ISSN 1392–1207. MECHANIKA. 2021 Volume 27(3): 265–269

Study of Mechanical Properties of Roselle Fiber Reinforced Vinyl Ester Biocomposite Based on the Length and Content of Fiber

Muthuraja RAMAKRISHNAN*, Sarala RAMASUBRAMANIAN, Venkatarajan SUBBARAYALU***, Athijayamani AYYANAR******
**Department of Mechanical Engineering, ACGCET, Karaikudi-630003, Tamilnadu, India,*
E-mail: muthu.maha92@gmail.com (Corresponding author)
***Department of Mechanical Engineering, ACGCET, Karaikudi-630003, Tamilnadu, India*
****Department of Physics, ACGCET, Karaikudi-630003, Tamilnadu, India*
*****Department of Mechanical Engineering, GCE, Bodinayakanur-625582, Tamilnadu, India*

crossref http://dx.doi.org/10.5755/j02.mech.26603

1. Introduction

In recent years the potentiality of natural cellulose fibers in polymer composites (thermosetting and thermoplastic) has received considerable attention among material scientists, engineers and researchers around the world for their good mechanical performance and eco-friendliness. The light weight, easy availability, renewability, and biodegradability as well as satisfactory specific mechanical properties of the plant based natural fibers make them an attractive alternative to synthetic fibers used in polymer composites [1 - 4]. The mechanical properties of Roselle and sisal fiber reinforced polyester hybrid composite were studied at dry and wet conditions. Composite plates were prepared with the fibers at a ratio of 1:1. Mechanical properties such as tensile, flexural and impact was determined based on the length and content of fibers and also found that when the fiber content and length of the Roselle and sisal fibers are increased, the tensile and flexural strength of the composite increased. It was also observed that increase of length and content of fibers decreases the mechanical properties of the composites at wet conditions [5]. Athijayamani et al. [6] investigated the mechanical properties such as tensile, flexural, shear and impact strength, of unidirectional aligned bagasse fibers reinforced vinyl ester composite. The authors found that a significant improvement was identified in tensile and flexural properties. The impact strength was improved from the initial addition of bagasse fibers.

Jute fabric and jute mat fiber reinforced unsaturated polyester hybrid composites were prepared by a modified hand lay-up technique and characterized based on mechanical properties. Mechanical properties (tensile and flexural) of jute mat composites increased by increasing the weight percentage of fiber with the addition of the jute fabric as skin layers.The notch sensitivity of the composites was increased with decreasing of characteristic distance by adding the skins [7]. Palanikumar and Subbiah [8] analyzed the mechanical and vibration behavior of bio Caryota fiber reinforced polyester composites for different weight fraction. Composite plates were prepared using compression molding technique. It was observed that composites having 40 wt% of fibers show better mechanical and vibration behavior. The influence of fiber content(20-50 wt%) on mechanical and thermal properties of Kenaf fiber-reinforced polyurethane composites were studied and found that 30 wt% fiber loading exhibited the better tensile strength, but modulus values increased with increase of fiber content. Flexural properties were increased with increase of fiber loading. Moreover, the impact strength and thermal stability were decreased with fiber loading [9].

Mechanical properties of Curaua fibers reinforced Poly(hydroxybutyrate-co-valerate) composites were evaluated and observed that the addition of the fiber is improved the mechanical properties of composite. Better properties were displayed at composites having the fiber load of 20 and 30 wt% [10]. Sivaraj and Rajeshkumar [11] evaluated and studied the effect of process parameters on tensile flexural and impact strength of coir and bagasse fiber reinforced polyester-based hybrid composites and also predicts the properties of random oriented hybrid composites. The authors found that the 30% of coir fiber and 10% of bagasse fiber with 60% of polyester resin show the best values of tensile strength, flexural strength and impact strength. In the present study, the effects of fiber length (3 and 13 mm) and content(10, 20, 30, 40 and 50 wt%) of Roselle fibers on the mechanical properties of vinyl ester composites are evaluated. Composites are prepared by a simple hand lay-up method.

2. Experimental details

2.1. Materials

Roselle fibers are separated and extracted from stem of Roselle plants (Fig. 1, a and b). For the production of fiber, the stems of Roselle plants were harvested at the bud stage. The stalks were tied into bundles and left on the field to retting in water for 3-5 days. The retted stems are washed in running water and then, the top portion of the stems is removed by manually.Finally, the separated fibers are dried in sunlight for 24 hours. After that, they were prepared in two forms: (i) short, (ii) long. The Roselle fibers are white or golden white in color. The shape varies from fiber to fiber, and also non uniform, which depends on the age after growing and area of cultivation of the plant. The typical properties of Roselle fibers used in this study are given in Table 1.

Commercially available vinyl ester resin, Trade name Satyen Polymer Pvt. Ltd., Bangalore, India, was used as a polymer resin matrix and supplied by GVR Enterprise, Madurai, Tamilnadu, India. Methyl Ethyl Ketone Peroxide and N–N dimethyl aniline were used as a catalyst and promoter respectively. All chemicals used in this study were tested at Saint-Gobain Vetrotex India Ltd. The typical properties of vinyl ester are listed in Table 2.

Table 1

The typical properties of Roselle fibers used in this study

Properties	Rosele fibers
Appearance	White or golden white
Length, m	0.1 – 1.0
Diameter (50 samples), mm	0.14 – 0.29
Density (Archimedes principle), g/cm^3	1.31
Tensile strength, MPa	80.193–235.019
Young's Modulus, GPa	7.460–18.802

Table 2

The physical properties of vinyl ester used in this study

Properties	Vinyl ester
Appearance	Golden white
Density (Archimedes principle), g/cm^3	1.145
Viscosity, cps	400
Specific gravity	1.09

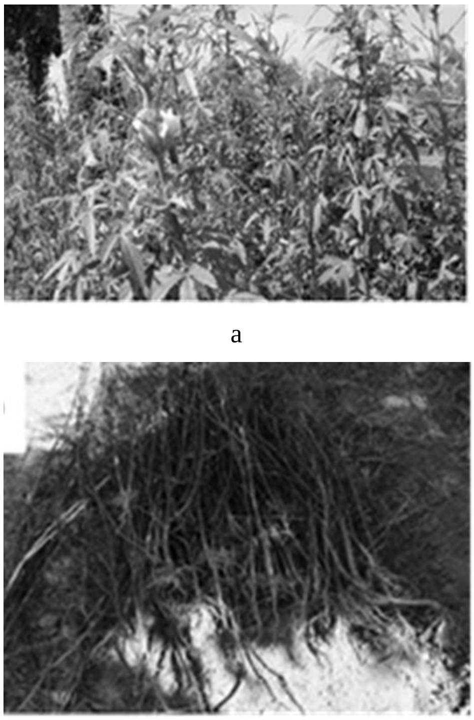
For comparative study, a neat resin plate was cast with accelerator and catalyst in the mould of 150 X 20 X 3 mm. Totally, five samples were tested according to the ASTM D 638 for the tensile test and the ASTM D 790 for the flexural test. The average tensile strength is estimated as 29.6 MPa and the tensile modulus to be 1088.63 MPa. The average flexural strength is observed as 33.1 MPa and the flexural modulus to be 1127.3 MPa. The impact strength is observed as 0.87 KJ/m^2.

2.2. Preparation of composites

Composite plates were prepared using a simple hand lay-up technique.The prepared Roselle fibers at short(3 mm) and long (13 mm) lengths with five different fiber contents(10, 20, 30, 40 and 50 wt%) were mixed with the vinyl ester resin using a mechanical stirrer for 30 minutes and then promoter and also catalyst was added to that mixture. The mixing ratios of the fiber and resin matrix are 0:100, 10:90, 20:80, 30:70, 40:60, and 50:50 wt%, respectively. The mixture (mixing ratio of fiber and re was again stirred using a mechanical stirrer for 15 minutes. After that, the mixture was uniformly poured into a mould with the size of 150 X 150 X 3 mm at most care on the formation of air bubbles. Finally, the mould was closed and allowed to cure under atmospheric pressure for 48 h.

2.3. Characterization of composite specimens by mechanical properties

Composite specimens were cut from the prepared composite plates and characterized based on the mechanical properties such as tensile, flexural and impact strength according ASTM standards. The tensile strength of the composites was measured with a computerized FIE universal testing machine in accordance with the ASTM D 638 procedure at a crosshead speed of 5 mm/min. The flexural tests were performed on the same machine, using the 3-point bending fixture according to ASTM D790 with the crosshead speed of 5 mm/min. The impact strength of the samples was measured using an Izod impact test machine as per ISO 180. For statistical purpose, a total of five composite specimens for each combination were tested and their average values were recorded.



a

b

Fig. 1 Digital image of (a) Roselle plants and (b) stem of Roselle plants

3. Results and discussion

3.1. Effects of fibers with the length of 3 mm on mechanical properties

The mechanical properties of the Roselle fiber-reinforced vinyl ester composites with different fiber loading are presented in Fig. 2. The tensile test results show that with the increase in fiber loading the tensile property values of the Roselle fiber-reinforced vinyl ester composites are significantly increasing. The tensile strength and modulus of the composites are lower than that of the neat resin sample at 10 wt%. Composite reaches the tensile property value of the neat resin sample at 30 wt%. The maximum tensile strength value was observed at 40 wt%. An improvement of 25.63% is obtained at 40 wt% composite when compared to neat resin sample. Composites having the fiber content of 30 wt % and 50 wt % show the almost same tensile strength value. The tensile modulus value increased with fiber content from 10 wt% to 50 wt%. 50 wt% of composite shows the maximum tensile modulus value. As compared with neat resin samples, nearly 15.34 % improvement in the tensile modulus was observed.

The effect of fiber content on the flexural strength of the composite is shown in Fig. 3. As the fiber content increases in the composites up to 40 wt%, the flexural strength of composite is increased up to 47.8MPa. The flexural strength was starting to decrease with further increase of fiber content. Composite having the fiber content of 50 wt% shows the flexural strength 37.6 MPa. From the graph it is inferred that, the observed flexural strength is higher at the fiber content of 30 wt% than at 50 wt%. It is also observed that flexural strength decreases with increase in fiber content above 40 wt% fiber content. From the Fig. 3, it is clearly seen that flexural modulus of the composite material increases with an increase in the fiber content up to 50%. At lower fiber content (10 wt%), the flexural modulus of the composite is lower than the neat resin sample. The reason is that the initial addition of fibers to the resin matrix reduces the mechanical properties to some extent because the initial addition of fibers creates a non-uniform distribution due to the insufficient amount, therefore, the applied load (stress) cannot be properly transferred from the matrix to the fibers. As a result, the composites fail quickly and the flexural properties are decreased.

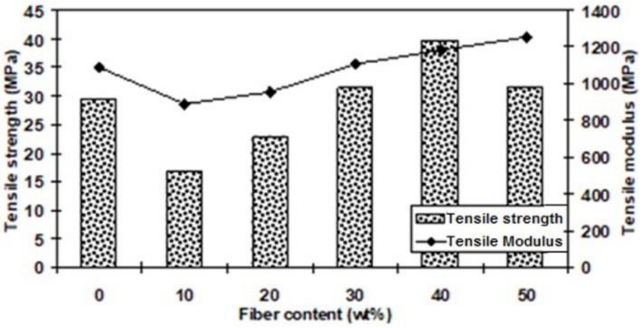


Fig. 2 Variations of tensile strength and modulus based on the fiber content after the test of Roselle/vinyl ester composites

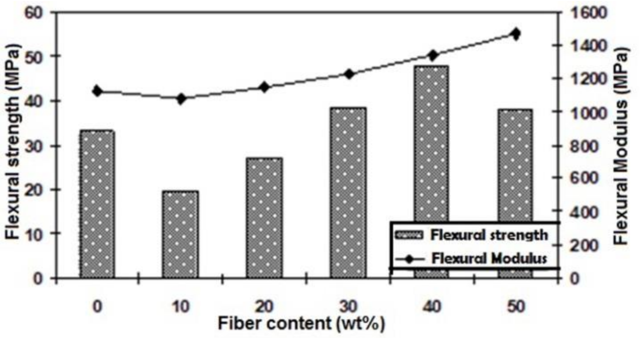


Fig. 3 Variations of flexural strength and modulus based on the fiber content after the test of Roselle/vinyl ester composites

Fig. 4 displays the effect of fiber content on the impact strength of the composites. From Fig. 4, an increasing trend in impact strength can be noted for the Roselle/vinyl ester composite from 10 to 40 wt%. The maximum impact strength value (1.34 KJ/m^2) of the Roselle/vinyl ester composites was noticed for 40 wt % composite. The percentage increase in the impact strength is 54.02% compared to neat resin sample. The minimum impact strength of 0.79 KJ/m^2 was noticed for the composite having the fiber content of 10 wt%.

3.2 Effects of fibers with the length of 13 mm on mechanical properties

Generally, the mechanical properties of polymer composites are markedly improved by adding the fibers to a polymer matrix since the fibers have higher strength and stiffness values than those of the matrices. The variation in tensile properties of Roselle/vinyl ester composite with the change in the content of the Roselle fiber is shown in Figure 5. Composites reach the tensile strength of the near resin sample at 20 wt%. The tensile strength values of composite increased with fiber content up to 40 wt%, i.e. the maximum value of tensile strength (54.2 MPa) and then started to decrease. As compared with neat resin samples, nearly 45.39% of the improvement in tensile strength was observed. After 40 wt% of fiber content, the vinyl ester resin matrix was insufficient to wet the Roselle fibers, entirely and led to the weak interfacial bonding between the fiber and the matrix. The tensile strength value of 30 wt% composite was higher than 50 wt% composite. The tensile modulus values of composites increased linearly from 10 wt% to 50 wt%. Composite reaches the tensile modulus of neat resin sample at 30 wt%. The maximum tensile modulus value was observed at 50 wt% composite. An improvement of 21.39% was achieved when compared with the neat resin sample.

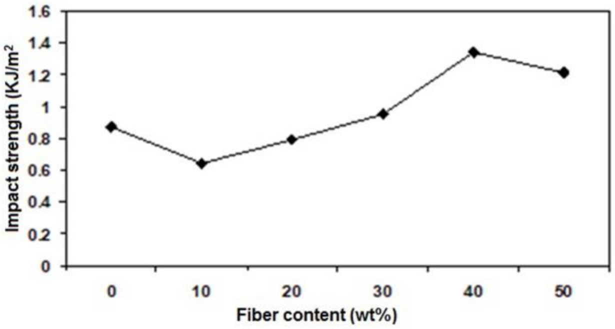


Fig. 4 Variations of impact strength based on the fiber content after the test of Roselle/vinyl ester composites

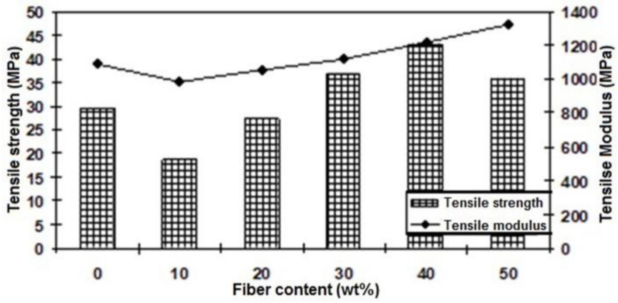


Fig. 5 Variations of tensile strength and modulus based on the fiber content after the test of Roselle/vinyl ester composites

Fig. 6 shows that the addition of fiber significantly affects the flexural strength of the vinyl ester composites. The flexural strength was the maximum for composite made of 40 wt% fiber content. The flexural strength decreases with increased the Roselle fiber content can be explained by the fiber and matrix interaction. When the content of Roselle fibers is increased in the composite, the compatibility between the Roselle fiber and the vinyl ester matrix is decreased [12]. It was observed that at fiber contents of approximately 50 wt%, the flexural strength and modulus are approximately 52.6 MPa and 1583.6 MPa respectively. It was found that the flexural modulus of the Roselle/vinyl ester composites increased steadily with the increase in fiber content where at 40 wt% fiber content it increased by 21.99% and at 50 wt% the increase was 40.48%.

Impact strength of Roselle/vinyl ester composites is presented in Fig. 7. Composites reach the impact strength of the neat resin sample at 20 wt%. It was identified that impact strength is increased up to 40 wt% and then started to decrease. An improvement of 73.56% at 40wt% composite was observed when compared to neat resin sample. 50wt% of the composite specimen presented a reduction in impact strength by 4.8% when compared to 40 wt% composite. It was observed that initially, a reduction of 10.13% is identified at 10 wt% composite when compared with the neat resin sample. After 10 wt% fiber content, the impact strength increased with fiber content.

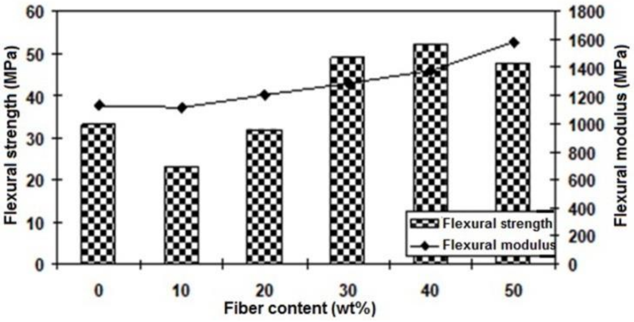


Fig. 6 Variations of flexural strength and modulus based on the fiber content after the test of Roselle/vinyl ester composites

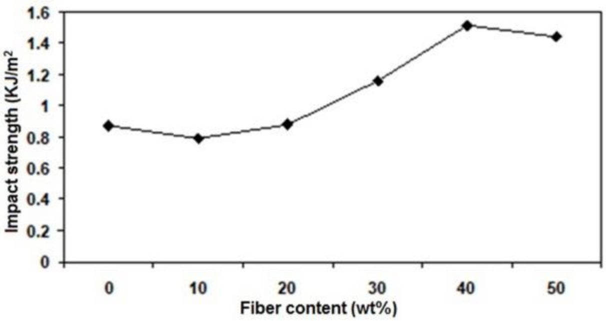


Fig. 7 Variation of impact strength based on the fiber content after the test of Roselle/vinyl ester composites

Finally, it may be observed from the Figs. 2 – 7 that at 40 wt% of fiber content shows the better mechanical properties as compared to others. Figure 8 shows the digital image of the fractured composite specimen (40 wt%) after tensile, flexural and impact tests. From the Fig. 8, it can be identified that the brittle fracture is observed with less fiber pull out during the testing of composite materials. It was proved that there is sufficient bonding between the fiber and the matrix at 40 wt%.

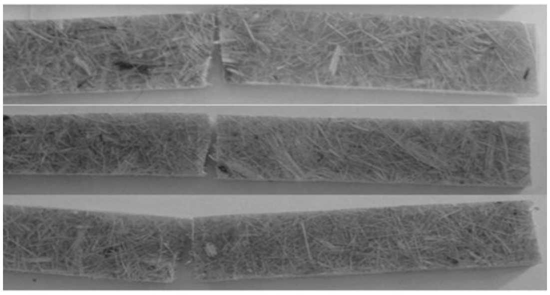


Fig. 8 Digital image of the fractured composite specimens after (a) tensile test, (b) flexural test and (c) impact test

It can be seen from the above Figs. 2 – 7, there is a significant effect on the mechanical properties of composites due to Roselle fiber reinforcement in a vinyl ester resin matrix at all cases of fiber contents. A considerable change can be identified at the strength values of composites having the fiber length of 13 mm. Composites having the fiber length of 3 mm also show the moderate change on the mechanical properties at all cases of fiber contents. It was identified that there is no much level of compatibility of Roselle fibers with vinyl ester resin matrix. Generally, the main highlighted problem with the plant based natural fiber was its hydrophilic nature in their surface, which affects the interfacial adhesion between the fiber of hydrophilic nature and a matrix of hydrophobic nature. It can be noticed from the above discussion that the optimal fiber content in order to obtain the highest mechanical properties in Roselle/vinyl ester composites was 40 wt%.

4. Conclusion

Mechanical properties of vinyl ester composites reinforced with the Roselle fibers were experimentally evaluated in this study. Mechanical strength values such as tensile, flexural , and impact, of composite material were greatly influenced by fiber content as well as fiber length. All the strength values increase with increasing of fiber content up to 40%, after which they are decreasing at two cases of fiber length. It is observed that composites with the fiber length of 13 mm show the maximum mechanical properties compared to composites with the fiber length of 3 mm. Tensile and flexural modulus values have increased linearly with fiber content from 10 to 50 wt%. Besides, the impact strength of the composite material was increased with increasing the fiber content. Finally, it can be concluded that the optimal fiber content in order to obtain the highest mechanical properties in Roselle/vinyl ester composites is 40 wt%.

References

1. **Jagadeesh, V.; Venkatasubbaiah, K.; Lakshumu Naidu, A.** 2019. Experimental study on mechanical behavior of natural hybrid composites filled with ground nut shell ash. Mechanics and Mechanical Engineering, 23: 218–227.
   https://doi.org/10.2478/mme-2019-0029.
2. **Ho, M., Wang, H., Lee, J., Ho, C., Lau, K., Leng, J., Hui, D.** 2012. Critical factors on manufacturing processes of natural fibre composites, Composite Part B, 8: 3549–3562.
   https://doi.org/10.1016/j.compositesb.2011.10.001.
3. **Rocha, J.; Ribeiro, J. E.; Queijo, L.;** 2017. Comparison of mechanical properties of polyester composites reinforced with autochthonous natural fibres: Flax and hemp, Materials Design and Applications 65: 125–134.
   https://doi.org/10.1007/978-3-319-50784-2_10.
4. **Khan, M. Z. R.; Srivastava, S. K.; Gupta, M. K.** 2018. Tensile and flexural properties of natural fiber reinforced polymer composites: A review, Journal of Reinforced Plastics and Composites 37: 1435-1455.
   https://doi.org/10.1177/0731684418799528.
5. **Athijayamani, A.; Thiruchitrambalam, M.; Natarajan, U.; Pazhanivel, B**. 2009. Effect of moisture absorption on the mechanical properties of randomly oriented natural fibers/polyester hybrid composites, Material Science and Engineering A 517: 344-353.

https://doi.org/10.1016/j.msea.2009.04.027.

6. **Athijayamani, A.; Stalin, B.; Sidhardhan, S.; Alavudeen, A.** 2016. Mechanical properties of unidirectional aligned bagasse fibers/vinyl ester composite, Journal of Polymer Engineering 36(2): 157–163. https://doi.org/10.1515/polyeng-2014-0325.
7. **Elbadry, E. A.; Aly-Hassan, M. S.; Hamada, H.** 2012. Mechanical properties of natural jute fabric/jute mat fiber reinforced polymer matrix hybrid composites, Advances in Mechanical Engineering pp.1-12. https://doi.org/10.1155/2012/354547.
8. **Palanikumar, K.; Subbiah, V.** 2019. Bio Caryota fiber reinforced polymer composites: Mechanical properties and vibration behavior analysis, Journal of Bionic Engineering 16: 480–491. https://doi.org/10.1007/s42235-019-0039-y.
9. **El-Shekeil, Y. A.; Sapuan, S. M.; Abdan, K.; Zainudin, E. S**. 2012. Influence of fiber content on the mechanical and thermal properties of Kenaf fiber reinforced thermoplastic polyurethane composites, Materials and Design 40: 299-303. https://doi.org/10.1016/j.matdes.2012.04.003.
10. **Ross, L. V.; Scienz, L. C.; Zatter, A. J**. 2013. Effect of curauá fiber content on the properties of poly(hydroxybutyrate-co-valerate) composites, Polymer Composites 34: 450-456. https://doi.org/10.1002/pc.22432.
11. **Sivaraj, P.; Rajeshkumar, G**. 2014. Prediction of mechanical properties of hybrid fiber reinforced polymer composites, International Journal of Engineering Research 3: 21-25. https://doi.org/10.1016/j.compositesb.2011.08.023.
12. **Hossain, S.; Rahman, M. M.; Jamwal, A.; Gupta, P.; Thakur, S.; Gupta, S.** 2019. Processing and characterization of pine epoxy based composites, AIP Conference Proceedings 2148(030017): 1-6. https://doi.org/10.1063/1.5123939.

M. Ramakrishnan, S. Ramasubramanian,
V. Subbarayalu, A. Ayyanar

STUDY OF MECHANICAL PROPERTIES OF ROSELLE FIBER REINFORCED VINYL ESTER BIOCOMPOSITE BASED ON THE LENGTH AND CONTENT OF FIBER

S u m m a r y

Mechanical properties of Roselle fiber reinforced vinyl ester biocomposite were studied based on the fiber content and length in the present communication. Usually, natural fiber reinforced polymer composites depend on some aspects such as fiber content, fiber length and orientation, the fiber-matrix adhesion. Composite plates were prepared by a simple hand lay-up technique for two different fiber lengths (3 and 13 mm) and five different fiber content (10, 20, 30, 40 and 50 wt%). Composite specimens were tested according to ASTM and ISO standards and their results were recorded. Experimental results showed that mechanical properties such as tensile, flexural and impact, increases with increase of fiber content up to 40 wt% after which it is decreases at both the fiber length. However, modulus values were increased linearly with fiber content of 10 to 50 wt%. Composites with the fiber length of 13 mm show the high level of mechanical properties compared to composites with the fiber length of 3 mm at all combinations of fiber contents. It is observed that the optimal fiber content is 40 wt%, which can be used to obtain the maximum property level in the Roselle fiber reinforced vinyl ester composites.

Keywords: biocomposite, natural fibers, fiber length, fiber content, mechanical properties.

Received June 09, 2020
Accepted June 02, 2021