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STUDY OF THE MECHANICAL BEHAVIOR OF BIO LOADED FLEXIBLE PVC BY COCONUT AND HORN FIBERS SUBJECTED TO AGING

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Abstract- Innovation in industrial fields is developed by bringing added values to human life, with systems that meet specific requirements with a low price, suitable lightness, and a long lifespan. Recycling is a process whose action is to recover waste and reintroduce it, after treatment, into the production cycle. several wastes are simply incinerated or thrown into nature without recycling, among these wastes we find cow horns as well as coconuts which are used in this article as bio-fillers added to recycled PVC to improve its mechanical characteristics and increase the number of recyclability. The experimental study is accompanied by a numerical study represented in this article by three models of numerical calculations (finite element, double inclusion, and Mori-Tanaka) to validate the results of the experiments. After validation of a model of artificial aging of PVC, Numerical modeling is carried out according to three models aforementioned to predict the mechanical characteristics of bio-loaded PVC, and choose a bio-load which improves the material and which also makes it possible to increase the recyclability number of PVC. The results obtained showed an improvement in the mechanical characteristics of the simulated flexible PVC using these two-natural bio-fillers that respect the environment and exhibit lower costs and higher lightness.

Keywords: Flexible PVC, Aging Model, Coconut, Cow Horn, Numerical Models.

1. INTRODUCTION

During the last decades, the use of plastics has increased and will continue to increase due to the reliability, lightness, low cost and recyclability of its materials. The increased use of these materials results in tons of waste all over the world.

Recycling is a process for recovering its waste, among the recycled plastic waste, we mention PVC which covers most industrial sectors [1-5], [24-25].

Polyethylene is at the top of the most used plastic materials, while PVC is ranked second with a recycled mass under Vinyl Plus in 2016 which increases thanks to the initiatives of the EuPC organizations [6], which integrate research into the study of activities of recycled PVC.

We will use the difference method, which consists in minimizing the differences between the experimental and numerical results in order to better converge towards what we want. Recycling PVC is becoming a big necessity these days. This operation consists of adding bio-fillers to the recycled PVC in an attempt to increase its recyclability.

The recycling of flexible PVC requires the addition of fillers improving its mechanical properties and obtaining environmentally friendly composites.

In this analysis, we will use two types of fillers (coconut and cow horn fibers) which will be added to recycled PVC, and studied by three numerical models [8,9]. This study will attempt to digitally enhance the recycling of flexible PVC by reinforcement with the aforementioned charges.

2. ARTIFICIAL AGING

2.1. Description of Artificial Model

The flexible PVC sample is illustrated in Figures 1 and 2.

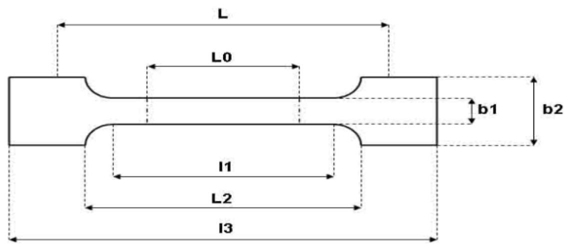


Figure 1. Normalized specimen

Figure 2. Flexible PVC specimen [1]

The flexible PVC is exposed for 7 days to an intermittent temperature of 55 °C, 104 min to simulate the day and the same duration to simulate the night. Two aging configurations are used: aging under normal conditions [3], and accelerated aging:

- Artificial aging at a constant temperature (328.15 K) by an oven.
- Aging under normal conditions for 10 hours at the average Moroccan temperature ($T_{average}$ = 300.15 K)

Table 1 shows that the average Moroccan reference temperature is of the order of 300.15 K.

Table 1. Moroccan average temperature [1]

OUARZAZATE	Average temperature for 60 years (K)	Maximum average temperature (K)	Minimum average temperature (K)	Record maximum temperature in 60 years (K)	Record minimum temperature in 60 years (K)	Average precipitation (K)
year	299.15	300.15	284.15	319.15	265.15	283.65
January	281.15	291.15	294.15	299.15	268.15	273.95
February	284.15	293.15	276.15	304.15	268.15	273.65
March	288.15	296.15	279.15	312.15	271.15	274.45
April	291.15	300.15	283.15	314.15	272.15	273.65
May	295.15	304.15	286.15	318.15	276.15	273.45
June	299.15	309.15	290.15	322.15	281.15	273.45
July	303.15	313.15	293.15	323.15	287.15	273.45
August	302.15	311.15	293.15	320.15	316.15	273.65
September	298.15	306.15	289.15	316.15	283.15	274.65
October	292.15	300.15	284.15	306.15	276.15	274.65
November	287.15	295.15	280.15	303.15	271.15	274.65
December	282.15	290.15	275.15	301.15	265.15	274.45

2.2. Results and Discussion

Figures 4, 5, 6 and Table 2 together show the results obtained experimentally by the traction machine illustrated in Figure 3, and numerically by the numerical model of finite element computation allowing the prediction of the behavior of composite materials [10-19].

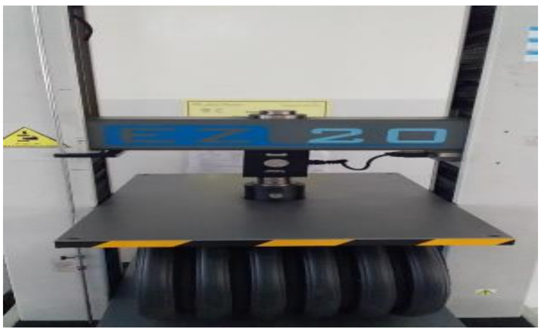


Figure 3. Machine EZ-20

The results of the study obtained by the finite element computational model provide the experimental results. There is a decrease in breaking stress and an increase in rigidity.

In order to return these materials to their reference properties after several recycling, we tried to create a model for future experimental and numerical studies on the recycling of flexible PVC. The analyzes are carried out by the finite element method for PVC before and after aging. The sensitivity of flexible PVC to heat and ultraviolet rays for 7 days could modify the mechanical properties.

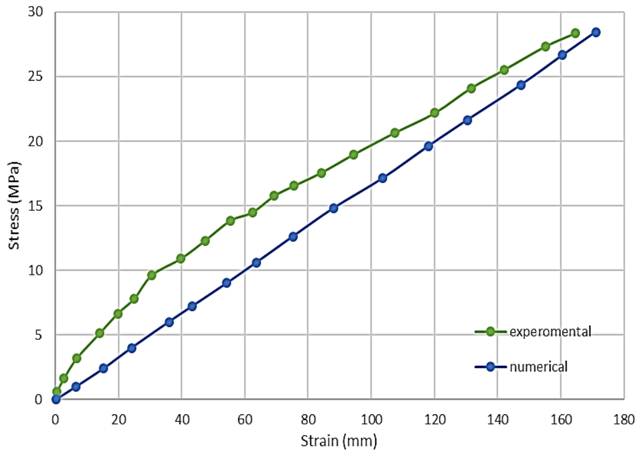


Figure 4. Stress-strain curves of flexible PVC before aging

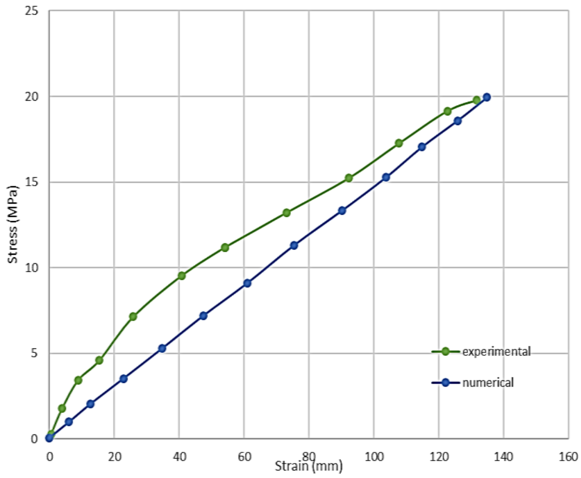


Figure 5. Stress-strain curves of flexible PVC after aging

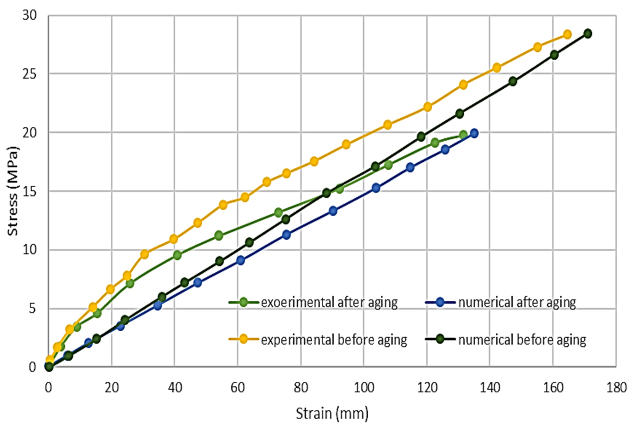


Figure 6. Stress-strain curves of flexible PVC before and after aging

Table 2. Numerical experimental study and modeling results

Flexible PVC	Stress at break (MPa)		Strain at break (mm)	
	Experimental	Numerical	Experimental	Numerical
Before aging	28	28	168	169
After aging	20	20	135	135

3. NUMERICAL MODELING OF BIO FILLED PVC

3.1. Finite Elements Model

This research is based on a good mesh of the bio-charged material then on the assembly of the subdomains [20-23]. Because of their numerical accuracy and the ease of convergence, we used the quadratic elements to have good results.

3.2. Mori-Tanaka Model

The model for Mori Tanak is defined as follows:

$$\epsilon(x) = \xi(I, C_0) : \epsilon^*, \forall x \in (I) \quad (1)$$

where, $\xi(I, C_0)$ is Eshelby tensor and ϵ^* is deformation of the Eshelby volume.

Strain concentration tensor:

$$B^{\varepsilon} = H^{\varepsilon}(I, C_{fibers}, C_{PVC}) \quad (2)$$

$$B^{\varepsilon} = (I + \zeta(I, C_{Fibers}) : C_0^{-1}{}_{Fibers}) : [C_{PVC} - C_{Fibers}]^{(-1)} \quad (3)$$

where, is the strain concentration tensor of fibers.

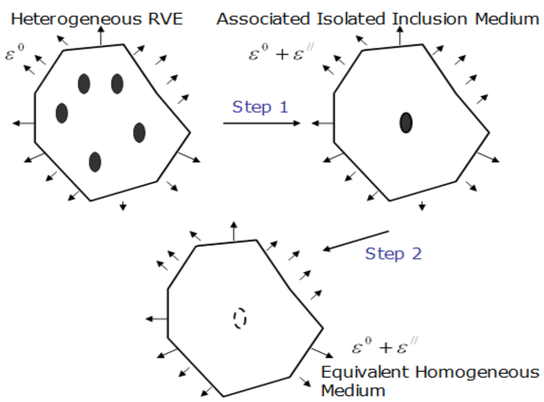


Figure 7. Mori Tanaka model [6]

3.3. Double Inclusion

The strain concentration tensor of cow horn and coir fibers on a flexible PVC matrix is shown in Equations (19) and (20).

$$B^{\varepsilon} = [(1 - \xi(\upsilon_1))((B_l^{\xi})^{(-1)} + \xi(\upsilon_1)((B_{\upsilon}^{\xi})^{(-1)}]^{(-1)} \quad (4)$$

$$\xi(\upsilon_1) = \frac{1}{2}\upsilon_1(1 + \upsilon_1) \quad (5)$$

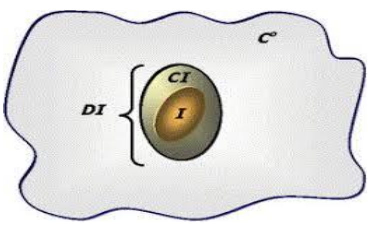


Figure 8. Double inclusion model [7]

3.4. Bio Loads

The bio-loads used in this article are of animal and natural origin which are in most cases rejected in the wild or simply incinerated, they are light at a lower cost. Numerical simulation makes it possible to derive the effect of these bio-fillers on flexible PVC after aging.

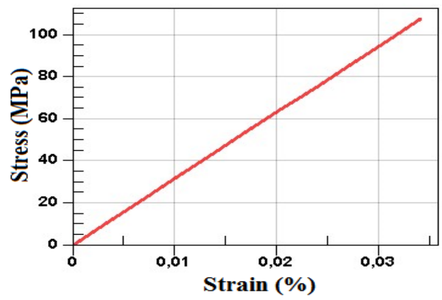


Figure 9. Horn fiber tensile test curve

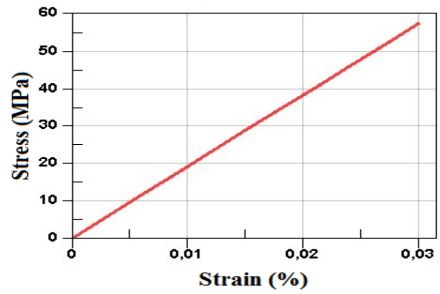


Figure 10. Coconut fiber tensile test curve

As shown in Table 3, the values of tensile stress and Young's modulus are higher for the two bio-loads, with elastic behavior.

Table 3. Numerical properties of Horns fibers in MPa

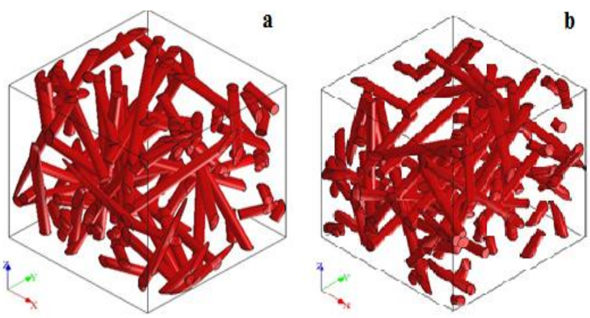
	Young modulus	Stress at break
Horn	3148.4	106.92
Coconut	1920	57

4. RESULTS AND DISCUSSION

Aging the PVC artificially with an aging model already studied has made it possible to modify the mechanical characteristics of the latter. In this article we numerically add a percentage of 10% of the bio-fillers (coconut and cow horns) to the aged PVC to a first recycling and we compare the results with a recycled sample without adding filler, and analyze the changes made to the PVC to get the one that improves the material the most

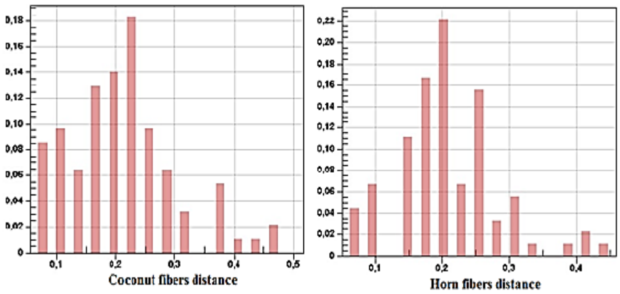
4.1. Bio-Loaded PVC

In this study, we select a random distribution of PVC filled with coconut and horn fibers as shown in Figure 11.



a) Bio filled PVC with Coconuts b) Bio filled PVC with cow horns

Figure 11. Structure of bio-loaded PVC



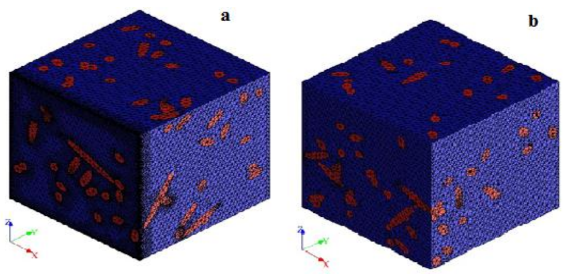
a) b)

Figure 12. Coconut and cow horns fibers distance

The table below shows the statistical distance for both cow horns and coconuts fibers in PVC. The meshes illustrated in Figure 13 are obtained by numerical modeling of cow horns and coconut. Mesh parameters for performing numerical calculations are described in Tables 5 and 6.

Table 4. Cow horns and coconuts fibers distance

PVC	Mean	Min	Max	Std dev
Bio-loaded with coconut	0.211	0.0619	0.511	0.0954
Bio-loaded with cow horns	0.205	0.056	0.454	0.0755



a) Bio-loaded PVC with Coconuts b) Bio-loaded PVC with horns

Figure 13. Mesh of bio-loaded PVC

Table 5. Parameters of mesh

PVC	Elements	Nodes	Size	Min Size
Bio-loaded by Coconut	240708	382996	0.029181	0.0058362
Bio-loaded by Horns	196736	310543	0.029181	0.0058362

We can reasonably conclude that the optimized fraction of loads in flexible PVC improving thermo mechanical properties is 9.5 Wt%.

Table 6. Optimal content and number of fibers used of bio-loads

PVC	Number of Fibers	Content (Wt%)
Bio-loaded by Coconut	32	9.5
Bio-loaded by Horns	32	9.5

For a quality mesh, the Rho and Gamma indicators must be moved away from 0 to ensure mesh accuracy. the finite element method gave us that Gamma is between 0.6 and 1, while Rho is between 0.4 and 0.8, which checks the quality of the mesh. Table 7 indicates the average Rho and Gamma criterion values obtained.

Table 7. Mean values of Rho and Gamma criterion

PVC	Gamma	Rho
Bio-loaded by Coconut	0.805	0.626
Bio-loaded by Horns	0.808	0.632

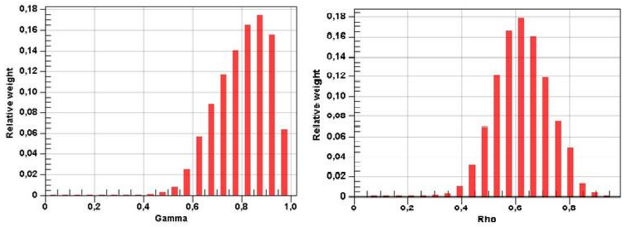


Figure 14. Distribution of indicators (Rho and Gamma) for flexible PVC bio-loaded by coconut

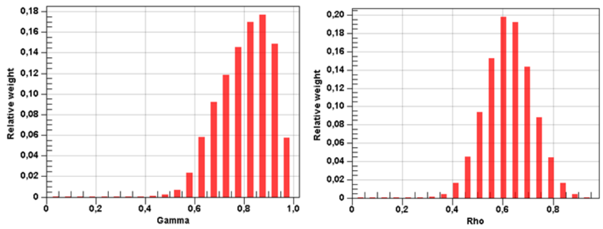


Figure 15. Distribution of indicators (Rho and Gamma) for flexible PVC bio-loaded by cow horns

4.2. Flexible PVC Under the Effect of Bio-Loads

The results of the three numerical models presented in Figures 16, 17 and 18, show the same results summarized in Tables 8 and 9.

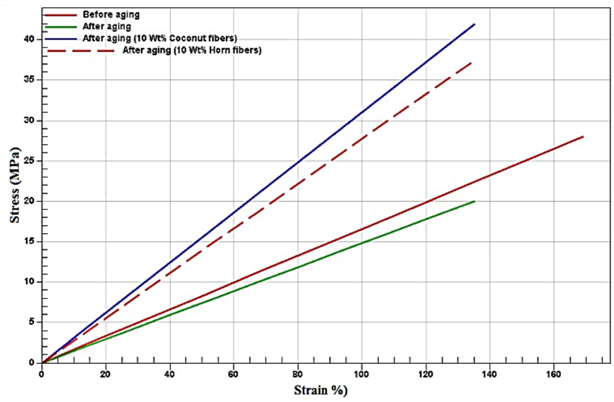


Figure 16. Tensile curves by the finite element modeling

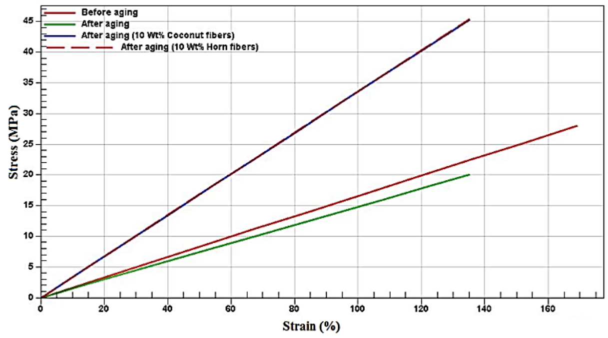


Figure 17. Tensile curves by Mori Tanaka model

The results of the numerical analysis by the three models (figures 16, 17, 18 and tables 8 and 9) on the flexible PVC aged and bio-loaded by cow horns and coconut with a percentage of 10% by weight analyzed by Mori-Tanaka and double inclusion models and of 9.5% by weight analyzed by the finite element method, show that the breaking stresses improve for a first recycling with the addition of the aforementioned bio-fillers.

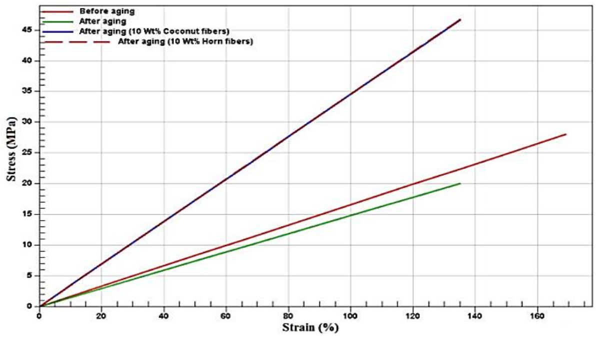


Figure 18. Tensile curves by the double inclusion model

Table 8. Numerical modeling of the stress at break for different fractions of Coconut fibers

Model	Content (Wt%)	Stress at Break (MPa)
Mori-Tanaka	0	20
	10	45.47
Double inclusion	0	20
	10	46.822
Finite element	0	20
	9.5	42.2

Table 9. Numerical modeling of the stress at break for different fractions of Horn fibers

Model	Content (Wt%)	Stress at Break (MPa)
Mori Tanaka	0	20
	10	45.517
Double inclusion	0	20
	10	46.875
Finite element	0	20
	9.5	37.5

5. CONCLUSION

After the experimental and numerical validation of an accelerated aging model which changed the mechanical characteristics of flexible PVC which were degraded by exposure to ultra-violet rays and heat. We added bio-fillers on the already degraded flexible PVC, the whole was crushed to draw samples recycled for the first time, and then numerically predict by three numerical calculation methods (finite elements, Double inclusion, and Mori-Tanaka) the behavior of the addition of its charges on this bio-charged material.

The fillers used are fibers of coconut and cow horn, at a percentage of 10% by the Mori-Tanaka and Double inclusion models and of 9.5% by weight by the finite element method leading to the performance characteristics optimal organic flexible PVC filled after aging.

the results show an improvement in the mechanical characteristics of the flexible PVC bio-filled with these two environmentally friendly fibers, which is lower in price and lighter.

In future work, by simulating other natural biofilters and using various fiber orientations, we will be able to use other numerical methods in order to check for bio composites with excellent mechanical properties.

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BIOGRAPHIES

Abdelghani Lakhdar was born in Kelaa of Sraghna, Morocco in 1981. He is a Ph.D. student at ENSET Institute, University Hassan II, Casablanca, Morocco since 2017. His research is focused on contribution to the experimental and numerical characterization of bio-based PVC subjected to aging.

Aziz Moumen was born in Inezgane, Morocco in 1987. He is a Ph.D. student at ENSET Institute, University Hassan II, Casablanca, Morocco since 2018. He has the expertise in modeling the mechanical properties of the biomaterials classified as eco composites and obtained by natural bio loading. His focus is based on contributing to solve the demands of production companies in terms of continuous improvement of industrial materials.

Khalifa Mansouri was born in AZILAL, Morocco, 1968. He got diploma from ENSET Mohammedia, Morocco in 1991, CEA in 1992 and Ph.D. (Calculation and optimization of structures) in 1994 from Mohammed V University in Rabat, Morocco HDR in 2010 and Ph.D. (Computer Science) in 2016 from Hassan II University, Casablanca, Morocco. He is now a teacher of computer science and researcher at ENSET Institute, University Hassan II, Casablanca, Morocco. His research is focused on real time systems, information systems, e-learning systems, industrial systems (modeling, optimization, and numerical computing).