

# Effects of the Wood Species on the Mechanical Characteristics in Case of Some E-glass Fibers/Wood Flour/Polyester Composite Materials

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*The paper describes some aspects concerning the effects of the type of wood species on some mechanical characteristics of some hybrid composite materials reinforced with both E-glass woven fabric and wood flour. It also shows the effects of the moisture absorption on the mechanical behaviour in bending after immersion in two different environments: water and seawater. The specimens were manufactured by reinforcing a polyester resin Copoly 7233 with both E-glass woven fabric EWR145 and wood flour. Two kinds of wood flour, oak wood flour and fir wood flour were used to manufacture the two composite materials tested. The immersion time was approximately eight months. The quantity of the moisture absorbed was greater in case of the immersion in water than in case of the immersion in seawater. Then, the both dried specimens and the wet ones were subjected to flexural tests by using the method of the three points. Finally, the experimental results obtained were analysed in terms of the nature of the immersion environment. Moreover, it was analysed the effect of the immersion time on the changing of the mechanical characteristics in case of woven fabric / oak wood flour / polyester. Finally, the paper recommends the using of the oak wood flour in case of the parts made of composite material analysed, that works in humid environment excepting the case when its salt content is greater.*

*Keywords: hybrid composite; wood flour; absorption; flexural test*

Nowadays, it is known the great interest for recycling of the large amount of wood waste [1] obtained during the different stages in the wood processing and wood applications such as furniture industry and building constructions. There were also preoccupations [2] concerning the manufacturing of the new composite materials by recycling of the other fibrous materials such as the textiles, carpets, composite materials reinforced with fibres and so forth.

Some previous studies [1, 3] had already shown that the wood wastes in the form of wood flour; fibres or pulp is suitable as filler for polyolefin matrix composites or for recycled plastics. Within a recent research [4], it was shown that the composites made of high-density polyethylene and fir wood flour as filler, treated with coupling agents (polypropylene maleate, 3–5 wt %), could be desirable as building materials due to their improved stability and strength properties.

Worldwide, there is a lot species of wood depending of the location on globe due to the nature of the climate. For example, for the temperate zone, among the specific species of wood could be: fir; oak; beech; carpinus; poplar; willow; maple, chestnut; wood of the fruit trees such as bird cherry, walnut and so forth. This means that practically, there are more kinds of wood flour or wood fibre that may be used as filler for a composite material based on polymer resin.

In the last years, many papers [5-7] focus on the aspects concerning the effects of the aggressive environmental conditions on the mechanical behaviour in case of the composite material. Moreover, there were taken into account the effects of the immersion time on the degradation of the mechanical characteristics [5]. On the

other hand other local problems need attention in laminated composite structures [8].

A previous research [9-14] marked out the advantages of the using of a polyester resin comparatively with a formaldehyde resin to manufacture the composite materials based on wood flour.

The present work focus on a comparatively analysis of the effects of water / seawater absorption on the degradation of the mechanical characteristics obtained in flexural test in case of the two hybrid composite materials made of a polyester resin reinforced with E-glass fibres and with wood flour as filler material. The difference between the structures of the two composites is given only by the species of wood from which the wood flour is made of.

Although the use of wood filler in plastic composites has several advantages over inorganic fillers, it may be safely said that the hydrophilic nature of the wood has a negative effect on performances of the wood-plastic composites. On the other hand, it is well-known that wood contains tannins and higher level of tannins is commonly associated with oak wood. Tannins are water-soluble phenol and poly-phenol compounds [3], which can form dark colour complexes with iron salts (ferric salts). Herein, it is consequently analysed the effect of the salts content of the seawater on both aspect of the composite surface and bending behaviour of the specimen after long time immersion in seawater.

## Experimental part

### Materials

First of all, two laminated composite plates having 6 mm in thickness, are manufactured by using the E-glass

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**Table 1**  
PHYSICAL AND CHEMICAL CHARACTERISTICS OF THE COLPOLY 7233 POLYESTER RESIN IN LIQUID STATE

Characteristic	Value	Unit of measure	Method
Density, 25 °C	1040 - 1080	kg/m <sup>3</sup>	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	Minutes	MP 471
Setting time (Hardening time)	30 - 55	Minutes	MP 471
Exothermic Peak	160 - 180	°C	MP 471
Ignition temperature	34	°C	DIN 51 755

**Table 2**  
MECHANICAL CHARACTERISTICS OF THE COLPOLY 7233 POLYESTER 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 <sup>2</sup>	ISO 179
Elongation in tensile test	1,5 - 2	%	ISO R 527
Toughness Barcol	35 - 45	-	EN 59

woven fabric EWR145 to reinforce a Colpoly 7233 polyester resin mixed with either oak wood flour or fir wood flour. Both hybrid composite materials contain six layers of E-glass woven fabric and the same weight ratio of the wood flour. To accelerate the polymerisation process, a chemical agent was certainly mixed with the polyester resin before of the admixture of the wood flour. Moreover, a coupling agent in form of power was used to improve the interaction between the polyester resin and the wood flour used as filler.

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

The physical and chemical characteristics of the Copoly 7233 resin in liquid state are shown in the table 1 while the mechanical characteristics of the same resin without reinforcing are shown in the table 2.

#### Work method

The specimens for the flexural test were cut from each plate. The specimens have parallelepipedous shape whose dimensions were 120mm x15mm x 6mm (thickness) taking into account the recommendation of the European standards [14, 15] for flexural test by using the method of the three points in case of the reinforced plastic materials.

Before bending test, some specimens were immersed in water while the others were immersed in natural seawater from *Black Sea*, at room temperature and the water absorption was periodically recorded in case of each type of composite material analysed by considering the recommendations of the actual European Standards [16].

With this purpose in view, all specimens made of the both laminated composites were firstly, before immersion, dried during 3 days at 40°C. Then, some specimens made of the composite material filled with wood flour were immersed in water / seawater at room temperature, for 5853 h (≈ 8 months and 3 days). Some of specimens made of the other one composite material with fir wood flour, were immersed during 5612 h (≈ 7 months, 3 weeks and 2 days) in the both environments. 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 ± 0.001 g.

After immersion, the both dried and wet specimens were subjected to flexural test by using the method of the three points. The results obtained (Young's modulus  $E$  and maximum flexural normal stress  $\sigma_{max}$ ) 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 figure 1 shows one of the specimens during bending test. To analyse the rupture area, the figure 2 shows two damaged specimens after testing. The maximum force capacity is ±15 kN. During the flexural tests, the speed of loading was 3 mm/min..

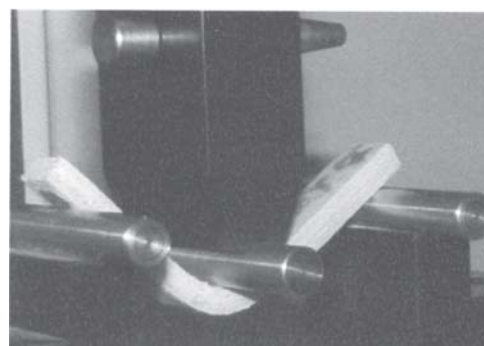


Fig. 1. Specimen subjected to bending test

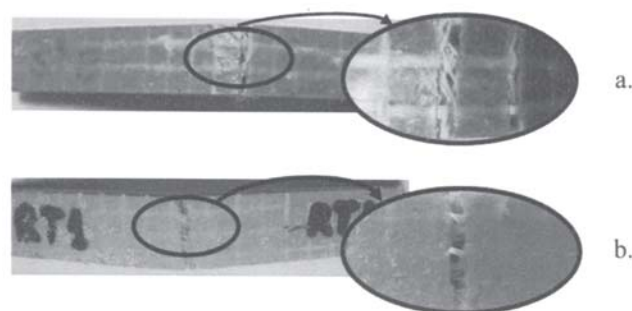


Fig. 2. Photos of the damaged specimens made composite materials filled with: a) oak wood flour; b) fir wood flour

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) in form of files having 200-300 lines. Therefore, the average values of the following quantities could be computed: Young's modulus  $E$  in flexural test; flexural rigidity  $EI_z$ ; maximum bending stress  $\sigma_{max}$  at maximum load; deflection  $v_{max}$  at maximum load etc.

## Results and discussion

### Absorption data

The absorption data recorded for the both composite materials analysed are comparatively shown in case of the both immersion environment: water (fig.3) and seawater (fig. 4), respectively. It may be easily observed that the two absorption curves recorded in case of the composite material filled with fir wood flour is located below the one recorded in case of the other one composite filled with oak wood flour. The cause may be assigned to resinous nature of the fir wood. Therefore, the greater resin content of the fir wood flour acts as a barrier against the water absorption. The average value of the water content (fig. 3) was 10.73% while the seawater content (fig. 4) recorded was 9.72% after immersion during 5853 h, in case of the composite filled with oak wood flour. In case of the other one composite material filled with fir wood flour, the water content (fig. 3) was equal to 8.02% while the seawater content was 6.50% after 5612 h of immersion. Therefore, like the other previous works showed, it was recorded again a smaller quantity of the moisture absorbed during the immersion in seawater than in case of the immersion in water. The salts of the seawater act again like a barrier against the moisture absorption.

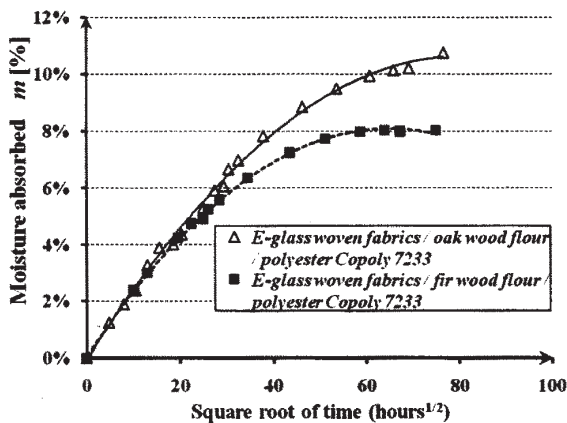


Fig. 3. Data of the absorbed moisture during immersion in water

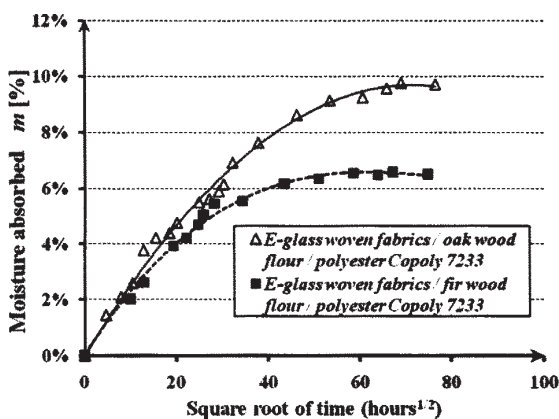


Fig. 4. Data of the absorbed moisture during immersion in sea water

There is a small difference between the absorption curves recorded during the first 400-600 h of immersion. It follows that the diffusivity of the moisture inside the composite material, has approximately the same value in the both cases: water environment and seawater environment.

### Mechanical characteristics in flexural test

Experimental results recorded during bending tests, may be graphically drawn by using  $F-v$  coordinates. It may be noted that Young's modulus was computed for data points located on the linear portion of the  $F-v$  curve.

First of all, it is shown the changing of the mechanical properties in case of the E-glass / fir wood flour / polyester composite. Statistical distributions of the results recorded for Young's modulus  $E$  and for the maximum flexural stress  $\sigma_{max}$  were graphically drawn in the figures 5 and 6, respectively.

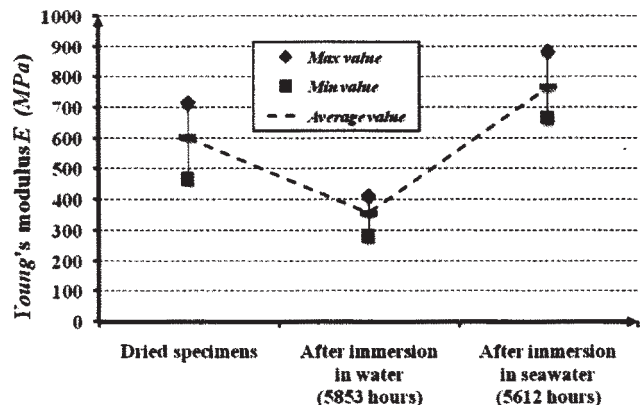


Fig. 5. Statistical distribution of the values recorded for Young's modulus in case of the composite with fir wood flour

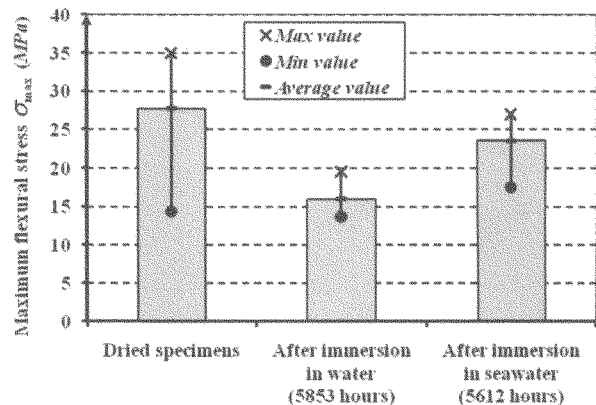


Fig. 6. Statistical distribution of the values recorded for maximum flexural stress in case of the composite with fir wood flour

In case of the composite material with fir wood flour, Young's modulus  $E$  (fig. 7) decreases from 601.1 MPa down to 356.2 MPa (with 40.7 %) after 5621 h of immersion in water while it increases up to 766.0 MPa (with 27.5%) after the same immersion time in seawater. In the same manner, the maximum flexural stress  $\sigma_{max}$  (fig. 8) decreases from 27.7 MPa down to 16.0 MPa (with 42.2%) after immersion in water and it decreases down to 23.5 MPa (with 15.2%) after immersion in seawater.

In case of the E-glass woven fabric / oak wood flour / polyester composite, it may be observed generally speaking, the increasing of both Young's modulus  $E$  (fig. 9) and maximum flexural stress  $\sigma_{max}$  (fig. 10) after immersion in wet environment. Therefore, this remark confirms once

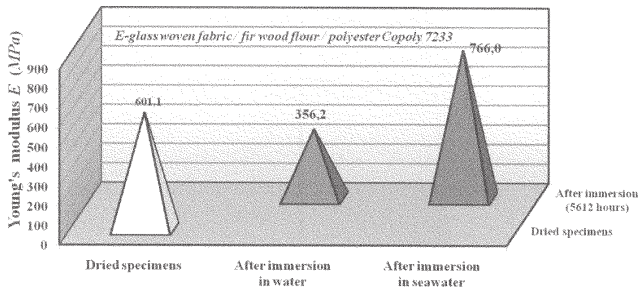


Fig. 7. The effects of water /seawater absorption on Young's modulus E in case of E-glass EWR145 / fir wood flour / polyester Copoly 7233

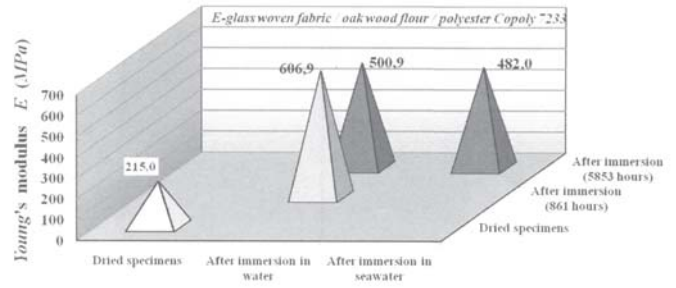


Fig. 9: The effects of water /seawater absorption on Young's modulus E in case of E-glass EWR145 / oak wood flour / polyester Copoly 7233

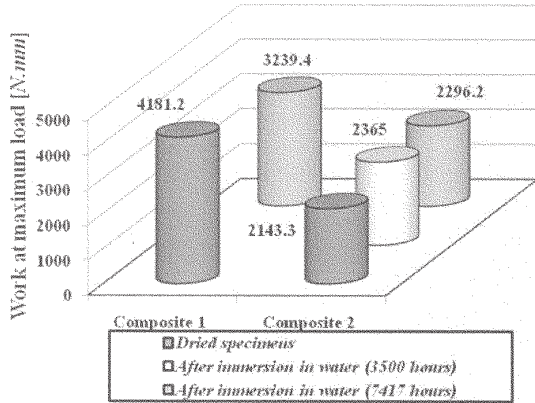


Fig. 8. The effects of water /seawater absorption on on the maximum flexural stress in case of E-glass EWR145 / fir wood flour / polyester Copoly 7233

again the well-known property of the oak wood concerning the hardening by aging over the years. In fact, the keeping of the materials completely immersed in water, represents an accelerate process of aging.

More exactly, in case of the composite material filled with oak wood flour, Young's modulus E (fig. 9) increases from 215.0 MPa up to 500.9 MPa (with 132.9%) after 5853 h of immersion in water while it increases up to 482.0 MPa (with 124.2%) after the same immersion time in seawater. In the same time, the maximum flexural stress  $\sigma_{max}$  (fig. 10) increases from 21.0 MPa up to 25.0 MPa (with 19.05%) after 5853 h of immersion in water while it decreases down to 17.5 MPa (with 16.67%) after the same immersion time in seawater.

In case of the composite material filled with oak wood flour, it was also analysed the effect of the immersion time in water on the changing of the mechanical characteristics. Therefore, Young's modulus increased with 182.28 % after

861 hours of immersion in water while the increasing was only with 132.9%) after 5853 h of immersion. With other words the increasing of the immersion time leads to a decreasing of the rigidity. The results concerning the changing of the maximum flexural stress  $\sigma_{max}$  show contrary that the maximum flexural stress  $\sigma_{max}$  increases with 7.14 % after 861 h and it increases with 19.05% after 5853 h of immersion.

### Residual deformations after flexural test

But, the most important remark remains that concerning the values of the maximum deflection  $v_{max}$  of the midpoint of the specimens during and after the flexural test (table 3). The values recorded for this quantity are shown in the table 3 in case of the dried specimens made with oak wood flour. It may easily observe that the maximum residual deflection  $v_{max}$  after approximately 30 min. after flexural test had finished, was much smaller than the maximum deflection recorded at maximum load and also, than the one recorded at the final test. This remark remains valid in case of all specimens tested in this work.

Figure 11 comparatively shows the shapes of the specimens immediately after flexural test and after approximately 30 min after the flexural test finished in case of the specimens filled with oak wood flour (fig. 11, a) and in case of the specimens filled with fir wood flour (fig. 11, b), respectively.

The reason of this mechanical behaviour could be assigned to the oak wood flour used to manufacture the composite specimen because no suchlike observation was recorded in the previous researches [5, 6] when E-glass / polyester composite materials were tested. Practically, this unexpected mechanical behaviour of the new hybrid composite after the flexural test could be owing to a good combination between the rheological behaviour

Specimen No.	1	2	3	4	5
$v_{max}$ at max. load	22.143	29.513	19.984	39.387	31.504
$v_{max}$ at final of the flexural test	58.674	54.592	59.396	59.400	59.396
$v_{max}$ after $\approx$ 30 minutes after test	7.1	5.2	5.8	4.1	5.7

Table 3  
MAXIMUM VALUES OF DEFLECTION  $v_{max}$  IN CASE OF THE DRIED SPECIMENS MADE OF COMPOSITE MATERIAL FILLED WITH OAK WOOD FLOUR

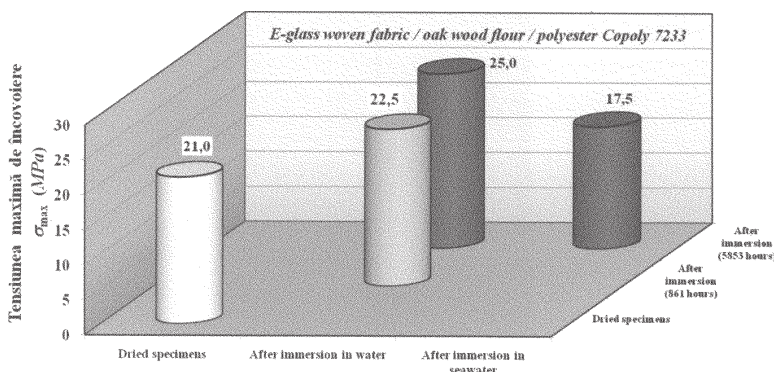


Fig. 10. The effects of water /seawater absorption on on the maximum flexural stress  $\sigma_{max}$  in case of E-glass EWR145 / oak wood flour / polyester Copoly 7233

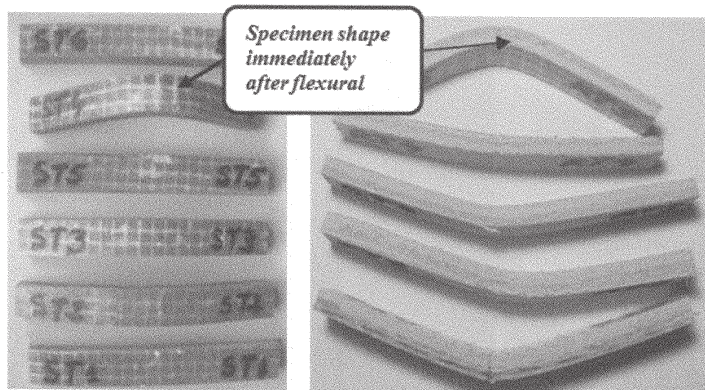


Fig. 11. Changing of the shapes of the specimens after  $\approx 30$  min after the flexural test finished in case of the specimens filled with: a) oak wood flour; b) fir wood flour

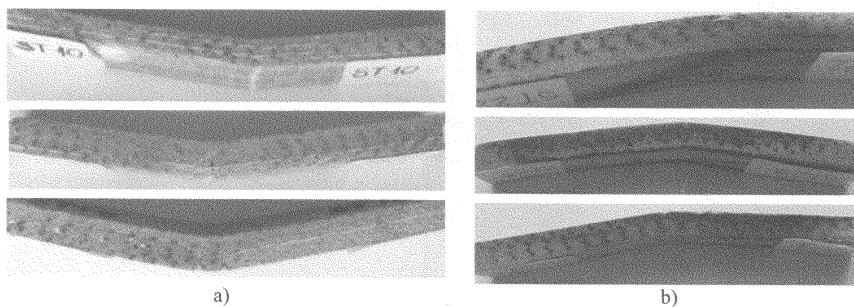


Fig. 12. Photos of the edges of the specimens made of E-glass / oak wood flour / polyester after 5853 h of immersion in: a) water; b) seawater

of wood and the shape memory, property that is assigned to the E-glass fibres.

#### Damaged areas of the composite materials

The figure 12, shows two photos of some specimens made of E-glass / oak wood flour / polyester composite material after 5853 h of immersion in water (fig. 12,a) and seawater (fig. 12, b), respectively. It may be easily observed that more specimens analysed had similar black spots located on the cut edges of the specimens, especially in case of the specimens immersed in seawater.

Since there was no spot before immersion in water, it may be assumed that the oxidation of the resin could be one of the causes of the spot appearance. Pronounced degradation observed in case of the specimens kept in water is assigned to the fungus, algae and micro-organisms that live within seawater. It is already known that these use the polyester resin like a nutriment.

Moreover, it was remarked that in case of the specimens immersed in seawater, the damaged areas located on the specimen edge are larger in case of the composite material filled with oak wood flour than in case of the other one type of composite. The greater content of the tannin in case of oak wood than in case of the fir wood, could be the cause of the greater degradation of the specimens made of the E-glass / oak wood flour / polyester composite material.

#### Conclusions

It could be remarked a smaller degradation of the mechanical characteristics in case of the hybrid composite material filled with fir wood flour after immersion in water than in case of the immersion in seawater. This happened because the quantity of the water absorbed is greater than that one of the seawater absorbed. This remark is like the one made in a previous paper [5] when it was tested a polymeric composite material reinforced with E-glass woven fabric that didn't contain wood flour.

The increasing of the Young's modulus  $E$  in case of the composite filled with oak wood flour, shows us that the specimens become more rigid after immersion in seawater while their flexural strength decreases a little.

Moreover, it was remarked a greater degradation of the material (large black stains) over the entire surface corresponding to the edges of the specimens immersed in seawater. The cause of this degradation may be assigned to the greater tannin content that oxidize more intensively under the action of salts existing in seawater.

Finally, it should remark that the absorption of water leads to the increasing of both rigidity and maximum flexural normal stress  $\sigma_{max}$  in case of the hybrid composite material with oak wood flour. Contrary, the absorption of water leads to the decreasing of the mechanical characteristics (rigidity and strength) in case of the other one composite with fir wood flour. It follows that wood oak flour should be recommended as filler for the parts that works in water environment and that made of the hybrid composite material involved. If the humid environment contains salts fir wood flour should be used as filler because the greater content of the tannins associated to the oak wood leads to the appearance of the large dark stains over the surface of the composite.

Taking into account the low mechanical characteristics obtained in bending test, these kinds of hybrid composite materials should be used only to manufacture products that are not strength members. However, taking into account the recycling necessity of the large quantity of wood wastes, the low costs of manufacture for the new composites, it may recommend them for the boards in construction, furnish ornaments, carcasses etc.

In the next researches there will be searched new ways for improving the structure of the hybrid composite materials tested by using the other types of glass woven fabric whose mechanical characteristic are better.

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