The Effects of the Immersion Time on the Mechanical Behaviour in Case of the Composite Materials Reinforced with *E*-glass Woven Fabrics

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The paper describes aspects concerning the effects of the immersion time in water, on some mechanical characteristics of some composite materials reinforced with E-glass woven fabrics. The specimens were manufactured by reinforcing a polyester resin Copoly 7233 with both woven fabric EWR300 made of E-glass fibres and chopped E-glass fibres. The hand lay-up technology was used to manufacture the specimens with different pressures in the moulding step: low pressure and high pressure, respectively. The first of all, some specimens were immersed in water and the data regarding the moisture content were periodically recorded. Then, the wet composite specimens were subjected to the flexural test (three point method) after 3500 h of immersion and 7417 h of immersion, respectively. Finally, the experimental results obtained in case of the immersed specimens were comparatively analysed with the results recorded in case of the dried specimens subjected to the bending test too. Moreover, the mechanical characteristics of the specimens were analysed taking into account the different manufacture methods used. It is also shown a comparison concerning the results obtained in cases of the two kinds of reinforcements used.

Keywords: composite; moisture; absorption; flexural test

Composite materials reinforced with woven fabrics are increasingly used in case of the application of aerospace industry, automotive industry, naval applications [1]. Over the years the manufacturers and researchers from aviation field, automotive industry, analysed either theoretically or experimentally [1-5] the composite materials reinforced with woven fabrics. Therefore, that class of the composite materials was considered as composites having good mechanical characteristics while the manufacturing costs are lower.

In the last years, many papers [1-3] focus on the aspects concerning the effects of the aggressive environmental conditions on the mechanical behaviour in case of the composite material. Herein, it is approached the subject concerning the effects of the water absorption on the mechanical characteristics of some composite materials made of E-glass woven fabrics / polyester Copoly 7233. Moreover, the research focuses on the effects of the immersion time on the degradation of the mechanical characteristics in case of these composite materials.

The woven fabrics EWR300 are usually used as isulator material in case of constructions applications (buildings, pipes). By reinforcing of the epoxy / polyester resins, EWR300 woven fabrics are also used to manufacture tanks, cisterns, containers, basins for chemical industry or to manufacture laminated or structure elements for machine-building industry.

Experimental part

Materials

First, the laminated composite plates are manufactured and their structure is shown in the table 1. A lower pressure was used to manufacture one of the plates (Composite 1) by using hand lay-up technology while higher pressure was used for the other one (Composite 2) by using automatic technology.

It may be noted that some layers of the laminated composites are made of woven fabrics *EWR*300 / polyester *Copoly* 7233 while the others are reinforced with chopped *E*-glass fibres (table 1). The different layers are laid alternately. Some characteristics of the EWR300 woven fabrics made of continue E-glass fibres, are known: weight $\gamma=315 \pm 5\%$ g/mm^2; thickness g = 0.3 $\pm$ 0.05 mm;tensile strength σ =1750 N/ a narrow strip of 50 x 0.3 mm^2 in case of the warp; tensile strength σ=2500 N/ a narrow strip of 50 x 0.3 mm^2 in case of the weft.

The physical and chemical characteristics of the *Copoly 7233* resin in liquid state are shown in the table 2 while the mechanical characteristics of the same resin without reinforcing are shown in table 3.

Methods

The specimens where cut from each plate for the bending test (three-point method). The dimensions of the specimen and the scheme of loading (three-point method) for the flexural test are shown in the figure 1 [6, 7].

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Table 1

STRUCTURE OF LAMINATED COMPOSITE MATERIALS ANALYSED

Composite	Resin	Layers / Reinforcement	Manufacturing processes
Composite material 1	*Polyester resin Copoly 7233*	• 9 layers randomly reinforced / chopped E-glass fibres 100 g / m^2 • 8 layers / woven fabric EWR300 made of E-glass fibres 300 g / m^2	*Hand lay-up technology – high pressure*
Composite material 2		• 8 layers / woven fabric EWR300 made of E-glass fibres 300 g / m^2 • 10 layers randomly reinforced / chopped E-glass fibres 100 g / m^2	*Hand lay-up technology – low pressure*

Table 2

PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE COLPOLY 7233 RESIN IN LIQUID STATE

Characteristic	Value	Unit of measure	Method
Density, 25 °C	1040 - 1080	kg/m^3	ISO 2811
Content of phenyl-ethylene (stiren)	37 - 41	%	MP 4221
Viscosity Brookfield, 25 °C, 2/20 rpm	400 – 550	mPa*s	ISO 3219
Gel-time, at 25 °C (100 g resin + 1 % MEKP 50)	20 – 30	Minuts	MP 471
Setting time (Hardening time)	30 – 55	Minuts	MP 471
Exothermic Peak	160 – 180	°C	MP 471
Ignition temperature	34	°C	DIN 51 755

Table 3

MECHANICAL CHARACTERISTICS OF THE COLPOLY 7233 RESIN WITHOUT REINFORCING

Characteristic	Value	Unit of measure	Method
Heat distortion point (HDT)	75 - 85	°C	ISO 75 A
Glass transition temperature	90 – 110	°C	ISO 537
Tensile stress in tension	50 - 60	*MPa*	ISO R 527
Flexural stress	80 - 90	*MPa*	ISO 178
Modulus of elasticity E	3600 - 3900	*MPa*	ISO R 527
Impact strength	8 – 12	*kJ/m^2*	ISO 179
Elongation in tensile test	1,5 – 2	%	ISO R 527
Toughness Barcol	35 - 45	-	EN 59

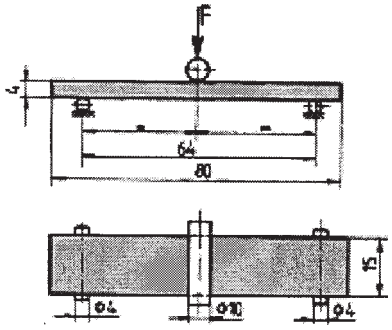


Fig. 1. Dimensions of the specimen and scheme of loading for the bending test

Before bending test, some specimens were immersed in water at room temperature and the water absorption was periodically recorded in case of each type of composite material analysed by considering of recommendations of the actual European Standards for plastics [8]. With this purpose in view, some specimens made of the both laminated composites were firstly dried during 3 days at 40°C. Then, some specimens were immersed in water at room temperature for 3500 h (H ≈ 4 months and 3 weeks) and for 7417 h (H ≈ 10 months and 1 week), respectively.

After immersion, the both dried and wet specimens were subjected to flexural test. The results obtained in the bending test for 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. Figure 2 shows the specimen during testing. The maximum force capacity is ±15 kN. During the flexural tests, the speed of loading was 1.5 mm/min as the European Standards [6, 7] recommend.

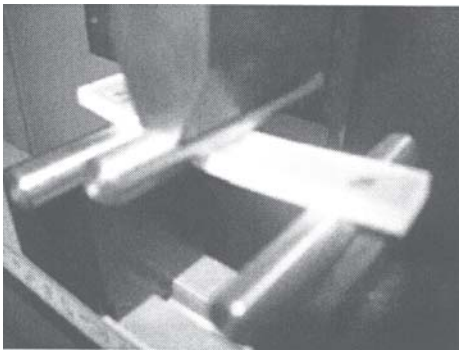


Fig. 2. Specimen subjected to bending test

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 specimens, stres σ and strain ε) in form of files having 200-300 lines. The testing machine gave us the results of a statistical calculus for each set of specimens tested. Therefore, the average values of the following quantities could be automatically computed: Young's modulus *E* in bending; flexural rigidity EI_z; maximum bending stress σ_{max} at maximum load; deflection v_{max} at maximum load; maximum bending strain ε_{max} at maximum load; mechanical work to maximum load or the stored strain energy etc.

Results and discussion

Absorption data

The absorption data recorded in case of the both composite materials analysed are shown in the figure 3. It may be easily observed that the absorption curve recorded in case of the composite material 2 is located below the one recorded in case of the composite 1. There is quite a small difference between the two absorption curves recorded. It follows that the diffusivity of the water inside the composite material, has approximately the same value in the both cases.

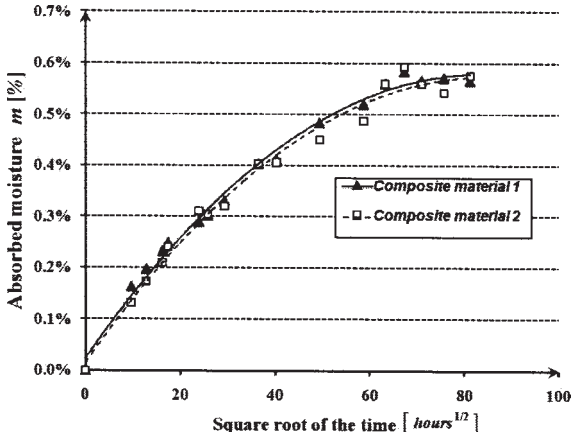


Fig. 3. Data of the absorbed moisture

After 5734 h of immersion in water, the quantities of the absorbed water were 0.572 % in case of the Composite 1 and 0.543 % in case of the Composite 2, respectively. Further, after 7417 h of immersion in water, the quantities of the absorbed water were 0.566% in case of the Composite 1 and 0.576 % in case of the Composite 2, respectively. Therefore, it may be assumed that the two composite materials approach the water saturation.

Bending test

Experimental results recorded during bending tests, may be graphically drawn by using *F* – v coordinates. *F* - v curves of the experimental data in case of the composite materials tested, are shown in the figure 4 and 5, respectively. Analyzing the both figures, it may be observed that *F* - v curves obtained in case of the dried specimens (gray lines), are located above the curves recorded for the specimens kept in water for 3500 h and 7417 h , respectively. It follows that the strength of the immersed specimens decreases.

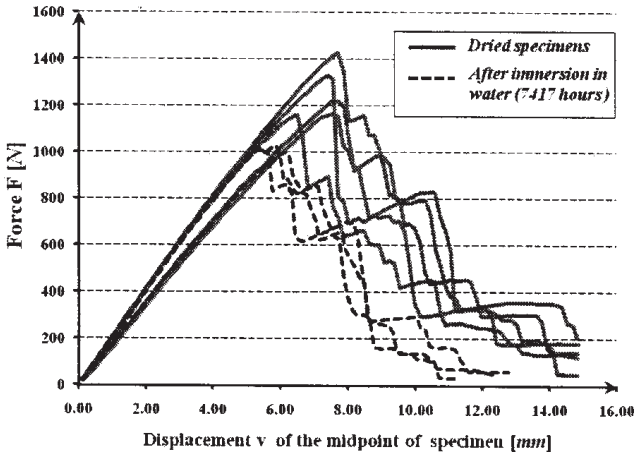


Fig. 4. F-v curves recorded for both dried and immersed specimens made of composite 1

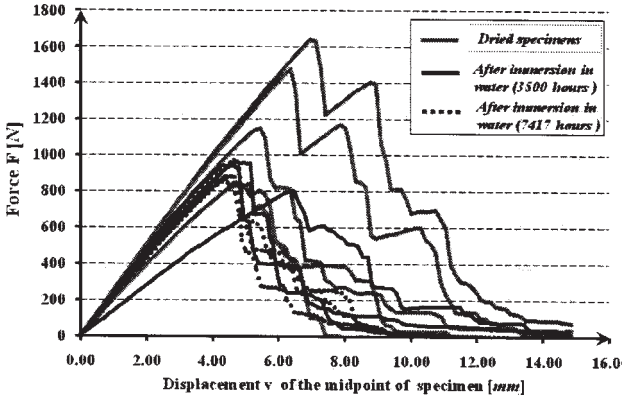


Fig.5. F-v curves recorded for both dried and immersed specimens made of composite material 2

The experimental results for the mechanical characteristics (flexural modulus *E*, maximum bending stress σ_{max} at maximum load, mechanical work at maximum load and at maximum extension**),** are shown in the figures 6-9, respectively.

It may be noted that Young's modulus was computed on the linear portion of the σ - ε curve. It can be remarked that generally speaking, the both Young's modulus *E* for bending (or flexural modulus) and maximum normal stress σ_{max} decrease due to the degradation during water immersion (fig. 6 and 7).

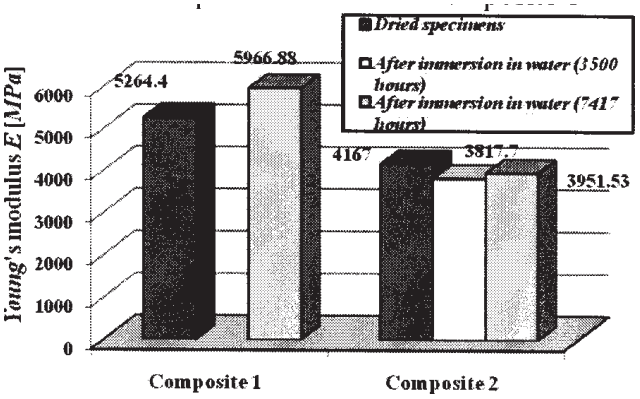


Fig. 6.The effects of the immersion time in water on Young's modulus E in case of bending

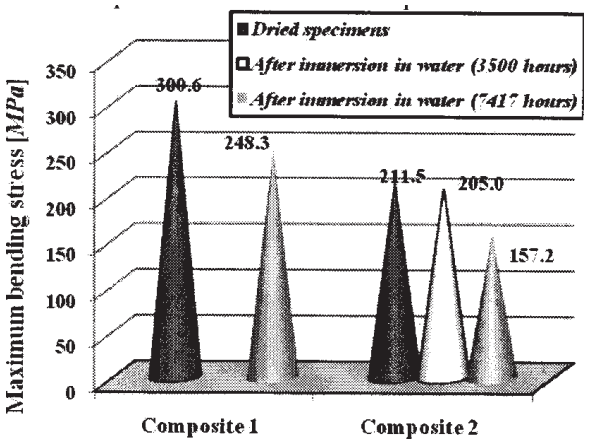


Fig. 7. Effects of the water absorption on the maximum bending stress σ_{max}

In case of the composite 1, the maximum normal stress σ_{max} decreases from 300. 6 MPa to 248.3 MPa (with 17.4 %) while the flexural modulus *E* increases from 5264.4 MPa to 5966.88 MPa (with 13.3%) after 7417 h of immersion (fig. 6 and 7). The increasing of the Young's modulus *E* and the shapes of F-v curves shows us that the specimens

Table 4
AVERAGE VALUES OF SOME PROPERTIES OF TESTED SPECIMENS

Property	Unit of measure	Specimen type	Composite 1	Composite 2
Flexural rigidity EI_z	$x10^4[N \cdot mm^2]$	*Dried specimens*	80.171	93.548
		After immersion in water (3500 hours)	-	64.167
		After immersion in water (7417 hours)	90.6853	101.7002
Maximum load F_{max}	$[N]$	*Dried specimens*	1165.2	855.99
		After immersion in water (3500 hours)	-	805.5
		After immersion in water (7417 hours)	1023.2	914.9
Extension at maximum load v_{max}	$[mm]$	*Dried specimens*	7.353	5.533
		After immersion in water (3500 hours)	-	5.356
		After immersion in water (7417 hours)	5.788	4.584
Maximum bending strain ε_{max} at maximum extension		*Dried specimens*	0.1175	0.13751
		After immersion in water (3500 hours)	-	0.09811
		After immersion in water (7417 hours)	0.1002	0.1250

made of composite *1* become more rigid after immersion while their flexural strength decreases. The reason of this degradation could be the lower pressure used in manufacturing process of the composite material *1*. It is known that the lower pressure in the manufacturing process involves a higher number of air pockets. In the same time, the link at the level of the interface between the layers of a laminated composite is affected by the using of a lower pressure during the manufacturing.

In case of the composite 2, the flexural modulus *E* decreases from 4167 MPa to 3817.7 MPa (with 8.4%) after 3500 h of immersion while it becomes 3961.5 MPa (decreasing with 4.9 %) after 7417 h of immersion (fig. 6). The maximum normal stress σ_{max} decreases from 211.5 MPa to 205 MPa (with 3.1 %) after 3500 h of immersion and it decreases to 157.2 MPa (with 25.7 %).

Moreover, the mechanical works done (the internal strain energy stored) until maximum load (fig. 8) or until maximum extension (fig. 9) increase a little in case of the composite 2. On the other hand, the mechanical work done decreases in case of the composite material 1: the mechanical work done until the maximum load decreases with 22.5 %; the mechanical work done until the maximum extension decreases with 26.4 %.

Other experimental results of the statistical calculus gave us by the testing machine, are shown in the table 4. In case of the composite material 1, since flexural rigidity EI_z increases the both extension v_{max} at maximum load and maximum bending strain ε_{max} at maximum extension decreases after 7417 h of immersion.

But, the most important remark is generally speaking, the acute degradation of the maximum normal stress σ_{max} obtained after immersion in water for approximately ten months (fig. 7). It may be noted that the degradation of the maximum normal stress σ_{max} in case composite 2 is more acute than in case of the composite 1 after the same time of immersion in water (7417 h).

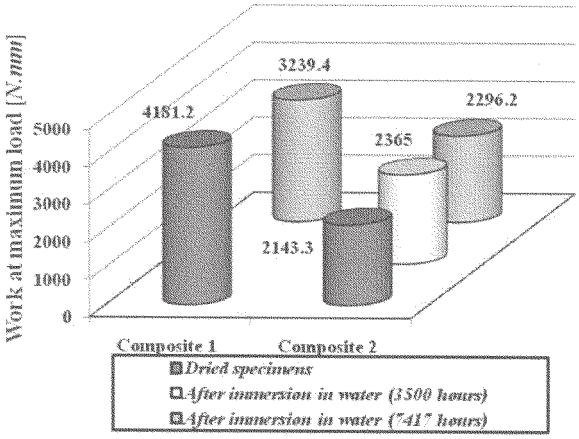


Fig. 8., Effects of the water absorption on the mechanical work done until maximum load

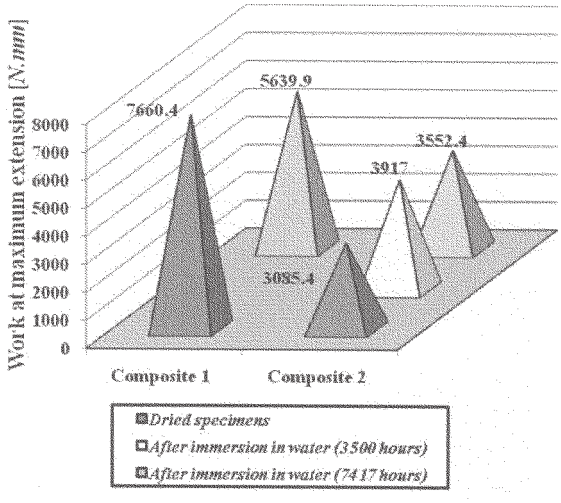


Fig. 9. Effects of the water absorption on the mechanical work done until maximum extension

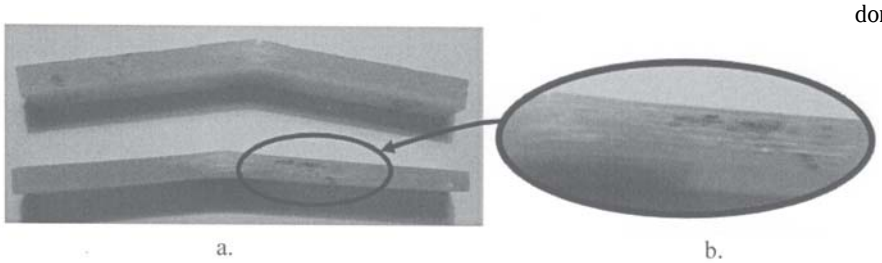
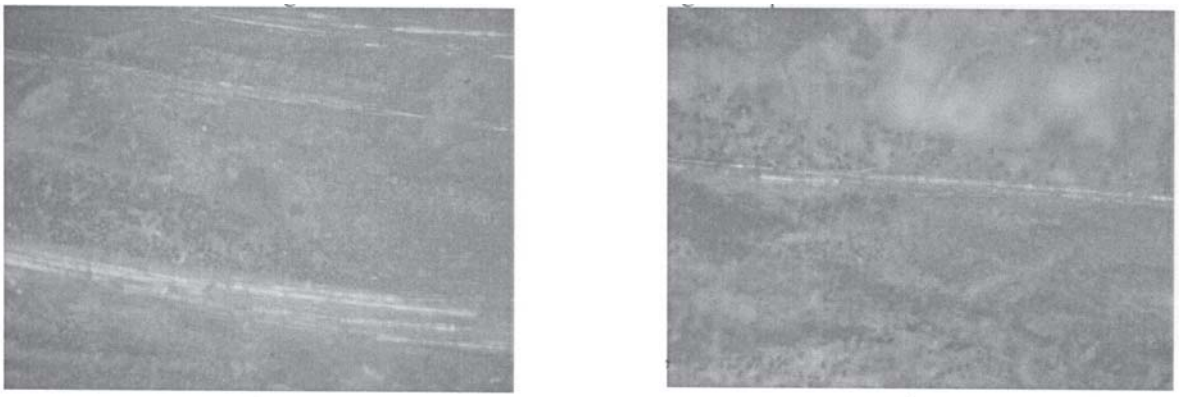


Fig. 10. Photos of the damaged composite materials



a. b.

Fig. 11. Specimen photos acquired by using a metallographic microscope, after 7417 h of immersion (zoom 100x)

It may be remarked that the mechanical characteristics of the composite 1 are better than the same characteristics recorded in case of the composite 2. The specimens made of composite material 1 are stiffener than the ones made of composite 2. In the same time, the flexural strength is better in case of the composite 1. Moreover, since the degradation of the maximum normal stress σ_{max} is lower in case of the composite material 1 than in case of composite 2 after 7417 h of immersion, we may assume that the chemical stability of composite 1 is better. The results shown are against to our expectations.

On the other hand, the results concerning the maximum extension at maximum load v_{max} (table 4) show that the specimens made of composite material *1* are more flexible than the specimens made of composite material *2*. The lower pressure used during manufacture of the composite *1* could explain its higher flexibility.

Damaged areas of the composite materials

The figure 10, a shows a photo of the two specimens after 7417 h of immersion in water while the figure 10, b is detailed photo of a damaged area located on the surface of the specimen. It was observed that more specimens analysed had similar brown spots located on the cut edge of the specimens. Since there was no spot before immersion in water, it may assume that the oxidation of the resin could be the cause of the spot appearance. The photos acquired by using a metallographic microscope (fig.11), confirms this opinion.

Conclusions

Like the previous researches [1, 2, 4], analysing of the actual experimental results shows that the rigidity and the strength decrease due to the water absorption inside the composites reinforced with *E*-glass woven fabrics .

Taking into account that the quantities of the absorbed water are approximately the same in case of the both cases analyzed, the cause of the different degradation could be only the different laminated structure of the composite materials analyed or the manufacturing technology.

It may remark that technology of manufacturing is very important concerning the mechanical behaviour of the composite structures under normal environmental conditions and in wet environments too.

From point of view of the reasons shown in this paper, it is recommendable to take into account the results of this paper in the manufacturing process of the structures made of the composite materials and not only. Design of the structures made of composite materials based on polymer resins reinforced with *E*-glass woven fabrics could also consider the degradation of the mechanical characteristics due to the long time exposure in wet environments.

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