Influence of Content and Arrangement of Reinforcements on Properties of Polyester Laminates

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This paper investigates mechanical properties of polyester laminates reinforced with different layers of glass fibres with additives. Testing plates were made by soaking of reinforcements with resin and applying manual air extraction using hand roller. On the basis of results of testing for obtaining tensile, flexural and interlayer strength, modulus of elasticity, impact toughness and content of inorganic matter, it is concluded that mechanical properties of polyester laminates depend not just on "composition" but on voids which are as inhomogeneities present in boundary of matrix and reinforcements too.

Keywords: *polyester laminates, glass fibres, reinforcements, influence, mechanical properties, porosity, structure.*

1. INTRODUCTION

Polyester laminates are composites on the base of unsaturated resins reinforced with glass fibres. The application of glass fibre as reinforcement enables production of composites having high specific strength [1]. Those laminates are firm and rigid. By changing number and layer position of reinforcements, it is possible to affect mechanical properties of laminates. Modifications of number of layers of reinforcements, their redistribution and thickness can create optimal conditions for achievement of laminate highly improved properties [2,3]. Polyester laminates are used in civil engineering, food and car industry, agriculture but in naval industry too. In exploitation they are subjected to different types of loadings as well as influence of the environment. Research of properties and damage of polyester laminates represents extremely complex and demanding field of study [4]. In production of small series usually hand procedure is used for air extraction, but for larger series a new procedure is increasingly used called infusion under pressure lamination and injection pressing in vacuum ("RTM procedure" Resin Transfer Moulding). This paper describes investigation of influence of arrangement, type and number of reinforcements on mechanical properties of polyester laminates made by soaking and manual air extraction procedure using hand roller. These results should be helpful in further investigation on laminates with the same type of reinforcements but produced by "RTM" procedure.

2. COMPOSITION AND PREPARATION OF TESTING PLATES

For testing purpose seven plates made of polyester laminate were prepared. Dimension of all seven plates were ≈ 500 mm × 200 mm. Figure 1 schematically shows distribution of reinforcements within matrix across the cross section of plates. Two sides of plate can be distinct:

- side "A", rough side with polyester resin on it and
- side "B", smooth and shiny side with gel coat additive for aesthetic effect.

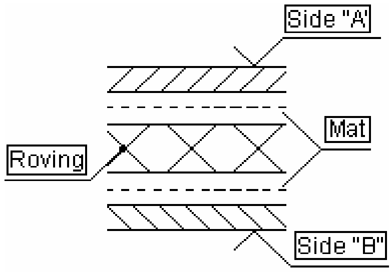

Figure 1. Schematic layout of reinforcement in the matrix of plates

Air extraction was done manually by hand roller, Fig. 2.

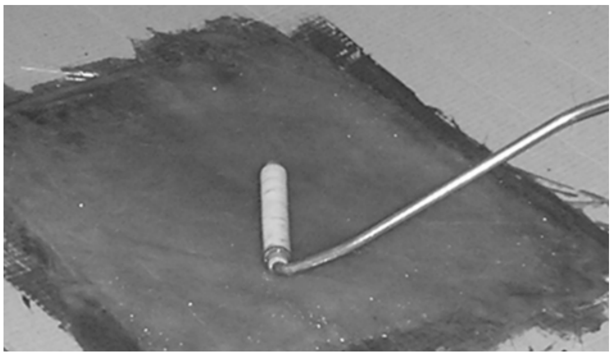

Figure 2. Production procedure by soaking and by pressing the air out (by hand roller)

In order to check influence of plate composition on plate properties, the test probes have been made. Properties, number of test probes as well as standard according to which testing was performed, are shown in Table 1. The composition of test plates is shown in Table 2.

Figure 3 shows examples of application of polyester laminates for making of outer parts of vehicles. As another example, a reservoir for exploitation in

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agricultural and food industry is shown in Figure 4a. After mechanical damage the same reservoir was successfully repaired by manual procedure what is shown in detail in Figure 4b.

Table 1. Tests probes, norm and number of the specimens

No.	Properties	Norm	No. specimens
1	Tensile strength	DIN 53455	3
2	Tensile module of elesticity	Din 53457	3
3	Flexural strength	Din 53452 side “A” and side “B”	5 + 5
4	Interlayer strength	BS 2782 side “A” and side “B”	5 + 5
5	Impact test by Charpy 4 J, 4 mm × 6 mm (specimen without combine)	DIN 53453 side “A” and side “B”	5 + 5
6	Content of inorganic matter	DIN 52330	1

Table 2. Composition of tested polyester laminate plates

No.	Plate composition				
	Side “A”				Side “B”
1	resin	3 × mat 450 g/m^2	2 × mat 450 g/m^2	gelcoat	
2	resin	2 × mat 450 g/m^2	1 × roving 300 g/m^2	2 × mat 450 g/m^2	gelcoat
3	resin	2 × mat 300 g/m^2	combimat	1 × mat 450 g/m^2	gelcoat
4	resin	1 × mat 450 g/m^2	2 × roving 300 g/m^2	1 × mat 450 g/m^2	gelcoat
5	resin	3 × mat 450 g/m^2	2 × mat 450 g/m^2	gelcoat	
6	resin + calcite	1 × mat 450 g/m^2	2 × roving 300 g/m^2	2 × mat 300 g/m^2	gelcoat
7	SER*	2 × mat 450 g/m^2	3 × mat 450 g/m^2	gelcoat	

*self extinguishing resin

3. TEST RESULTS

After the probes had been prepared from plates, the tests were conducted according to test plan. During tests the structure of cross-section was recorded. Previous measurement of thickness of plates and testing of content of inorganic matter (glass fibres) in plates was done and results are shown in Table 3.

Table 3. Plate thickness and content of inorganic matter

Plate number	Content of inorganic matter [%]	Thickness [mm]
1	49.49	3.8
2	44.76	4.1
3	42.06	4.2
4	47.85	3.9
5	51.49	4.2
6	44.79	4.0
7	44.65	4.8

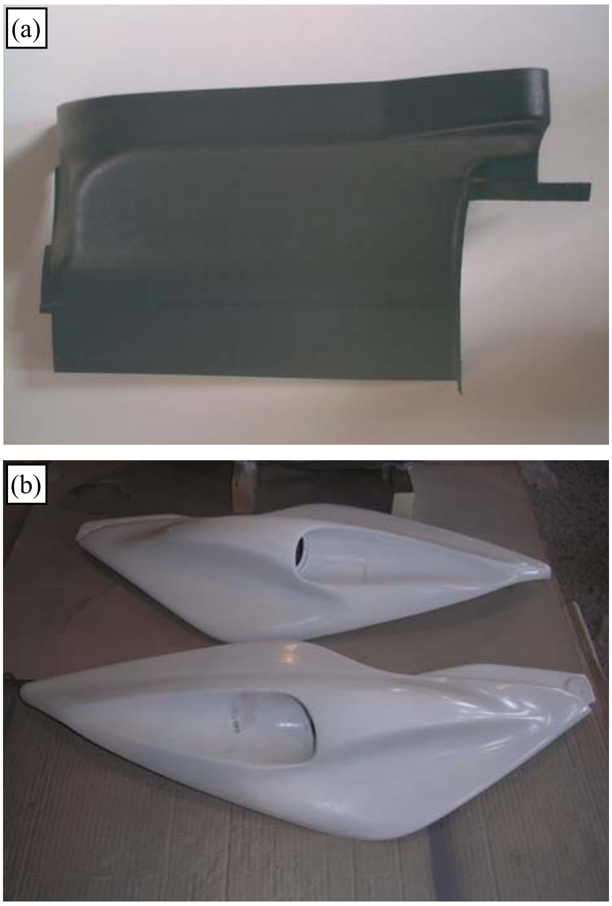

Figure 3. Parts of the truck: (a) exterior and (b) interior

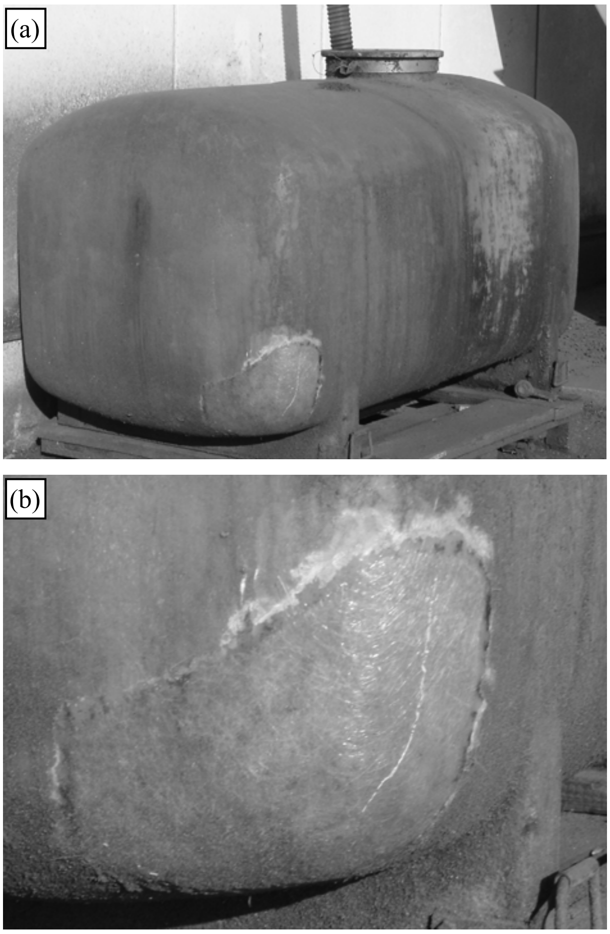

Figure 4. (a) repaired reservoir and (b) detail of repaired damage

3.1 Mechanical properties of plates

Results of testing for determination of tensile strength and tensile modulus of elasticity, obtained as arithmetic mean value from measurements on three specimens, are shown in Table 4.

Table 4. Arithmetic mean value of tensile strength and tensile modulus of elasticity

Plate number	Tensile strength [MPa]	Tensile modulus of elasticity [MPa]
1	126.6	8,803
2	117.4	12,073
3	105.9	10,916
4	without fracture	12,791
5	106.1	8,734
6	130.7	10,101
7	100.3	6,083

For tests conducted on side “A” and side “B” of laminates, the arithmetical mean values of flexural strength are calculated and shown on Table 5, interlayer strength in Table 6 and impact toughness in Table 7.

Table 5. Flexural strength

Plate number	Flexural strength [MPa]	
	Side “A”	Side “B”
1	239.8	242.4
2	251.1	239.5
3	202.7	233.5
4	247.1	291.0
5	157.3	212.0
6	209.0	175.2
7	156.6	175.3

Table 6. Interlayer strength

Plate number	Interlayer strength [MPa]	
	Side “A”	Side “B”
1	21.9	23.7
2	23.7	24.5
3	16.8	19.8
4	18.7	21.8
5	24.9	25.1
6	19.3	22.8
7	15.0	18.2

Table 7. Impact toughness

Plate number	Impact toughness [kJ/m^2]	
	Side “A”	Side “B”
1	62	77
2	76	92
3	87	88
4	77	115
5	71	75
6	77	89
7	62	73

4. ANALYSYS OF RESULTS

In order to link results of testing for obtaining mechanical properties to structure of laminates, the cross-sections of plates were recorded under light microscope using polarized light. Those recordings are helpful in spotting defects in structure, like presence of irregularities in boundary region between laminates and matrix, which can point out the reasons of difference between plate properties. Medium-high ranking of Plate 4 is most likely the outcome of homogeneous structure (Fig. 5a) as well as highest number of layer fabrics (two layers) in the middle of the plate. Average ranking of Plate 6 can be explained by average content of voids (Fig. 5b) and by presence of two layers of fabrics in the middle of the plate.

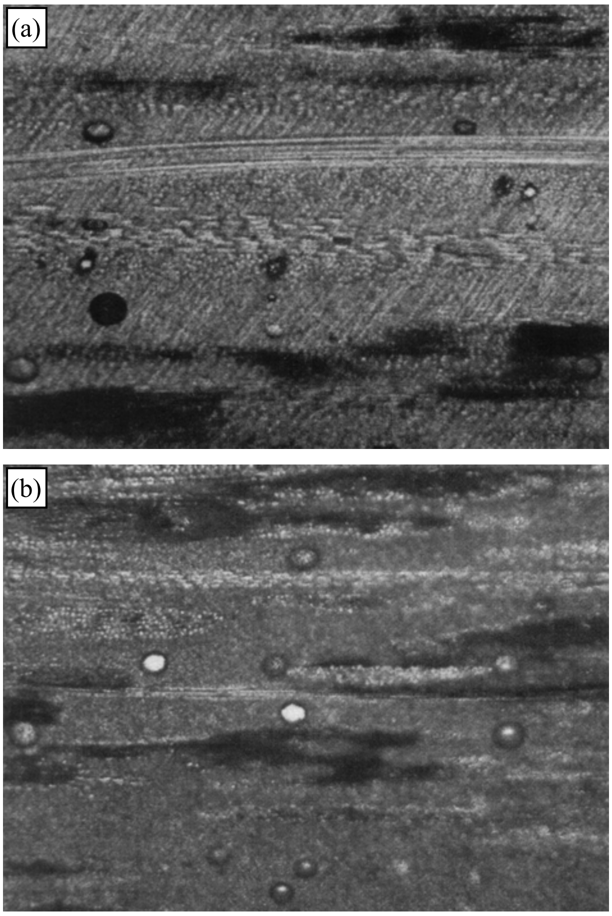

Figure 5. Cross section of: (a) Plate 4 and (b) Plate 6; 100X

Difference in ranking of Plates 2 and 5 (both of them have two layers of the fabrics in the middle of the plate) is the result of significant content of voids (Fig. 6a and 6b).

Pronounced poor ranking of Plate 7 compared to Plate 1, and particularly to other plates, is the effect of not just smaller content of reinforcements (no fabrics) but also of obvious inhomogeneities in structure (Fig. 7a and 7b).

Slightly lower mechanical properties of Plate 3 can be associated to smaller number of reinforcement layers even though the structure of cross-section shows presence of porosity in the form of voids, Fig. 8.

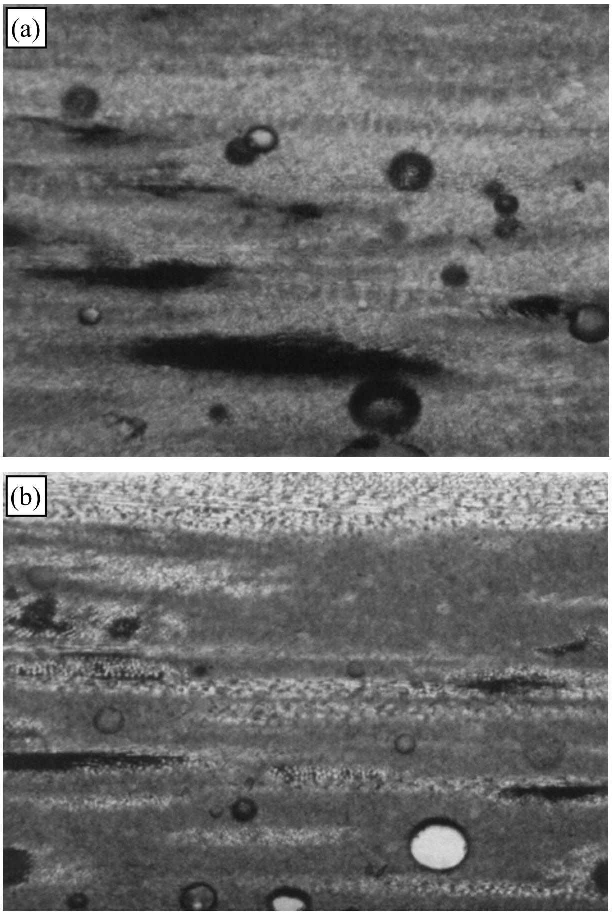

Figure 6. Cross section of: (a) Plate 2 and (b) Plate 5; 100X

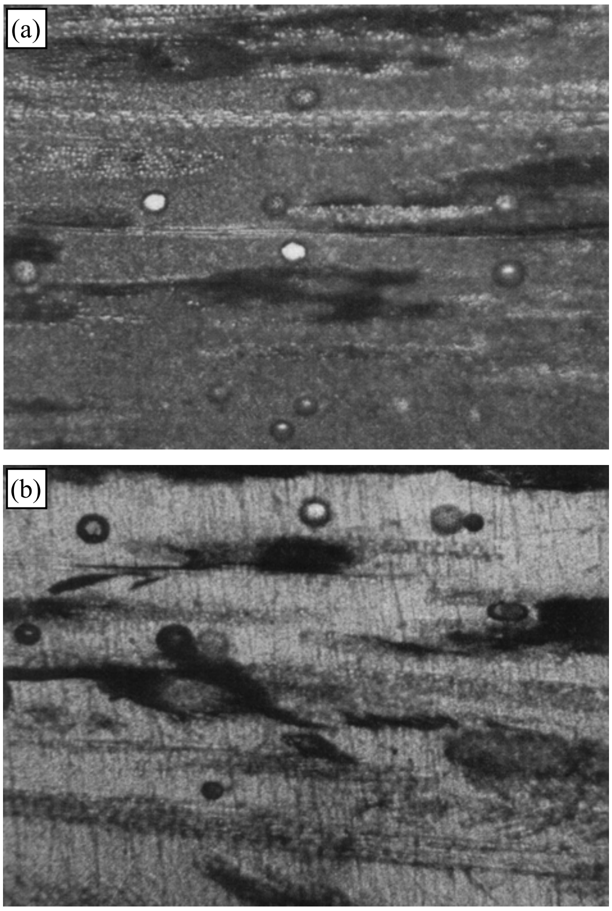

Figure 7. Cross section of: (a) Plate 7 and (b) Plate 1; 100X

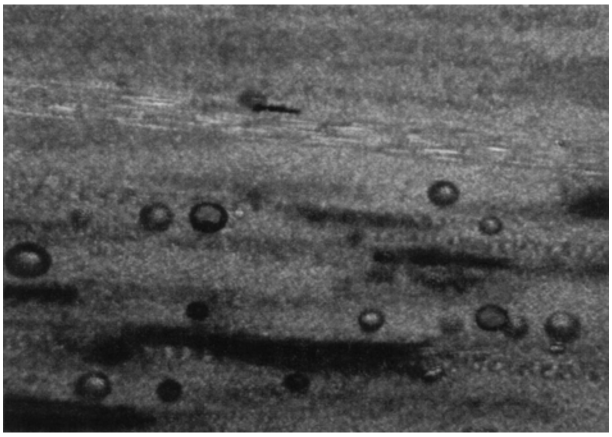

Figure 8. Cross section of Plate 3; 100X

5. CONCLUSION

Various factors can have effect on mechanical properties of material. Besides the type and content of reinforcements, the condition in boundaries between reinforcements and matrix also plays an important role. In production by soaking (applicable in production of test plates used in this investigation) it is very important to use adequate technique (e.g. using hand roller) to extract air in order to reduce number of present voids in boundary surfaces. This procedure is mainly used in production for smaller series, where just one side of product has to be smooth. In order to associate results of testing for obtaining mechanical properties to structure of laminates, the cross-sections of plates were recorded under light microscope using polarized light. Those recordings can contribute to identifying defects and irregularities which can indicate a certain possibility of further laminate damage. An optimal way to obtain better mechanical properties of composite materials is done by changing layers of reinforcements and their distribution as well as reinforcement's thickness. Results of performed tests indicate that porosities (air voids) have a significant effect on laminate mechanical properties. As further investigation, the possibility of application of infusion under pressure lamination and injection pressing in vacuum ("RTM procedure" Resin Transfer Moulding) should be analyzed in order to reduce presence of air voids i.e. to get more homogeneous structure. That should result in better mechanical properties, especially for smooth and upper surface (Side "A"), which is important in application where both sides have to be aesthetically smooth.

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УТИЦАЈ УДЕЛА И РАСПОРЕДА СТАКЛЕНИХ ВЛАКАНА НА МЕХАНИЧКА СВОЈСТВА ПОЛИЕСТЕРСКИХ ЛАМИНАТА

Влатко Марушић, Илија Ћепина, Пејо Коњатић

У раду су истраживана механичка својства полиестерских ламината ојачаних различитим слојевима стаклених влакана уз додатке пуниоца и адитива. Испитиване плоче су израђене натапањем ојачивача смолом уз ручно истискивање мехурића ваздуха помоћу ваљка. На основу резултата испитивања чврстоће (затезне, савојне и између слојева), модула еластичности, жилавости и удела неорганских састојака, констатовано је да механичка својства полиестерских ламината зависе не само од „композиције“ него и од шупљинама које су, као нехомогености, преостале на граници основа/ојачивач.