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Research Article

Experimental and Numerical Analyses of Alfa/Polyester Composite Under Three-Point Bending

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ABSTRACT

This study investigated the effects of atmospheric aging through three summer months on the mechanical properties of polyester reinforced with different mass rates of alfa fibers (Stipa Tenacissima). For this purpose, three-point bending tests were performed on pure polyester and polyester /alfa fiber composite specimens. A finite element model of flexural testing was developed to analyze the mechanical behavior of the Alfa/polyester composite. The test results showed that the alfa coarse fibers with 30 wt % were capable of enhancing the mechanical properties of the polyester/alfa composite.

1. Introduction

Polyester resins are now widely employed in a variety of materials engineering disciplines, including aerospace composite material matrices, adhesives, sealants, and protective coatings. Epoxy resins have become a good material for engineering applications due to their high chemical and corrosion resistance, good mechanical and thermal qualities, flexibility, and good electrical properties. In comparison to other resins, such as urethanes and epoxies, it is also reasonably priced, and in many cases, it provides better performance. It also has amazing physical and chemical qualities [1].

Vegetable fibers have seen a sharp increase in application as reinforcement for plastic composite materials during the past few years across all industrial sectors, including the aerospace and automobile industries [2-5]. Alfa grass is a kind of tussock grass that grows in semi-arid and dry parts of southwestern Europe and North Africa [6]. Alfa is a Mediterranean plant with a heterogeneous structure consisting mainly of cellulose (40–50%), lignin (between 17.71 and 24%), hemicellulose (from 22.15 to 28%), and 5%wax [7]. Alfa fibers have captivated researchers and engineers in various

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fields such as packaging, construction, biomedical, and automotive industries. Moreover, Alfa fiber-based composites are important to the development of high-performance engineering materials because of their easy availability, recyclability, and environmental friendliness. Alfa fibers have recently been employed in a few research areas to strengthen thermoplastic and thermosetting polymers [8 - 11].

Analyzing these resources' mechanical behavior is crucial for efficient usage and exploitation. The study of the bending behavior of composites derived from biological sources has garnered a great deal of interest in the last several years. The goal of Bahloul et al, research was to determine the impact of Alfa fibers on cement mortar's mechanical and thermal resistance [12]. The flexural properties of starch-based composites reinforced with alfa grass are examined by Espinach et al. [13]. Khaldi et al investigated the mechanical characteristics of anisotropic Alfa vegetable fibers and epoxy resin, as well as the viscoelastic properties of the interphase between the matrix and Alfa fibers, using an experimental approach and a numerical model [14]. Composites made of Alfa fibers and polyethylene with a high density also showed a significant improvement in tensile strength [15]. Ajouguim et al. investigate the viability of adding raw Alfa fibers to cement mortar in a mildly prepared form. They look at how the mortar's mechanical and physical characteristics have changed as Alfa fibers have been added [16].

This research aimed to examine the mechanical behavior of polyester resin reinforced with different mass rates of alfa fibers (10, 20, and 30 wt.%) at different sizes (fine and coarse) of short Alfa fibers under atmospheric aging conditions. Based on the mechanical tests, compared to pure polyester. The coarse and fine fibers were used to realize the composites polyester/alfa. A finite element model of bending test specimens was created to analyze the fracture behavior of the polyester/alfa composites.

2. Materials and Methods

All the specimens were composed of Alfa fibers and polymer (polyester resin) matrix composite. Alfa fibers were harvested from the region of Bougtob El Bayadh (South-West area of Algeria) in October 2020. The matrix used is Unsaturated Polyester Resin (UPR) supplied by Concordal SPA (Algiers, Algeria), and obtained by a mixture of primary resin with a Methyl Ethyl Ketone Peroxide (MEKP) polyester catalyst, it is a chemical compound used in the polymerization of unsaturated polyester resins. MEKP acts as a powerful catalyst, promoting the polymerization reaction and hardening the composite material. With a weight ratio of 100/2 (For 100 g of resin 2 g of hardener is added).

2.1. Preparation of Alfa Fibers

Based on reference [17], the fibers were first cleaned under tap water to remove surface contaminants. Then, first, it was sun-dried for four days. This environmental process will remove most of the moisture in the Alfa fibers, making them more straightforward to crush. After that, they were dried in a vacuum oven for 4 h at 75°C. Next, Alfa stems were divided into tiny pieces of 3-5 cm length before being crushed with a blade crusher. Figure 1(a).

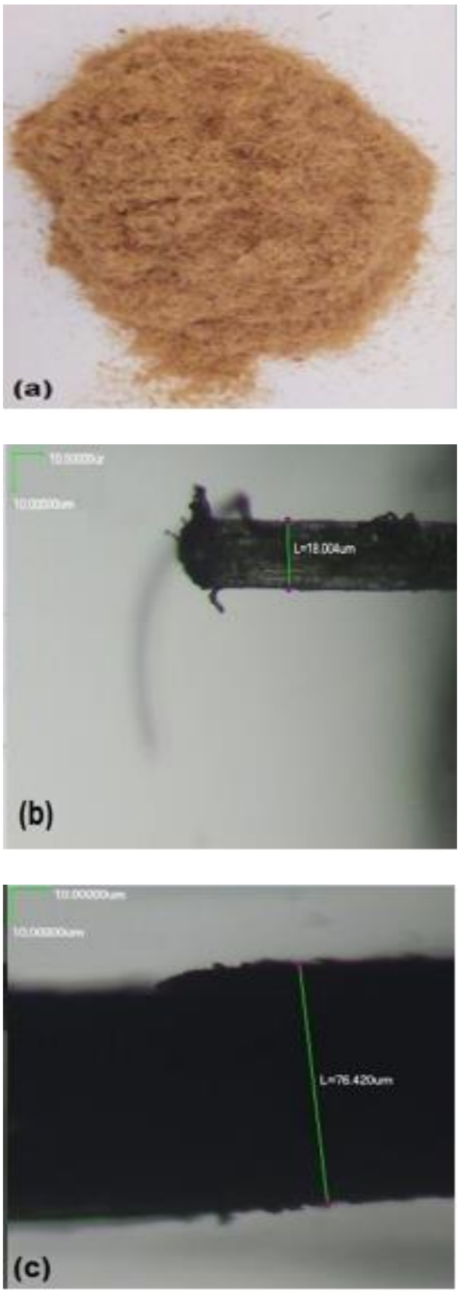

Fig. 1. Alfa fibers: (a) Crushed Alfa fibers, (b) Fine fibers, (c) Coarse fibers.

A blade crusher was used for the mechanical treatment to enhance the fibers' individualization. Secondly, the fibers are sieved with a filter to obtain a fine size lies between 15 and 20 µm in diameter, see Figure 1 (b), and coarse size lies between 70 and 80 µm in diameter, see Figure 1 (c). Optical micrographs of coarse and fine Alfa fibers were photographed on the optical microscope, OPTIKA, Model: HDMI Easy–4083. 13E. Finally, Sodium hydroxide was used in an alkaline treatment to increase fiber compatibility. For 48 hours, the crushed fibers were immersed in a 5wt% concentration solution of NaOH. After immersion, before being used, the fibers were dried at room temperature for 48 hours after being washed with fresh water to remove any remaining NaOH.

2.2. Preparation of Polyester/Alfa Composites

As reinforcing fillers, two varieties of 5% alkali-treated Alfa fibers (coarse and fine sizes) were employed. Alfa fibers were vacuum-dried for four hours at 75 °C to eliminate any absorbed moisture and stop the creation of voids before the extrusion procedure. The initial step in creating complex composite specimens is to combine Alfa fibers with polyester resin (UPR) for three distinct fiber weight ratios (10, 20, and 30 wt%). Then, the mixture of polyester resin/Alfa fibers was injected into a mold using injection-compression molding under a pressure of 3 bars for 24 hours at room temperature. The length, width, and thickness of bending specimens are 140 x 20 x 4.7 mm^3, respectively (Figure 2).

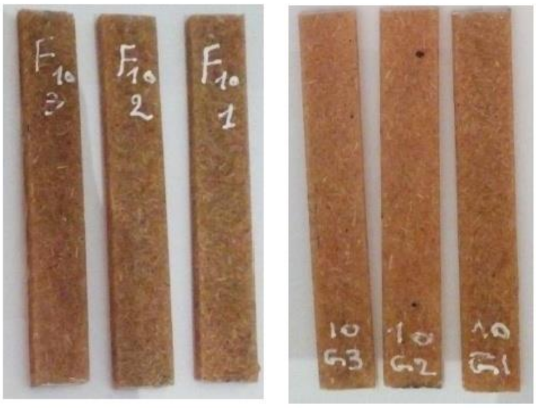

Fig. 2. Polyester/Alfa composite specimens for bending test.

2.3. Natural Aging

The environments of Mediterranean weather were considered. As, sunlight, air and relative humidity (RH) are the key parameters involved in Alfa/polyester composite aging processes in the atmosphere.

The experiment was started on July 23rd 2022 for an exposure duration of 3 months in Mascara City (North of Algeria). Temperatures range from 15 °C in the morning to 45 °C at 1 p.m. from July 23rd to October 23rd and the relative humidity fluctuated between 3% and 65%.

2.4. Bending Tests

Three-point bending tests were performed on a BED 100 tensile testing machine with a capacity of 1KN equipped with a test speed control system (Figure 3).

Fig. 3. Bending testing machine.

All the tests were performed at the speed of 6 mm/min. Flexural test specimens of the non-reinforced polyester and polyester reinforced with different proportions of Alfa fibers (10, 20, and 30 wt %) were tested under two different conditions: the first under normal conditions and the second after natural aging for 3 months. For each proportion of Alfa/polyester composite, two sizes of Alfa fibers (Coarse and fine) were used.

The flexural tests were performed according to the ASTM D 790 standard. The dimensions of the bending specimens were 140 mm in length, 20 mm in width, and 4 mm in thickness, and the distance between supports was 110 mm (Figure 4).

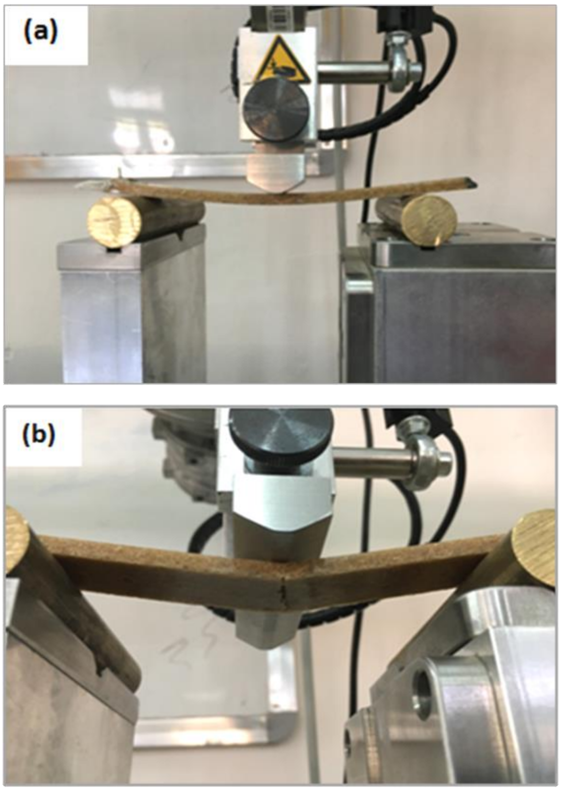

Fig. 4. Sequence of the experimental 3-point bending test until failure: (a) Initial state, (b) Final state.

The resulting stress and strain for a rectangular sample under a load in a three-point bending setup is given by the formulas (equations 1 and 2) below:

$$\sigma = \frac{3FL}{2bd^2} \quad (1)$$

$$\varepsilon = \frac{6Dd}{L^2} \quad (2)$$

where F is the load (N), L is the length of the support span, b is the width d is the thickness of the bending specimen and D is the maximum deflection of the center of the beam.

The Timoshenko beam theory (equation 3) provides the value of the deflection w:

$$\mathrm{w} = \frac{Fl^3}{4Ebh^3} = \frac{Fl^3}{48EI} \quad (3)$$

Equation 4 provides the resultant Young's modulus:

$$\mathrm{E} = \frac{dF}{dw} = \frac{l^3}{48I} \quad (4)$$

2.5. Finite Element Analysis

Considering the mechanical testing, finite element models of bend specimens were developed to analyze the fracture and stresses-strain curves of the polyester resin reinforced with different volumes of two sizes of alfa fibers (coarse and fine), and commercial benchmark. The geometry of the bending mechanism is shown in Figure 5, the analysis was performed using the ABAQUS/explicit program [18].

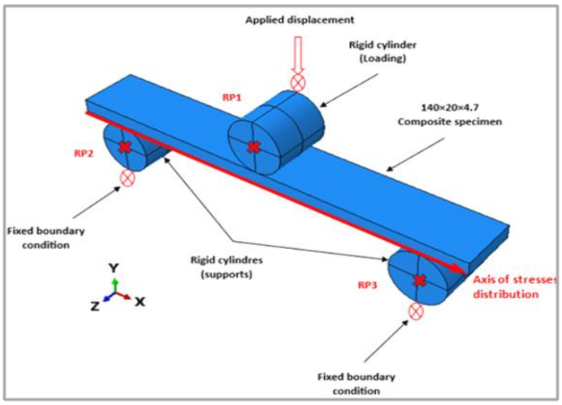

Fig. 5. Loading and boundary conditions applied to the model.

2.5.1. Validation of Numerical Bending Model

Numerical modeling is considered a validation of the experiment findings. Numerical computes are carried out in three dimensions, using the ABAQUS software, based on finite element development. Among the variety of elements available in the ABAQUS documentation, The boundary conditions have been defined in such a manner as to reproduce as well as possible the real conditions of the test. In fact, there are three boundary conditions applied to the model, the contact lines of the sample with the supports are blocked in translation along x, y, and z (Ux=Uy=Uz=0). The displacements of the punch are locked along x and z (Ux=Uz=0), with the application of a displacement in the y direction. All models were loaded to failure using 0.001 mm displacement increments in shear.

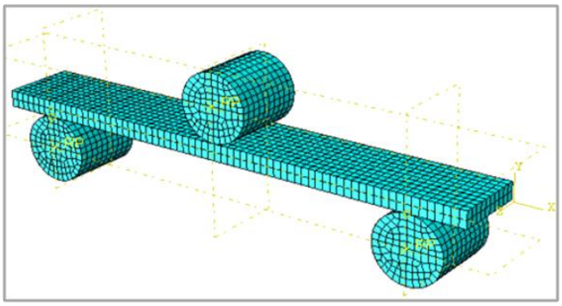

Fig. 6. The finite element mesh model (sample, punch, and supports).

For all cases under bend loading conditions, the finite element analysis established the distribution of von Mises stresses and shear stresses vs strain in the composite (Figure. 6).

2.5.2. X-FEM and Fracture Criterions

To pretend the crack nucleation and growth numerically we applied the X-FEM in the polyester/alfa composites. The criterion of the maximum principal stress (σ_1) was chosen for the damage initiation as specified in Eq. (5) [19]. However, when the maximum principal stress becomes bigger than the tensile strength of the composite material, the crack presence can be seen, and the factor fe refers to the stress ratio in an element (e):

$$f^e = \frac{\sigma_1^e}{\langle \sigma_{max}^* \rangle} \quad (5)$$

Fracture energy Gc shows the criterion of crack propagation. In addition, supplementary numerical parameters are necessary to ensure the computation convergences which are 0.01 for Damage Initiation Tolerance and 10e-05 for the viscosity coefficient and the dissipated energy fraction. This value allowed the calculation in a reasonable time without influencing the final result (the viscous dissipation energy remains much lower than strain energy during the whole calculation). Hence, only 1400 elements of the specimen mesh have been enriched, the head being subjected to a concentrated force which enrichment would cause inadequate cracking.

2.5.3. Finte Element Model

A numerical simulation of the bending test was performed in order to replicate laboratory test results. Numerical analysis was performed using the finite element method (FEM) with Abaqus explicit. Three-dimensional finite element models of specimens made of alfa/polyester composite were created based on mechanical testing in order to assess the stress fracture in polyester reinforced with varying volumes of alfa fibers for benchmarking purposes. Flexural simulations were conducted on Alfa composite materials using finite element analysis (FEA) software ABAQUS 2022. This software was utilized to generate the model and refine the finite element specifics, including contact properties, boundary conditions, and meshing the details of numerical modeling. The dimensions used in these simulations were identical to those employed in the experiments conducted in the current study. The geometrical model is composed of a plate composite, of the following size: length, L = 140 mm, width, w = 20 mm, thickness, e = 4.7 mm. Three pins 19 mm in diameter were in contact with the specimen to apply the three-point bending loading. The supports and puncher were modeled using discrete rigid elements. Figure 5 displays the finite element model. The mechanical properties of the composite were derived from the experimental results obtained and are shown in Table 1&2. The Maxps damage model is used to simulate material damage when the material properties are simplified to linear elasticity. The puncher and the two supports are designed to be rigid without regard to the setting of its material properties. For a reasonable computational time, the stable time increment was 1E-9. The creation of operation points RP-1, RP-2, and RP-3 allowed for the more reasonable setting of "load" and "boundary conditions." Three special points are defined and bound to three rigid bodies in the model. The puncher was linked to the point RP-1 and configured as a "rigid body." The left and the right supports were similarly configured as a "rigid body" and bound to the points RP-2 and RP-3 respectively. A reference point (RP-1) was established in the middle of the FE model's top surface, as shown in Figure 5. The direct cyclic was the step process. The boundary condition of "Displacement/ Rotation" was assigned to the composite model's bottom surface. The interaction between the loading puncher and the specimen is assumed to have general contact, as is the interaction between the supports and the specimen. The puncher was allowed to move freely along the z-axis, which is perpendicular to the face of the composite plate. An imposed displacement "U" is applied longitudinally to the specimen. In fact, there are three boundary conditions applied to the model, the contact lines of the sample with the supports are blocked in translation along x, y, and z (Ux=Uy=Uz=0). The displacements of the punch are locked along x and z (Ux=Uz=0), with the application of a displacement of 10 mm in the y direction (Uy=10 mm), in order to simulate the loading. The composite component was loaded with displacement increments of 0.01 mm in shear until it failed. Tables 1 and 2 show the material attributes that were used, which were expressed in terms of yield strength, yield strain, Young's modulus, and Poisson's ratio for all related components. All materials were assumed to exhibit homogeneous materials. Based on a mesh convergence study, hexahedral elements of type C3D8R are used to mesh the generated model. For two-dimensional contact analysis, however, ABAQUS advises the use of C3D8R hexahedral elements for the combination. The element type of each component is set to C3D8R. The Alfa composite specimen's "approximate global size" was set to 1 mm, while the puncher and supports were set to 2 mm. A study on mesh convergence was carried out, processing a number of runs with constant boundary conditions. There are 1400 elements and 2343 nodes in the entire finite element model. The numerical analysis determined the bending stresses versus strain and von Mises stresses distribution in the composite for all cases under pure bend loading conditions.

3. Results and Discussion

In this investigation, the mechanical behavior failure of polyester reinforced with different mass rates of alfa fibers was analyzed. The stress-strain curves exhibit the bend loading response of the non-reinforced polyester and polyester reinforced with different fractions of two sizes (coarse and fine) of natural fibers (0, 10, 20, and 30 wt%). The three-point bend specimen of the pure polyester and polyester/alfa composite was tested under two different conditions: the first under normal conditions and the second after natural aging for 3 months. Using experimental data, the finite element method was used to analyze the stress distributions in validated numerical models.

3.1. Experimental Results

An analysis of the results revealed that the mechanical behavior of alfa/polyester composites occurred in two phases: elastic linear behavior followed by a nonlinear part (plastic deformation and damage) until the fracture of the material. From the bending test, the stress-strain curves of polyester/alfa composite reinforced with different fractions of reinforcement for both alfa fiber sizes (fine and coarse) were plotted. The mechanical properties of the composite such as Young's modulus, ultimate stress, and ultimate strain were deduced from these curves.

3.1.1. Effect of Fiber Content

Three alfa contents (10% w/w, 20% w/w, and 30% w/w) were studied in comparison to neat Polyester. The behavior was measured thanks to bending tests. Figure 7 illustrates the stress-strain curves of the bend loading response of polyester resin reinforced with different fractions of alfa fibers (10, 20, 30wt %). The curve of the pure polyester resin was taken as a reference for the comparison. As found in this figure, the flexural strengths and Young modulus of the composites at all reinforcement ratios were greater than polyester resin. Moreover, the mechanical properties of the composites increase with increasing fiber content, reaching the highest value at 30%.

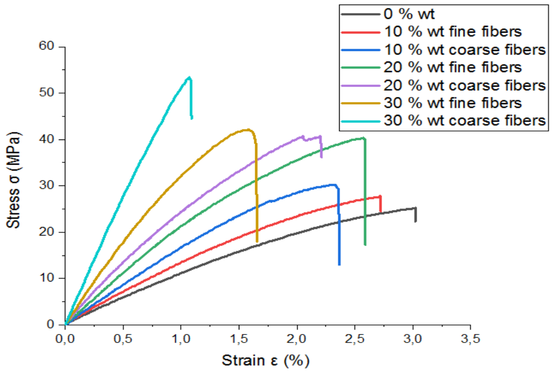

Fig. 7. Stress-strain polyester/Alfa composite with different fractions of reinforcement (0, 10, 20, 30 wt%) for both sizes of Alfa fibers (fine and coarse).

It can be seen also that the effect of alfa coarse fibers is more significant than fine fibers on the strength of the polyester/alfa composite. The ultimate stress of the non-reinforced polyester is about 25 MPa, whereas the presence of 30 wt% coarse alfa fibers increases this resistance to 110 % and 68% for the fine alfa fibers. This improvement in bending strength confirms that the coarse fibers act as the best reinforcement. These results show that the flexural modulus and maximum flexural strength increase with increasing fiber content.

3.1.2. Effect of Particle Size

The effect of particle size on the mechanical properties investigated in this study is highly significant as shown in table 1 and table 2. In general, increasing fiber size improves the modulus of elasticity and maximum strength in flexural tests. This result is consistent with previous reports on wood-particle thermoplastic composites [20-22]. As flexural Young modulus shows a steady increase with increasing fiber size at 30 wt% content (table 1, 2). It rises from 4 GPa at fine particle sizes to 6.01 GPa at coarse particle sizes. Flexural strength development also demonstrates that particle size has greater influence at higher fiber load (30 wt%), with approximately 26.61 % higher strength when fiber size increases from fine to coarse. The poor performance of fine fibers can be attributed to weak interfacial bonding and poor transfer of loads from the fibers to the matrix. However, the reinforcement reduces the ultimate strain of the polyester/alfa composite but the rate of this reduction depends on the alfa fiber content and size. The ultimate strain of the polyester is 3.2%, hence this value is reduced to 1.6% for the composite reinforced with 30 wt% of alfa fine fibers, and 1% for the polyester reinforced with 30 wt% of coarse fibers. This reduction of ultimate strain by the alfa is mainly due to the high stiffness of the alfa fibers. Consequently, the presence of alfa fibers in the polyester decreases its plasticity.

Table 1. Mechanical properties of polyester/alfa composite reinforced with fine fibers.

	Unaged composite				Aged composite			
	σ_{ultime}(MPa)	ε (%)	E(MPa)	ν	σ_{ultime}(MPa)	ε (%)	E(MPa)	ν
Neat matrix	25.24	3.02	1202	0.3	18.40	2.57	1001	0.3
10 wt % fibers	27.77	2,72	2003	0.3	20	2,32	1265	0.3
20 wt % fibers	40.34	2,57	2200	0.3	20.3	1,55	2024	0.3
30 wt % fibers	42.2	1,58	4000	0.3	31	1,72	2850	0.3

Table 2. Mechanical properties of polyester/alfa composite strengthened with coarse fibers.

	Unaged composite				Aged composite			
	σ_{ultime}(MPa)	ε (%)	E (MPa)	ν	σ_{ultime}(MPa)	ε (%)	E (MPa)	ν
Neat matrix	25.24	3.02	1202	0.3	18.40	2.57	1001	0.3
10 wt % fibers	30.25	2,33	2220	0.3	22.63	2,08	1710	0.3
20 wt % fibers	40.72	2,20	3200	0.3	29.8	1,62	2310	0.3
30 wt % fibers	53.43	1,07	6010	0.3	39.13	1,58	3480	0.3

3.1.3. Effect of Environmental Aging

After exposure of the samples during the three summer months, the materials underwent different types of attacks, first and foremost the combined action of solar UV light and oxygen, There was the absorption of UV rays from sunlight by the polymer matrix causes photodegradation or Photo-oxidation characterized by the degradation of the surface of a polymer and the scission of the molecular chains which initiates the cracks causing the degradation of the mechanical properties. This process is the most important factor in polymer weathering.

The stress-strain curves for different polyester/Alfa composites and pure polyester affected by atmospheric aging are shown in Figure 8.

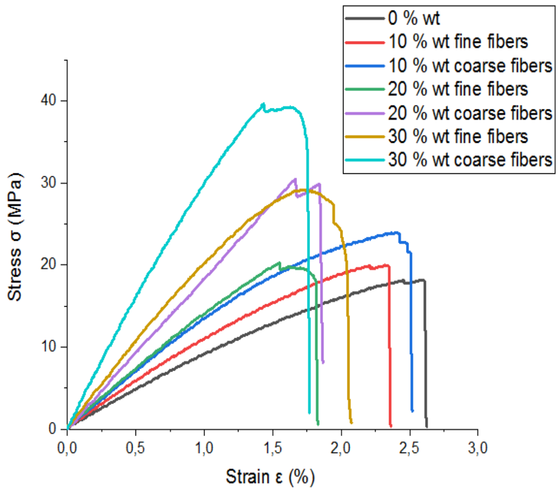

Fig. 8. Effect of three months of atmospheric aging on the mechanical behavior of the different categories of the polyester/Alfa composite.

For the comparison of ultimate stress and strain of the different polyester/Alfa composite categories, before and after atmospheric aging conditions. Relative to non-affected composite by atmospheric aging, the reduction of the ultimate stress lies between 25% and 45%. We note that the ultimate stress of the composite reinforced with 30 wt% of coarse and fine Alfa fiber are about 54 MPa and 42 MPa, respectively. Therefore, the values were reduced to 41 MPa and 29 MPa after atmospheric aging as illustrated in Figure 9. This decrease can be attributed to the appearance of surface anomalies (microcracks), which amplified the local stresses thereby reducing the mechanical resistance of the material. When the samples were exposed to UV radiation, all properties of both biocomposites were degraded due to surface oxidation, changes in matrix crystallinity, and interfacial degradation [23]. The mechanical properties of both biocomposites were degraded, with a significant decrease. Subsequently, thermal and humidity aging are considered the major causes of long-term failure of composites exposed to the atmosphere. There are several consequences of atmospheric aging, namely the degradation of the mechanical properties of the matrix, the differential swelling linked to the concentration gradients, and the damage at the matrix/reinforcement interface [24].

When the composites are exposed to different environmental conditions and especially to moisture from the environment, the cellulosic fibers will swell. Consequently, the shear stresses will rise at the fiber/matrix interface. Thereby, the debonding risk of the interface augments. Joseph et al found that the composites after water absorption induced an increase in the mechanical proprieties' degradation of natural fibers [25]. In addition, the diminution of thermal stability can lead to the degradation of polymer, fibers, and polymer/fiber interface loosening [26].

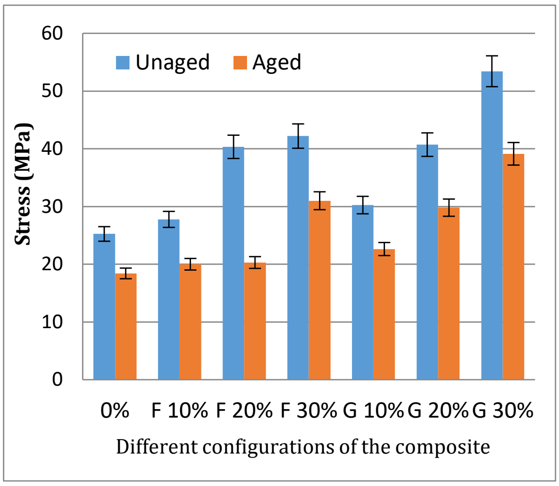

Fig. 9. Effect of three months of atmospheric aging on the bending strength of the polyester/Alfa composite with different fractions of reinforcement (0, 10, 20, 30 wt%) for both sizes of Alfa fibers (fine and coarse).

Figure 10 illustrates the evolution of Young's modulus of unaged and aged composites with respect to fiber content. As shown in this figure, an important Young's modulus increase with fiber addition was observed for all composite types.

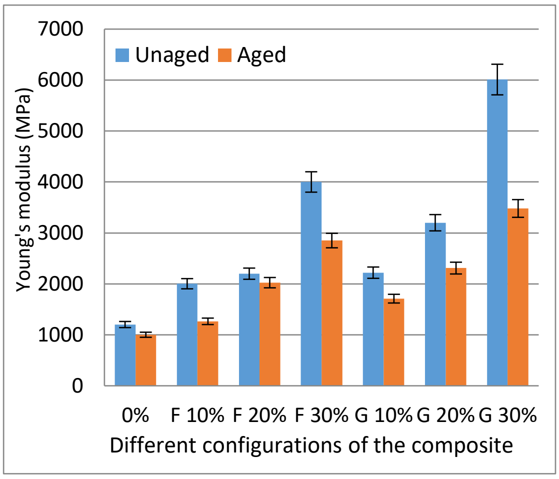

Fig. 10. Young's modulus variation of different Polyester/Alfa composites (Coarse and fine size).

This significant increase can be attributed to lower porosity and an indication of a strong interphase (Figure 11). Cavities whose genesis is connected to structural faults begin in the amorphous phase when the material is mechanically loaded [27]. The stress concentration can be located in the defects and leads to the creation, initiation, and propagation of the crack in the material [28].

Furthermore, the composite with coarse fibers exhibits a much higher Young's modulus than the one with fine fibers and neat polyester resin. These findings demonstrate that variations in Young's modulus are caused by atmospheric aging. Indeed, atmospheric aging induces a decrease in Young's modulus for all aged composites and this variation was amplified by Alfa fiber content. Moreover, the reduction of Young's modulus is less than 1% for the pure polyester caused by natural aging and reached 40% for the composite reinforced with 30 wt% of coarse Alfa fibers. Numerous studies have detailed the linear evolution of the longitudinal Young's modulus with the volume filling ratio.[29–31], where relationships between the filling percent and the composites' mechanical properties were shown.

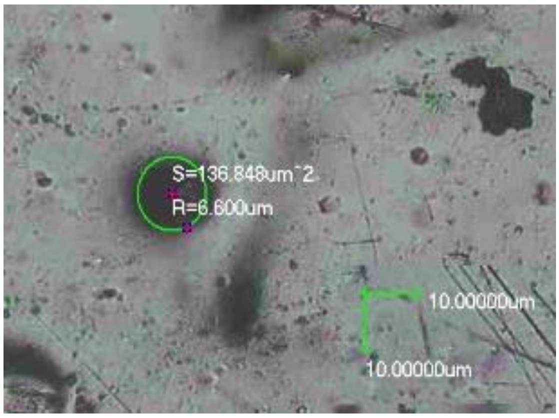

Fig. 11. Microvoids observed experimentally in the polyester/Alfa composite.

3.2. Numerical Analysis and Validation

To examine the specifics of the composite Alfa polyester's bending resistance ability, its deformation mode during the bending process is shown in Figure 12, where the general case's experimental and numerical deformation states were compared. Clear fracture in Zone (a) (marked with red lines) can be seen both in the experiment and simulation. They align rather well with one another. These details of composite Alfa polyester further demonstrate the numerical model's applicability and validity.

The comparison between the FE and experimental findings (stress-strain curves) of both alfa/polyester composite cases (fine and coarse alfa fibers) reinforced with different fractions of fibers (0, 10, 20, and 30 wt%) is illustrated in Figure 13. The experiment findings and FE results are in good agreement, as seen in the figure, with an estimated average relative inaccuracy of less than 15% in the perceived strength. The continuum damage mechanics-based model appears to be sufficient for simulating the failure of the alfa/polyester composite.

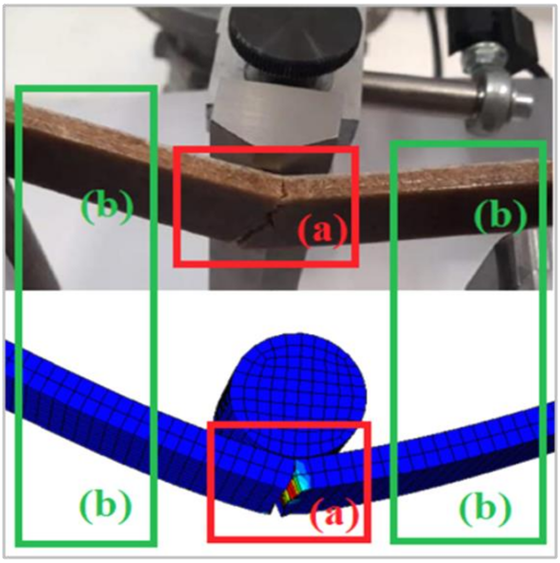

Fig. 12. Central area failure: experimental and numerical

appear to be accurately captured by the numerical data, and the average relative error in the apparent stress is estimated as <15%. These composites' experimental and numerical curves show the same shape with a tolerable error. The existence of voids, discontinuities, and porosity in the fiber and matrix might cause this error.

Higher strength and fracture energy are typically associated with mostly shear loading due to bend loading conditions, which tends to cause numerous damages such as fracture of the polyester and alfa fiber as well as decohesion of the polyester/alfa fiber interface.

Data from the flexural analysis can be used to forecast the failure behavior of composite materials, suggesting that the constitutive principles chosen for damage initiation and evolution appear to be plausible.

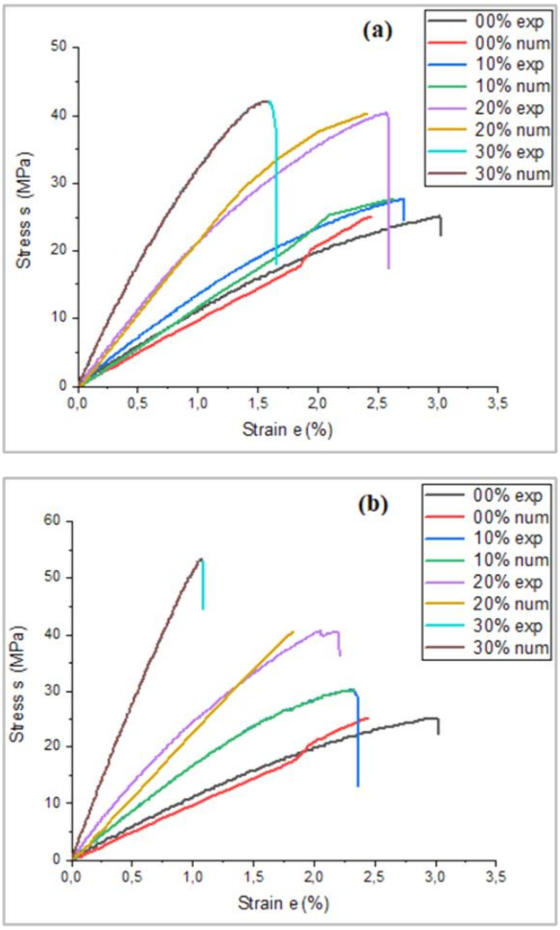

Fig. 13. The experimental and numerical stress-strain curves of unaged Alfa/polyester composite with different fractions of reinforcement (0, 10, 20, 30 wt%) for both sizes of alfa fibers: (a) fine fibers and (b) coarse fibers.

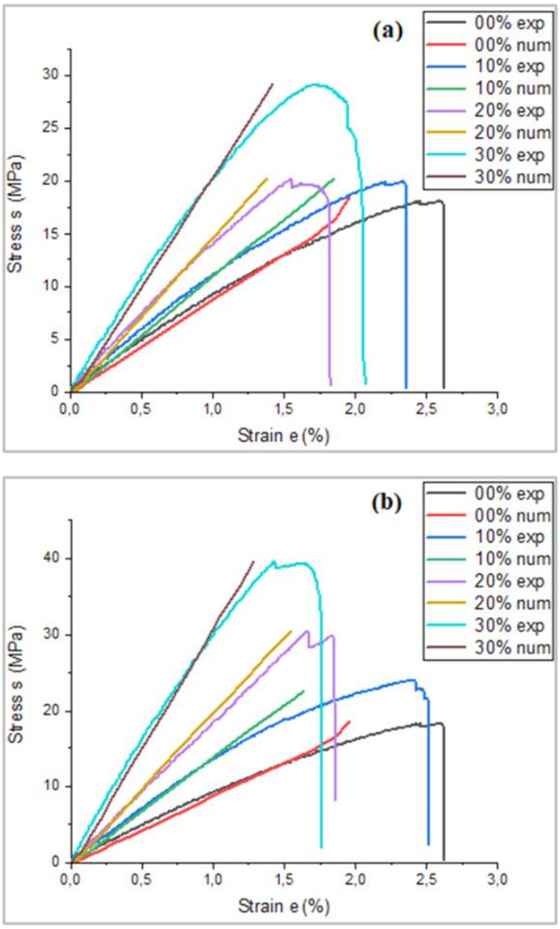

Fig. 14. The experimental and numerical stress-strain curves of aged Alfa/polyester composite with different fractions of reinforcement (0, 10, 20, 30 wt %) for both sizes of alfa fibers: (a) fine and (b) coarse.

Figure 14 shows a comparison of the predicted and the experimental stress versus strain curves of all cases of aged alfa/polyester composite for bending loading conditions. The overall mechanical reactions found in the studies

3.3. Van Mises Stress Distributions

Figure 15 illustrates the von Mises stress distributions along the longitudinal axis of the composite specimen. According to this figure, for all cases of composites, it has been seen that the highest von Mises stress is noted in the middle of the specimen. It seems that the von Mises stress values found in the composite reinforced with coarse fibers are greater than the stress values in the composites reinforced with fine fiber. The analysis of the von Mises stress distribution at different weight fractions (0%, 10 %, 20 %, 30 %) can be seen in this figure, revealing that the curve of the von Mises stress at 30% is different from those at the other fractions. Without reinforcement, the polyester has a maximum stress of around 23 MPa., in polyester reinforced with 30% fine and coarse alfa fiber, this value increases to 38 MPa and 50 MPa. The association between the effects of the percentage of alfa fiber and its size increases the strength of the alfa/polyester composite.

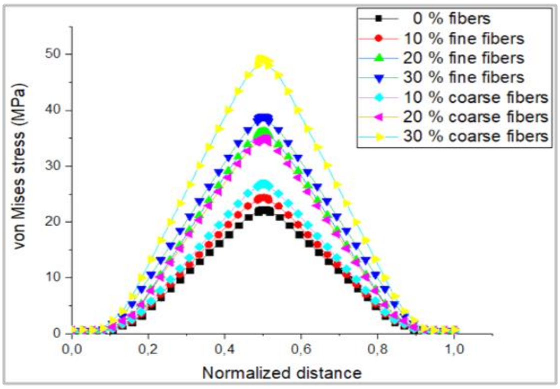

Fig. 15. Von Mises stress distributions: Young polyester/Alfa composite with different fractions of reinforcement (0, 10, 20, 30 wt%) for both sizes of Alfa fibers (fine and coarse).

By comparing the values of the maximum von Mises stresses in the unaged and aged tests, it can be observed that natural aging has a significant effect on the degradation of the mechanical properties of alfa/polyester composite. For pure polyester (without reinforcement), three months of aging decreased the stress concentration by more than 30%; this reduction reaches 28%, in the case of the alfa/polyester composite reinforced with 30% of coarse alfa fibers (Figure 16).

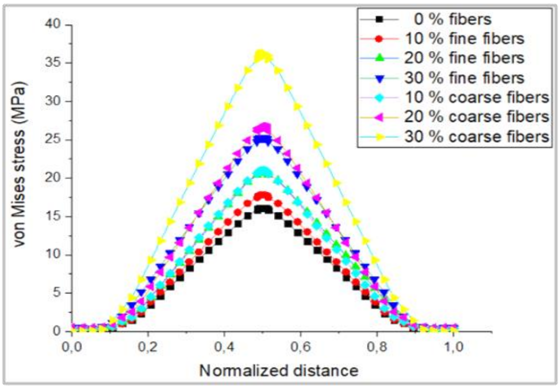

Fig. 16. Von Mises stress distributions: Aged polyester/Alfa composite with different fractions of reinforcement (0, 10, 20, 30 wt%) for both sizes of Alfa fibers (fine and coarse).

4. Conclusions

In this study, three-month periods of aging settings were applied to polyester/alfa composites. In the investigation, it was found that environmental aging and filler percentage had a significant impact on composite materials properties. Therefore, the current research allows for the deduction of the following findings:

- Alfa fibers can strengthen polymer matrices.
- The strength of the composite reinforced with the coarse fibers of alfa is more effective than the fine fibers one.
- The increase of alfa fibers percentage was beneficial for the improvement of composite mechanical properties.
- The three months of atmospheric aging for a specific environment contributes to the deterioration significantly the composite mechanical behavior.
- The simulation results showed strong agreement with the experimental results.
- The addition of UV stabilizers is suggested to enhance the outdoor performance of natural fiber/polymer composite and to achieve a balance between strength and durability requirements for natural fiber composites.

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Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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