International Conference “Mechanika-2023”

Review on the experimental and numerical investigations of natural fibre-based hybrid composites

Mostafa Sadeghian

Faculty of Mechanical Engineering and Design, Kaunas University of Technology, Studentu 56, 51424 Kaunas, Lithuania

Abstract

In this paper, a review of several mechanical analyses of natural fibre-based hybrid composites is considered. These examples include experimental, numerical, and finite element modelling (FEM) investigations. In the experimental examination, different mechanical tests considering these materials are considered. In the numerical investigation, various related theories and numerical methods are introduced. Also, a brief explanation of the FEM simulation of the natural fibre-based hybrid composites utilizing Abaqus software is simulated and carried out. In recent years, there has been an increased interest in the use of natural fibres in the fabrication of advanced composites, highlighting the importance of these materials. In fact, natural fibres are obtained from the crop harvesting, which are utilized as a reinforcement in the composite matrix. There are numerous merits of employing natural fibres compared to synthetic fibres, including low price, high toughness, good specific strength features, reduced skin sensitivities, suitable thermal and acoustic properties, low density, biodegradability, and no release of excess carbon dioxide to the atmosphere when the fibres are composted.

Introduction

Polymer matrix composites (PMCs) with various combinations of synthetic fibers (as reinforcements) and petroleum-derived matrix (or Synthetic matrix) have been investigated in many studies. PMCs have superior tribological and mechanical features, including higher fatigue resistance and better mechanical strength, better electrical insulation performance, higher damping characteristics than monolithic materials. The major disadvantages of petroleum-derived polymer is that they are non-biodegradable and not environmentally friendly materials. Conventional polymer composite may end up in seas and landfills by the end of their product life cycle which causes serious drawbacks to our planet. In order to overcome this issue, biodegradable fibers are incorporated with a synthetic matrix which create the partially bio-composites. It is also defined as green composites in which either of the constituents must be derived from renewable resources. Due to highly acceptable recyclability, less health risk, environmental sustainability, superior mechanical characteristics, the applications of green composites have been rapidly increased in the field of biomedical, aerospace, automobile, structure and etc.

Due to highly acceptable recyclability, less health risk, Low weight, environmental sustainability, superior mechanical characteristics, the applications of natural fiber-based composites have been rapidly increased in various fields including biomedical, aerospace, automobile, structure and etc[1, 2]. Also, natural fiber-based composites have been intensively studied as replacements for synthetic fiber composites in many papers in recent years[3, 4]. Recently, the mechanical features of natural fiber composites have significantly increased. composite processing, extraction and interfacial manufacturing and fiber treatment can enhance the qualities of natural fiber composites[5, 6].In recent years natural fiber composites/hybrid composites draw the attention of many researchers. For instance, Atmakuri and his colleagues[7] studied mechanical characteristics (including flexural test, contact angle measurement, and interlaminar shear test of the flax/hemp fibers hybrid composites. They concluded that the hemp/flax composites with a weight fraction of 25/15, illustrated the maximum flexural Strength and flexural modulus as 84.80MPa and 3.30GPa, respectively. Moreover, pure flax demonstrated the highest interlaminar shear strength (13.09MPa) due to its cellulose content and higher tensile behavior in nature. Yadav and Singh[8] reviewed processing methods, applications, and properties of natural fiber composites. They concluded that the characteristics of the fiber reinforced composites mostly relied on the weight fraction and fiber orientations which the correct selection of these factors can cause the fabrication of natural fiber-based composites with better mechanical characteristics. Malalli et al.[9] studied the mechanical behavior of natural fiber-based composites as well as their potential applications. Jeyapragash et al.[10] investigated mechanical characteristics of natural fiber-particulate composites. Dattatreya et al.[11] examined natural fibers hybrid composites for automotive applications. Some of the most commonly used plant fibers are discussed below:

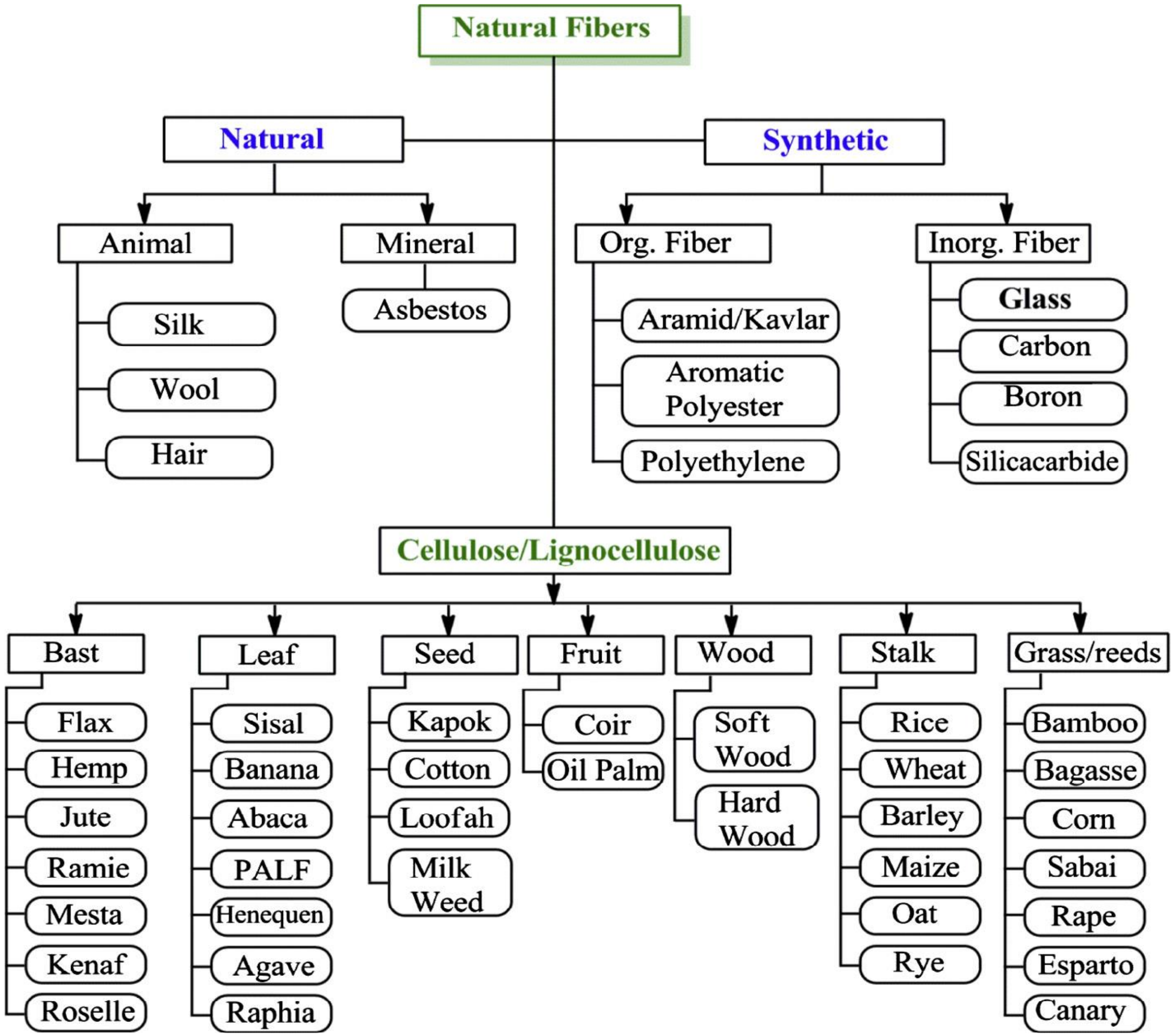


Fig. 1. Classification of natural and synthetic fibers [2]

Table 1. Summary of some papers considering hybrid composites with natural elements.

Reference	Reason and main results of the study	The year
Ref.[12]	How melamine urea formaldehyde (MUF) affects the treatment of various percentages of coir fiber and fibrous chips reinforced trilayered bio-composites. Mechanical parameters (tensile, flexural, and internal bonding strengths), thermal properties, as well as morphological, microstructural, and bonding mechanisms were investigated. The thermo-mechanical results show that bio-composite panels can be successfully formed.	2021
Ref.[13]	The mechanical properties of a hybrid composite composed of a polyester matrix and natural fibers such as sisal and cattail were investigated. The researchers discovered that increasing the fiber weight fraction from 5 % to 20 % at a given fiber blend ratio of 50/50 improved the mechanical properties.	2020
Ref.[14]	This experimental investigation used Alfa fibers and clay particles for reinforcing a polypropylene matrix, with a constant total filler 30 %, to create a hybrid composite using ecological elements. The mechanical parameters altered with filler %, and the thermal stability of the matrix was increased with increasing the clay.	2017
Ref.[15]	In comparison to oil palm, the tensile characteristics of the hybrid composites improved as the jute fiber content increased, demonstrating that adding jute fiber to an epoxy/palm composite enhanced the storage modulus and shifted the damping factor to a higher temperature range.	2013
Ref.[16]	The fabrication of hybrid composites reinforced with jute is woven and Empty Fruit Bunch fiber was the subject of this paper. Tensile and flexural experiments revealed that using jute woven in the pure Empty Fruit Bunch composite improved the mechanical capabilities of hybrid composites.	2010
Ref.[17]	The goal of this project was to create hybrid composites using a polyester matrix, banana fibers, and sisal fibers. Combining two fibers had a favorable impact on flexural strength, with the tensile strength improving with hybridization and reaching a higher value at a 1:4 ratio of sisal and banana.	2005

Experimental studies of natural fiber composites

Table 2. Examples of different natural fibers, matrices, methods and key findings of related papers.

Fibers	Matrix	Method	Key findings	References
Woven & kenaf fiber	Polyoxymethylene	Hand lay up	The mechanical test results are discussed, and the properties of the interwoven hybrid composite is superior than that of the woven POM/kenaf composite because of the balanced stress distribution in the matrix. A particular combination Kenaf/Kevlar (KF30/KV70) shows highest tensile strength & modulus	[18]
Palm and pineapple leaf Fibers	polypropylene	twin-screw compounder	The initial properties of polyolefin/plant fiber composites are discussed. Through rheology, the positive reinforcement effect of PP/pineapple leaf composite was proved.	[19]
Bamboo Original fibers and bamboo viscose fibers/ flax fibers	polypropylene	Stainless steel mold	Explored the possibility of replacing flax fibers with two different types of Bamboo fiber.	[20]
Basalt fiber hemp fiber	HDPE	Injection molding	The results show that it is necessary to optimize the heat treatment process of basalt fiber, and provide detailed information about the mechanical property loss that may occur after thermodynamic treatment. After pyrolysis treatment, the life of the basalt fiber reinforced composite material ends. HDPE15B15HMA shows better tensile strength	[21]

Numerical studies of natural fiber composites

Some authors considered the examination of natural fiber-based composites analytically. For instance, Ramaswamy et al.[22] perused static analysis of natural fiber cross-ply composites using classical plate model and higher order plate theory. They observed that higher order model has more accurate results than the classic theory. Oller et al.[23] presented a homogenized constitutive model to study reinforced curved fibers composite using 3D finite element analysis. Prasad et al.[24] studied static and dynamic analysis of jute/glass fiber reinforced hybrid composites based on the higher order theory using the finite element method (FEM). Based on their numerical results, the fundamental frequencies of the glass-jute-jute-glass hybrid composite beam were 65.42 %, 58.27 %, 24.52 %, and 3.50 % higher than those of the hybrid jute-jute- jute-jute, jute- glass- glass-jute, jute-glass-jute- glass and glass- glass- glass-glass composite beams under clamped boundary conditions. Also, from their the bending analysis, the deflection values of jute hybrid composite beams were lower than those in jute-jute- jute-jute composite beams in each ply orientation and boundary condition. The deflection values of the jute-glass- glass-jute hybrid composite beam is 37.32 % smaller than that of the jute-jute- jute-jute composite beam under clamped boundary condition.

Numerical studies of natural fiber composites

The displacement-field equations of the fiber-based composite beam's considering higher order shear deformation theory are as follows[24]:

$$u = u_0 + z\psi_x - \frac{4z^3}{3h^2}\varphi_x \qquad (1)$$

$$w = w_0 \qquad (2)$$

In which the displacements along the x and z axes are defined by u and w, respectively. Moreover, the mid-surface displacements are u0 and w0.

Moreover, the strain-displacement equations for the composite beam are as follows[24]:

$$\varepsilon_x = \frac{\partial u_0}{\partial x} + z\left(\frac{\psi_x}{\partial x}\right) - \frac{4z^3}{3h^2}\left(\frac{\varphi_x}{\partial x}\right) \qquad (3)$$

$$\varepsilon_{xz} = \frac{\partial w_0}{\partial x} + \psi_x - \frac{4z^2}{h^2}\varphi_x \qquad (4)$$

Numerical studies of natural fiber composites

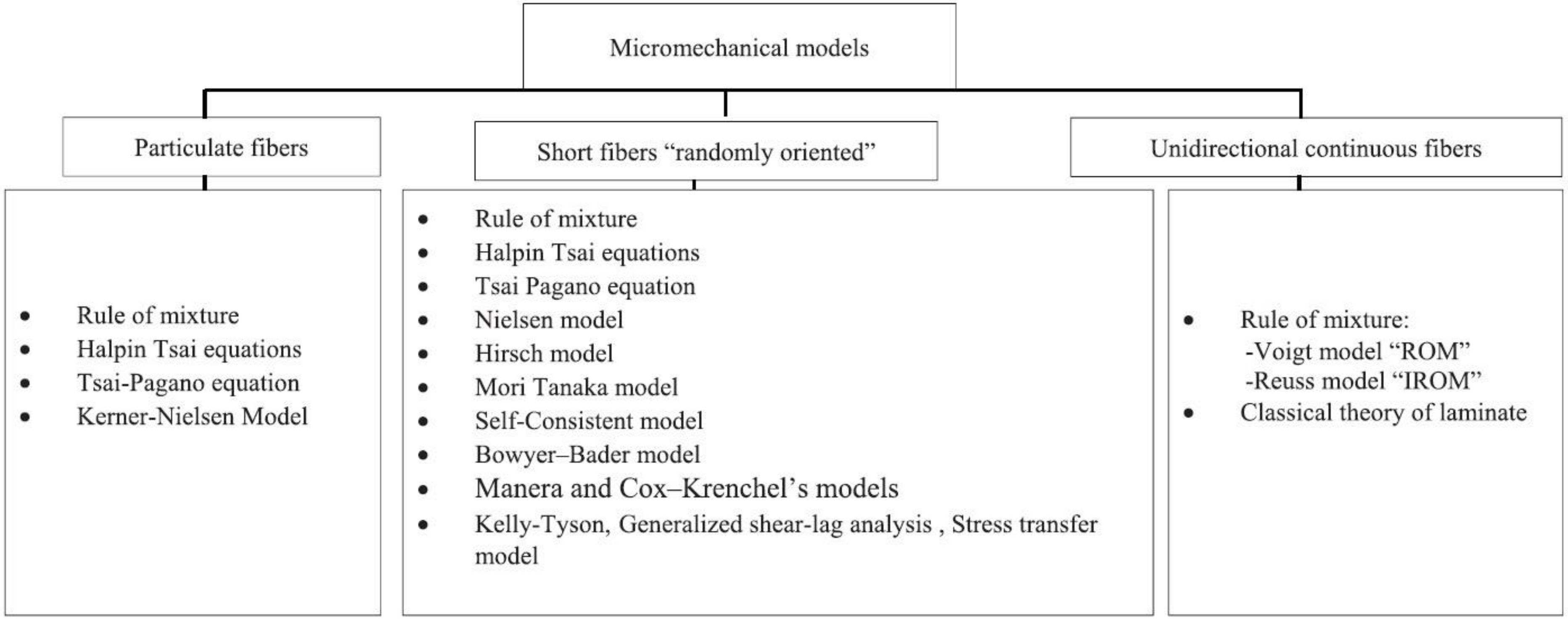


Fig. 2 Classification of micromechanical models[25]

Finally, the obtained equations can be solved using different numerical methods including the differential quadrature method, dynamic relaxation technique, Runge-Kutta approach, Levy-type solution and etc.

FEM simulation of natural fiber composites

These are many questions for creating new types of composites (or any other objects) that can be easily replied to digitally with some simulation software based on the FEM. FEM makes early concept decisions better and decreases the need for the fabrication of physical prototypes. Moreover, it makes it able to test performance and check the behavior of an object that simply cannot be performed in the laboratory. Cakiroglu and Bekdaş[26] investigated the buckling of natural fiber-based composites using finite element analysis. Davoodi and his colleagues[27] simulated car bumper beams with developed natural-based hybrid composites. The impact examination of short hemp fibers composites utilizing finite element modeling was carried out by Puech et al. They concluded that the applied FEM is in proper harmony with the experimental test especially for the fracture growth pattern.

In the following, the description of how to model natural fiber-based composites as well as an example of the syntenic-natural fiber hybrid composite for the FEM model is presented. This paper is about the principles behind the generation of randomly positioned fibers in a 2D quadrilateral representative volume element (RVE) with a test case for composite materials here. The random positioning of fibers is accomplished using the Monte Carlo Method. Monte Carlo simulation is, in essence, the generation of random objects or processes by means of a computer. These objects could arise "naturally" as part of the modeling of a real-life system, such as a complex road network[28].

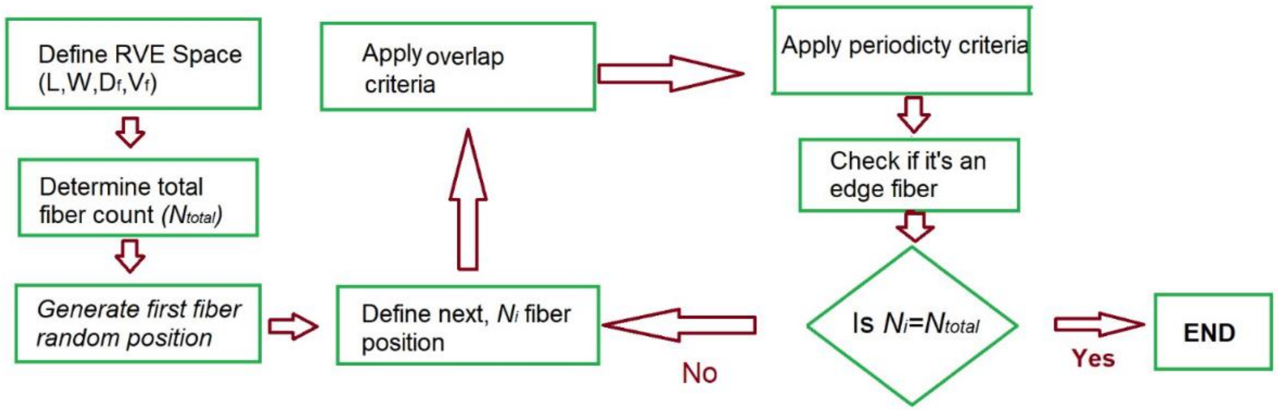
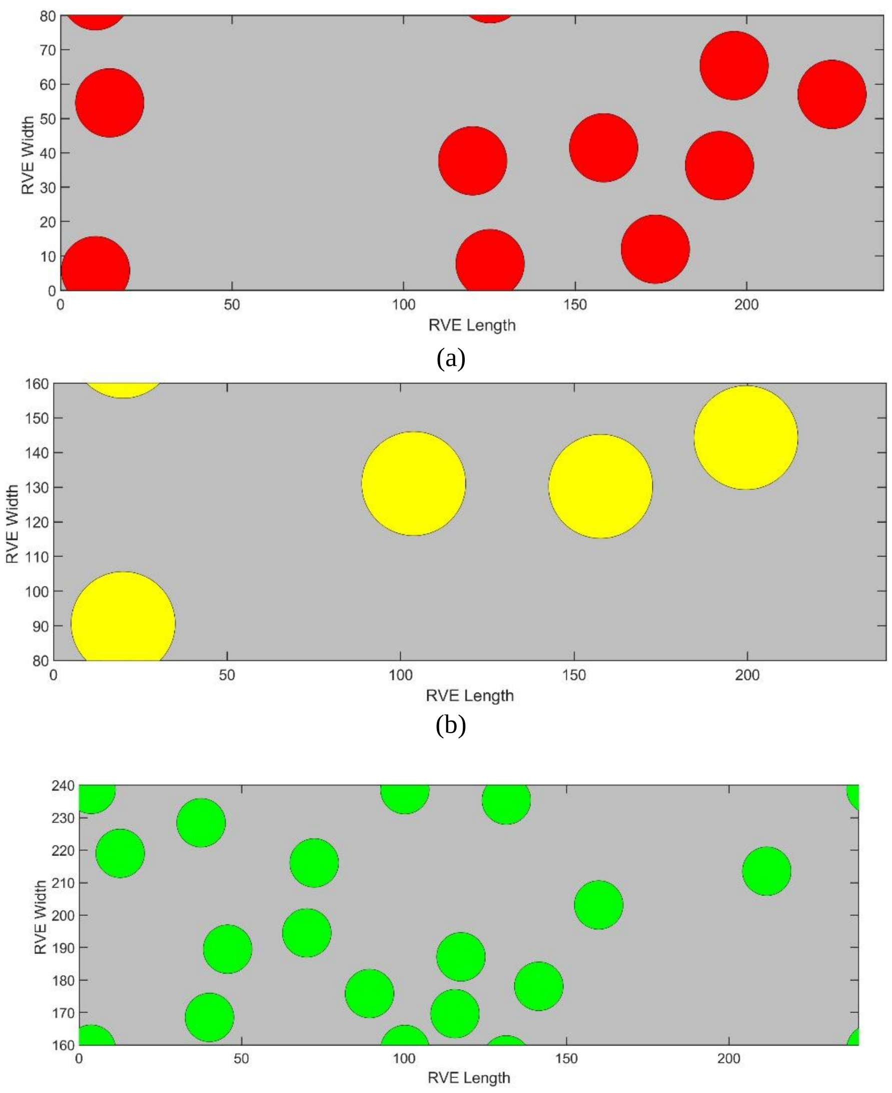


Fig. 3 The algorithm of the present study using the Monte Carlo method.



(a)

(b)

(c)

Fig. 4 The schematic of various fibers in the matrix: (a) E-glass fibers, (b) pineapple fibers, (c) Jute fibers

Conclusions

This paper reviews the natural fibers-based composites in three different categories including experimental, theoretical and FEM as well as considering mechanical properties, processing methods, different natural fibers and matrices. There are numerous advantages of utilizing natural fiber-based composites compared to synthetic fibers, including low price, high toughness, good specific strength features, reduced skin sensitivities, suitable thermal and acoustic properties, low density, biodegradability, and no release of excess carbon dioxide to the atmosphere when the fibers are composted. It is concluded that fabrication methods can have an effective role in improving the mechanical properties of natural fiber composites. Also, FEM makes early concept decisions better and decreases the need for fabrication physical fabrications of natural fiber composites. The Mont Carlo algorithm is one of the essential techniques for simulating fiber-based composites using FEM due to clarifying the positions of fibers. Using MATLAB and considering the Monte Carlo algorithm and the related material properties, the number of examined fibers and their positions are obtained.

References

1. Singh, M.K., et al., *A comprehensive review of various factors for application feasibility of natural fiber-reinforced polymer composites.* Results in Materials, 2023. **17**: p. 100355.
2. Jino, L., et al., *Review on natural fibre composites reinforced with nanoparticles.* Materials Today: Proceedings, 2023.
3. Dimple, G.P. Singh, and R. Mangal, *A comprehensive review of natural fiber reinforced composite and their modern application.* Materials Today: Proceedings, 2023.
4. Maithil, P., P. Gupta, and M.L. Chandravanshi, *Study of mechanical properties of the natural-synthetic fiber reinforced polymer matrix composite.* Materials Today: Proceedings, 2023.
5. Vigneshwaran, S., et al., *Recent advancement in the natural fiber polymer composites: A comprehensive review.* Journal of Cleaner Production, 2020. **277**: p. 124109.
6. Ramdani, N., M. Derradji, and E.O. Mokhnache, *Natural fiber reinforced polybenzoxazine composites: A review.* Materials Today Communications, 2022. **31**: p. 103645.
7. Ayyappa Atmakuri, et al., *Investigation of Mechanical Properties of Hemp and Flax Fibers Hybrid Composites for Biomedical Applications.* Mechanika, 2019. **25**: p. 149-155.
8. Yadav, V. and S. Singh, *A comprehensive review of natural fiber composites: Applications, processing techniques and properties.* Materials Today: Proceedings, 2022. **56**: p. 2537-2542.
9. Malalli, C.S. and B.R. Ramji, *Mechanical characterization of natural fiber reinforced polymer composites and their application in Prosthesis: A review.* Materials Today: Proceedings, 2022. **62**: p. 3435-3443.
10. Jeyapragash, R., V. Srinivasan, and S. Sathiyamurthy, *Mechanical properties of natural fiber/particulate reinforced epoxy composites – A review of the literature.* Materials Today: Proceedings, 2020. **22**: p. 1223-1227.
11. Dattatreya, K., et al., *Mechanical properties of waste natural fibers/fillers reinforced epoxy hybrid composites for automotive applications.* Materials Today: Proceedings, 2023.
12. Hasan, K.M.F., et al., *Thermo-mechanical properties of pretreated coir fiber and fibrous chips reinforced multilayered composites.* Sci Rep, 2021. **11**(1): p. 3618.
13. Mbeche, S.M., P.M. Wambua, and D.N. Githinji, *Mechanical Properties of Sisal/Cattail Hybrid-Reinforced Polyester Composites.* Advances in Materials Science and Engineering, 2020. **2020**: p. 6290480.
14. Boujmal, R., et al., *Alfa fibers/clay hybrid composites based on polypropylene: Mechanical, thermal, and structural properties.* Journal of Thermoplastic Composite Materials, 2017. **31**(7): p. 974-991.
15. Jawaid, M., et al., *Effect of jute fibre loading on tensile and dynamic mechanical properties of oil palm epoxy composites.* Composites Part B: Engineering, 2013. **45**(1): p. 619-624.
16. Jawaid, M., H.P.S. Abdul Khalil, and A. Abu Bakar, *Mechanical performance of oil palm empty fruit bunches/jute fibers reinforced epoxy hybrid composites.* Materials Science and Engineering: A, 2010. **527**(29): p. 7944-7949.
17. Idicula, M., et al., *A study of the mechanical properties of randomly oriented short banana and sisal hybrid fiber reinforced polyester composites.* Journal of Applied Polymer Science, 2005. **96**(5): p. 1699-1709.
18. Jambari, S., et al., *Woven Kenaf/Kevlar Hybrid Yarn as potential fiber reinforced for anti-ballistic composite material.* Fibers and Polymers, 2017. **18**(3): p. 563-568.
19. Chollakup, R., H. Askanian, and F. Delor-Jestin, *Initial properties and ageing behaviour of pineapple leaf and palm fibre as reinforcement for polypropylene.* Journal of Thermoplastic Composite Materials, 2015. **30**(2): p. 174-195.
20. Gu, F., et al., *Can bamboo fibres be an alternative to flax fibres as materials for plastic reinforcement? A comparative life cycle study on polypropylene/flax/bamboo laminates.* Industrial Crops and Products, 2018. **121**: p. 372-387.
21. Sarasini, F., et al., *Effect of basalt fibre hybridisation and sizing removal on mechanical and thermal properties of hemp fibre reinforced HDPE composites.* Composite Structures, 2018. **188**: p. 394-406.
22. Ramaswamy, S., et al., *Study on application of higher order lamination plate theory over various applications of natural fiber cross-ply composites.* Materials Today: Proceedings, 2022. **60**: p. 822-826.
23. Oller, S., et al., *A theoretical homogenized constitutive model formulation for matrix composite materials reinforced with curved fibers.* Composite Structures, 2023. **304**: p. 116432.
24. Prasad, M., et al., *Static and dynamic characteristics of jute/glass fiber reinforced hybrid composites.* Structures, 2023. **50**: p. 954-962.
25. Chichane, A., R. Boujmal, and A. El Barkany, *Bio-composites and bio-hybrid composites reinforced with natural fibers: Review.* Materials Today: Proceedings, 2023. **72**: p. 3471-3479.
26. Çakıroğlu, C. and G. Bekdaş, *Buckling analysis of natural fiber reinforced composites.* Challenge Journal of Structural Mechanics; Vol 7, No 2 (2021)DO - 10.20528/cjsmec.2021.02.001, 2021.
27. Davoodi, M.M., et al., *Concept selection of car bumper beam with developed hybrid bio-composite material.* Materials & Design, 2011. **32**(10): p. 4857-4865.
28. Chiang, M.Y.M., et al., *Prediction and three-dimensional Monte-Carlo simulation for tensile properties of unidirectional hybrid composites.* Composites Science and Technology, 2005. **65**(11): p. 1719-1727.