Adding Fillers to Change the Mechanical Behaviour of the Glass Composite Materials

Camelia CERBU, Horatiu TEODORESCU and Luminita SCUTARU

Abstract— **The paper proposes a way of using of the recycled rubber as filler to manufacture a hybrid composite material based on epoxy resin reinforced with glass woven fabrics. Two composite materials are analysed: an epoxy composite material reinforced only with glass fibres; a hybrid composite reinforced both with glass fibres and recycled rubber. The same kind of glass woven fabric is used in both cases. One comparatively presents the mechanical characteristics of these composite materials, measured in: flexural test by using the method of the three points and impact testing. Additionally, the modulus of elasticity E and maximum normal stress σ are determinate in tensile test in case of the new hybrid composite. Moreover, it was analysed the free vibrations of a rectangular plate made of the hybrid composite. Finally, the natural frequencies and the damping factor were obtained. One observed that additionally reinforcing with rubber particles lead to the increasing of the impact strength.**

Index Terms— **glass; rubber; flexural test; tensile test, recycling.**

I. Introduction

Papers published during the last years in the field of the composite materials, marks out the concerns in the direction of the using of the recycled materials as fillers to manufacture new composite materials.

One of the first field of application of such kind of fillers was civil construction by incorporation of the recycled materials from vegetable waste in a matrix based on polymer-modified cement [1].

The most works [2, 3] had already shown the manufacturing methods and experimental results concerning to the mechanical behaviour in case of the composite materials filled with wood flour obtained by recycling of the wood wastes. The lignocelluloses fibres are usually treated with coupling agents and then, these are mixed with high-density polyethylene [2] to manufacture composite materials. It was shown [3] that the nature of wood flour (wood specie) is very important in case of the composite structures that are mechanically loaded in humid environment.

Another paper [5] took into consideration the thermo-mechanical recycling of post-consumed plastic bottles, especially the ones made of polyethylene terephtalate (PET), and its use as composite materials for engineering applications.

Also, it wasn't neglected the topic of manufacture of the composite materials filled with particles obtained by recycling of the discs of type CDs / DVDs [6].

On the other hand, the aluminium wastes could be used to manufacture an hybrid sandwich structure having CFRP laminates as core material and aluminium as skin like the one analysed in the work [7].

Recent experiments [8] showed that incorporating of the rubber particles as aggregates in cement composites, was detrimental to compressive and to tensile strengths. It also induced a significant decrease of the modulus of elasticity.

To improve the mechanical characteristics of the composites reinforced with glass fibres, the present work proposes the incorporating of the milled recycled rubber at the interface area between layers made of glass woven fabric. Taking into account the local problems in composites [9], the mechanical testing of such new hybrid composite became a necessity.

To be able to evaluate the performances of the new composite material from the mechanical behaviour point of view, some mechanical tests were carried out: flexural test, tensile test, an impact test (Charpy test), free vibration testing of a rectangular plate. Moreover, some mechanical characteristics are compared with the ones obtained in case of the composite reinforced only with glass woven fabric.

II. Materials Tested And The Method Of Work

The first of all, an epoxy resin was used to manufacture three composite plates having the dimensions 470 x 270 mm^2: one plate was reinforced only with glass woven fabric; the other two plates were reinforced with both glass woven fabric and milled recycled rubber.

Table I. Coding of the specimens made of composite materials filled with wood flour that was tested

No.	Code of the specimens	Resin	Reinforcement
1	WE1R_01....WE1R_10	epoxy resin	E-glass woven fabric (8 layers) + recycled rubber
2	WE1_01... WE1_10		E-glass woven fabric (8 layers)

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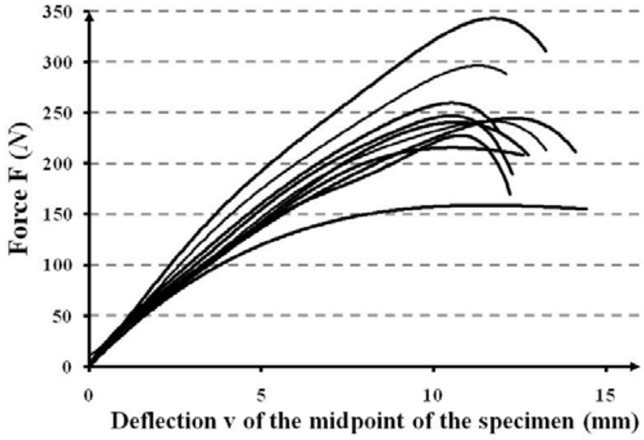

Fig. 1. F-v curves recorded in flexural test in case of the composite WE1 reinforced only with glass woven fabric

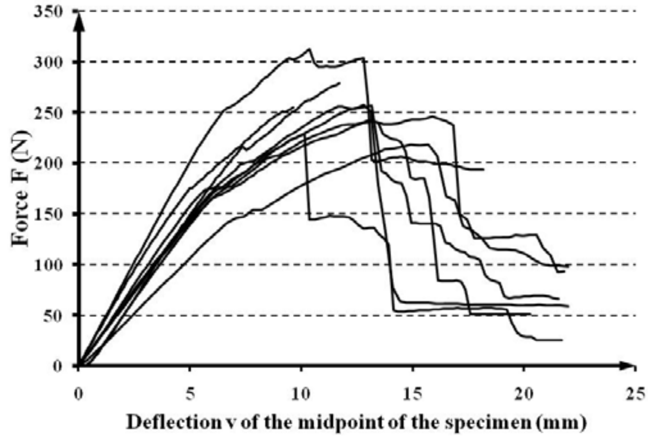

Fig. 2. F-v curves recorded in flexural test in case of the composites WE1R filled additionally with rubber

The composition of the composite materials tested and their codification are shown in Table I. Notation WE1 shows that glass woven fabric is made of E-glass fibres and R denotes rubber used as filler material.

The both composite material contained eight layers of E-glass woven fabric and the same volume of the epoxy resin. To accelerate the polymerisation process, a hardener agent was certainly mixed with the epoxy resin before the adding of the milled recycled rubber.

Moreover, aluminium oxide in form of power (63 μm) was used to improve the interaction between the epoxy resin and the glass woven fabric in case of the composite that doesn't contain rubber.

The plates were kept at room temperature and dried environment for three weeks. Then, the specimens were cut from the plates for the flexural test (three-point method), tensile test and Charpy test (impact test) according to the European standard [10-12].

LR5K Plus (maximum force F_{max} = 5 kN) machine manufactured by LLOYD Instruments, was used for the flexural test and LS100*Plus* machine (maximum force F_{max} = 100 kN) was used for tensile test.

The speed of loading was 1.5 mm/min during the both bending (flexural test) and tensile test. Before each test of a specimen, the dimensions of its cross-section were accurately measured, the measuring accuracy being equal to 0.01 mm.

These were considered as input data in the software program of the machine. In case of the flexural test, the testing equipment allowed us to record pairs of values (in form of files having 100-150 recordings): force F and deflection v at midpoint of the specimen. The testing machine also gave us the results of a statistical calculus for the set of the specimens tested. Therefore, the average values of the following quantities could be accuracy computed: Young's modulus E in flexural test; flexural rigidity EI_z; maximum bending stress σ_{max} at maximum load; mechanical work W done until the maximum force, deflection v_{max} at maximum load etc.

In the same manner, the testing machine recorded pairs of values during the tensile tests: tensile force F and elongation Δl of the tensile specimen. It may note that to obtain more data about mechanical behaviour in tensile test, an extensometer is initially mounted on each tensile specimen tested. The extensometer is a strain-measuring device used to record data concerning to the changing of the normal strain ε during testing. The soft of the testing machine allows the statistical calculus of the average values of some quantities: elastic modulus E (Young's modulus); tensile rigidity EA; maximum normal stress σ_{max}; elongation Δl; maximum normal strain ε_{max}; mechanical work done by the applied force or the strain energy stored U and so forth.

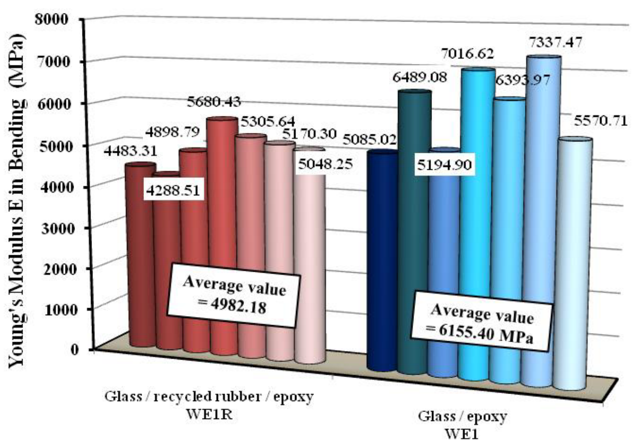

Fig. 3. Values of Young's modulus E measured in flexural test

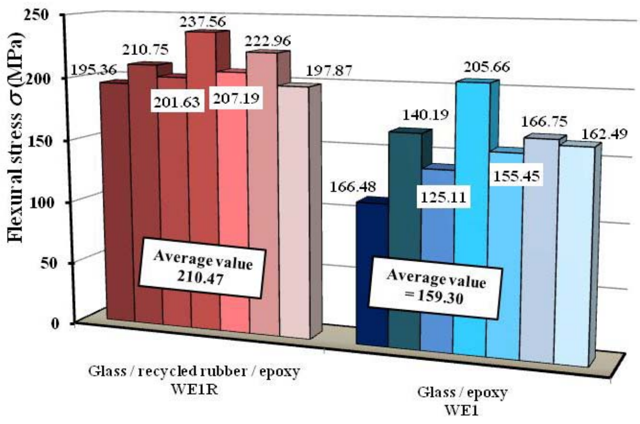

Fig. 4. Maximum values of normal stress σ_{max} recorded in flexural test

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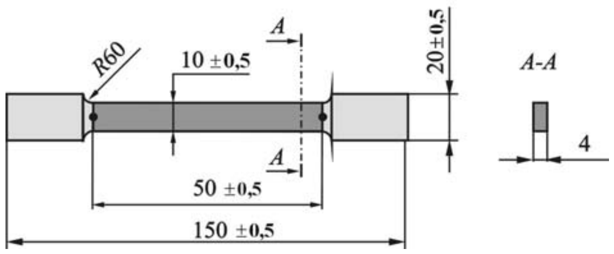

Fig. 5. Shape and dimensions of the specimens for tensile test

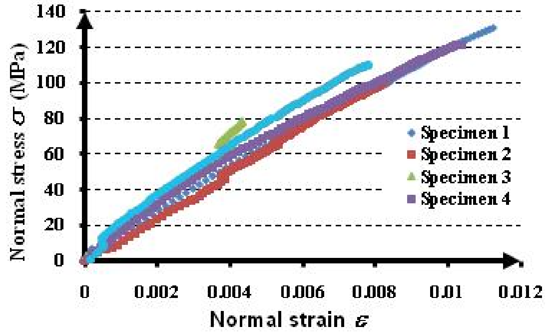

Fig. 6. Stress-strain curves (σ-Ɛ) recorded in flexural test in case of the specimens made of polyester resin

In respect of the Charpy impact test, the notched specimen having rectangular shape 80x10x4 according with [11], is simply supported at its ends while the pendulum hammer hits the specimen on the opposite side of the notch.

The notch of type B whose dimensions and shape are as per [12], is usually introduced into the material specimen in order to produce a stress concentration and thus promote failure in the case of the ductile materials. Moreover, the notch may be used to align the Charpy specimen with respect to the simple supports. The dimensions of the notched cross-section were recorded for each specimen before impact testing. Then, the specimens were subjected to Charpy test.

The impact is produced by swinging the pendulum hummer against the test specimen from a height h. When it is released the hammer swings through an arc, hits the target specimen and after fracturing, it reaches a height h'. The difference between the initial energy and the remaining energy represents a measure of the energy required to fracture the specimen. This quantity is called failure energy in Charpy test and it is denoted by W.

The failure energy W was measured and recorded automatically by the testing equipment, in case of each specimen tested. Finally, the impact strength of each composite specimen was computed by using the following formula:

$$K = \frac{W}{A}, \quad (1)$$

where A represents the aria of the specimen cross-section where the notch is manufactured.

To experimentally analyse the free vibrations of the second hybrid composite plate, it was cut so as its final dimensions were 440x240 mm^2. The mass of this plate was 0.488 kg. The testing method used consists in the hitting in the middle of the plate, with an impact hammer specially designed for soft structures. The replications to the vibrations of the rectangular plate was acquired by using of four accelerometers that record the signal on the transverse direction to the composite plate. These accelerometers were symmetrically located with respect to the middle of the plate where the impact hammer hits. The signals acquired by accelerometers were displayed on the monitor and then, applying the frequency response function, the values of the first natural frequencies and corresponding damping factor were obtained.

III. Results And Discussions

The force-displacement curves (F-v) recorded in case of all specimens subjected to the flexural test, are shown in the figures 1 and 2, respectively. The elastic modulus E was computed by using the linear portion of the F-v curves and the values obtained in case of all specimens tested are shown in the figure 3. On the other hand, the maximum values of the normal stress σ_{max} are graphically shown in the figure 4.

It may observe that the additionally reinforcing with milled recycled rubber leads to an increasing with 23.55% of the modulus of elasticity E (fig.3). On the other hand, the maximum value of the normal stress σ_{max} decreases with 24.31% (fig.4).

Then, the tensile specimens (fig. 5) made of hybrid composite material WE1R (glass fabric / rubber / epoxy), were subjected to tensile test. Fig. 6 presents the stress-strain curves (σ-Ɛ) based on electronic data recorded from tensile testing machine by using the corresponding Nexygen Plus soft. The tensile modulus E was computed again on the linear portion of the σ - Ɛ curve. The mechanical characteristics determinate in tensile test are shown in the Table II. It may observe the greater deviations of the values recorded in case of the third specimen with respect to the other ones. Neglecting the results obtained for this specimen, the average values of the main mechanical characteristics are obtained: Young's modulus E=8300.62 MPa; maximum normal stress σ_{max}=115.85 MPa.

Table III shows the results concerning to the impact strength K obtained during the Charpy test. It may remark that additionally reinforcing with milled recycled rubber, leads to the increasing of this characteristics with 67.5 %.

Table II. Values of some mechanical characteristics determinate in tensile test in case of the composite with rubber WE1R

No. Specimen	Young's Modulus E (MPa)	Maximum Force F_{max} (N)	Stress σ at Max. Load (MPa)	Extension Δl at Max. Load (*mm*)	Strain ε at max. Load	Work W to max. Load (N·mm)
1	7488.04	2749.11	131.54	0.5691	0.01138	843.978
2	7526.89	2602.98	100.11	0.4155	0.00831	551.993
3	10082.95	1749.67	78.81	0.2174	0.00435	178.984
4	8969.28	2674.84	121.58	0.5232	0.01046	794.607
5	9218.25	2368.15	110.15	0.3886	0.00777	513.107

Table III. Values of the impact strength K=W/A determinate in Charpy impact test in case of the two composites

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No. of specimen	Resilience W / A (kJ/m^2)	
	WE200-glass / recycled rubber / epoxy	WE200-glass / recycled rubber / epoxy
1	70.31	111.20
2	63.19	111.26
3	81.25	134.32
4	81.25	113.38
5	63.19	107.64
6	60.48	94.69
7	75.00	139.37
8	81.99	113.23
9	82.51	145.43
10	62.54	138.54
Average value	72.17	120.91

In respect of the free vibration testing, the first value of the natural frequency recorded was equal to 15.544 Hz. Fig. 7 shows the changing of the damping factor with respect to the natural frequencies in case of the rectangular plate made of hybrid composite material denoted with WE1R.

By using a digital microscope with USB connexion, some photos (Fig. 8) of the cross-section of the specimens are acquired.

The photo of the cross-section of the specimen made of hybrid composite (Fig. 8.b) shows that two layers reinforced with glass woven fabric are separated with a layer made of milled rubber / epoxy.

IV. Conclusions

One could remark that in case of the composite material additionally reinforced with recycled rubber, the resilience K (impact strength) was greater (120.91 KJ/m2) than the corresponding value obtained in case of the composite material reinforced only with glass woven fabric when the average value recorded was equal to 72.17 kJ/m^2 .

This new composite material also showed good mechanical characteristics in the both flexural test and tensile test.

The work also showed the results concerning the values of the natural frequencies and the corresponding damping factors.

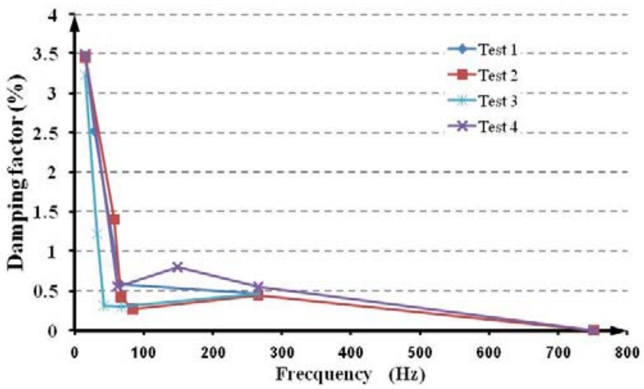
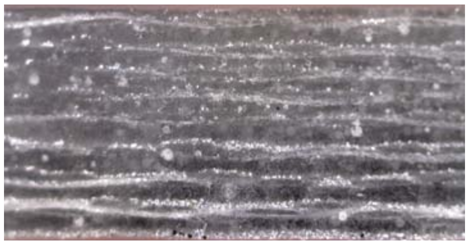


Fig. 8. Damping factor versus frequency in case of the plate made of composite WE1R



a.

b.

Fig. 8. Photos (by using a digital microscope) of a cross-section of the composite material: a.WE1; b. WE1R

It follows that to improve the impact strength K of the composite material based on such epoxy resin reinforced with glass woven fabrics, recycled rubber should be used to additionally reinforce the resin.

From ecological point of view, the using of the milled rubber obtained from shredded non-reusable tires represents a research subject of a great interest during the last years.

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