



HAL
open science

Natural fiber alfa/epoxy randomly reinforced composite mechanical properties identification

Sofiene Helaili, Moez Chafra, Yvon Chevalier

► To cite this version:

Sofiene Helaili, Moez Chafra, Yvon Chevalier. Natural fiber alfa/epoxy randomly reinforced composite mechanical properties identification. Structures, 2021, 34, pp.542-549. 10.1016/j.istruc.2021.07.095 . hal-03836819

HAL Id: hal-03836819

<https://hal.science/hal-03836819>

Submitted on 8 Jun 2023

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Natural fiber alfa/epoxy randomly reinforced composite mechanical properties identification

Sofiène Helaili^{a,b,*}, Moez Chafra^{a,c}, Yvon Chevalier^d

^a Carthage University, Tunisia Polytechnic School, LASMAP (LR03ES06), Rue El-Khawarizmi, BP 743, 2078 La Marsa, Tunisia

^b Carthage University, ISTEUB, 2 Rue de l'Artisanat Chargaia 2, 2035 Tunis, Tunisia

^c Tunis EL Manar University, IPEIEM, Campus Universitaire, B.P 244, Tunis 2092, Tunisia

^d Laboratoire d'Ingénierie des Systèmes Mécaniques et des Matériaux (LISMEA), SUPMECA, 93407 Saint-Ouen, France

In recent years, there has been a growing interest in the international scientific community to study natural fiber composites. Natural fibers have interesting mechanical features, such as strength, lightness, and elongation at break. Natural fibers are also bio-sourced, biodegradable and recyclable. When used with plastic or recyclable matrices, natural fiber composites, such as alfa fiber, can also be reused and recycled. The growing global environmental and new environmental regulations have encouraged research on new recyclable composites environment friendly. The recyclable composite must satisfy minimal mechanical properties to be widely used in furniture, automotive or construction industries. To produce a natural fiber composite that can be fabricated widely, in this paper, composite materials were fabricated using the Epoxy resin as matrix and the natural Alfa fiber (*tipa tenacissima* L.) as reinforcement. The Alfa fibers are short and randomly distributed. Molding technique is used to produce the composite. To judge the usage of the composite in structural applications, the mechanical properties of the biobased composite are identified by numerical homogenization and by experiments. The finite elements numerical homogenization technique is based on a representative cell reinforced with short fibers. Tensile tests were performed. The experimental results validate the numerical model. The results show that reinforcing with Alfa fibers with a 10% volume fraction increase the elastic modulus by about 24.16% compared to Epoxy. Composite failure stresses reached 28.01 MPa which is higher than 14.64 MPa the value of the unreinforced Epoxy failure stress experimentally determined. With better arrangement and higher concentrations, such composites can at least be used for secondary structural uses.

1. Introduction

There has been considerable interest in designing new materials for several specific applications within the past decades, such as building more resistant and lighter structures, for example cement mortars [1], thermal insulation, for example when used in compacted earth bricks [2], or acoustic-insulation, as an example composite material based on alfa and wood fibers [3,4]. Moreover, there has been a rising interest in using natural fibers, especially biodegradable ones, Palm fibers [5], Jute [6], Alfa [7,8], and other natural fibers [9,10]. Applications have spread to automotive and are becoming widely used in civil engineering, aerospace, and biomechanics [11] as well.

Examples of such materials include the Alfa plant, which is abundant in North Africa (see Fig. 1) and South Europe in the West Mediterranean

region. Tunisia possesses substantial resources of Alfa plants with promising physical and mechanical characteristics. These resources can be positively exploited while preserving availability. For example, there is growing interest in using Alfa-based composites in the medical field in Tunisia, specifically in orthopedic applications. Volumes fractions, orientations of Alfa fiber [12,13] and replacing glass fibers in composite materials was studied [14]. Effects of chemical treatments on mechanical and permeability properties was studied [15,16], mechanical behavior of a polypropylene reinforced with alfa fiber shows good characteristics [17,18]. Alfa fibers can be used with a matrix combined to supplementary materials as a hybrid composite [19,20].

It has been shown that these plants are chemically [21] inert, and a priori, no dermatological or respiratory reactions are reported due to harvesting or fabrication. To manipulate the Alfa plant, no special

* Corresponding author.

E-mail address: sofiene.helaili@ept.rnu.tn (S. Helaili).



Fig. 1. Alfa plant.

Table 1
Characteristics of the ALFA fiber.

	Mean Value	Variation rate (%)	Tolerance interval at 95%
Modulus of elasticity (GPa)	18.42	30.5	8.7;25.3
Failure stress (MPa)	229.3	31.7	145;368.3
Elongation at failure (%)	1.43	27.9	0.83;4.8

protective equipment is necessary.

In Tunisia, most raw materials used in the fabrication of orthopedic devices are imported. That raises the cost of manufacturing and puts a burden on the Tunisian economy. Therefore, this work's main goal is to incorporate local materials in the fabrication of orthopedic devices. It is planned to achieve this aim by elaborating a new composite material where the reinforcement consists of natural fibers extracted from Alfa plants [22] or Agave [23].

2. Materials and methods

The natural fibers are extracted from Alfa leaves. Alfa (Esparto) is a plant that grows in dry areas of the West Mediterranean region and can be found abundantly in the Tunisian Midwest. It is used mainly in the production of high-quality paper and cellulose paste. It is a common plant that grows in semi-arid areas in the Mediterranean region. Its height is between 50 and 80 cm, the diameter of the fiber rope varies

between 1 and 2 mm; its harvest is organized once per year over six months (September to February).

To be suitable for reinforcement, the Alfa plant must go through an extraction process that transforms it from the leaf form to the essential microfiber. Transformation from the leaf form to the microfiber form was performed to remove lignin, which connects the fibers as ropes. The chemical process consists of boiling the ropes or sheets in sodium hydroxide and bleach. It is noted that boiling in sodium hydroxide and bleach process leads to significant degradation of the fibers under the action of this oxidizing agent that attacks all substances accompanying the cellulose, leaving only the micro-cellulosic fiber or fibril.

Based on reference [24] the fibers were modified by chemical treatments, maleic anhydride, styrene, acrylic acid, and acetic anhydride. The acetic anhydride and the styrene treatments allowed an increase in the moisture resistance and the mechanical properties of the fibers and allowed a decrease of the water permeability of the composite. Boiling in sodium hydroxide and bleach has another advantage of reducing the fibers' moisture uptake. Reviews the latest trends in chemical modifications and characterizations of natural fibers are detailed in reference [25]. In its natural state, the Alfa fiber absorbs water and swells (up to 1% in its long axis and 15% in its radial axis), which detrimentally affects the fiber's mechanical characteristics and could lead to premature failure of the resulting composite. Chemically treated and combined with Epoxy, the alfa fiber-reinforced composite can have better mechanical properties [26,27]. Alfa fiber reinforced composites can be used as structures for crash safety applications [28] and for prosthesis in the biomechanics field.

The natural fiber's mechanical properties are determined by direct measurement using a tensile machine in accordance with the ISO 13934-1 [29] standard. Properties are listed in the table below Table 1 from Ref. [30].

2.1. Finite element model description and hypothesis

Two finite element models are developed. The first is Alfa/Epoxy 10%, which is identical to physical test specimens. The second model varies fiber concentration from 11% to 17%.

Finite elements models are developed using ANSYS APDL solver. Tetrahedral first order finite elements were used to have a better meshing effect between the matrix and the fibers. The mesh size was decreased until the results converged in constant values not depending on the mesh size. The fibers are randomly distributed. The interface between the fiber and the matrix is considered as glued, no sliding in considered.

The elementary representative volume is shown in Fig. 2. To determine the homogenized equivalent properties of the composite, the cell is subject to different elementary displacements. The mean stress and the mean strain are then calculated to determine the composite moduli.

2.2. Numerical homogenization approach

For an orthotropic material, the stiffness matrix C has the following form:

$$[C] = \begin{pmatrix} C_{11} & C_{12} & C_{13} & 0 & 0 & 0 \\ C_{12} & C_{22} & C_{23} & 0 & 0 & 0 \\ C_{13} & C_{23} & C_{33} & 0 & 0 & 0 \\ 0 & 0 & 0 & C_{44} & 0 & 0 \\ 0 & 0 & 0 & 0 & C_{55} & 0 \\ 0 & 0 & 0 & 0 & 0 & C_{66} \end{pmatrix}$$

To determine the homogenized stiffness matrix C, three tensile tests and three shear tests should be applied. As an example, test 1 is a tensile test in Y1 direction (see Table 2). The imposed displacement is $E = \langle 1, 0, 0, 0, 0, 0 \rangle$.

The following table summarizes all these tests.

After applying these six tests, all components of the stiffness matrix

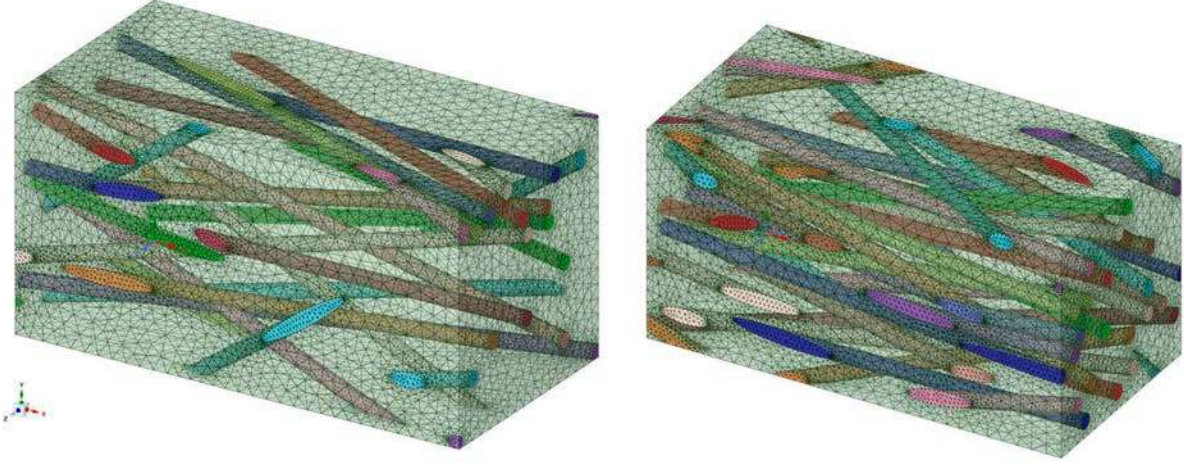


Fig. 2. Elementary finite element cell with randomly distributed fibers.

can be determined and then the elastic moduli of the material given by the following matrix form:

$$[C_{Hom}^{-1}] = \begin{pmatrix} \frac{1}{E_x} & \frac{-\nu_{yx}}{E_y} & \frac{-\nu_{zx}}{E_z} & 0 & 0 & 0 \\ \frac{-\nu_{xy}}{E_x} & \frac{1}{E_y} & \frac{-\nu_{zy}}{E_z} & 0 & 0 & 0 \\ \frac{-\nu_{xz}}{E_x} & \frac{-\nu_{yz}}{E_y} & \frac{1}{E_z} & 0 & 0 & 0 \\ 0 & 0 & 0 & \frac{1}{2G_{yz}} & 0 & 0 \\ 0 & 0 & 0 & 0 & \frac{1}{2G_{zx}} & 0 \\ 0 & 0 & 0 & 0 & 0 & \frac{1}{2G_{xy}} \end{pmatrix}$$

Components are then identified, and results are given in the results section in Table 3.

2.3. Preparation process

Resin 862 and Epikure W were mixed, respecting the ratio 100: 26.4, for half an hour through magnetic stirring. After homogenizing, the solution was degassed under a vacuum to remove trapped gasses. To make the composite, alfa fibers were randomly placed in manually made silicone molds (to get appropriate samples for electrical and mechanical tests). Then, the Epoxy solution was cast onto the molds (see Fig. 3), and the remaining air bubbles were gently removed.

The samples were heated, cured for 2 h at 90 °C, and progressively cooled to room temperature. Finally, they were left in the desiccator until they were dried entirely to remove humidity.

The length of the specimens (see Fig. 4) is 150 mm, the width is 25 mm, and the measured thickness is 5.54 mm.

2.4. Methods

The experimental work was conducted according to ISO 527-4 [31]. ISO 527-4 is an international testing standard for determining the tensile properties of fiber-reinforced plastic composites. Type 2 specimens are rectangular with a constant cross-section and are suitable for testing fiber materials with thermoset and thermoplastic matrices. Type 2 is used (see Fig. 4).

The composite testing machine (see Fig. 5) is the Instron 5866 from Texas A&M University. For the composite specimens, the applied loads

vary from zero to 3880,11 N for Test A, 1209,78 N for Test B and 539,23 N for Test C (see Fig. 6).

Specimens made from the Epoxy matrix non reinforced with Alfa fibers are made to determine stress at failure and elastic modulus of the non-reinforced matrix.

3. Results

3.1. Results of the finite element analysis

After simulation and identification of the elastic moduli of the composite for several alfa fiber volume fractions, the results are indicated in Table 3. Transversal elastic moduli E_y and E_z are vary close, this leads that the composite is a transverse isotropic material rather than an orthotropic material. Longitudinal module E_x is different and higher than transvers moduli.

3.2. Results of experimental work

Based on the specimen's dimensions and the measured tensile strain and tensile stress, the calculated modulus of elasticity is 4.62 GPa for Test A, 4.29 GPa for Test B and 3.92 GPa for Test C (see Fig. 7).

Compared to the modulus of elasticity of Epoxy, which is 3.78 GPa, the Alfa fiber added more stiffness to the composite and have shown better values of elongation before failure. Composite failure stresses reached 28.01 MPa (see Fig. 7) which is higher than 14.64 MPa the value of the unreinforced Epoxy failure stress (see Fig. 8).

The tests values are reported in Table 4:

4. Discussion

The composite materials studied in this paper present many advantages, such as good mechanical strength. Due to the abundance of Alfa plants in Tunisia and the molding technique used, this solution is a low-cost solution. The homogenized numerical results show a good correlation with the physical test results. The estimated error reached 7.31% for Test A. During the manufacturing process, the conventional treatment is minimal, reducing the overall cost and energy consumption. The natural fibers of these plants offer excellent thermo-mechanical properties in addition to the low weight. It has been shown that these plants are "Inert" and a priori no dermatological (during harvesting) or respiratory reactions (during fabrication). Hence, no special protective equipment is necessary, as is the case with mineral fibers. In terms of the environment, these materials are biodegradable and recyclable. The reinforcement with alfa fiber, shows an improvement in the elongation

Table 2
Tensile and Shear stresses in the identification method.

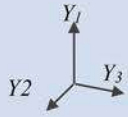
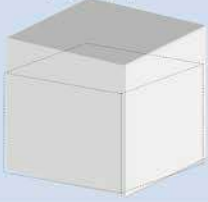
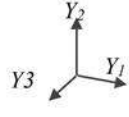
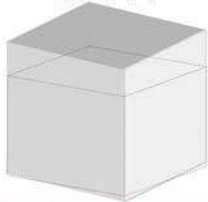
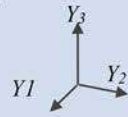
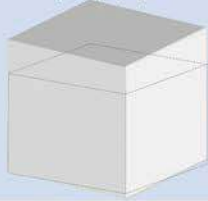
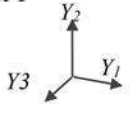
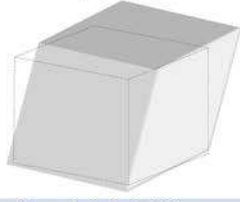
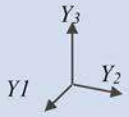
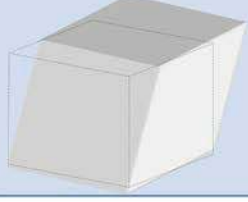
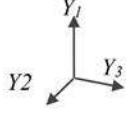
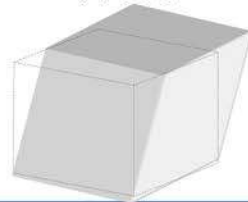
Test	Strain	D_matrix coefficients
Tensile Test 1 	$E = \langle 1, 0, 0, 0, 0, 0 \rangle$ 	$\begin{Bmatrix} \Sigma_1 \\ \Sigma_2 \\ \Sigma_3 \\ \Sigma_4 \\ \Sigma_5 \\ \Sigma_6 \end{Bmatrix} = \begin{Bmatrix} C_{11} \\ C_{12} \\ C_{13} \\ 0 \\ 0 \\ 0 \end{Bmatrix}$
Tensile test 2 	$E = \langle 0, 1, 0, 0, 0, 0 \rangle$ 	$\begin{Bmatrix} \Sigma_1 \\ \Sigma_2 \\ \Sigma_3 \\ \Sigma_4 \\ \Sigma_5 \\ \Sigma_6 \end{Bmatrix} = \begin{Bmatrix} C_{12} \\ C_{22} \\ C_{23} \\ 0 \\ 0 \\ 0 \end{Bmatrix}$
Tensile test 3 	$E = \langle 0, 0, 1, 0, 0, 0 \rangle$ 	$\begin{Bmatrix} \Sigma_1 \\ \Sigma_2 \\ \Sigma_3 \\ \Sigma_4 \\ \Sigma_5 \\ \Sigma_6 \end{Bmatrix} = \begin{Bmatrix} C_{13} \\ C_{23} \\ C_{33} \\ 0 \\ 0 \\ 0 \end{Bmatrix}$
Shear test 1 	$E = \langle 0, 0, 0, 1, 0, 0 \rangle$ 	$\begin{Bmatrix} \Sigma_1 \\ \Sigma_2 \\ \Sigma_3 \\ \Sigma_4 \\ \Sigma_5 \\ \Sigma_6 \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \\ 0 \\ C_{44} \\ 0 \\ 0 \end{Bmatrix}$
Shear test 2 	$E = \langle 0, 0, 0, 0, 1, 0 \rangle$ 	$\begin{Bmatrix} \Sigma_1 \\ \Sigma_2 \\ \Sigma_3 \\ \Sigma_4 \\ \Sigma_5 \\ \Sigma_6 \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ C_{55} \\ 0 \end{Bmatrix}$
Shear test 3 	$E = \langle 0, 0, 0, 0, 0, 1 \rangle$ 	$\begin{Bmatrix} \Sigma_1 \\ \Sigma_2 \\ \Sigma_3 \\ \Sigma_4 \\ \Sigma_5 \\ \Sigma_6 \end{Bmatrix} = \begin{Bmatrix} 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ C_{66} \end{Bmatrix}$

Table 3
Mechanical properties of Alfa/Epoxy randomly reinforced composite.

Fiber %	10%	11%	12%	13%	14%	16%	17%
Ex (MPa)	4984.3	5387.5	5532.5	5680.4	5825.4	6116.8	6256.0
Ey (MPa)	4316.5	4391.1	4473.4	4503.1	4584.5	4769.0	4741.1
Ez (MPa)	4308.9	4392.6	4443.7	4485.1	4565.6	4703.9	4730.4
Gxy (MPa)	1615.3	1619.7	1650.0	1667.5	1692.8	1753.8	1756.8
Gyz (MPa)	1572.7	1590.9	1605.9	1631.2	1646.9	1668.7	1720.7
Gzx (MPa)	1637.3	1620.7	1634.1	1654.4	1685.9	1712.7	1753.2
Nu xy	0.3547	0.3566	0.3577	0.3580	0.3589	0.3605	0.3602
Nu xz	0.3607	0.3570	0.3571	0.3578	0.3584	0.3590	0.3604
Nu yz	0.3654	0.3759	0.3768	0.3799	0.3792	0.3781	0.3841
Density (kg/L)	1.1838	1.1864	1.188	1.1912	1.1936	1.1984	1.200



Fig. 3. Alfa/Epoxy composite mold.



Fig. 4. Alfa/Epoxy test specimen's.



Fig. 5. Instron 5866 tensile test machine.

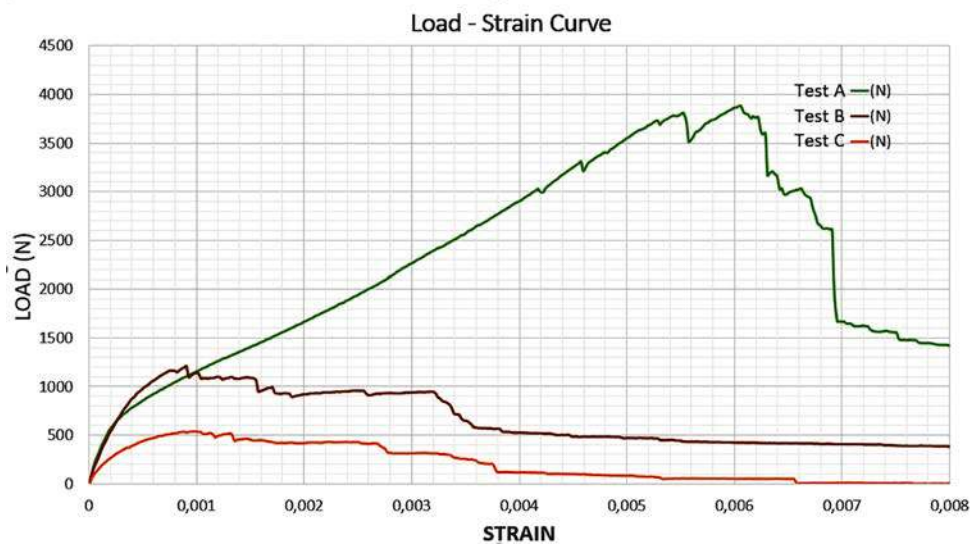


Fig. 6. Tensile force vs. Tensile Strain curves for tests A, B & C.

at failure from 0.39% for a non-reinforced matrix to 0.60% for reinforcement in the case of Test A. The specimen used in Test A have seems to have a good interface adhesion between the matrix and the fibers because this is the same hypothesis used in numerical model that give close results. If the process of fabrication guarantees the adhesion between the fibers and the matrix, the composite can give good mechanical properties such as the stress at failure, the elastic modulus and elongation at failure.

5. Conclusion

The numerical analysis in this paper showed a linear increase of the composite flexural modulus with increased fiber content (see Table 3), with a substantial increase in stress and elongation at failure compared to a non-reinforced Epoxy (see Table 4). Reinforcing with Alfa fibers with a 10% volume fraction increase the elastic modulus by about 24.16% compared to Epoxy. The improvement of mechanical properties is proved in reference [27] and can reach 56–75% in tensile modulus. The incorporation of fibers in the resin with a good arrangement has

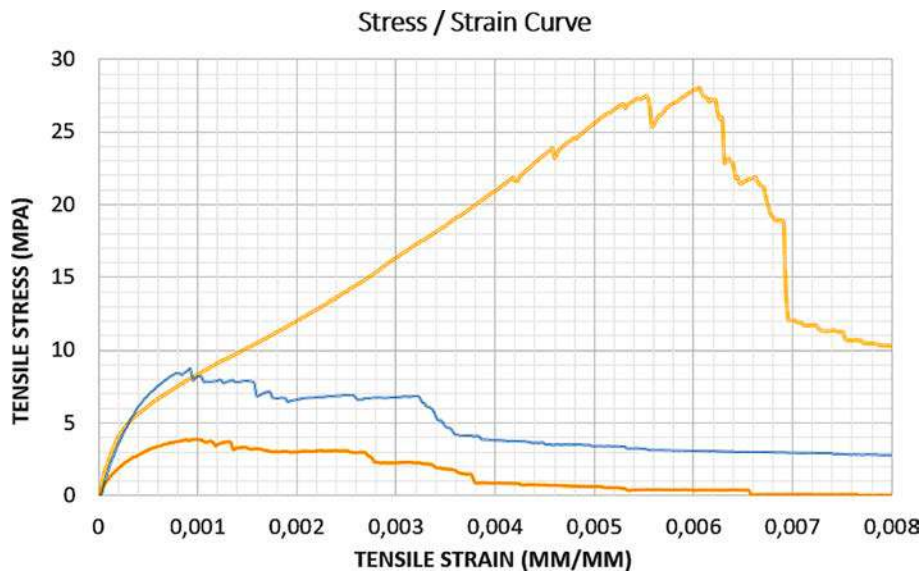


Fig. 7. Tensile force vs. Tensile Strain curves for tests A, B & C.

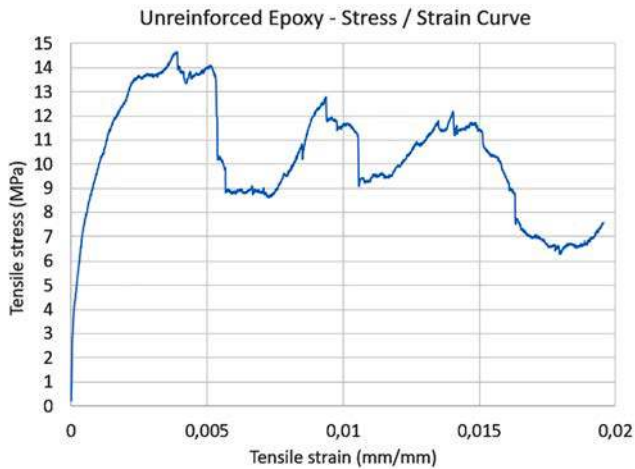


Fig. 8. Tensile force vs. Tensile Strain curves for Unreinforced Epoxy.

Table 4

Ex elastic modulus in the x-direction.

Material	Epoxy	Alfa/Epoxy Test A	Alfa/Epoxy Test B	Alfa/Epoxy Test C
Extension (mm)	0,58	0,91	0,136	0,15
Elongation %	0,39	0,60	0,09	0,10
Load (N)	464,92	3880,11	1209,78	539,23
Tensile strain (mm/mm)	3,87 E-03	6,06 E-03	2,036 E-03	0,993 E-03
Tensile stress (MPa)	14,62	28,01	8,73	3,89
Ex (10% – Table 3) (GPa)	3,78	4,62	4,29	3,92
%error to FEM model	24,16%	7,31%	14,33%	21,35%

brought an improvement in the composite strength and extension observed in test A. The fibers are also expected to prevent crack propagation, which improves the structure's expected life. Other mechanical properties like compression, bearing, and shear properties can be studied before a wide usage in industrial applications.

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.

Acknowledgments

Special thanks to Professor Ridha BEN CHEIKH and many thanks to our colleagues from the ENIT Laboratory: Materials, Optimization, and Energy for Sustainability (LR-MOED-ENIT / LR-11-ES16) for their help in the treatment of Alfa fiber.

Special thanks to Professor Zoubeida Ounaies and Texas A&M University.

References

- [1] Ajouguim S, Page J, Djelal C, Waqif M, Saâdi L. Impact of Alfa fibers morphology on hydration kinetics and mechanical properties of cement mortars. *Constr Build Mater* 2021;293:123514. <https://doi.org/10.1016/j.conbuildmat.2021.123514>.
- [2] Ajouguim S, Talibi S, Djelal-Dantec C, Hajjou H, Waqif M, Stefanidou M, et al. Effect of Alfa fibers on the mechanical and thermal properties of compacted earth bricks. *Mater Today: Proc* 2021;37:4049–57. <https://doi.org/10.1016/j.matpr.2020.07.539>.
- [3] Cherradi Y, Rosca IC, Cerbu C, Kebir H, Guendouz A, Benyoucef M. Acoustic properties for composite materials based on alfa and wood fibers. *Appl Acoust* 2021;174:107759. <https://doi.org/10.1016/j.apacoust.2020.107759>.
- [4] Sair S, Mansouri S, Tanane O, Abboud Y, El Bouari A. Alfa fiber-polyurethane composite as a thermal and acoustic insulation material for building applications. *SN Appl Sci* 2019;1:667. <https://doi.org/10.1007/s42452-019-0685-z>.
- [5] Masoud F, Sapuan SM, Ariffin MKAM, Nukman Y, Bayraktar E. Experimental analysis of heat-affected zone (HAZ) in laser cutting of sugar palm fiber reinforced unsaturated polyester composites. *Polymers* 2021;13:706. <https://doi.org/10.3390/polym13050706>.
- [6] Prasad L, Saini A, Kumar V. Mechanical performance of jute and basalt fiber geogrid-reinforced epoxy hybrid composite material. *J Nat Fibers* 2021;18:694–704. <https://doi.org/10.1080/15440478.2019.1645789>.
- [7] Mechakra H, Nour A, Lecheb S, Chellil A. Mechanical characterizations of composite material with short Alfa fibers reinforcement. *Compos Struct* 2015;124:152–62. <https://doi.org/10.1016/j.compstruct.2015.01.010>.
- [8] El-Abbassi F, Ayad R, Lamdouara N, Kebir H, Sabhi H, Buet S, Assarar M. Elaboration, analyse et modélisation mécanique numérique d'agro-composites à base de fibres courtes d'alfa. *MATEC Web of Conferences* 2014;11:01039. <https://doi.org/10.1051/mateconf/20141101039>.
- [9] Zini E, Scandola M. Green composites: an overview. *Polym Compos* déc 2011;32(12):1905–15.
- [10] Bogoeva-Gaceva G, Avella M, Malinconico M, Buzarovska A, Grozdanov A, Gentile G, et al. Natural fiber eco-composites. *Polym Compos* févr 2007;28(1):98–107.
- [11] Helaili S, Mankai W, Chafra M. Pressure Calculation and Fatigue of a Trans-tibial Prosthetic Socket Made from Natural Fiber Composite. In: Feki N, Abbas MS,

- Taktak M, Amine Ben Souf M, Chaari F, Haddar M, éditeurs. *Advances in Acoustics and Vibration III* [Internet]. Cham: Springer International Publishing; 2021 [cité 5 juin 2021]. p. 199–209. (Applied Condition Monitoring; vol. 17). Disponible sur: https://link.springer.com/10.1007/978-3-030-76517-0_22.
- [12] Brahim SB, Cheikh RB. Influence of fibre orientation and volume fraction on the tensile properties of unidirectional Alfa-polyester composite. *Compos Sci Technol* 2007;67:140–7. <https://doi.org/10.1016/j.compscitech.2005.10.006>.
- [13] El-Abbassi FE, Assarar M, Ayad R, Bourmaud A, Baley C. A review on alfa fibre (Stipa tenacissima L.): From the plant architecture to the reinforcement of polymer composites. *Composites Part A: Appl Sci Manuf. janv 2020*;128:105677.
- [14] Abdallah Y, Ben Cheikh R, Paiva MC. Could alfa fibers substitute glass fibers in composite materials. *IPP 7 mars 2019*;34(1):133–42.
- [15] Bledzki A. Composites reinforced with cellulose based fibres. *Progr Polymer Sci mai 1999*;24(2):221–74.
- [16] Chafra M, Chevalier Y. Directional damage and failure of composite materials under cyclic loading. *IJVD 2005*;39:163.
- [17] Zrida M, Laurent H, Rio G. Numerical study of mechanical behaviour of a polypropylene reinforced with Alfa fibres. *J Compos Mater 2016*;50:2883–93. <https://doi.org/10.1177/0021998315615201>.
- [18] Arrakhiz FZ, Elachaby M, Bouhfid R, Vaudreuil S, Essassi M, Qaiss A. Mechanical and thermal properties of polypropylene reinforced with Alfa fiber under different chemical treatment. *Mater Des 2012*;35:318–22. <https://doi.org/10.1016/j.matdes.2011.09.023>.
- [19] Rajesh, M., Kandasamy, J., Mallikarjuna Reddy, D., Mugeskannan, V., Kar, V.R., 2021. Experimental Characterization for Natural Fiber and Hybrid Composites, in: Jawaid, M., Hamdan, A., Hameed Sultan, M.T. (Eds.), *Structural Health Monitoring System for Synthetic, Hybrid and Natural Fiber Composites*. Springer Singapore, Singapore, pp. 71–83. 10.1007/978-981-15-8840-2_6.
- [20] Benyamina B, Mokaddem A, Doumi B, Belkheir M, Elkeurti M. Study and modeling of thermomechanical properties of jute and Alfa fiber-reinforced polymer matrix hybrid biocomposite materials. *Polym Bull 2021*;78:1771–95. <https://doi.org/10.1007/s00289-020-03183-7>.
- [21] Labidi K, Cao Z, Zrida M, Murphy A, Hamzaoui AH, Devine DM. Alfa fiber/polypropylene composites: Influence of fiber extraction method and chemical treatments. *J Appl Polym Sci 2019*;136:47392. <https://doi.org/10.1002/app.47392>.
- [22] Berrekheroukh N, Sereir Z, Vivet A, Adda Bedia EA, Fekrar A. Experimental and numerical models to study the creep behavior of the unidirectional Alfa fiber composite strength by the photoelasticity method. *Mech Time-Depend Mater 2021*. <https://doi.org/10.1007/s11043-021-09500-5>.
- [23] Prasad L, Singh V, Patel RV, Yadav A, Kumar V, Winczek J. Physical and mechanical properties of rambans (Agave) fiber reinforced with polyester composite materials. *J Nat Fibers 2021*;1–15. <https://doi.org/10.1080/15440478.2021.1904481>.
- [24] Bessadok A, Roudesli S, Marais S, Follain N, Lebrun L. Alfa fibres for unsaturated polyester composites reinforcement: Effects of chemical treatments on mechanical and permeation properties. *Compos A Appl Sci Manuf 2009*;40(2):184–95.
- [25] John MJ, Anandjiwala RD. Recent developments in chemical modification and characterization of natural fiber-reinforced composites. *Polym Compos févr 2008*;29(2):187–207.
- [26] Mittal V, Saini R, Sinha S. Natural fiber-mediated epoxy composites – a review. *Comp Part B: Eng 2016*;99:425–35.
- [27] Arrakhiz FZ, Malha M, Bouhfid R, Benmoussa K, Qaiss A. Tensile, flexural and torsional properties of chemically treated alfa, coir and bagasse reinforced polypropylene. *Comp Part B: Eng 2013*;47:35–41.
- [28] Helaili S, Chafra M, Chevalier Y. Hybrid Aluminum and Natural Fiber Composite Structure for Crash Safety Improvement. In: Karaman I, Arróyave R, Masad E, éditeurs. *Proceedings of the TMS Middle East — Mediterranean Materials Congress on Energy and Infrastructure Systems (MEMA 2015)* [Internet]. Cham: Springer International Publishing; 2016 [cité 5 juin 2021]. p. 249–58. Disponible sur: http://link.springer.com/10.1007/978-3-319-48766-3_25.
- [29] ISO 13934-1:2013(en), Textiles — Tensile properties of fabrics — Part 1: Determination of maximum force and elongation at maximum force using the strip method.
- [30] Helaili S, Chafra M. Anisotropic visco-elastic properties identification of a natural biodegradable ALFA fiber composite. *J Comp Mater 2014*;48(13):1645–58.
- [31] ISO 527-4:1997(en), Plastics — Determination of tensile properties — Part 4: Test conditions for isotropic and orthotropic fibre-reinforced plastic composites, 1997.