THE STUDY OF A COMPOSITE MATERIAL REINFORCED WITH FLAX FIBERS PUT TO THE CREEP-RECOVERY TEST WITH VARIABLE SHEAR

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SUMMARY: This paper is dedicated to the study of the mechanical behavior of a composite material reinforced with flax fibers with an orientation ±45° with respects to the load direction and symmetrical to the median plane, during a series of 4 creep-recovery tests with variable shear stress. During the entire testing process, a creep period of 1 hour was chosen and for the recovery period a minimum of 24 hours, this being necessary for the strain stabilization of the specimen. After the received information was processed the evolution of strain deformation was further analyzed during all cycles. After the load is removed, the material has the tendency to recover to its original dimension. As the strain deformation is rising on both periods of creep and recovery, this shows us the strain deformation depends on time and that after each recovery period the cumulative plastic deformations takes place.

KEYWORDS: creep, flax, recovery, reinforcement, cumulative.

1. Introduction

In the last decades, the greenhouse effect has become a real problem for humanity and the environment. Different agricultural/transporting activities have been increasing this effect due to different activities that lead to high emissions of carbon dioxide and methane [1].

In the automotive industry, this problem led to finding new solutions to reduce fuel consumption and at the same time, the overall mass of automobiles. The mass reduction could be done by replacing the classic materials (metals, plastic, or glass) with light materials like polymers or composite materials, replacing that lead to a fuel reduction of 16% to 24%. The actual tendency is to raise the renewable resources and promote the green industry, the aim being to replace glass fibers with natural fibers, in this way the reducing mass of automobiles can be done. In comparison, the flax fiber has a density of 1.5 g/cm^3, considerably lower than the density of glass fiber, which is 2.5 g/cm^3. The utilization of natural fibers was increased in the automotive industry for non-structural and semi-structural applications, some retailers are using them for manufacturing different parts such as car seats, sound insulation panels, and linings [2].

This paper is aimed at composite materials reinforced with flax fibers. These fibers have been used in Europe for decades, centuries even in certain industries. These fibers have big potential, all studies done until now do not clarify significant number of aspects regarding the behavior of these composites. Most of the studies presented in the literature are for composites reinforced with flax fibers orientated at 0° or 90° with respects to the load direction, the orientation at ±45° being insufficiently researched to provide the potential of this material.

2. Current stage

This paper is concentrated on the study of a composite material reinforced with flax fibers symmetrically orientated at ±45° with respects to the median plane of the material, subject to a series of creep-recovery tests with variable shear stress. A creep period of 1 hour was chosen and for the recovery period a minimum of 24 hours. This test was performed at the Department of Strength of Materials, University POLITEHNICA Bucharest.

3. Creep-recovery testing

The creep represents the strain variation in time, in which the material is subjected to continuous stress [3]. The recovery from creep represents the decrease of the deformation after removing the load applied during creep [4].

The tested composite material is found in the literature under the name of „angle-ply” due to the symmetrical orientation of the reinforcing fibers at ±45° against the median plane, the reinforcing angle being alternating and different from 0° and 90° [5].

3.1. Method and machinery

A test bench with a double lever mechanism was used for loading during testing, shown in Fig. 3.1, on which a force cell was mounted, shown in Fig. 3.2, and a data acquisition box was used for recording the experimental data, shown in Fig. 3.3.

The machine used for testing is a test bench with levers, with an amplification factor of 26, shown in Fig. 3.1. His components are: 1 – jack to facilitate the application of weights; 2 – counterweight for force balancing in the unloaded position; 3 – levers: 4 – force cell; 5 – grips; 6 – upper tank adjustment crank; 7 – pan.

The load cell is a transducer that converts force into a measurable electrical output [6]. The load cell used, shown in Fig. 3.2, is dedicated to measuring the tensile and compression force up to 20kN. In the load cell is a calibrated elastic element mounted with four strain gauges, two for tensile and two for compression mounted in a Wheatstone bridge, in this way the membrane and strain gauges are elastically deformed by the force applied on one of the two measuring directions [7].

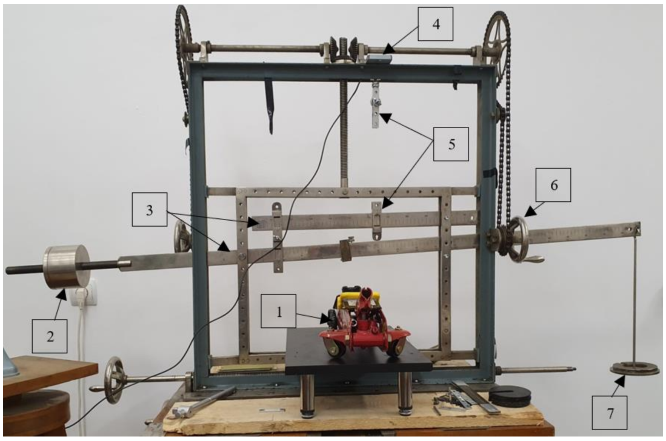

Fig. 3.1 Test bench with levers

Fig. 3.2 Load cell

The method used during the experiment is resistive tensiometry for strain recording. A specimen was mounted on the test bench, equipped with aluminum plates on each end for facilitating the mounting procedure, with two strain gauges for the measuring directions (longitudinal and transverse), along with a dummy specimen used for eliminating compensating possible errors that can appear due to bending, or environmental factors, such as temperature and humidity.

The load cell and the two test bars are connected to the data acquisition system HBM MX840B, shown in Fig. 3.3, connected to a computer for the transmission and recording of the force and deformation using the following 3 channels: channel 1 is used for recording the data from the load cell, channel 2 for recording the longitudinal strain and channel 3 for the transverse strain.

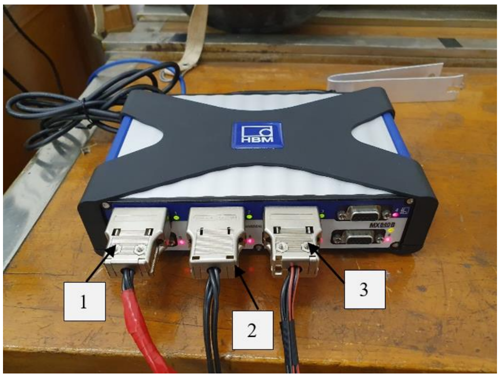

Fig. 3.3 Data acquisition system HBM MX840B

3.2. Preparation and testing

Preparation of the test bars was done by mounting the strain gauges for each direction (longitudinal and transverse). The mounting was done using the following steps: drawing of guidelines for accurate strain gauge positioning, cleaning of the surface with acetone, and gluing them using a cyanoacrylate adhesive. The adhesive was left to dry for at least 24 hours.

After this period, soldering terminals were attached, on which the wires connected to the data acquisition system were welded. This was done to ensure that any improper management of the wires would not pull on the strain gauges directly and to avoid breaking them.

The correlation of the homologous strain gauges found on the two specimens (test and dummy) was done by connecting the wires so the longitudinal direction from each test bar is identical, as well as the transverse direction, these being connected in full Wheatstone bridge in the data acquisition system. The Wheatstone bridge is an electric circuit that contains electrical resistance mounted in series and parallel, used for measuring the unknown electrical resistance by balancing two legs of the bridge circuit [8].

In Fig. 3.4 the test bar dimensions with aluminum plates are presented and in Fig. 3.5 the fully equipped test bar.

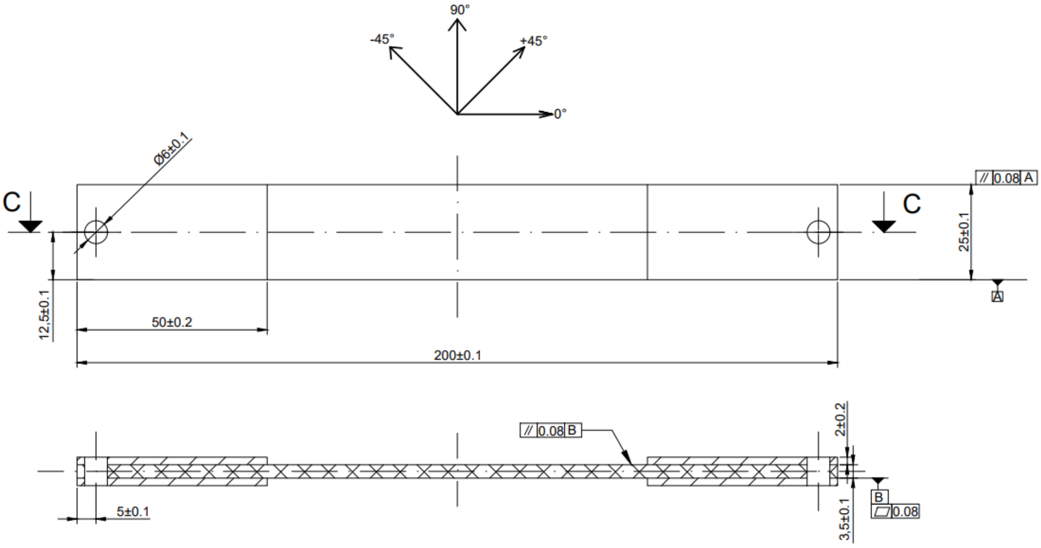

Fig. 3.4 Specimen dimensions

Fig. 3.5 Fully equipped test bar

The test parameters of the 4 cycles are shown in Table 3.1. The test was done at medium humidity of 50% and a laboratory's ambient temperature of 23ºC. A period of 1 hour was chosen for creep and for the recovery period a minimum of 24 hours, this being necessary for the stabilization of the specimen. The creep shear stresses have been chosen based on the shear strain-shear stress curves presented by Stochioiu et al. [10], so that as many cycles as possible can be achieved and failure can be avoided during testing. Obtaining the creep stress was achieved by determining the necessary force developed and amplified by a series of weights, weights that were placed on the plate of the test bench.

Table 3.1 Test parameters

Crt. Nr.	Creep stress τ [MPa]	Force F [N]		Creep period [hours]	Recovery period [hours]	Recording frequency [Hz]	Effective creep stress $\tau_{efectiv}$ [MPa]
		Calculated	Applied				
1	5	811.13	850.15	1	95 ore 35 min	2	5.19
2	10	1622.26	1652.30		24 ore 35 min		10.18
3	15	2433.39	2464.27		44 ore 36 min		15.19
4	20	3244.52	3270		94 ore 55 min		20.15

The effective creep stress was calculated using the relation (3.1) and the applied force using the relation (3.2), obtained from the first relation [9].

$$\tau_{12} = \frac{F_i}{2A} \quad (3.1)$$

- where: τ_{12} – shear stress [MPa]; F_i – applied force at „i” moment [N]; A – section area [mm^2], with A=81.11 mm^2.

$$F_i = 2 * A * \tau_{12} \quad (3.2)$$

3.3. Experimental results

During testing, due to the long period, more than 2 million data points were recorded, for the 4 cycles, these being processed using MATLAB R2021b.

Due to the orientation of the flax fibers at ±45º, the determination of the shear strain was made with the relation (3.3) [4].

$$\gamma_{12i} = \varepsilon_{Xi} - \varepsilon_{Yi} \quad (3.3)$$

- where: γ_{12i} – strain deformation at „i” moment [%]; ε_{Xi}– longitudinal deformation at „i” moment [%]; ε_{Yi} – transverse deformation at „i” moment [%] [4].

After the data was processed, the evolution chart of shear strain γ on the entire testing period was made and shown in Fig. 3.6. Can be seen that the strain deformation has a time dependency, this being confirmed by the testing done by Stochioiu et al. [10].

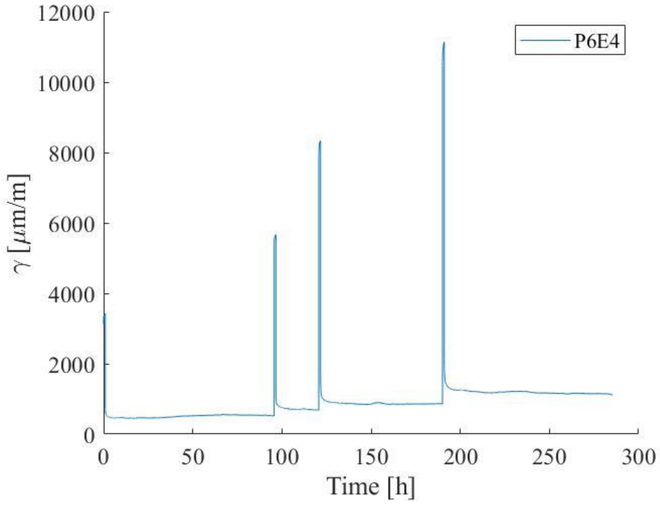

Fig. 3.6 Strain deformation during testing

From the signal, the creep period (see Fig. 3.7) and the recovery period (see Fig. 3.8) have been extracted. During the creep period, the evolution of strain deformation confirms the time dependency and the range of values is similar to the one during the mechanical characterization done by Stochioiu et al. [10].

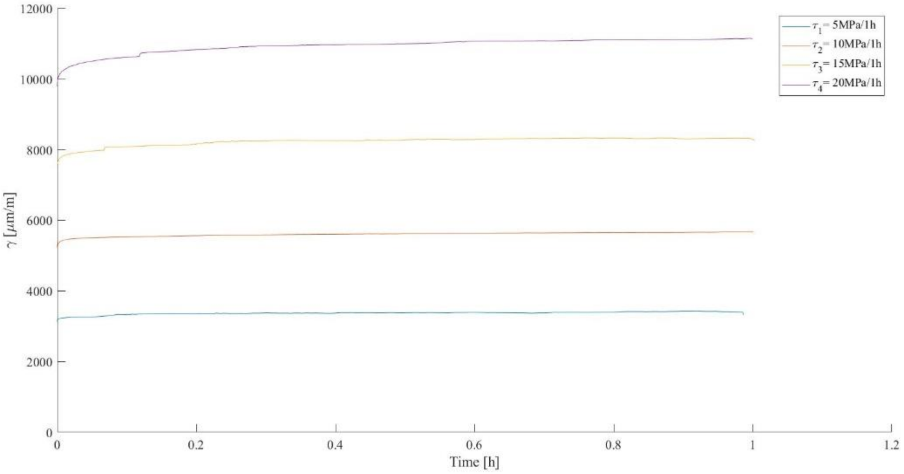

Fig. 3.7 Strain deformation during creep

The tendency of the material to return to its original form can be seen in Fig. 3.8, but taking into consideration that, during the recovery period the specimen is not loaded and the strain deformations are increasing, can be concluded that they are form during the creep periods and they are constant during recovery periods. This is possible due to the sliding of microfibrils and their tendency to progressive alignment with the load direction, leading to plastic deformations, this being a characteristic of viscoelastoplastic behavior [11].

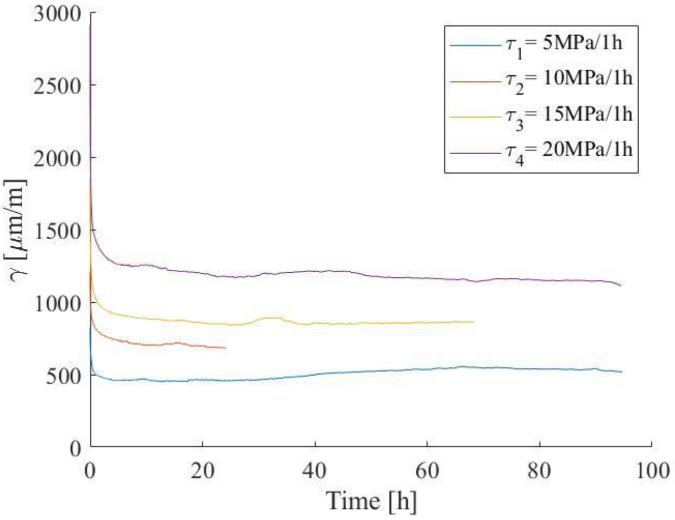

Fig. 3.8 Strain deformation during recovery

As was mentioned, at the end of all recovery periods, plastic deformations are present. They have been extracted and shown in Fig. 3.9. The chart's abscissa was done using the values of creep shear stress, at logarithmic scale, and chart's ordinate was done using the values obtained for plastic deformations, at linear scale so the linear evolution can be observed. Their presence confirms the time dependency of the strain deformations.

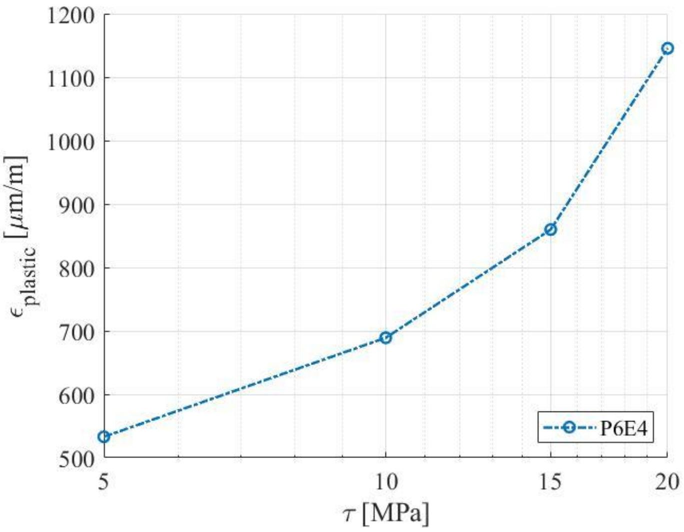

Fig. 3.9 Cumulative plastic deformations

4. Conclusions

In this paper was done and presented the study of the mechanical behavior of a composite material reinforced with flax fibers symmetrically orientated at ±45° along the median plane. This material was subject to a series of 4 creep-recovery tests with variable shear. During the entire testing process, a creep period of 1 hour was chosen and for the recovery period a minimum of 24 hours, this being necessary for the stabilization of the test bar, the test is done at the laboratory's ambient temperature of 23°C and medium humidity of 50%.

After the test was done more than 2 million data points were registered with a registration frequency of 2Hz, processed, and rarefied using Matlab R2021b.

Processing the experimental data allowed us to determine and observed the strain deformation evolution during the entire testing, also its time dependency, being extracted the necessary information for observing the mechanical behavior during the creep and recovery periods. So it can be seen that in every creep period a strain deformation is presented as being constant during every recovery period. The material has the tendency to return to its original form after the load is removed, but because of the microfibrils' tendency to slide and rotate along the load direction, the strain deformation from one cycle to another is increasing due to the presence of plastic deformations.

After this observation at the end of each recovery period, the plastic deformations have been extracted, strengthening the argument that the studied composite material has a time-dependent strain deformation and also a viscoelastoplastic behavior.

5. References

[1] *** - „Efectul de seră”, Valid at: https://ro.wikipedia.org/wiki/Efect_de_seră, access at 19.03.2022.

[2] M. Pervaiz, S. Panthapulakkal, B. KC, M. Sain, și J. Tjong, „Emerging Trends in Automotive Lightweighting through Novel Composite Materials”, *Mater. Sci. Appl. Sci. Res. Publ.*, vol. 07, nr. 01, pp. 26-38, 2016, DOI: 10.4236/msa.2016.71004.

[3] *** - „Fluaj”, Valid at: http://www.dex-tex.info/dictionartextil/id.Fluaj/i.html, access at 10.02.2022.

[4] *** - „Revenirea din fluaj”, Valid at: http://www.dex-tex.info/dictionartextil/id.Revenire+din+fluaj/i, access at 10.02.2022.

[5] P. K. MALLICK, *Fiber-reinforced composites: materials, manufacturing, and design*. CRC press, 2007, DOI: 10.1201/9781420005981 .

[6] ***, „Load cell”, Valid at: https://en.wikipedia.org/wiki/Load_cell, access at 30.03.2022.

[7] HBM, „Mounting Instructions - U9B”. [Online]. Valid at: https://www.manualslib.com/manual/1374974/Hbm-U9b.html#manual.

[8] *** - „Wheatstone Bridge”, Valid at: https://en.wikipedia.org/wiki/Wheatstone_bridge, access at 28.03.2022.

[9] ASTM, „D3518/D3518M-18 - Standard Test Method for In-Plane Shear Response of Polymer Matrix Composite Materials by Tensile Test of a ±45° Laminate”, 2018. DOI: 10.1520/D3518_D3518M-18.

[10] C. Stochioiu, A. Deca, A. Hadar, și H. Gheorghiu, „In-plane Shear Response of a Flax Fiber-epoxy Resin Composite Subjected to Repeated Loading and Creep-recovery Cycles”, *Mater. Plast.*, vol. 58, no. 4, pp. 179-186, 2021, DOI: 10.37358/MP.21.4.5543.

[11] K. Charlet, C. Baley, C. Morvan, J. P. Jernot, M. Gomina, și J. Bréard, „Characteristics of Hermès flax fibers as a function of their location in the stem and properties of the derived unidirectional composites”, *Compos. Part A Appl. Sci. Manuf.*, vol. 38, nr. 8, pp. 1912-1921, 2007, DOI: 10.1016/j.compositesa.2007.03.006.