

Mechanical and Thermal Properties Studies on the sustainable chopped Caryota Fiber Reinforced Polyester Composites (CFRPC)

S.Vijayakumar^a, Mayandi Kalimuthu^b, T. Premkumar^c, G. Kalusuraman^d

^a Department of Mechanical Engineering & Mar Ephraem College of Engineering and Technology, Tamil Nadu, India .

^b Department of Mechanical Engineering, Kalasalingam Academy of Research and Education Anand Nagar, Krishnankoil-626126, Virudhunagar Dt, India.

^c Department of Mechanical Engineering, SRM Madurai College for Engineering and Technology, Madurai 626125, TN, India

^d Department of Agricultural Engineering, Kalasalingam Academy of Research and Education Anand Nagar, Krishnankoil-626126, Virudhunagar Dt, India

Abstract. This paper investigates the fracture toughness, tensile strength, impact resistance, and hardness of Caryota fiber composites with fiber contents of 30 wt%, 35 wt%, 40 wt%, and 45 wt%, and fiber lengths of 10 mm, 25 mm, 50 mm, and 100 mm. The compression moulding technique used to fabricate the laminates. The effects of fiber content and fiber length on the mechanical and thermal properties of Caryota fiber-reinforced polyester composites (CFRPC) were studied. Optimal mechanical performance was observed at 40 wt% fiber content. Further increases in fiber loading led to reduced mechanical properties due to poor interfacial adhesion between the fiber and resin. This makes caryota fiber reinforced composites as a substitute light weight material. Microstructure interfacial mechanism was studied for the SEM. Fibers are widely used in applications such as automotive, aerospace, household items, and sports goods. Natural fibers are lightweight, low-cost, readily available, and offer high stiffness and strength relative to their weight.

Keywords: Chopped caryota fiber, mechanical, thermal properties and SEM analysis.

1 Introduction

In recent years, bio fibers have been increasingly used in various applications such as automotive, aerospace, household items, and sports goods. Their appeal lies in being biodegradable, eco-friendly, readily available, and low in density.

*Corresponding author: vijayakumar@marephraem.edu.in, k.mayandi@klu.ac.in

Bio fibers also offer high strength and stiffness relative to their lightweight nature. Composites made from bio fibers are easy to process, cost-effective, and environmentally sustainable. Testing these materials provides valuable insights into their toughness, which is crucial for engineering assessments. Fracture toughness, in particular, is a key design parameter in the manufacturing of structural components. Santhanam et al. [1] used a polyester matrix and banana fibre and manufactured glass fibre with different fibre volume fractions and 10 mm chopped lengths to make laminates by hand lay-up. The mode I fracture hardness of polyester composites reinforced with banana fibres was found to be similar to that of composites strengthened with glass fibres. This suggests that banana fibre could be used in other ways in the future. Sheikh Parweenali Khudhur et al. The study looked at how sugar palm fiber-reinforced epoxy composites behaved when they were in different orientations. The results showed that fibres treated with seawater were more resistant to breaking than fibres that had not been treated. Silva, R.V., et al. Researchers made treated and raw sisal fiber-reinforced polyurethane composites and found that the treated fibres worked better than the unprocessed ones. Three different weave designs were used to make banana fiber-reinforced epoxy composites by Venkateshwaran et al [4]. The mechanical properties of the regular weave were better than those of the other designs. The weaved composites' dynamic properties were also looked at. Vasumathi.M [5] made hybrid laminates with and without biofiber. It was found that laminates with biofiber reinforcement had higher flexural and elastic elasticity, while laminates without biofiber reinforcement had higher flexural strength. The results of the experiments and the analysis were very similar. Palanikumar et al. [6] used the hand lay-up method to make sandwich fiber-reinforced polyester composites with different amounts of nano-clay. Based on the study, adding 4 weight percent of nano-clay improved the physical, bending, and impact qualities. There were also X-ray and SEM studies. Anbusagar NNR [7] the hand lay-up method was used to make glass fiber-reinforced PS foam sandwiches with and without nano-clay loading. The study discovered that adding 4 wt% nano-clay made the vibrations better, and SEM research showed that adding more nano-clay made the fiber-matrix stick together better. Angsagar NNR [8] We made sandwich hybrid reinforced polymer composites with and without nano-clay using the hand lay-up method and different loading situations. The study found that 2 wt% nano-clay loading maximized flexural strength, while 6 wt% nano-clay loading achieved the highest impact strength. SEM analysis also examined shear deformation and bending load-bearing performance of the core and skin. Anbusagar et al [9] Glass fiber-reinforced polymer composites with four different nano-clay loadings were fabricated using the hand lay-up technique. The study found that 4 wt% nano-clay maximized tensile, flexural, and deformation properties. SEM analysis showed that increasing nano-clay improved fiber-matrix adhesion.

Jayapaul Utilising the hand lay-up method, woven coir polyester composites that had been treated with different concentrations and lengths of NaOH, in addition to untreated composites, were manufactured. The research found that treated composites had better machinability and mechanical attributes, such as reduced tool wear, torque, and thrust force. A comparison was made between the machinability behaviour and mathematical and regression frameworks. With the use of the hand lay-up method, Palanikumar et al. [11] created glass fibre sandwich laminates with Styrofoam cores and different loadings of nano-clay. Results showed that glass fibre composites with 4 wt% nano-clay had higher flexural strength and 6 wt% nano-clay had higher impact strength.

Venkateshwaran et al [12] Banana fiber epoxy-reinforced polymer composites were fabricated, and the study found that the experimental mechanical performance closely matched the modified rule of mixtures. Vasumathi.M [13] The study replaced carbon fiber with jute and fabricated fiber-metal laminates (FML) using compression molding. The results showed that fiber orientation and stacking sequence provided the best mechanical

properties, making it a viable alternative to aluminum and magnesium metals. Muralimohan Rao et al [14] The study explored replacing conventional metals with synthetic fibers and incorporating natural fibers into composites to reduce environmental impact.

Sahari. Jet al. [15] Using biodegradable matrices to create bio-composites, this research measured the impact strength, flexural modulus, modulus ratio, and tensile modulus of green composites at different volume fractions.

2.1 Caryota fiber extraction

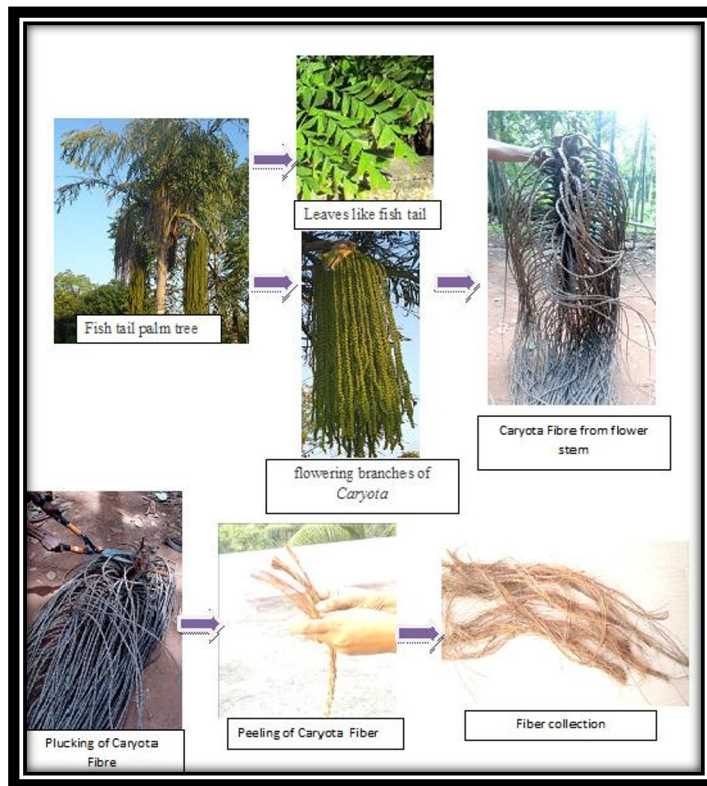


Fig.1. Extraction process of caryota fiber

Caryota fiber is extracted from the flower stem of the fish tail palm tree. The stem is cut, dried in sunlight for 24 hours, and then the urns are removed. The 3-4 meter long stems are cut to the desired length, soaked in water for 3 hours, and softened by pounding with a wooden mallet. The fibers are then manually isolated and used for composite preparation.

2.2 Composite Fabrication

Caryota fibers of varying lengths (10 mm, 25 mm, 50 mm, and 100 mm) and wt% were randomly oriented in the lower die. Polyester resin, accelerator, and catalyst were added, and the upper die was placed. A 50 Kg/cm² hydraulic load was applied at 60°C for 30

minutes. Composites with different wt% and fiber lengths were produced, maintaining a constant overall weight.

2.3. Testing of composite specimen

In accordance with ASTM D3039, the tensile tests were carried out on the specimen, which measured 20 cm × 2 cm × 0.3 cm. In addition, the fracture toughness specimen, which measured 10cmx10cm x0.3cm and included two holes and a centrally cut notch, was tested in accordance with ASTM D638. In accordance with ASTM D256, the dimensions of the impact test specimen are 6.5 cm × 1.3 cm × 0.3 cm. The composite specimen, which had dimensions that were in accordance with the ASTM D785–98 digital Rockwell hardness tester, was subjected to hardness testing. Each of the five samples was subjected to testing, and the average result was recorded for each test. All of the tensile, flexural, and fracture toughness tests were carried out with the help of the Instron Universal Testing Machine (UTM). For testing, the crosshead speed should be set at 10 mm/min.

2.4. SEM and Thermal testing

Caryota fiber's thermal stability was evaluated by thermogravimetric analysis (TGA) using a Perkin Elmer STA 8000. Placing the measured fibre sample in an Al₂O₃ crucible, it was heated under an inert nitrogen environment from 28°C to 720°C at a steady rate of 10°C/min. Nitrogen is a gas that is inert and utilised in the environment. Researchers looked at how much mass the fibre lost as a function of temperature. In a study conducted by Narayanasamy et al. in 2020.

3. Results and discussion

3.1 SEM and TGA&DSC analysis of fiber

The TGA and DSC curves for Caryota fibre are shown in Figure 2. When assessing biofiber as a composite reinforcement, thermal stability is essential (Fiore, Scalici, and Valenza 2014). Because the fibre is hydrophilic, moisture evaporation results in an initial mass loss of 6.75 percent between 28°C and 120°C. Up to 270°C, the DSC curve demonstrates thermal stability. Cellulose degrades due to thermal degradation, which starts with chain branching and polysaccharide breakdown in hemicellulose (Nurazzi et al. 2021). Between 240°C and 360°C, there is further mass loss (62%) which signifies the beginning of fibre degradation as a result of the cellulose, pectin, and hemicellulose linkages breaking. Caryota fibres may be appropriate for low-temperature composite applications, according to TGA and DSC data.

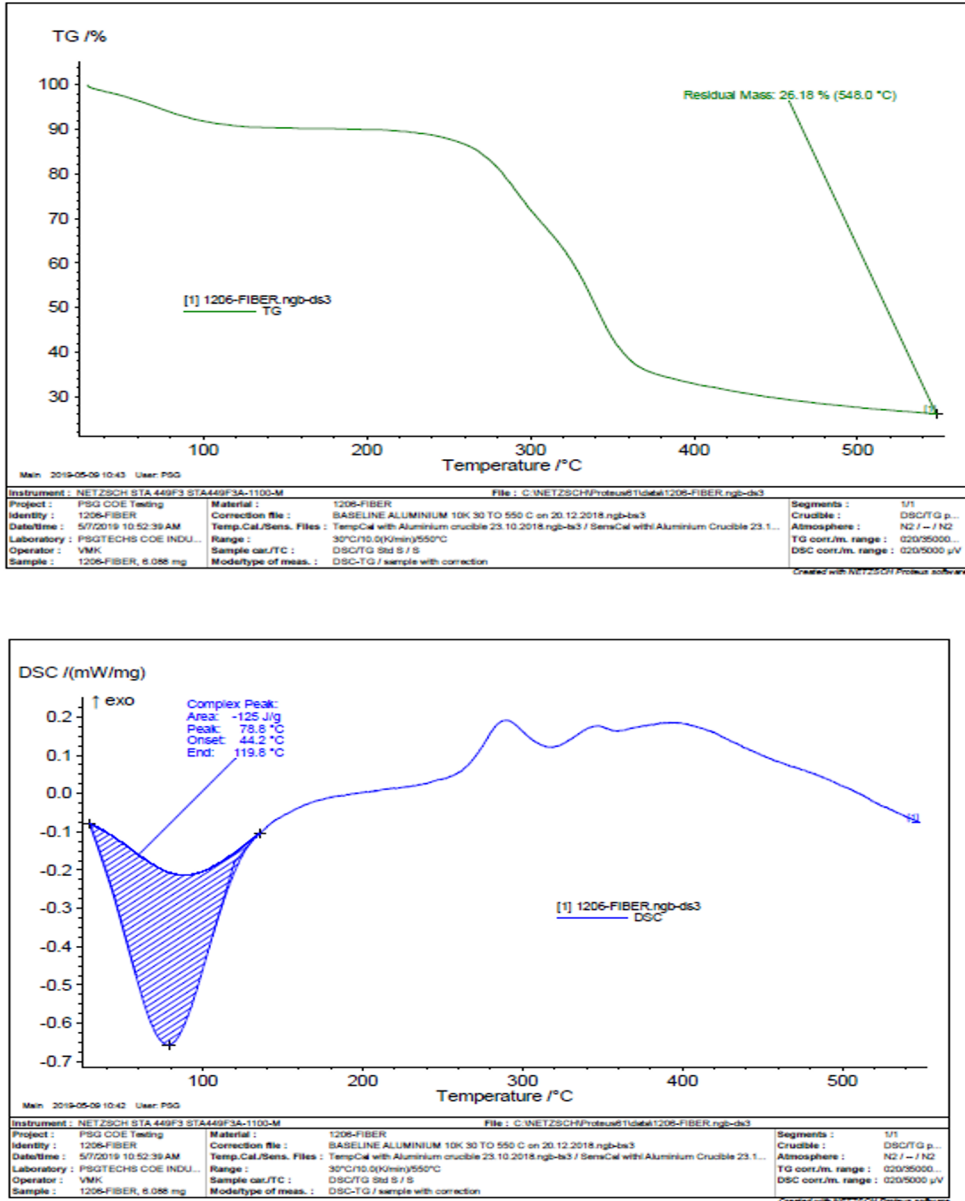


Fig. 2. TGA and DSC testing of individual fiber

3.2 Tensile strength

Figure 3 shows the tensile stress of CFRPC with varying fiber wt% and fiber lengths. The tensile strength of Caryota fiber depends on fiber orientation and content. The composite shows optimal strength at 40 wt% fiber content, with a tensile stress of 19 MPa, lower than other fiber composites like palmyra, empty fruit bunch, and sisal [20, 21]. Beyond 40 wt%, tensile stress decreases due to reduced elasticity and weaker fiber-matrix bonding, making 40 wt% the optimal fiber content for maximum tensile strength.

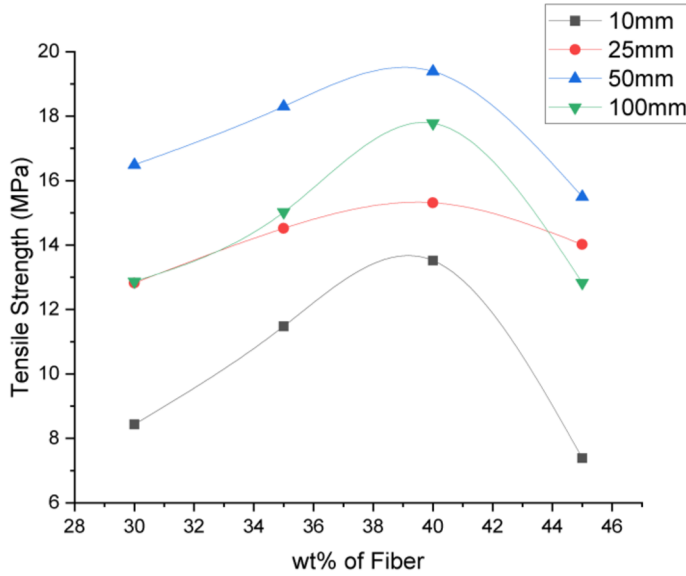


Fig. 3. Tensile strength Vs fiber wt%

3.3. Specific tensile strength Figure 4 shows the specific tensile stress of Caryota fiber at varying fiber lengths and wt%. Specific tensile strength, the ratio of tensile strength to mass density, is crucial for reducing dead load in engineering applications. The study found that increasing fiber wt% enhances specific tensile strength. At 40 wt% fiber content, the CFRPC shows a specific tensile strength of 22 kNm/kg due to the fiber's lower density of 0.850 g/cc (19). For lightweight applications, CFRPC is ideal due to its maximum specific strength, even without considering stiffness.

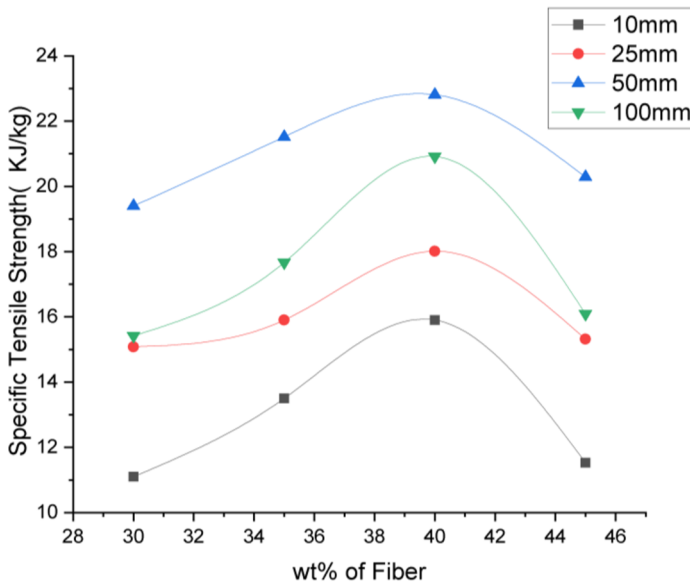


Fig. 4. Specific tensile strength Vs fiber wt%

3.4. Fracture toughness Figure 5 The fracture toughness of the CFRPC with the different wt% for the different fiber length. It shows the variation of fracture toughness increase in fiber wt% and different fiber length. The fracture toughness 40wt% of fiber loading is optimum of 6.746J,for the fiber length of 25mm.Further increasing the fiber loading of 45wt%,the fracture toughness decrease to 4.455J,for the same fiber length.For increasing the fiber length of 50mm and 100mm the fracture toughness decreases to 5.684J and 5.115J for the fiber content of 40wt%.There are several factors in considering the fracture toughness of CFRPC material. The poor interfacial adhesion due to crack is simply initiated ,because of micro-crack formed between the fiber and matrix. The another way is the energy absorption in the fiber that promotes the crack propagation of It is observed that increases in wt% fiber loading, the fracture toughness increases the composites. Effective load transfer occurs between the fiber and matrix up to 40 wt% fiber content. Beyond this, increasing fiber length and content reduces fracture toughness due to poor fiber-matrix interaction. The polyester matrix improves ductility, with 40 wt% composites showing maximum fracture toughness. At 45 wt%, increased ductility and reduced brittleness result in lower fracture toughness. Thus, 40 wt% is the optimal fiber content for peak fracture performance.

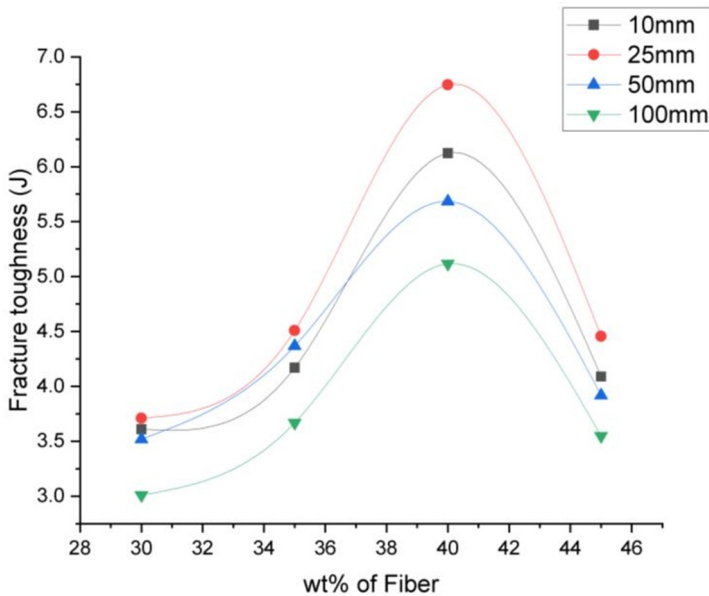


Fig. 5.Fracture toughness Vs fiber wt%

3.5. Impact energy Figure 6 shows the impact strength of CFRPC with varying fiber wt% and lengths. Impact resistance was assessed through impact tests. Poor interfacial bonding and micro-crack formation between fiber and matrix affect impact strength. Increased fiber content enhances material hardness and impact energy. Impact energy rises from 30 to 45 wt% fiber content, peaking at 40 wt%. However, at 45 wt%, impact energy decreases due to poor fiber-matrix bonding, leading to fiber pull-out and splitting.

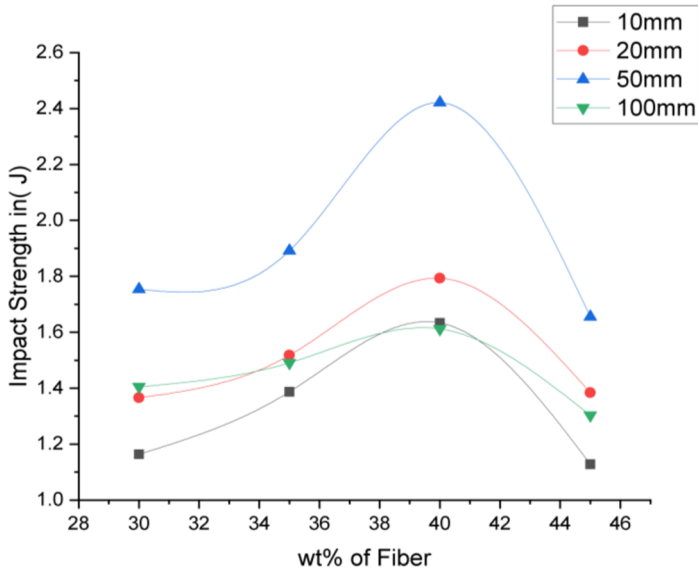


Fig. 6. Impact energy Vs fiber wt%

3.6. Hardness Figure 7 shows the hardness of CFRPC at different wt%. Hardness reflects surface strength under external loads and depends on the interfacial adhesion between fiber and resin. The optimum hardness is achieved at 40 wt% fiber content. Increasing fiber content beyond 40 wt% reduces mechanical properties due to decreased fiber-matrix adhesion, resulting in lower hardness.

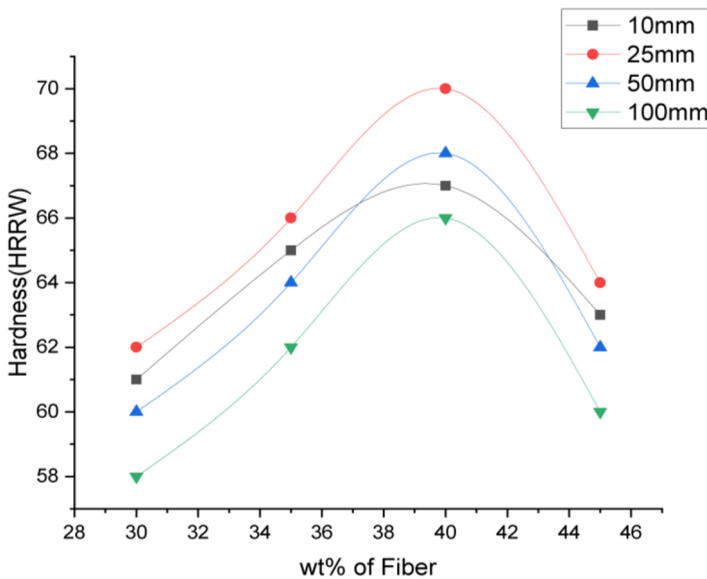


Fig. 7. Hardness Vs fiber wt%

3.7. Morphology analysis Figures 9(a)-(d) show the SEM microstructure of tensile-damaged CFRPC specimens. At 30 wt%, lower fiber loading increases matrix adhesion but leads to microcrack initiation due to poor fiber-matrix bonding. Figures 9 & 10(c) show the fracture surface at 35 wt%, where insufficient fiber-matrix bonding causes composite damage and minimal delamination. At 35 and 40 wt%, better fiber-matrix adhesion is observed, with 40 wt% showing a honeycomb structure and strong adhesion. However, at 45 wt%, excessive fiber loading causes void formation, reducing mechanical performance due to poor load transfer between fiber and matrix. Figure 8 shows the cross-sectional image of individual Caryota fibers, with a cell radius of 220 μm . The high lignin content in Caryota fiber increases stiffness and strength.

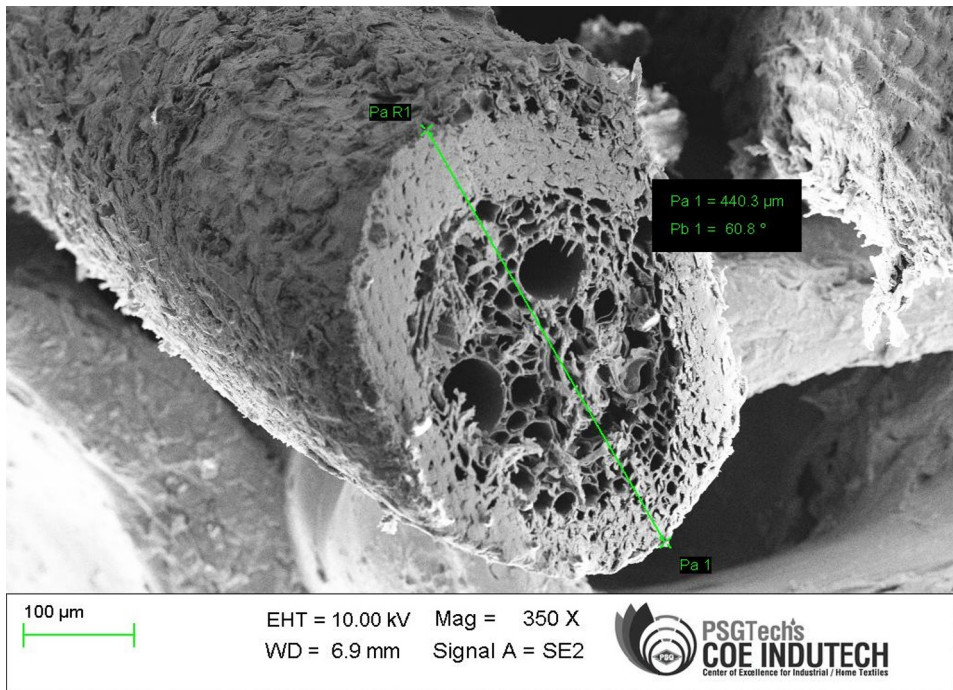
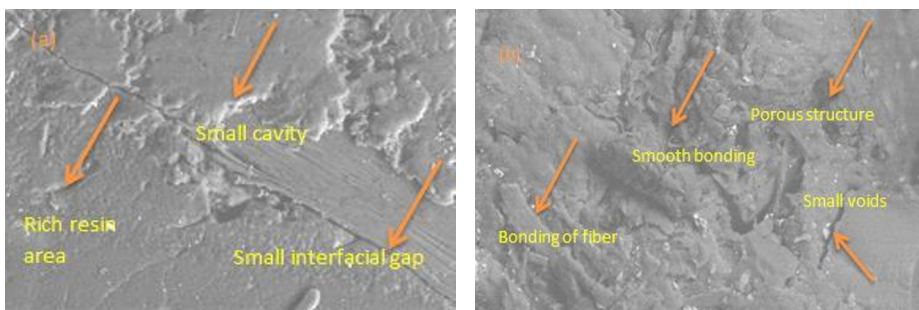


Fig. 8. SEM images of cross sectional view of fiber



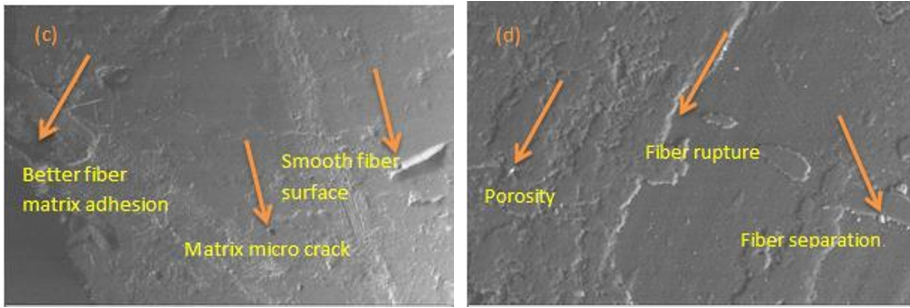


Fig. 9. SEM images of tensile fractured specimens (a)30wt% of fiber,(b)35wt% of fiber,(c)40wt% of fiber and(d)45wt% of fiber.

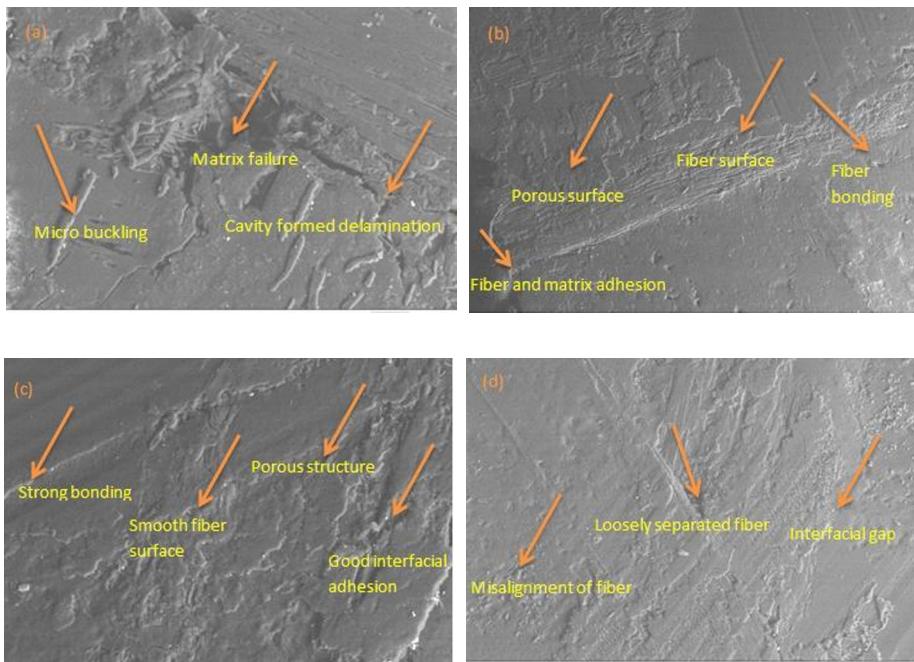


Fig. 10. SEM images of fracture toughness fractured specimens (a)30wt% of fiber,(b)35wt% of fiber,(c)40wt% of fiber and(d)45wt% of fiber.

4. Conclusion

Caryota fibre is an excellent substitute for synthetic fibres and may be used to create bio-green composites, according to research on the mechanical and thermal characteristics of the fibre. With its exceptional mechanical performance in the polyester matrix, caryota's density (about 0.85 g/cc) yields a specific tensile stress of 22 KNm/kg. Caryota fibre reinforced composites' mechanical performance is compared to composites with different weight percentages of fibre loading. It is discovered that a composite with 40 weight percent fibre content has superior strength, hardness, and energy. When the fibre composition of the composite ranges from 30 weight percent to 45 weight percent, SEM

microstructure examination of the cracked tensile specimen reveals fibre splitting, delamination, fractures, and interfacial cracks. Samples loaded with 40 weight percent fibre had the least amount of fibre breaking and delamination, which results in high loads being transferred between the fibre matrix. The TGA and DSC demonstrate that caryota fibre is stable up to 400 °C, which is the temperature at which the polymerisation process occurs. Car door panels, electrical components, and other interior automotive components may all benefit from the 40wt% caryota fibre reinforced composite materials.

References

- [1] V. Santhanam, M. Chandrasekaran, N. Venkateshwaran, A. Elayaperumal, Mode I Fracture Toughness of banana fiber and glass fiber reinforced composites, *Adv. Mater. Res.* 622–623, 1320–1324 (2013).
- [2] P.A. Khudhur, S. Omer, Z. A. Basim, K. Zainab, Fracture Toughness of Sugar palm fiber reinforced epoxy composites, *Int. J. Sci. Res.* 2013, 273–279.
- [3] R.V. Silva, D. Spinelli, W.W. Bosefilho, S.C. Neto, G.O. Chierice, J.R. Tarpani, Fracture toughness of natural fibers/castor oil polyurethane composites, *Compos. Sci. Technol.* 66, 1328–1335 (2006).
- [4] N. Venkateshwaran, A. Elayaperumal, R.H. Arwin Raj, Mechanical and dynamic mechanical analysis of woven banana/epoxy composites, *Polym. Environ.* 2012, 1–5.
- [5] M. Vasumathi, V. Murali, Experimental investigation on the impact of presence of natural fiber on the mechanical performance of a lightweight hybrid bonded laminate, *Int. J. Eng. Technol.* 6, 236–241 (2014).
- [6] K. Palanikumar, N.R.R. Anbusagar, P.K. Giridharan, Study of sandwich effect on nanoclay polyester resin GFR face sheet laminates, *Compos. Struct.* 125, 336–342 (2015).
- [7] N.A.A. Anbusagar, K. Palanikumar, Dynamic analysis of OMMT nanoparticle reinforced resin GFR-PS foam sandwich laminates, *Sci. Technol.* 9, 1–4 (2016).
- [8] N.R.R. Anbusager, P.K. Giridharan, K. Palanikumar, Mechanical behavior of Glass-Jute sandwich polyester composites to flexural and impact loading, *Eur. J. Sci. Res.* 2, 148–155 (2012).
- [9] N.R.R. Anbusager, K. Palanikumar, R. Vigneswaran, M. Rajmohan, P. Sengottuvel, Tensile and flexural properties of glass fiber reinforced nano polymer composite panels, *Appl. Mech. Mater.* 766–767, 372–376 (2015).
- [10] S. Jayabal, S. Velumani, P. Navaneethkrishnan, K. Palanikumar, Mechanical and machinability behaviors of woven coir fiber reinforced polyester composite, *Fibers Polym.* 14, 1505–1514 (2013).
- [11] K. Palanikumar, N.R.R. Anbusagar, P.K. Giridharan, Influence of nano particle on flexural and impact properties of sandwich structures, *Adv. Mater. Res.* 602–604, 174–177 (2012).
- [12] N. Venkateshwaran, A. Elayaperumal, Modeling and evaluation of tensile properties of randomly oriented banana/epoxy composites, *J. Reinf. Plast. Compos.* 30, 1957–1967 (2016).
- [13] M. Vasumathi, V. Murali, Effect of alternate metals for use in natural fibre reinforced fiber metal laminates under bending, impact and axial loading, *Sci. Direct* 64, 562–570 (2013).
- [14] M.M. Rao, K. Mohana Rao, A.V. Ratna Prasad, Fabrication and testing of natural fiber composite: Vakka, Sisal, bamboo and banana, *Mater. Des.* 31, 508–514 (2010).
- [15] J. Sahari, S.M. Sapuan, Natural fibre reinforced biodegradable polymer composites, *Adv. Mater. Sci.* 30, 166–174 (2011).