Mechanical Characterization of the Glass Fibres / Rubber / Resin Composite Material

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The paper proposes a way of using of the recycled rubber for the manufacturing of a hybrid composite material based on epoxy resin, reinforced both with glass woven fabrics and with recycled rubber. One presents the mechanical characteristics of this composite material, measured in: flexural test by using the method of the three points and impact testing with Charpy pendulum. The work also describes some aspects concerning to the effects of the water absorption on the mechanical behaviour in flexural testing after 2980 h (124 days) of immersion in water, at room temperature. Finally, the experimental results obtained were comparatively analysed for both the dried and wet specimens. One could remark a degradation of the mechanical characteristics (elastic modulus E, flexural strength σ, mechanical work W until the maximum force). Concerning the impact behaviour, it was measured the failure energy U and then computed the resilience K (impact strength). It was observed that additionally reinforcing with rubber particles leads to the increasing of the resilience K.

Keywords: hybrid composite; recycled rubber; absorption; bending; impact

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

The most works [1, 2] had already presented the results concerning the manufacturing of the composite materials filled with wood flour obtained by recycling of the wood wastes. Usually the wood flour treated with coupling agents is mixed with high-density polyethylene [1]. The work [2] showed the effects of the nature of wood flour (wood specie) on the mechanical characteristics of such composite materials especially when these are used in humid environment [3].

The incorporation of the recycled materials from vegetable waste in a matrix based on polymer-modified cement is a feasible alternative that has gained ground in civil construction [4].

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 was not neglected the topic of manufacture of the composite materials filled with particles obtained by recycling of the discs of type CDs / DVDs [6].

Of great interest for the objective of the present research was a recent scientific work [7] which focused on the designing a cement composite exhibiting a high level of deformation before macro cracks appear by incorporating of the rubber tyre particles, partly replacing the natural sand aggregates. The experiments showed that incorporating rubber particles as aggregates was detrimental to compressive and to tensile strengths but, it induced a significant decrease of the modulus of elasticity and it was beneficial in terms of deformation.

Taking into account the above idea concerning the using of the rubber particles, the present work proposes the using of such particles to additionally reinforce a composite material reinforced with glass fibres. The main purpose consists in the incorporating of the rubber particles at the interface area between layers made of glass woven fabric, to improve the mechanical characteristics taking into account the local problems in composites [8]. To be able to evaluate the performances of the new composite material from the mechanical behaviour point of view, two mechanical tests were carried out: flexural test by using the method of the three points and an impact test (Charpy test). Moreover, the paper analyses the effects of the moisture on the mechanical behaviour in flexural test after long time immersion in water.

Experimental part

Materials

The first of all, a laminated composite plates having 4 mm in thickness, was manufactured by using the E-glass woven fabric to reinforce an epoxy resin mixed with fir wood flour. The hybrid composite material contains eight layers of E-glass woven fabric as it is shown in the figure 1. Moreover, figure 2.a shows a photo of a cross-section of the laminated composite material by using a digital microscope (100x). The recycled rubber in form of particles whose dimensions are smaller than 500 μm, was obtained by recycling the wastes of automotive tyres. Figure 2,b shows the homogeneity of the structure obtained by mixture of recycled rubber with the resin. The weight ratio of the reinforcement materials (glass woven fabric and wood flour) was equal to 34%. To initiate and to accelerate the polymerisation process, a hardener agent was certainly mixed with the epoxy resin before of the admixture of the wood flour.

A lower forming pressure was used to manufacture the plate by using hand lay-up technology.

The epoxy resin is widely used for manufacturing of the laminated composite materials by handing lay-up technology, injection with low pressure and filament wrapping. This kind of resin has a good behaviour for impregnation of timber. The physical and chemical characteristics of the epoxy resin in liquid state are shown

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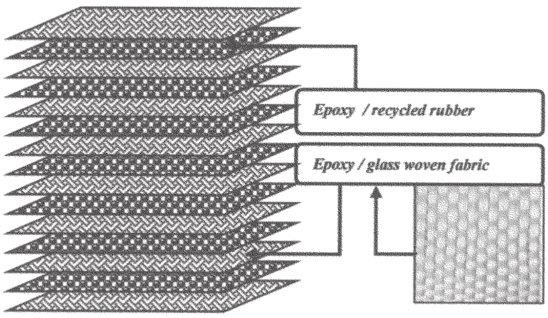


Fig. 1. Structure of the laminated composite material tested

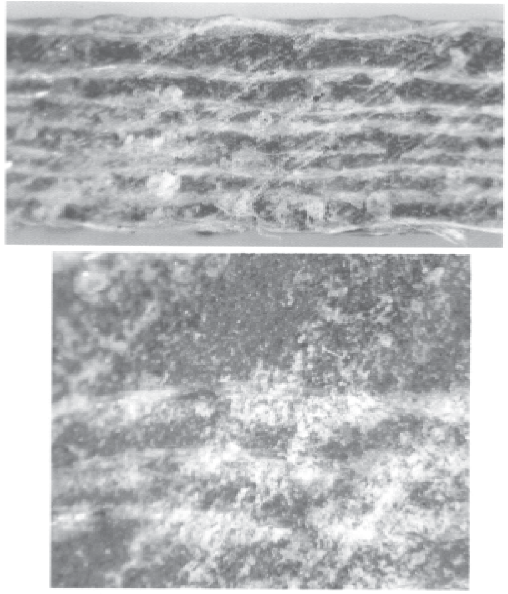


Fig. 2. Photos of a cross-section of the laminated composite material by using a digital microscope: a.100x; b. 200x

Table 1
PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE EPOXY RESIN USED, IN LIQUID STATE [9]

Characteristic	Value	Unit of measure	Method
Density, 25 °C	1.15	g/cm^3	ISO 1675: 1985
Viscosity, 25 °C	1550	mPa·s	Brookfield LVT
Mixture ratio with hardener agent	32 (weight ratio) 38 (volume ratio)	%	-
Gel-time, at 23 °C (100 g resin + 32 g hardener)	2.5	Hours	-
Manipulation time (100 g resin + 32 g hardener)	60	Minutes	-
Glass transition temperature	80	°C	ISO 11359: 2002°C9188

Table 2
MECHANICAL CHARACTERISTICS OF THE EPOXY RESIN (WITH HARDENER) WITHOUT REINFORCING [9]

Characteristic	Value	Unit of measure	Method
Tensile stress in tension	70	*MPa*	ISO 527: 1993
Flexural stress	120	*MPa*	ISO 178: 2001
Modulus of elasticity E	3100	*MPa*	ISO 178 :2001
Impact strength - Charpy (unnotch specimen)	40	kJ/m^2	ISO 179
Elongation in tensile test	5	%	ISO 527: 1993
Toughness	83	Shore D15	ISO 868: 2003

in the table 1 while the mechanical characteristics of the same resin without reinforcing are shown in the table 2. Analysing its properties, one may remark that this resin has: lower viscosity, good mechanical properties. It has also a good behaviour in wet environment [9].

Work method

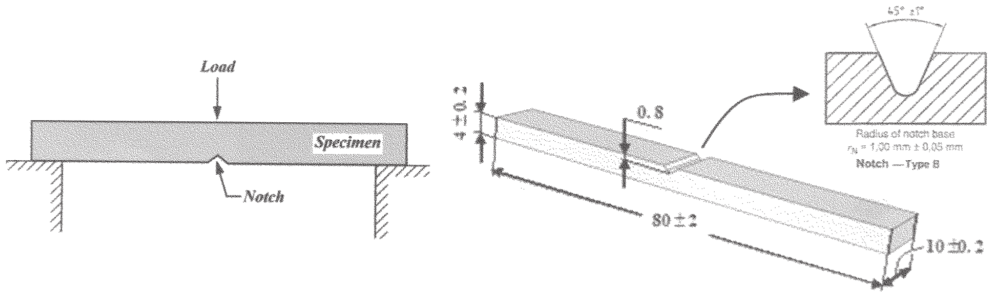
The both kinds of specimens, for the flexural test and Charpy test, were cut from the plate. The specimens have parallelepiped shape whose dimensions were 80mm x10mm x 4mm (thickness) taking into account the recommendation of the European standards for the flexural test by using the method of the three points [10] and the Charpy test [11] in case of the reinforced plastic materials.

Before bending test, some specimens were immersed in water at room temperature. The water absorption was periodically recorded by considering of recommendations of the actual European Standards [12].

With this purpose in view, all specimens were firstly, before immersion, dried during 3 days at 40°C. Then, some specimens made for the flexural test were immersed in water at room temperature, for 2980 h (≈ 4 months and 4 days). The water tanks were covered to minimise evaporation and the water was changed every month to keep conditions constant. To monitor the uptake of water, quantified by the moisture content m, the specimens were periodically removed from the tanks, dried superficially with absorbing paper and weighted on an electronic balance (maximum mass 250 g) accurate within ± 0.0001 g.

After immersion, both the dried and wet specimens were subjected to flexural test by using the method of the three points. The results obtained (Young's modulus E, maximum flexural normal stress σ_{max}, mechanical work W to maximum force) in case of the wet specimens were compared with the ones obtained in case of the dried specimens (blank test).

The testing equipment used for flexural test consists of hydraulic power supply. The maximum force capacity is ±15 kN. During the flexural tests, the speed of loading was 1.5 mm/min..



a. b.

Fig. 3. Specimen used for Charpy test:
a.Scheme of loading;
b. Shape and dimensions of the specimen

Before each flexural test of a specimen, the dimensions of the cross-section were accurately measured and then, they were considered as input data in the software program of the machine. The testing equipment allowed us to record pairs of values (force F and deflection v at midpoint of the flexural specimen) in form of files having 200-300 lines. Therefore, the average values of the following quantities could be computed with accuracy: 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 respect of the Charpy test, figure 3.a shows the scheme of loading used in this test while the dimensions of the specimen are shown in figure 3.b, according to [11]. The notch 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. Herein, the notch type B [11] is made (fig. 3.b). Moreover, the notch may be used to align the Charpy specimen with respect to the simple supports of the Charpy pendulum so that the pendulum hammer hits the specimen on the opposite side of the notch.

The dimensions of the 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, it 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 *U*.

The failure energy *U* was measured and recorded automatically by the testing equipment, in case of each specimen tested. Finally, the resilience (also called the impact strength) of each composite specimen was computed by using the following formula:

$$K = U / A \qquad (1)$$

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

Results and discussions

Absorption data

The absorption data recorded for composite material analysed is shown in figure 4. The average value of the percentage of the absorbed water was equal to 1.67 % after 2980 h of immersion. The cause of the small quantity of moisture absorbed may be assigned to hydrophobe nature of the rubber.

After immersion in water, no spots or colour changing were observed on the cut edges of the specimens.

Mechanical characteristics in flexural test

Experimental results recorded during bending tests, may be graphically drawn by using *F*–v coordinates where v

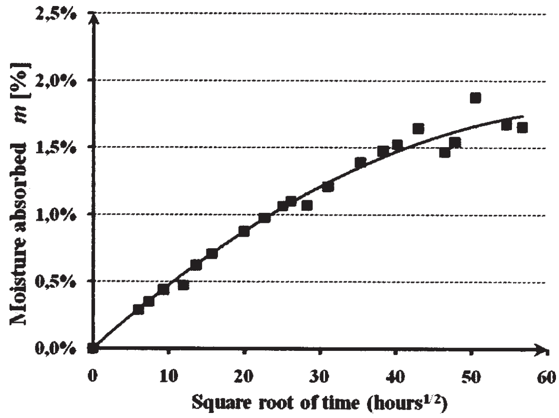


Fig. 4. Data of the absorbed moisture during immersion in water

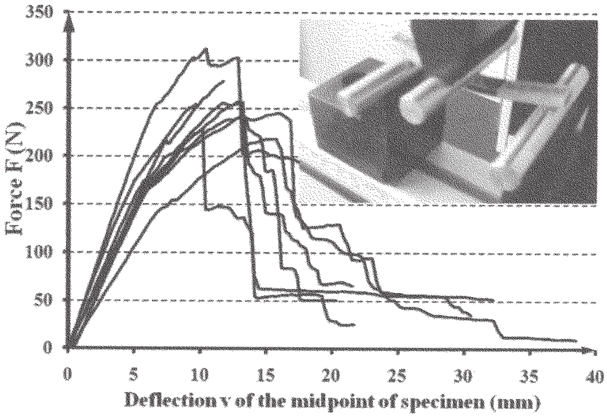


Fig. 5. Force-deflection F-v curves recorded in flexural test

represents vertical deflection of the midpoint of the specimen. Figure 5 shows these curves in case of the dried specimens. It may be noted that Young's modulus was computed for data points located on the linear portion of the *F*–v curve (for v=1÷4.5 mm) like the european standards [10] recommends.

The changing of some mechanical properties after immersion in water for 2980 h, is graphically analysed for: Young's modulus E (fig. 6); maximum flexural stress σ_{max} (fig. 7); mechanical work W done to maximum force (fig.8).

One may observe that Young's modulus E (fig. 6) decreases from 4982.18 MPa down to 3872.89MPa (with 22.27 %) after 2980 h of immersion in water. In the same manner, the maximum flexural stress σ_{max} (fig. 7) decreases from 210.47 MPa down to 141.54 MPa (with 32.75%). Analysing figure 8, one may observe that the average value of the mechanical work *W* done until the maximum force, recorded also a decreasing from the value 1927.97 N·mm down to the value 1467.64 N·mm (with 23.88 %).

From F-v curves recorded in flexural test one could remark that the maximum force F_{max} decreased with 16.78 %, from the mean value 248.17 N (dried specimens)

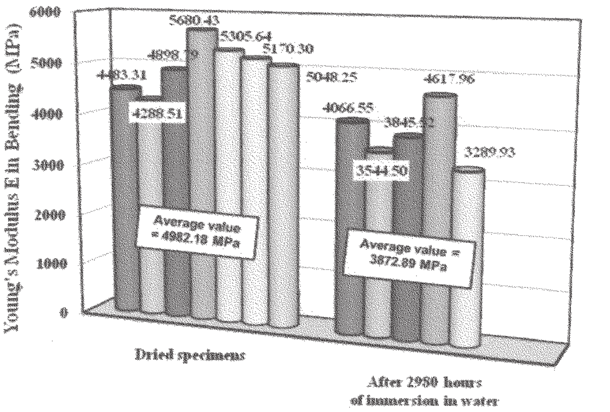


Fig. 6. The effects of water absorption on *Young*'s modulus *E* in case of E-glass woven fabric / recycled rubber / epoxy

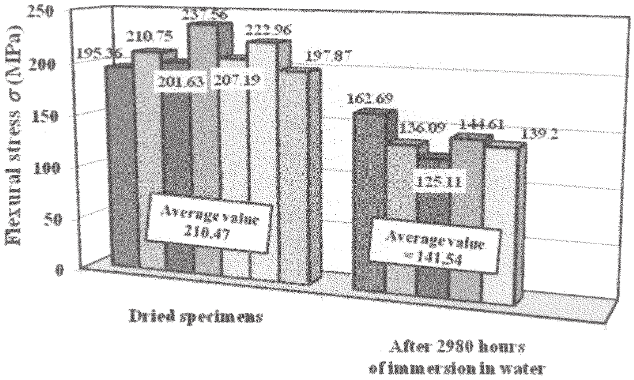


Fig. 7. The effects of water absorption on the maximum flexural stress σ_{max} in case of E-glass woven fabric / recycled rubber / epoxy

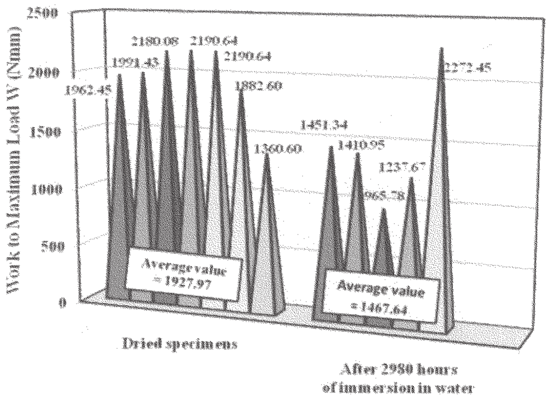


Fig. 8. The effects of water absorption on the work W to maximum load, in case of E-glass woven fabric / recycled rubber / epoxy

down to 206.52 N (wet specimens). Moreover, the maximum value of the vertical deflection v_{max} at maximum force also decreased a little from 13.23 mm to 11.34 mm (with 1.89 %).

Mechanical characteristics in Charpy test

To easily analyse the values obtained for the resilience K (impact strength), figure 9 shows graphically the value of this quantity recorded in case of all specimens tested. One may remark that the scattering factor of the values of resilience K is quite small. The average value of the impact strength K is equal to 99.74 kJ/m^2 and one may remark that it is greater than the value 40 kJ/m^2 that characterize the epoxy resin (with hardener) without reinforcing (table 2).

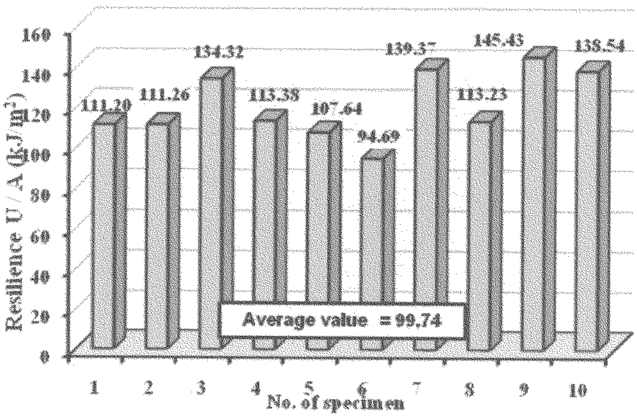


Fig. 9. Mean values of the resilience U/A in case of the dried specimens made of the composite material tested

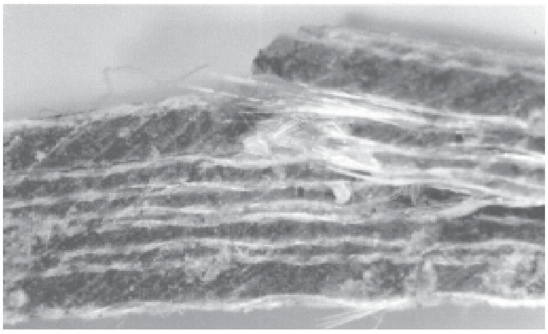


Fig. 10. A photo of the specimen at noth area after Charpy test

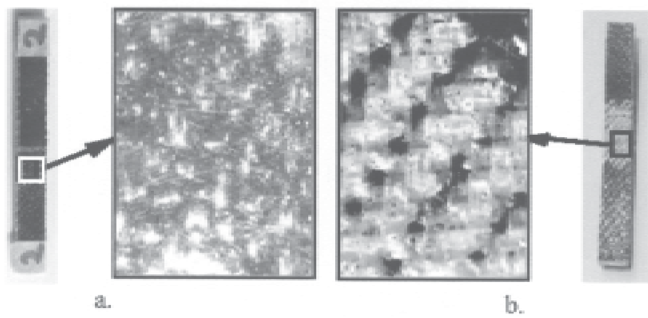


Fig. 11. Delaminations at the surface of the specimen in Charpy test: a.Before testing; b. Delamination on the opposite side of the notch

Damaged areas of the composite materials in Charpy test

A photo of such a composite specimen at notch area after Charpy test, is shown in the figure 10. All specimens tested were partially broken during the impact test. This happened because the composite specimen was excessively deformed during the impact so that the hummer catched the specimen and dropped it before its complete rupture. This is the reason that only the first layers were completely damaged after impact test.

Expanded images of the surface of the specimens (fig. 11) before and after impact, showed that delaminations occurred. In fact, the delamination were observed on the opposite side of the notch (fig. 11, b) when the glass woven fabric delaminated from the structure of epoxy / recycled rubber.

Conclusions

The data concerning to the moisture absorption after 2980 h of immersion in water, showed that the new hybrid composite absorbed a small quantity of water (1.67 %).

This new composite material also showed good mechanical characteristics in the flexural test: Young's modulus E=4982.18 MPa and flexural normal stress σ_{maxx}=210.47 MPa. But, the decreasing of these properties with 22.27 % in case of the Young's modulus E and with 32.75 % in case of the maximum normal stress σ, leads to the recommendation to avoid applications involving mechanical loading in wet environment.

One could remark that in case of the composite material additionally reinforced with recycled rubber, the resilience K (impact strength) was with 38.20 % greater 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 [13]. It follows that to improve dynamical properties (resilience 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 rubber particles obtained from shredded non-reusable tyres represents a research subject of a great interest during the last years. Moreover, this paper shows that the shredded rubber may be used to manufacture new hybrid composite materials whose mechanical characteristics are improved with respect to the ones corresponding to the composite materials reinforced only with glass woven fabric.

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