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EVALUATION OF MECHANICAL PROPERTIES OF VINYLESTER COMPOSITES REINFORCEMENT WITH BANYAN BARK FIBER

Agus Dwi Catur*, Jazuly K.H.**, Paryanto D.S. ***, Rudy Sutanto****, Nasmi H.S.*****, Pandri P.******

*, **, ***, ****, *****, ******Material Laboratory, Engineering Faculty, University of Mataram, Mataram City, Indonesia
* agus.dc@unram.ac.id

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ABSTRACT

Natural fiber-based composites are increasingly being developed as an alternative environmentally friendly material to replace synthetic fibers. This study evaluates the mechanical properties of vinylester composites reinforced with banyan bark fiber, focusing on tensile and bending strengths. The study aims to analyze the effect of fiber volume fraction on the mechanical properties of the composite and evaluate the potential of banyan bark fiber as a mechanical reinforcement.
The research methodology involves fabrication of composites with fiber volume fractions of 10%, 15%, and 20%, using the hand lay-up method. Tensile and bending tests were carried out according to ASTM standards to obtain mechanical strength data. Data were analyzed using ANOVA to determine the significance of differences in mechanical properties between specimens.
The results showed that the addition of banyan bark fiber did not increase the mechanical properties of the composite, but rather decreased them. The tensile strength of pure vinylester resin of 40.225 MPa decreased to 16.1 MPa, 18.8 MPa, and 14.1 MPa at fiber volume fractions of 10%, 15%, and 20%, respectively. A similar pattern occurred in the bending strength, which decreased from 75.298 MPa to 51.779 MPa, 44.473 MPa, and 38.786 MPa. This decrease was associated with low fiber tensile strength (30.1 MPa) and suboptimal fiber-matrix adhesion. The conclusion shows that banyan tree bark fiber is not effective as the main mechanical reinforcement in vinylester resin under these conditions. Further research is needed to improve fiber-matrix adhesion through fiber modification and fabrication process optimization.

INTRODUCTION

The increasing popularity of natural fiber-based composite materials among scientists and industries is mainly driven by the growing environmental awareness and demand for sustainable and biodegradable alternatives. Natural fibers, such as bamboo, coconut fiber, and agricultural waste products, offer advantages including low cost, lightweight properties, and favorable strength-to-weight ratios, making them suitable for a variety of applications, especially in the automotive and construction sectors (Kumar et al., 2023) (Naveen et al., 2023) (Aziz et al., 2023). Furthermore, advancements in processing technologies have improved the mechanical properties and thermal stability of these composites, further promoting their use (Gurupranes et al., 2023) (Sun et al., 2023). The shift towards environmentally friendly materials in line with global sustainability goals is driving the industry to adopt natural fiber composites as a viable alternative to traditional materials (Kumar et al., 2023) (Aziz et al., 2023). One of the natural fibers that has begun to be considered in various studies is the banyan tree bark fiber, which is expected to function as a reinforcement in the resin matrix for structural applications.

Vinylester resin, known for its high mechanical strength, corrosion resistance, and ability to be used in various industrial applications, is a common choice as a matrix for composites. The incorporation of graphene and eGain significantly improves the flexural strength and impact resistance of vinylester composites, with increases of up to 34.2% in flexural strength and 90.5% in non-notch impact strength observed with the addition of graphene (Dong et al., 2023) (Dang et al., 2022)]. In addition, the use of bio-based fillers, such as tamarind and date seed fillers, has been shown to improve tensile and flexural properties by 1.51 and 1.44 times, respectively, promoting sustainability in composite production (Ershova, 2022). In addition, vinilester's ability to maintain its mechanical properties under a wide range of conditions, coupled with its compatibility with reinforcing fibers, makes it a versatile choice for high-performance applications, including military and structural applications (Lee et al., 2011) (Kubit et al., 2022).

Based on these advantages, it is expected that the use of banyan tree bark fiber can improve the mechanical properties of vinylester resin-based composites, especially in terms of tensile and bending strengths. However, this study showed surprising results, where the addition of banyan tree bark fibers actually caused a decrease in the mechanical properties of the composite. This finding requires further investigation to understand the limitations and potential of these natural fibers in the development of composite materials. Although the use of natural fibers in composite materials has shown significant potential, this study faced an unexpected problem related to the mechanical performance of banyan tree bark fibers. In the context of this study, banyan tree bark fibers were expected to strengthen vinylester resin, but the experimental results showed otherwise. The addition of these natural fibers actually caused a decrease in the tensile and bending strengths of the composite. This problem indicates that the banyan bark fiber has lower mechanical properties compared to the vinylester resin itself, so that when used as a reinforcement, instead of improving, it actually reduces the structural integrity of the composite material. This condition raises critical questions about the effectiveness of banyan bark fiber in reinforcing composites and demands an in-depth evaluation to understand the root cause of the performance decline.

The decrease in tensile and flexural strength of composites reinforced with certain natural fibers can be attributed to several factors, including the inherent mechanical properties of the fibers and their interaction with the matrix. Many natural fibers, such as coconut fiber and jute, exhibit lower tensile strength compared to synthetic fibers and even the polymer matrix itself, which can lead to compromised composite performance (Yadav & Mishra, 2024) (Prawesthi et al., 2023)]. In addition, fiber orientation and treatment significantly affect their mechanical properties e.g., fiber orientation at 90 degrees and specific treatments can increase tensile strength, but not all fibers respond positively to such modifications (Rosidah et al., 2023)]. Furthermore, moisture absorption can affect the interfacial bonding between the fibers and the matrix, resulting in reduced strength due to fiber delamination and matrix cracking (Lakshmikanthan et al., 2023). Thus, proper fiber selection and processing conditions are critical to optimize the mechanical properties of natural fiber reinforced composites (Venkatesh et al., 2023).

The main objective of this study was to evaluate the mechanical properties of vinylester resin-based composites reinforced with banyan tree bark fibers, especially in terms of tensile and bending strength. This study was conducted to better understand how the addition of natural fibers affects the mechanical performance of the composite. In this study, tensile and bending tests were conducted to determine how much influence the fiber volume fraction had on the composite strength. With the results showing a decrease in mechanical strength after fiber addition, this study attempts to explain this phenomenon and identify the factors that cause the performance of banyan tree bark fibers to not be in accordance with initial expectations. It is hoped that this study can make a significant contribution to understanding the potential and limitations of using natural fibers in the development of high-performance composite materials.

Extensive research has identified several types of natural fibers that effectively reinforce vinylester resins in composite materials. In particular, sisal, date palm, and hemp have been highlighted for their mechanical properties and sustainability. For example, sisal and date palm fibers, when combined, showed superior tensile and flexural strengths in hybrid composites (Boubaaya et al., 2024). In addition, hemp fibers have shown better tensile and flexural strengths compared to jute when used in epoxy matrices (Yadav & Mishra, 2024). The incorporation of recycled cellulose fibers has also been explored, enhancing the mechanical properties of vinylester composites (Alhuthali & Low, 2021). Furthermore, studies on roselle and coconut shell powder have shown promising tensile properties in vinylester composites (Navaneethakrishnan et al., 2021). Overall, these natural fibers present a viable alternative to partially replace synthetic fibers, contributing to the development of eco-friendly composite materials (Imon, 2024).

However, studies on banyan tree bark fiber are still very limited, and literature on its effectiveness as a reinforcement in composite materials is almost non-existent. This gap raises the need to further explore the potential of banyan tree bark fiber in composite material applications. Previous studies have shown that natural fibers can strengthen composites (Boubaaya et al., 2024, Kadam et al, 2024, Gupta & Pansule, 2024, Aredla et al, 2024), but the results of this study show the opposite, where the addition of banyan tree bark fiber actually decreases the mechanical strength of the material. Therefore, this study aims to fill the gap in the literature by revealing why banyan tree bark fiber fails to improve, and instead decreases, the performance of vinylester composites. These results are expected to provide new contributions to the development of natural fiber-based composites and guide future research in the use of more appropriate and effective fibers.

This study offers a new contribution to the science of natural fiber-based composites by exploring banyan tree bark fiber as a reinforcement in vinylester resin. Despite the growing trend of using natural fibers in material development, the findings of this study show an unexpected result: the addition of banyan bark fibers actually decreases the mechanical strength of the composite. The novelty of this study lies in the critical evaluation of the failure of banyan bark fibers to improve the mechanical properties of the composite, which is contrary to the general expectation of natural fibers. These findings provide a deeper understanding of the limitations of banyan bark fibers and have the potential to direct further research towards natural fiber optimization or more innovative approaches in strengthening composite materials. This study is important because it provides insight into the selectivity and caution in choosing the right natural fibers for composite applications that require high mechanical performance.

Research Methods

This study was conducted using an experimental approach to evaluate the mechanical properties of vinylester composites reinforced with banyan tree bark fibers. Composites were prepared with various fiber volume fractions, namely 10%, 15%, and 20%, to study the effect of fiber addition on tensile and bending strengths (Figure 1). Vinylester resin was chosen as the main matrix because of its good mechanical properties and stability in structural applications (Gao et al., 2023). Banyan tree bark fibers were processed and used as reinforcement in the form of random fibers.

Figure 1 Fiber preparation, fabrication, tensile and bending testing of composites.

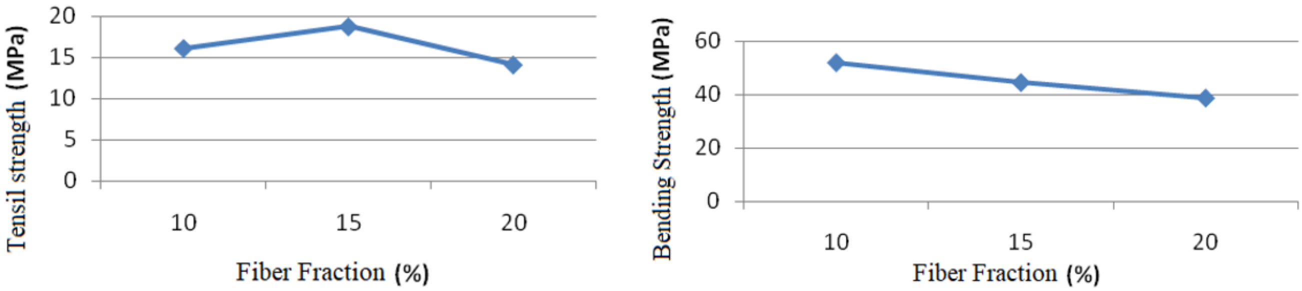
Vinylester resin was used as the composite matrix and mixed with hardener according to the manufacturer's recommended mixing ratio of 1%. The banyan tree bast fibers were dried and processed into random fibers. The fibers were then screened to ensure uniform fiber size and quality before being mixed with the resin. A mixture of vinylester resin and banyan tree bast fibers was prepared for each fiber volume fraction (10%, 15%, and 20%). The resin and fibers were mixed evenly using an electric stirrer to ensure homogeneous fiber distribution in the resin matrix. The mixed composite was poured into a rectangular mold and cured at room temperature for 24 hours.

Tensile testing was carried out according to ASTM D638 standard. Test specimens were cut from the hardened composite with standard dimensions. Testing was carried out using a universal testing machine with a testing speed set at 5 mm/min. Each fiber volume fraction was tested three times, and the average tensile strength value was recorded. Bending testing was carried out using the three-point bending method according to ASTM D790 standard. The test specimens were cut to the appropriate dimensions, and the tests were carried out using a bending test machine with a testing speed set at 2 mm/min. The bending test results included the modulus of elasticity and maximum stress recorded for each fiber volume fraction.

The tensile and bending test data were analyzed to evaluate the effect of fiber volume fraction on the composite strength. The mechanical strength at each volume fraction was compared with the strength value of pure vinylester resin to determine the contribution of fibers to the mechanical properties of the composite.

Results and Discussion.

The results of mechanical property tests show that the addition of banyan tree bark fiber to vinylester resin reduces the tensile and bending strength of the composite compared to pure vinylester resin. In tensile testing, pure vinylester resin has a strength of 40.225 MPa. However, with the addition of fiber, the tensile strength decreases to 16.1 MPa at a fiber volume fraction of 10%, 18.8 MPa at a fiber volume fraction of 15%, and 14.1 MPa at a fiber volume fraction of 20% (figure 2a). This decrease is consistent with the tensile strength of banyan tree bark fiber, which only reaches 30.1 MPa, lower than pure vinylester resin. A similar pattern is also seen in bending tests. The bending strength of pure vinylester resin of 75,298 MPa decreased to 51,779 MPa, 44,473 MPa, and 38,786 MPa at fiber volume fractions of 10%, 15%, and 20%, respectively (Figure 2b). Statistical analysis using ANOVA confirmed that this decrease in mechanical properties was statistically significant ($p < 0.05$), indicating that the addition of banyan tree bark fiber did not contribute positively to the mechanical strength of the composite. These data indicate that although natural fibers are often considered as potential reinforcements, the intrinsic mechanical properties of the fibers must be carefully considered to ensure their effectiveness in strengthening the composite matrix (Ranjan et al, 2023).



a. b.

Figure 1 Tensile strength (a) and bending strength (b) of composites against fiber volume fraction.

The results of this study provide important insights into the limitations of using banyan tree bark fibers as reinforcement in vinylester resin matrices. The significant decrease in the tensile and bending strengths of the composites indicates that banyan tree bark fibers, with a tensile strength of 30.1 MPa, are unable to replace the role of effective reinforcement, especially compared to pure vinylester resin which has a tensile strength of 40.225 MPa and a bending strength of 75.298 MPa.

The lower tensile strength of natural fibers compared to their resins can be attributed to several intrinsic and extrinsic factors. Natural fibers exhibit non-uniformity in diameter and cross-sectional area, leading to variability in mechanical properties, as highlighted by inconsistent tensile strength measurements across studies (Madueke et al., 2022). In addition, the hydrophilic nature of these fibers affects their interaction with the resin matrix, affecting the overall tensile performance of the composites (Saidi et al., 2022).

These results indicate that although natural fibers have economic and environmental advantages, their intrinsic mechanical characteristics need to meet certain requirements in order to be effectively used in structural applications. The practical implication is that banyan bark fibers may be more suitable for use in non-structural applications or as filler in composites for purposes other than mechanical reinforcement, such as reducing weight or material cost. This study also emphasizes the importance of understanding and optimizing the characteristics of natural fibers before integration into composite materials for practical applications in the field.

Although this study successfully evaluated the mechanical properties of vinylester-banyan bark fiber composites, several limitations affected the results obtained. One of the main limitations is the low intrinsic mechanical strength of banyan bark fibers (30.1 MPa), which is unable to synergize with the vinylester resin matrix to improve the tensile and bending strength of the composite. In addition, the distribution of fibers in the matrix may be non-homogeneous, resulting in variations in mechanical properties between specimens. The fabrication method used can also affect the adhesion between fibers and the matrix, which is an important factor in load transfer in composites. These limitations suggest the need for further investigation of fiber processing, including chemical treatments to improve fiber-matrix adhesion, as well as the use of more controlled fabrication methods to ensure a more uniform fiber distribution. Morphological analysis at the fiber-matrix interface can also provide a deeper understanding of the failure mechanisms of this composite.

Based on the results of this study, there are several opportunities for further research development to overcome the identified limitations. One of the main suggestions is to perform surface treatments of the banyan tree bark fibers, such as chemical or thermal modification, to improve adhesion between the fibers and the vinylester resin matrix. This approach has the potential to improve load transfer in the composite, which can increase tensile and bending strengths. In addition, studies on the influence of fiber orientation and distribution in the matrix are needed, considering that uneven distribution can lead to degradation of mechanical properties. Further research can also include morphological analysis using electron microscopy to identify failure mechanisms at the fiber-matrix interface. Testing of other properties, such as resistance to impact, wear, or environmental conditions, can broaden the understanding of the potential applications of this composite. With this approach, future research can provide a more comprehensive solution to maximize the potential of natural fibers as efficient composite reinforcements.

The results of this study have significant implications for economic and environmental aspects, especially in the use of banyan tree bark fiber as a reinforcement for vinylester composites. From an economic perspective, banyan tree bark fiber offers abundant and inexpensive raw materials, potentially reducing the production cost of composites compared to synthetic fibers. However, the decrease in mechanical properties suggests that this fiber is more suitable for non-structural applications or as a filler material rather than as a primary reinforcement. From an environmental perspective, the use of natural fibers such as banyan tree bark supports the principle of sustainability because of its biodegradable nature and is based on renewable resources. However, the decrease in mechanical performance emphasizes the importance of innovation in fiber processing to increase its effectiveness. Overall, although the results of this study have not shown the expected results in terms of mechanical reinforcement, these findings provide a basis for the development of more environmentally friendly and economical natural fiber-based composite materials in the future. This study have not shown the expected results in terms of mechanical reinforcement, these findings provide a basis for the development of natural fiber-based composite materials.

Conclusion

This study evaluated the mechanical properties of vinylester resin-based composites reinforced with banyan tree bark fibers with a focus on tensile and bending strengths. The test results showed that the addition of banyan tree bark fibers did not increase, but rather decreased the mechanical strength of the composites compared to pure vinylester resin. The tensile strength of the composites decreased significantly from 40.225 MPa (pure resin) to 16.1 MPa, 18.8 MPa, and 14.1 MPa at fiber volume fractions of 10%, 15%, and 20%, respectively. A similar pattern was found in the bending strength, which decreased from 75.298 MPa to 51.779 MPa, 44.473 MPa, and 38.786 MPa. This poor mechanical performance was attributed to the lower fiber tensile strength (30.1 MPa) and possible poor adhesion between the fibers and the matrix. These results confirm that banyan tree bark fibers, under these conditions, are not effective as the main mechanical reinforcement for vinylester resins.

Suggestion

Further research needs to be focused on the modification of banyan tree bark fibers, such as chemical or thermal treatments, to improve fiber-matrix interfacial adhesion. This approach is expected to improve the effectiveness of load transfer in composites. Given the limited mechanical characteristics of the fibers, banyan tree bark fibers can be more directed to non-structural applications or as fillers in composites to reduce production costs without sacrificing performance. Further studies should consider more controlled fabrication techniques to ensure even fiber distribution and more consistent composite quality. To expand its potential applications, other composite properties need to be tested, such as impact resistance, thermal resistance, and environmental stability. This study opens up opportunities to further analyze the potential of banyan tree bark fibers as environmentally friendly and economical materials, considering reducing carbon footprints and material costs.

References

[1] Abdullah M.S. Alhuthali, Meng Low, Vinyl-ester composites reinforced with natural fibers and nanofillers Composite Materials Manufacturing, Properties and Applications, 2021, Pages 227-244

[2] Alok Ranjan, Pavan Kumar Singh, Development of Natural Fiber Reinforced Polymer Matrix Composites: A Critical Review, Macromolekular symposia, Volume413, Issue5, Special Issue: 4th National Conference on Materials and Device (NCMD) 2023, https://doi.org/10.1002/masy.202400118

[3] Andrzej Kubit, Magdalena Bucior, Rafał Kluz, Krzysztof Ochałek, Katarzyna Burnat, E¬ect of Nano llers on the Mechanical Properties of Vinyl EsterResin Used as a Carbon Fiber Reinforced Polymer Matrix, Advances in Science and Technology Research Journal, 2022, 16(4), 10–21, https://doi.org/10.12913/22998624/152053

[4] Anith Athierah Aziz, Sallehan Ismail, Siti Akhtar Mahayuddin, A Review of The Factors Affecting of The Properties of Bamboo Fiber Bio-Composite Materials, Malaysian Journal of Sustainable Environment Vol. 10 No.1 (2023) 275-298, Doi: 10.24191/Myse.V10i1.21264.

[5] Bin Dong, Rubin Wei, Xiaowei Wang, Siwei Fu, Wenting Zhang, Wen Zhai, Flexural strength and ballistic performance of vinyl ester resin/aramid fiber composites toughened by graphene nanosheets, Journal of Physics: Conference Series 2478, 2023, 072073 IOP Publishing, doi:10.1088/1742-6596/2478/7/072073.

[6] Chioma Ifeyinwa Madueke, Oguejiofor Miracle Mbah, Reginald Umunakwe, A review on the limitations of natural fibres and natural fibre composites with emphasis on tensile strength using coir as a case study, Polymer Bulletin, 2023, 80:3489–3506 https://doi.org/10.1007/s00289-022-04241-y

[7] Endang Prawesthi, Adinda E. Putri, Vilza Asylla, Sambodo A.W., Effect of Addition Ramie and Coconut Coir Fibers with Different Concentrations On Tensile Strength Of Acrylic Denture Base, Journal of Vocational Health Studies 07, 2023, p.24-31.

[8] Fandy Prihatna Suhada, Afira Ainur Rosidah, Vuri Ayu Setyowati, Suheni, The Influence of Fiber Orientation and Treatment Variation of Natural Fiber Reinforced Composites on Tensile Strength and Toughness, Journal of Applied Sciences, Management and Engineering Technology, Vol 4, No 1, 2023, page 21–28.

[9] Hariome Sharan Gupta, Sanjay Palsule, Comparisons of reported and predicted tensile properties of natural fiber reinforced HDPE composites, Interactions, Vol 245, article number 249, 2024

[10] Jincheng Gao, Xu Li, Jianhui Wei, Yuheng Zhang, Jihui Wang, Anxin Ding, Hygrothermal behavior of carbon ber fabric reinforced vinylester resin composite structures, Applied Composite Materials on March 12th, 2024, https://doi.org/10.1007/s10443-024-10216-1.

[11] K. Mohan Kumar, Venkatesh Naik, Vijayanand Kaup, Sunil Waddar, N. Santhosh, and H. V. Harish, Nontraditional Natural Filler-Based Biocomposites for Sustainable Structures, Advances in Polymer Technology, Volume 2023, Article ID 8838766, 15 pages, https://doi.org/10.1155/2023/8838766

[12] R. Venkatesh, Suhas Ballal, A. Mohana Krishnan, S. Prabagaran, S. Mohankumar, Elangomathavan Ramaraj, Effect of fiber layer formation on mechanical and wear properties of natural fiber filled epoxy hybrid composites, Heliyon 9 (2023) e15934, https://doi.org/10.1016/j.heliyon.2023.e15934

[13] Rabah Boubaaya, Mokhtar Djendel, Karima Sidhoum, Samir Benaniba, Oussama Kessal, Tahar Tayebi, Vol. 5 No. 2, 2024, Studies in Engineering and Exact Sciences, Curitiba, v.5, n.2, 2024

[14] Rakshitha Aredla, Hari Chandana Dasari, S. Sathees Kumar & Pravat Ranjan Pati, Mechanical properties of natural fiber reinforced natural and ceramic fillers for various engineering applications, Interactions, 2024, vol 245, no.249,

[15] Ravi Yerraiahgarahalli Venkataravanappa, Avinash Lakshmikanthan, Natesan Kapilan, Manjunath Patel Gowdru Chandrashekarappa, Oguzhan Der and Ali Ercetin, Physico-Mechanical Property Evaluation and Morphology Study of Moisture-Treated Hemp–Banana Natural-Fiber-Reinforced Green Composites, J. Compos. Sci. 2023, 7, 266. https://doi.org/10.3390/jcs7070266

[16] S. Navaneethakrishnan, V. Sivabharathi, S. Ashokraj, Weibull distribution analysis of roselle and coconut-shell reinforced vinylester composites,

Australian Journal of Mechanical Engineering, Volume 19, 2021, Issue 4

[17] S. V. Gurupranes, I. Rajendran, S. Gokulkumar, M. Aravindh, S. Sathish, and Md. Elias Uddin, Preparation, Characteristics, and Application of Biopolymer Materials Reinforced with Lignocellulosic Fibres, International Journal of Polymer Science, Volume 2023, Article ID 1738967, 22 pages, https://doi.org/10.1155/2023/1738967

[18] Sahib dua, Hardik Khatri, Jesuarockiam Naveen, M. Jawaid, K. Jayakrishna, M.N.F. Norrrahim, Ahmad Rashedi, Potential of natural fiber based polymeric composites for cleaner automotive component production -a comprehensive review, journal of materials research and technology 2023; 25, 1086 -1104, https://doi.org/10.1016/j.jmrt.2023.06.019

[19] Sandeep Yadav, Sanjay Mishra, Fabrication and Mechanical Characterization of Natural Fiber-Reinforced Polymer Composites, International Research Journal on Advanced Engineering Hub (IRJAEH), Vol. 02, Issue 06, June 2024, Page no: 1570- 1577

[20] Taufiq Saidi, Muttaqin Hasan, Zahra Amalia, Tensile Strength of Natural Fiber in Different Types of Matrixs, Aceh International Journal of Science and Technology, 11(2) 136-144 August 2022, doi: 10.13170/aijst.11.2.26175

[21] Thanh Kim Mai Dang, Mostafa Nikzad, Vi Khanh Truong, Syed Masood, Chung Kim Nguyen and Igor Sbarski, Thermomechanical Properties and Fracture Toughness Improvement of Thermosetting Vinyl Ester Using Liquid Metal and Graphene Nanoplatelets, Polymers 2022, 14, 5397, https://doi.org/10.3390/polym14245397.

[22] Tirupathi Kadam, J Suresh Kumar and Somashekar S. Hiremath, Dynamic Mechanical Analysis of Natural Fiber Hybrid Composites for Automobile Applications, Journal of Physics: Conference Series: 6th International Conference on Advancements in Materials and Manufacturing, Hyderabad, India, Volume 2837, IOP Publishing Ltd, 2024, DOI 10.1088/1742-6596/2837/1/012044

[23] Yongwoo Lee, Final report of SERDP Project WP-1755: Environmentally Compliant Vinyl Ester Resin (VER) Composite Matrix Resin Derived from Renewable Resources, 2011.

[24] Zhanying Sun, Yufeng Duan, Haoran An, Xin Wang, Shuang Liang & Na Li (2023) Research Progress and Application of Natural Fiber Composites, Journal of Natural Fibers, 20:2, 2206591, DOI: 10.1080/15440478.2023.2206591.