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Investigation of the mechanical properties of Acacia tortilis fiber reinforced natural composite

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ABSTRACT

The work presented in this paper is motivated by the fact that use of natural fiber materials for structural and non-structural applications have increased within the last two decades. In addition to the known benefits of composite materials as structural elements such as high specific modulus, high specific strength and low thermal conductivity, composites of natural fibers are eco-friendly materials and have minimum effect on environment and human health. However, the mechanical and structural performance of diverse natural fiber composites still need closer scrutiny. The objective of this study is to characterize the mechanical properties of a novel Acacia tortilis fiber reinforced polyester composite using experimental methods. In particular, the study focuses on determining the tensile and flexural properties of the composite at different fiber volume ratio, which was fabricated by hand lay-up methods. The results show that Acacia tortilis fiber reinforced polyester composites have generally competitive strength and Young's modulus compared with common natural fiber reinforced composites such as sisal, kenaf, coir natural fiber reinforced composite materials. In addition, NaOH treated samples exhibited higher strength and Young's modulus compared with their untreated counterparts, with few exceptions.

1. Introduction

Green composites are materials that are fabricated from biodegradable sources, where the fiber or matrix or both are recyclable and biodegradable. As a composite, a green composite material consists of reinforcement phase and matrix phase, where the former is embedded in the later. It is generally known that composites have high specific modulus, specific strength, low thermal conductivity and high temperature resistance as compared to the parent materials, matrix and reinforcement constituents. In most cases, however, it is expected that the composite exhibits mechanical/structural properties that are intermediate to the properties of the matrix and the reinforcement. That is why the automotive industry, aerospace industry, medical devices, marine, military and sporting goods are the sectors that are using extensive amount of composite materials [1–3]. The common types of composites, i.e. polymer matrix composites or synthetic polymers are petroleum-based products and hence cause problems to the human being and the natural environment as whole. They produce huge plastic wastes, consume extensive energy during fabrication process due to underdeveloped recycling methods and limited petroleum resources. But natural fiber reinforced composites, which are green composites, are the promising alternatives to substitute synthetic composites with inherent competitive properties [4]. Availability and eco-friendliness of natural fibers and their green composites attract the interest of many industries, researchers and scientists. Due to the positive effects to the environment, biodegradability and less susceptibility to health hazards during manufacturing, green composites are considered to be the future materials [5]. Mostly, green composites are fabricated from natural fibers of plants such as hemp, sisal, bamboo, jute, kenaf, coir and grasses [3].

Generally, the performance of natural fibers is affected by their nature and environmental conditions of the plants. The higher con-

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tent of cellulose and arrangement of microfibrils on the fibers result in better performance of natural fibers. Plant fibers such as those from Hemp, Jute, flax and kenaf contain higher amount of cellulose that lead to higher structural advantages. Also, the chemical composition and the growing condition of the plants, methods of extraction and types of treatment are the factors affecting the properties of natural fibers [6]. Those natural fibers are extracted from their original sources using different methods including manual extraction, decortication, retting and chemical techniques [7–8]. The extracted fibers undergo different types of chemical treatment that improve the adhesion and mechanical performance such as alkali treatment, silane treatment, alkali-silane treatment, acetylation, benzoylation, peroxide, and esterification [9]. Alkali treatment of the composite is primarily used to remove lignin content and separates the fiber bundles into smaller fibers [2]. The most well-known fabrication methods include hand lay-up methods, injection molding, pultrusion. The filament winding, press molding, resin-transfer molding and sheet molding are other techniques used for composite fabrication, which affect the performance of the composite [5,10–12]. Composite materials are characterized by investigating their mechanical properties such as tensile, compression and flexural properties, as well as their failure fracture and wear resistance. These are common properties employed to characterize composite materials [13–16].

Acacia tortilis plants are native and highly cultivated in the arid and semi-arid parts of Africa and Middle East and can have a better behavior of survival in harsh climates [17]. These plants are used as the main sources of firewood and charcoal for instance in the rural parts of Ethiopia, where this study is conducted. These plants have also the potential of improving soil fertility that leads to an increasing crop production [18]. Furthermore, Acacia tortilis plants have applications in medicine [19,20]. A previous study performed by the authors showed that Acacia tortilis fibers contain 61.89% cellulose, 21.26% lignin, and 17.43% wax, but the effects of alkali treatment on the chemical composition of the fiber was not experimented [21].In the same study, it is also reported that Acacia tortilis fiber can have competitive chemical composition and tensile properties compared with common natural fibers. To the best knowledge of the authors, however, there exists no previous reported literature on the application of Acacia tortilis fibers as reinforcement of other composites.

The aim of the study reported in this article is to characterize the mechanical capacity of a typical green composite, i.e. Acacia tortilis fiber reinforced polyester composite, through experimental investigation of the tensile and flexural properties. Following this introduction section, Section 2 provides the materials and methods used in the research, followed by discussion of the obtained results in the third section. The results are presented both in tables and graphs and discussed. The last section gives the conclusions drawn from the study.

2. Materials and methods

2.1. Materials

Phthalic Anhydride based TOPAZ-1110 TP unsaturated polyester resin was used as matrix material with Luperox® *K*10 catalyst. The natural fibers used as a reinforcement are extracted from Acacia tortilis bark and collected from a location called Modjo, in Oromia region, Ethiopia. The properties of Acacia tortilis fiber were experimentally determined in previous work of the authors [21] and that of polyester resin were obtained from [22]. Properties of both materials are given in Table 1. Sodium hydroxide was used for treatment of the samples. The tensile and flexural properties of the composites are tested using Instron Universal testing machine at University of Stavanger, Norway.

2.2. Composite fabrication

The natural fibers from Acacia tortilis fibers were extracted using manual extraction methods and alkali treated at 10 wt% and 20 wt% to ease separation of fiber bundles and remove unwanted substances, followed by drying inside an oven to ensure the removal of moisture. The chopped Acacia tortilis fibers are used at 15 wt% and 30 wt% fiber content to manufacture Acacia tortilis fiber reinforced polyester resin composite using hand lay-up method. Then, the composites were cured by hydraulic press for 24 h at 5 bar to ensure complete adhesion between the fiber and matrix, illustrated in Fig. 1.

2.3. Tensile and flexural test of the composite samples

The tensile and flexural properties of Acacia tortilis fiber reinforced composite were investigated by following ASTM D3039 [23] and ASTM D7264-15 standards [24]. The specimens were prepared by cutting the composite plates into standardized size using motorized vertical hacksaw at the dimension of 250 mm × 25 mm × 5 mm for tensile test and 135 mm × 20 mm × 5 mm for flexural test. Three-point bending test procedure was followed to conduct the flexural test. Both tests were performed on universal testing machine at the working feed speeds of 2 mm/s at room temperature as designated by ASTM standards and practiced in previous studies, illustrated in Fig. 2. As the test setup photo given in Fig. 2(a) shows, extensometers were used to register the sample extension of the tensile tests. All the properties were read from the computer that was attached to Universal testing machine (Fig. 2(b)). For experimental analysis, 5 (five) replica specimens were tested to get valid results for each test according to ASTM recommendations.

3. Results and discussion

3.1. Tensile property

The tensile and flexural property results of the Acacia tortilis fiber reinforced composites consisting of 15 wt% fiber and 30 wt% fiber are presented in Table 2. For each fiber category, three different treatments were considered: (1) untreated, (2) 10 wt% alkali (NaOH) treated and (3) 20% alkali (NaOH) treated. As the results in the table show, the composite that contained 10 wt% alkali treated 15 wt% fiber content exhibited higher tensile strength (20.14 MPa) but the lower tensile strength of 4.52 MPa was scored by the untreated 30 wt% fiber contained composite. Generally, tensile strength of alkali treated composites showed higher values compared with those untreated, except in one case (i.e. sample X2015 in Table 2) which showed lower tensile strength than the untreated sample of the same composition (sample X0015). The extension of the composites for 15 wt% fiber content are almost identical (0.85 mm), while the composites with 30 wt% fiber content showed some variations. The composite that contained untreated 30 wt% fiber content showed a maximum extension of 4.29 mm. When compared with the 30 wt% fiber content, the composite with 10 wt% alkali treated fiber showed higher deviation of sample extensions that need further investigation to understand the cause.

Comparing the effects of volume fraction of fiber content and NaOH treatment on Acacia tortilis fibre reinforced polymer composite, it is observed that the tensile strength of the composites showed improvement at 15 wt% fiber content, but these properties

Table 1
Properties of fiber and matrix.

	Density, g/cm^3	Tensile strength, MPa	Youngś modulus, MPa	Elongation%
Unsaturated polyester resin	1.2	50	3000	2.5
Acacia tortilis fiber	0.906	71.63	4209	1.328

Fig. 1. Composite fabrication process.

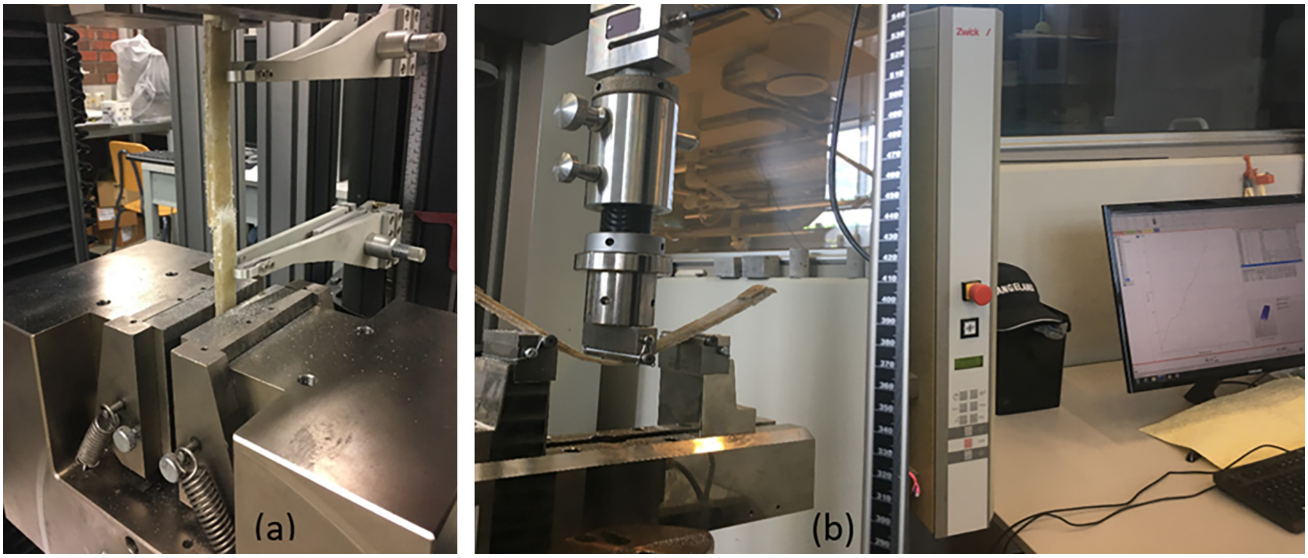

Fig. 2. Experimental test setup for (a) tensile test, (b) flexural test.

Table 2
Mechanical properties of Acacia tortilis fiber reinforced polyester composite.

Sample designation(wt% fiber)	Type of fiber treatment	Tensile Strength MPa	Young's modulus GPa	Extension mm	Flexural strength MPa
X0015 (15%)	Untreated fiber	15.80	3.07	0.86	70.72
X1015 (15%)	10% NaOH treated	20.14	3.04	0.85	25.61
X2015 (15%)	20% NaOH treated	15.68	3.39	0.85	130.05
X0030 (30%)	Untreated fiber	4.52	4.14	4.29	121.5
X1030 (30%)	10% NaOH treated	4.82	3.22	1.79	77.5
X2030 (30%)	20% NaOH treated	5.70	3.80	3.48	138

Table 3
Tensile and flexural strength properties of selected reference natural fibers.

Designation	Fiber type	Tensile strength MPa	Youngś modulus GPa	Flexural strength MPa	Reference
R01	Vakka reinforced composite	66	1.79	93.79	[25]
R02	Banana reinforced polyester composite	60.9	1.08	91.4	[25]
R03	Sisal reinforced polyester composite	65.5	1.6	98.1	[25]
R04	Bamboo reinforced polyester composite	126.2	2.48	128.5	[26]
R05	Hemp reinforced epoxy composite	60.89	4.95	118.35	[27]

decreased when the fiber content increased from 15 wt% to 30 wt%. Higher fiber content (from 15 wt% to 30 wt%) at untreated condition showed increased Young's modulus and flexural strength as expected, but the tensile strength of 30 wt% fiber dropped significantly. On the other hand, NaOH treatment of the samples with 30 wt% showed increased tensile strength with increasing percentage of treatment, while no conclusive trend as a function of percentage of NaOH treatment is observed for the rest of the properties. The tensile property comparison of Acacia tortilis fiber reinforced composite with other natural fiber reinforced composite showed weak performances. As illustrated in Fig. 3 (see also Table 3), both untreated and alkali treated fiber contained composite showed lower tensile strength compared with Vakka, Banana, Sisal, Bamboo and Hemp reinforced composites.

The maximum tensile strength for 15 wt% and 30 wt% fibre contained composite are 20.14 MPa and 5.7 MPa while the minimum strength values are 15.68 MPa and 4.5 MPa respectively. This result showed that Acacia tortilis fiber reinforced composite have lower tensile strength compared with Vakka reinforced composite (66 MPa) [25], Banana reinforced polyester composite (60.9 MPa) [25], Sisal reinforced polyester composite (65.5 MPa) [25], Bamboo reinforced polyester composite (126.2 MPa) [26] and Hemp reinforced epoxy composite (60.89 MPa) [27]. The lower result of the composites is expected due to the presence of higher Lignin amount (21.26%) in the fibers, which lowered the fiber strength that indirectly affect the performance of the composites.

In the case of the Young's modulus, the lower value (3.04 GPa) is scored by the composite that contained 10 wt% alkali treated 15 wt % fiber contained composites but the composite that contained untreated 30 wt% fiber showed higher Young's modulus (4.14 GPa). The result showed nearly similar values, but composites with untreated fiber showed better performance. Unlike tensile strength, the Youngus's modulus showed improvement at higher fibr content, i.e. for 30 wt% compared to 15 wt%, but in general NaOH treatment improved tensile strength of 30 wt% fiber contained composite, while no conclusive trend on the influence of the treatment on the tensile strength of 15 wt% fibre contained composite and the Young's modulus of both samples was observed.

Beside this, Acacia tortilis reinforced polyester composite has better modulus property compared to other common natural fiber reinforced composites, as illustrated in Fig. 4. This composite showed better modulus value compared to Vakka reinforced polyester composite (1.79 GPa) [25], Banana reinforced polyester composite (1.08 GPa) [25], sisal reinforced polyester composite (1.9 GPa) [26] and bamboo reinforced polyester composite (2.48 GPa) [25] but lower performance compared with untreated hemp reinforced epoxy composites (5.34 GPa) [26] and 5 wt% alkali treated hemp fiber reinforced epoxy composite (4.947 GPa) [27].

The failed Acacia tortilis fiber reinforced composite specimen under tensile load has cup-and-cone type of failure (Fig. 5) that can be an indication that the composite material behaves ductile, i.e. the composite material does not fail suddenly. It implies that the failures rather occurred because of weak tensile properties that are caused by higher content of Lignin, and this affected the strength of the composite indirectly. This is an indication that the composite can be used as substitute for metals in applications that demand not so high strength.

3.2. Flexural property

The three-point bending test showed that Acacia tortilis fiber reinforced polyester composites have good flexural performance.

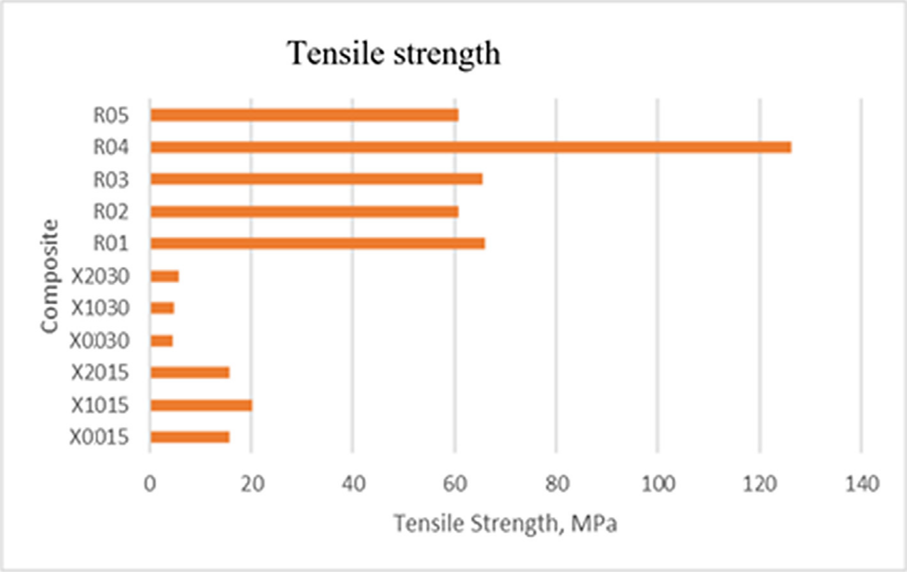

Fig. 3. Tensile strength comparison of different composites.

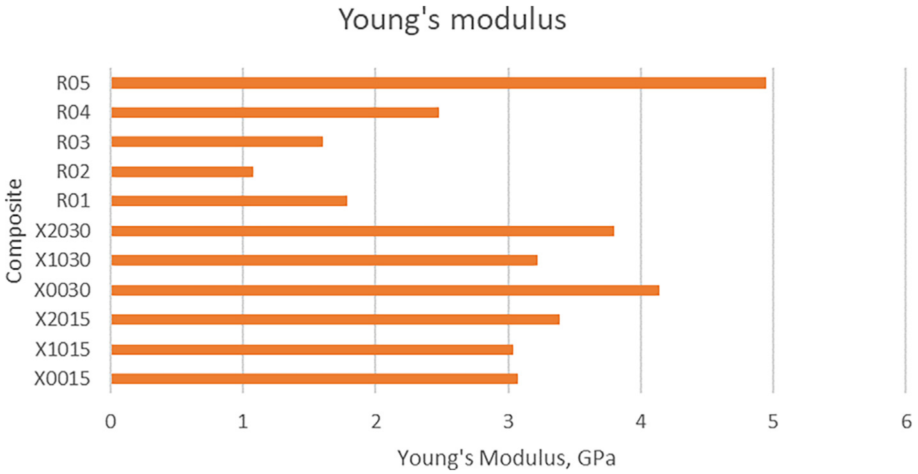

Fig. 4. Comparison of the Young's modulus of different composites.

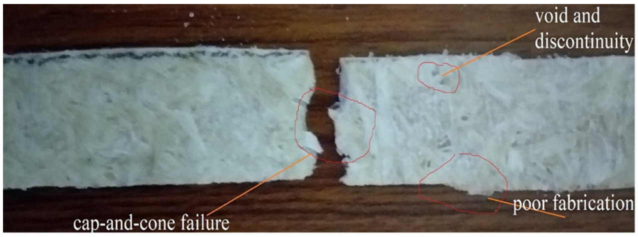

Fig. 5. Failure type for tensile specimen.

The maximum flexural strength (138.0 MPa) is obtained for composites that contained 20 wt% NaOH untreated and 30 wt% fiber contained composite but the lowest flexural strength of 25.61 MPa is scored by the composite that contained 10 wt% alkali treated 15 wt% fiber content. The composite that contained 20 wt% NaOH treated and 30 wt% fiber content showed higher values compared to other flexural specimens, but 10 wt% fiber contained composite scored lower flexural stress in both cases. The flexural properties of the composite increased when the fiber content increased by 15 wt% but alkali treatment does not show any relationship with flexural strength.

Due to several reasons, however, these results are not sufficient to conclude that Acacia tortilis fiber reinforced composites have lower strength. The type of failure that was observed on flexural specimen was cup-and-cone failure as illustrated in Fig. 6 below, which showed that the composite has ductile nature. Fibers of nonuniform diameter and length, poor specimen preparation, higher void content and size variation may result such lower performances.

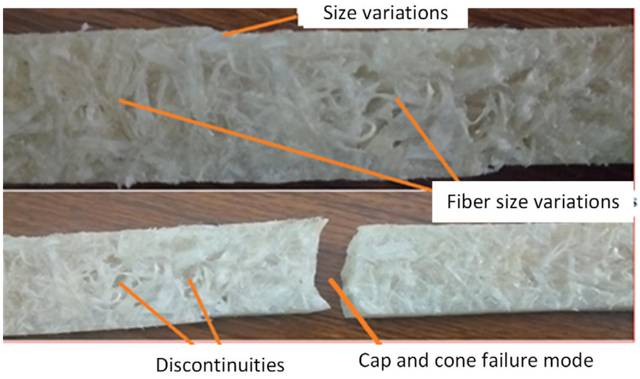

Fig. 6. Failure type for flexural specimen.

This result was consistent with the studies reported by other researchers on natural fiber reinforced composites as illustrated in Fig. 7. Excluding the composite that contained 20 wt% alkali treated 15 wt% fiber contained composite and untreated 30 wt% fiber contained composite, other Acacia tortilis fiber reinforced polyester composites showed lower flexural strength compared to Jowar fiber reinforced polyester composite (134 MPa) [25], bamboo fiber reinforced polyester composite (127.1 MPa) [24], hemp fiber reinforced epoxy composite (114.02 MPa) [27], sisal fiber reinforced polyester composite (99.5 MPa) [25], vakka fiber reinforced polyester composite (93.79 MPa) [24], banana fiber reinforced polyester composite (91.4 MPa) [24] and jute fiber reinforce epoxy composites (85 MPa) [28].

4. Conclusions

This study focused on the fabrication and characterization of Acacia tortilis fiber reinforced polyester composite. Two categories of fiber compositions, i.e. 15 wt% and 30 wt%, of composite samples were manufactured by hand-layup method and all tests were performed according to ASTM standards. In addition to fiber content, the influences of alkali treatment were studied. The experimental results showed that tensile and flexural properties of the composite are affected by both the alkali treatment and contents of the fibers. Lower fiber content, i.e.15 wt% fiber composites, both treated and untreated, showed higher tensile strength and lower flexural property compared with the composite containing higher fiber content, i.e. 30 wt%, while the performance in terms of tensile and flexural properties in general increases with alkali treatments. The low performance of the 30 wt% specimen can be attributed to the manner of specimen fabrication using hand lay-up, which is known to introduce porosities in the composite when higher volume (weight) fraction reinforcements are employed [29]. This is a phenomenon observed due to air bubbles trapped when pouring resin into the fiber. Though the Acacia tortilis fiber reinforced polyester composites studied in this research are observed to have better Young's modulus and relatively good flexural properties compared to other common natural fiber reinforced composites, their tensile strengths are lower. Thus, these materials can be recommended for light weight and low to medium strength demanding applications.

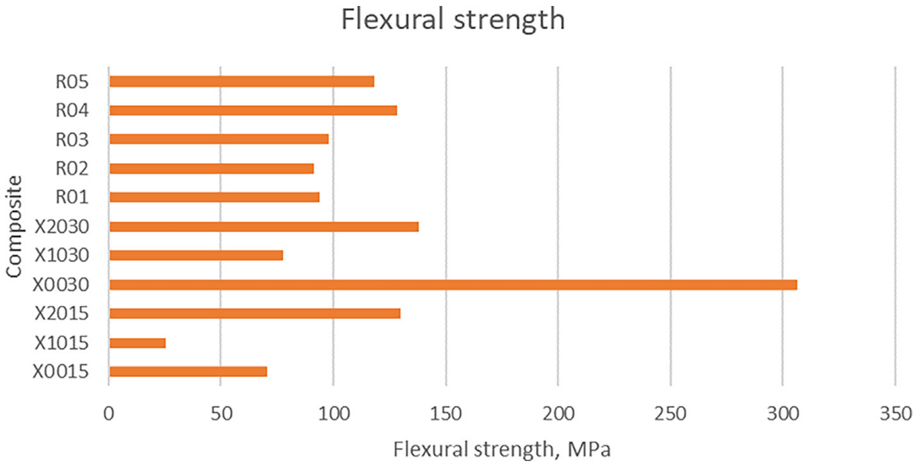

Fig. 7. Flexural strength comparison of different composite.

CRediT authorship contribution statement

Jonathan B. Dawit: Data curation, Formal analysis, Investigation, original draft. **Hirpa G. Lemu:** Supervision, Validation, Review & editing. **Yohannes Regassa:** Conceptualization, Methodology. **Adugna D. Akessa:** Investigation.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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References

[1] B.A. Amel, M.T. Paridah, R. Sudin, U.M.K. Anwar, A.S. Hussein, Ind. Crop. Prod. 46 (2013) 117–123.
[2] A.Q. Dayo, A. Zegaoui, A.A. Nizamani, S. Kiran, J. Wang, M. Derradji, W.-A. Cai, W.-B. Liu, Mater. Chem. Phys. 217 (2018) 270–277.
[3] C. Elanchezhian, B.V. Ramnath, G. Ramakrishnan, M. Rajendrakumar, V. Naveenkumar, M.K. Aravanakumar, Mater. Today: Proc. 5 (1) (2018) 1785–1790.
[4] G. Sara, S. Nikles, E.M.B. Wenzig, K. Ardjomand-Woelkart, R.M. Hathout, S. El-Ahmady, A.A. Motaal, A. Singab, R. Bauer, Biochem. Syst. Ecol. 78 (2018) 21–30.
[5] A. Gebrekirstos, D. Teketay, M. Fetene, R. Mitlöhner, For. Ecol. Manage. 229 (1–3) (2006) 259–267.
[6] M.P. Ho, H. Wang, J.H. Lee, C.K. Ho, K.T. Lau, J. Leng, D. Hui, Composites Part B 43 (8) (2012) 3549–3562.
[7] N. Jauhari, R. Mishra, H. Thakur, Mater. Today: Proc. 2 (4–5) (2015) 2868–2877.
[8] E.V.M. Kigondu, G.M. Rukunga, J.M. Keriko, W.K. Tonui, J.W. Gathirwa, P.G. Kirira, B. Irungu, J.M. Ingonga, I.O. Ndiege, J. Ethnopharmacol. 123 (3) (2009) 504–509.
[9] A. Kumre, R.S. Rana, R. Purohit, Mater. Today: Proc. 4 (2) (2017) 3466–3476.
[10] K. Lau, P. Hung, M.H. Zhu, D. Hui, Composites Part B 136 (2018) 222–233.
[11] T.P. Mohan, K. Kanny, Composites Part A 43 (11) (2012) 1989–1998.
[12] K.L. Pickering, M.G.A. Efendy, T.M. Le, Composites Part A 83 (2016) 98–112.
[13] R. Potluri, V. Diwakar, K. Venkatesh, B.S. Reddy, Mater. Today: Proc. 5 (2) (2018) 5809–5818.
[14] M.N. Prabhakar, J. Song, Int. J. Biol. Macromol. 119 (2018) 1335–1343.
[15] J.I.P. Singh, V. Dhawan, S. Singh, K. Jangid, Mater. Today: Proc. 4 (2) (2017) 2793–2799.
[16] K. Rao, M. Mohan, K.M. Rao, Compos. Struct. 77 (3) (2007) 288–295.
[17] A.V.R. Prasad, K.M. Rao, Mater. Des. 32 (8–9) (2011) 4658–4663.
[18] K. Senthilkumar, N. Saba, N. Rajini, M. Chandrasekar, M. Jawaid, S. Siengchin, O. Y. Alotman, Constr. Build. Mater. 174 (2018) 713–729.
[19] R. Sepe, F. Bollino, L. Boccarusso, F. Caputo, Composites Part B 133 (2018) 210–217.
[20] H.S.S. Shekar, M. Ramachandra, Mater. Today: Proc. 5 (1) (2018) 2518–2526.
[21] J.B. Dawit, Y. Regassa, H.G. Lemu, Results Mater. 5 (2020) 100054.
[22] I.M. Daniel, O. Ishai, Engineering mechanics of composite materials, NY, Oxford Univ, Press, 2006.
[23] Standard (ASTM)., D3039/D3039M – 14 Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials, American Soc. for Testing and Materials. 15 (2015) 1–13.
[24] ASTM D7264/D7264M – 15, Standard test method for flexural properties of polymer matrix composite materials. 15.03 (2015).
[25] ASTM, D790–17, Standard test method for flexural properties of unreinforced and reinforced plastics and electrical insulating materials, American Soc. for Testing and Materials. 14 (2003) 02.
[26] N. Tarabi, H. Mousazadeh, A. Jafari, J. Taghizadeh-Tameh, Ind. Crops and Prod. 83 (2016) 545–550.
[27] S. Singh, S. Zafar, M. Talha, W. Gao, D. Hui, Thin-Walled Struct. 132 (2018) 700–716.
[28] Y. Zhou, M. Fan, L. Chen, Composites Part B 101 (2016) 31–45.
[29] B. Madsen, H. Lilholt, Compos. Sci. Technol. 63 (2003) 1265–1272.