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ABRASIVE WEAR RESISTANCE OF GLASS FIBER REINFORCED POLYESTER LAMINATES

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Preliminary Note – Prethodno priopćenje

Tribological properties (Taber abrazer) and damages of fibre reinforced polyester laminates have been examined, depending on the number of reinforcing layers, their layout and thickness. The valorisation of properties was based on the composition of plates and the homogeneity of structure. Correlation between tribological and mechanical properties was determined by analysing test results.

Key words: polyester laminates, abrasive wear resistance, structure

Abrazijska otpornost trošenju poliesterskih laminata ojačanih staklenim vlaknima. U radu je istraživan utjecaj slojeva ojačala i njihovog rasporeda na tribološka (Taber abrazer) i mehanička svojstva te oblik oštećivanja poliesterskih laminata. Valorizacija svojstava izvršena je na temelju sastava ploča ali i homogenosti strukture odnosno udjela šupljina. Analizom rezultata ispitivanja utvrđeno je da postoji proporcionalna veza triboloških i mehaničkih svojstava.

Ključne riječi: poliesterski laminati, abrazijska otpornost trošenju, struktura

INTRODUCTION

The application of glass fibre as reinforcement enables production of composites with high specific strength. In this way, chemical inertness is achieved, which makes enables their application also in chemically aggressive environment [1]. Modifications of the number of reinforcement layers and their redistribution and thickness create optimal conditions for achieving their highly improved properties [2,3]. It should be pointed out that adhesion between fibres and the matrix represents the main precondition for transfer of stresses in composites. Unsaturated polyester resins reinforced with glass fibres (polyester laminates) can be used in civil engineering, naval architecture, car industry, agriculture, electric industry and electronics as well as in chemical industry. Depending on the field of application laminates are exposed to different predominant stresses. Research of properties and damages of polyester laminates represents an extremely complex and demanding field of study [4]. Interdependency between abrasive wear resistance, tensile strength and modulus, flexural and interlayer strength as well as impact test by Charpy on mass portion and structure of polyester laminates must be determined.

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EXPERIMENT

Seven samples of polyester laminates in plate form (size 500x700mm) were prepared for testing. Pressing the air out of the plates was done manually by roller (in order to decrease the number of voids on reinforcement /matrix boundary). A review of plate composition, layer of reinforcement (layers of mat and roving of glass fibres), additives and thickness is shown in Table 1.

Cross section of plates, reinforcement layout within the matrix is shown in Figure 1.a (schematic). Recording of plate cross sections, Figure 1.(b, c, d, e, f, g, h) was conducted on the light microscope under polarized light in order to link mechanical property test results with the structure of laminates.

There are two sides of plate:

– coarse side with polyester resin, side “A”,
– smooth and shiny side with gelcoat additive so as to obtain esthetical effect, side “B”.

Preliminary testing of the influence of structure on mechanical properties of plates were carried out (tensile strength, tensile modulus, flexural strength, interlayer strength, impact test by Charpy, content of inorganic matter) [5,6]. It was determined that these testing do not significantly depend only on the type and number of reinforcement but also on the homogeneity of the structure. Beside these testing, another test plate (100x100 mm) was used for determination of abrasive wear resistance. Testing of plates for their abrasive resistance was carried out on the test device Taber abraser Model 503

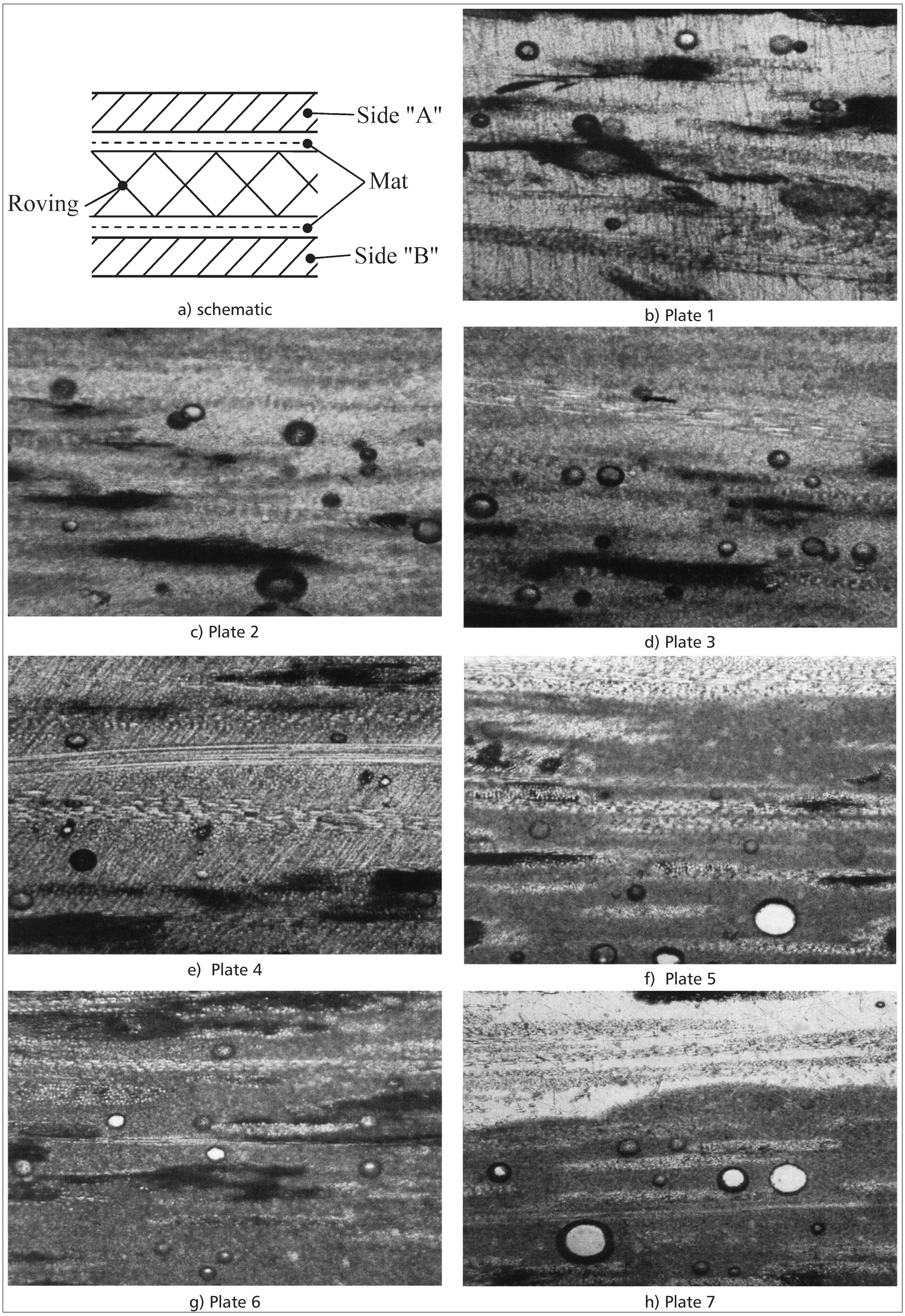

Figure 1. Schematic review of laminate (1.a) and specific laminate cross-sections (1.b, c, d, e, f, g, h), polarized light (100X)

Table 1. **Review of plate composition**

Nº Plate	Plate composition Side "A"				Side "B"	Thickness / mm
1	Resin	3x mat 450 g/m^2	2x mat 450 g/m^2	Gelcoat		3,8
2	Resin	2x mat 450 g/m^2	1x Roving 300 g/m^2	2x mat 450 g/m^2	Gelcoat	4,1
3	Resin	2x mat 300 g/m^2	Combimat	1x mat 450 g/m^2	Gelcoat	4,2
4	Resin	1x mat 450 g/m^2	2x Roving 300 g/m^2	1x mat 450 g/m^2	Gelcoat	3,9
5	Resin + calcite	3x mat 450 g/m^2	2x mat 450 g/m^2	Gelcoat		4,2
6	Resin + calcite	1x mat 450 g/m^2	2x Roving 300 g/m^2	2x mat 300 g/m^2	Gelcoat	4,0
7	Resin S E*	2x mat 450 g/m^2	3x mat 450 g/m^2	Gelcoat		4,8

* Self extinguishing resin

[7]. The panel side covered with gelcoat, used as protective decorative external surface layer, was examined (Side "B"). Wear resistance was examined by using abrasive discs, type Calibrase CS-17 (elastic). A standard test for abrasive wear without lubrication, in accordance with ASTM D-1044, was applied. The selected loading on discs amounted to 1000 g (the maximal allowed loading in standard test procedure). Based on the results acquired during probe testing, it was decided that plate sample testing in cycles should be applied; each cycle having 1000 plate revolutions, until appearance of the reinforcement (glass fibres) on the entire wear area caused by abrasive discs. Figure 2.a shows the position of the plate and abrasive discs and the ballast during testing. From the mass loss the Taber wear index was calculated by using the formula:

$$T_{ab_{it}} = \frac{\Delta m \cdot 1000}{6000}$$

Taber wear index (T_{abit}) represents loss of the mass in mg per 1000 revolutions of the examined plate. The lower wear index means better abrasive resistance. The number of plate revolutions on the device remained the same ($1s^{-1}$). Before the experiment, pre-testing was carried out. It was observed that after 4000 to 5000 plate revolutions, reinforcement (glass fibres) started to appear on the entire wear exposed surface. The characteristic appearance of the sample and the wear belt after 5000 revolutions of the plate are shown in Figure 2.b). Testing of plate mass loss was carried out by weighing prior to and after each cycle (precision 10^{-2}g). Vacuum level by which the vacuum pump tube sucks waste products from the plate surface was set at 50. Air humidity was approximately 50%, and temperature between 22 - 25 °C. The initial mass of plates, depending on the structure, was from 52.47 g (plate 4) to 67.52 g (plate 5).

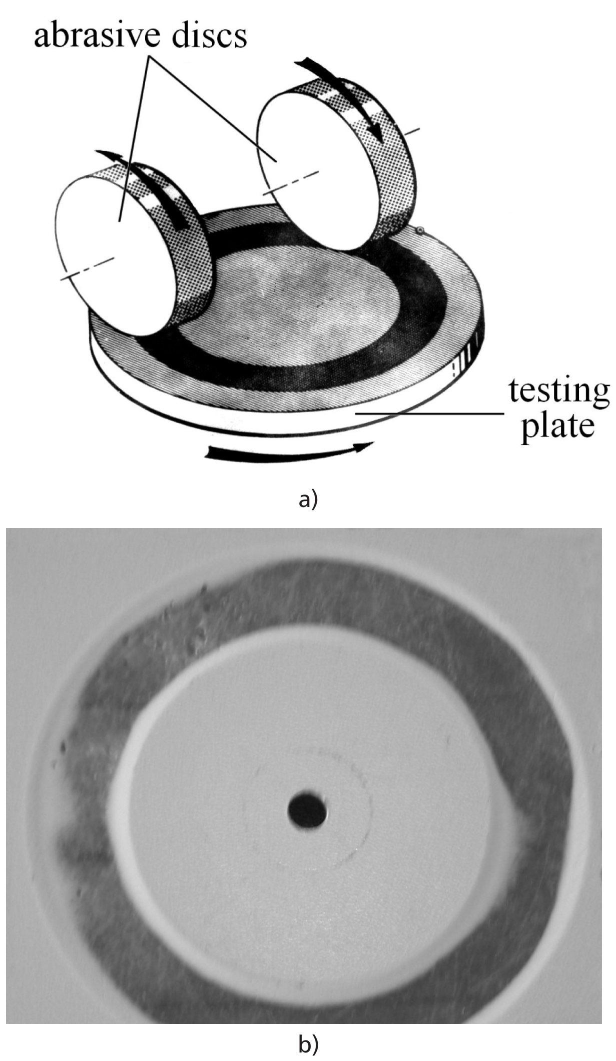

Figure 2. Schematic position of the plate and abrasive discs during Taber abraser testing (2.a) and characteristic appearance of the sample in the wear exposed belt after 5 cycle testing (2.b)

Table 2. **Mass loss of test plates (Side "B") and Taber wear index**

№ Plate	Mass loss by cycle Δm /mg						Sum Δm /mg	T_{abit}
	I	II	III	IV	V	VI		
1	400	410	410	330	210	210	1970	328
2	220	460	440	380	300	150	1950	325
3	580	440	360	350	280	210	2540	423
4	390	340	400	370	280	230	2010	335
5	410	440	500	440	320	250	2360	393
6	450	500	500	360	400	310	2520	420
7	480	510	520	480	370	330	2690	448

Sample plate mass loss for all 7 plates and calculated Taber wear index are shown in Table 2.

RESULTS AND ANALYSIS

Most of mechanical properties were tested on side "A" (resin) and side "B" (gelcoat). Considering that side "B" is smooth and shiny, these results were analysed in order to make a comparison of mechanical and tribological properties of polyester laminates. According to mechanical property test results, laminate plates (marked by serial numbers) were classified (marked by Roman numbers) from the best quality plates (I; II…) to the worst quality plates (VI, VII), Table 3.

Based on the comparison of test results, structure and composition of plate cross-section of tested polyester laminates, the following conclusions may be reached:

– average high classification of plate 4 is most probably the result of homogenous structure (Figure 1.e), and the biggest number of roving layers (two layers) in the middle of the plate,
– difference in plate classification 1 (no roving), 2 and 5 (having also two layers of roving in the central part) is due to the increased porosity of the material (Figure 1.b, 1.c and 1.f),
– average classification of the plate 7 is due not only to lesser content of reinforcement (no roving) but also to the evident lack of structure homogeneity (Figure 1.h). It was determined that the quality of gelcoat significantly affects abrasive wear resistance as well,
– the plate 2 has the best abrasive wear resistance; then plates 1 and 4,
– with increasing porosity of the structure, abrasive wear resistance decreases; plates 5, 6 and plate 3 and 7 have evident lack of homogeneity of structure.

CONCLUSION

By comparing the test results, it can be concluded that that diverse aspects of damage of polyester laminates might occur due to stress exposure. Laminates 5, 6 and 7

Table 3. **Classification of laminate plates of polyester composites according their tested properties**

Properties	Classes of lam. plates (1-7)						
	I	II	III	IV	V	VI	VII
Content of inorg. matter*	5	1	4	6	2	7	3
Tensile strength /Nmm^{-2}	-	6	1	2	5	3	7
Tensile modulus /Nmm^{-2}	4	2	3	6	1	5	7
Flexural strength /Nmm^{-2}	2	4	1	6	3	5	7
Interlayer strength/Nmm^{-2}	5	2	1	6	4	3	7
Impact test by Charpy /kJm^{-2}	4	2	6	3	1	5	7
Taber wear index**	2	1	4	5	6	3	7

*from higher reinforcement content (%) to the lower
** from higher to lower wear resistance

have the worst mechanical properties, which may be attributed to the presence of structural defects. It can be observed that laminates 1, 2 and 4 have best mechanical properties and higher abrasive wear resistance. The best correlation can be observed between flexural strength and wear resistance. Mechanical properties are influenced by diverse factors, not only by the type and the content of reinforcement, but also by conditions prevailing on the interface between reinforcement and the matrix. The difference (in wear resistance) can be explained by the presence of defects in shape of greater or smaller voids. Those voids are the result of air interference during the process of manufacturing (manually) and evaporative matter that appears during matrix hardening as well. It may be concluded that predominant load, prevailing in the field of application of the laminate, determines the approach to the selection of its composition. During the production process by soaking (applied in the production of all test plates), it is of the utmost importance to press the air out of the plates by application of adequate techniques (i.e. manually by using a roller), and so to reduce the voids present in adjacent planes. This technique is applied in the small batch production, where it is necessary that only one side remains smooth (gelcoat side). The application of newer procedures (e.g. infusion lamination under pressure), injection pressing in vacuum ("RTM procedure" - Resin Transfer Moulding) might enable smaller presence of air bubbles, i.e. better homogeneity of the structure. The application of this procedure might result in better mechanical properties and higher abrasive wear resistance, and especially in smoother surface, which is essential for some areas of application. It is evident that the procedures should be chosen based on the complexity of the product, as well as on the batch size.

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