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EVALUATION OF TENSILE PROPERTIES FOR PULTRUDED GLASS FIBRE REINFORCED POLYESTERS COUPONS

BY

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Abstract. This work studies the tensile properties in longitudinal and transverse direction of a pultruded composite material manufactured from E-glass fibres reinforced isophthalic polyesters (GFRP). Ten samples for each principal direction have been cut to size from strips 100x6 mm and loaded in tension. Instrumentation of the specimens with various transducers as extensometers, linear variable differential transducers, strain gauges, and load cell provided the data needed to determine the tensile ultimate strengths, strains and displacements, tensile moduli of elasticity and the Poisson's ratio. Experimental results have been compared and are in agreement with data obtained by numerical simulations using the ANSYS software. In comparison with the data provided by manufacturer, the values of tensile chord moduli of elasticity obtained experimentally are with 40% higher for the longitudinal direction and with 19% for the transverse direction.

Key words: glass fibres; isophthalic polyesters; tensile stress; tensile strains; tensile modulus; pultruded composites.

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1. Introduction

Pultrusion is a relatively simple process that enables the continuous production of composite profiles with constant cross section and different properties as required. Glass fibres and polyester resins are the most common raw materials used for the production of pultruded profiles.

Composites are used in the construction domain for the strengthening of old buildings, for new structures in aggressive environments as well as for new buildings as reinforcement for concrete and structural and non-structural elements, respectively.

The advantages of using pultruded glass fibre reinforced polyester (GFRP) strips and profiles are multiple. Low weight combined with high strength and convenient rigidity, high corrosion and UV resistance, long life and easy maintenance and assembly without using lifting equipment are just a few of the benefits that these materials can provide.

Tensile properties are needed in the design of GFRP pultruded structures. In this study the experimental results obtained from testing ten pultruded GFRP coupons for each direction (longitudinal and transverse) are presented in order to evaluate the ultimate strengths, ultimate strains and displacements, chord moduli of elasticity, and the Poisson's ratio.

Two finite element models have been conceived by using the ANSYS software and compared in terms of stresses and strains with the experimental and manufacturer values.

2. Experimental Program

For the experimental program ten samples for principal directions (longitudinal and transverse) have been prepared and tested according to D3039/D3039M and ASTM D4762-11a. This study is a part of a larger research program which is in progress in the Faculty of Civil Engineering and Building Services Iaşi.

2.1. Specimens Preparation

Specimens are manufactured from E-glass fibre reinforced isophthalic polyesters (Fiberline, 2013). Coupons have been cut to size from strips with a cross section 100 × 6 mm by using a universal cutting machine with diamond blade cutter. An epoxy bi-component adhesive, Adesilex PG1 has been used to bond the GFRP tabs attached at the ends of the samples (Mapei, 2013).

Samples have been instrumented under laboratory conditions with KFRP-5-120-C1-1 strain gauges for composite materials on both sides according to ASTM D3039/D3039M in order to evaluate the strains and the loading percentage. To evaluate the Poisson ratio, five samples have been instrumented with KFRP-2-350-D22-1 strain gauges with measuring grids in three directions, 0^0, 45^0 and 90^0, respectively.

Strain gauges have been glued on the specimens by using CC-33A cyano-acrylate base cement, respecting the prescriptions issued by the producer company (http://www.kyowa-ei.co.jp...).

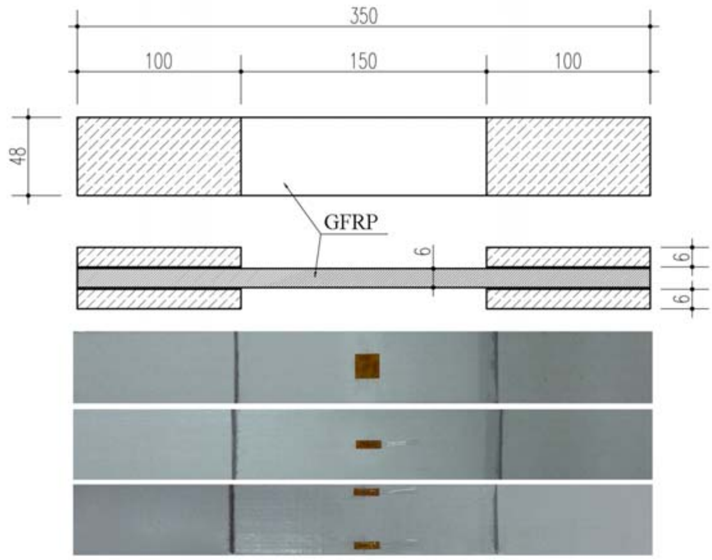


Fig. 1 – The specimen geometry for the longitudinal direction, 0^0.

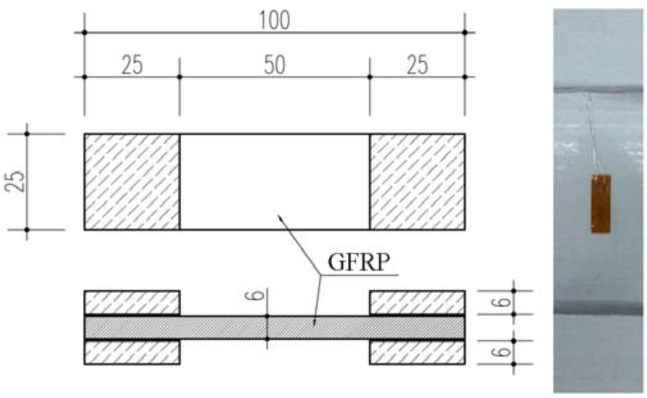


Fig. 2 –The specimen geometry for the transverse direction, 90^0.

The geometric characteristics and the instrumentation of the specimens with strain gauges are presented in Figs. 1 and 2.

2.2. Specimens Testing

Tensile tests on the specimens have been performed in a 1,000 kN universal testing machine with a constant crosshead movement of 2 mm/min according to ASTM D3039/D3039M-08. The positioning of the specimens in the testing machine clamps is presented in Fig. 3.

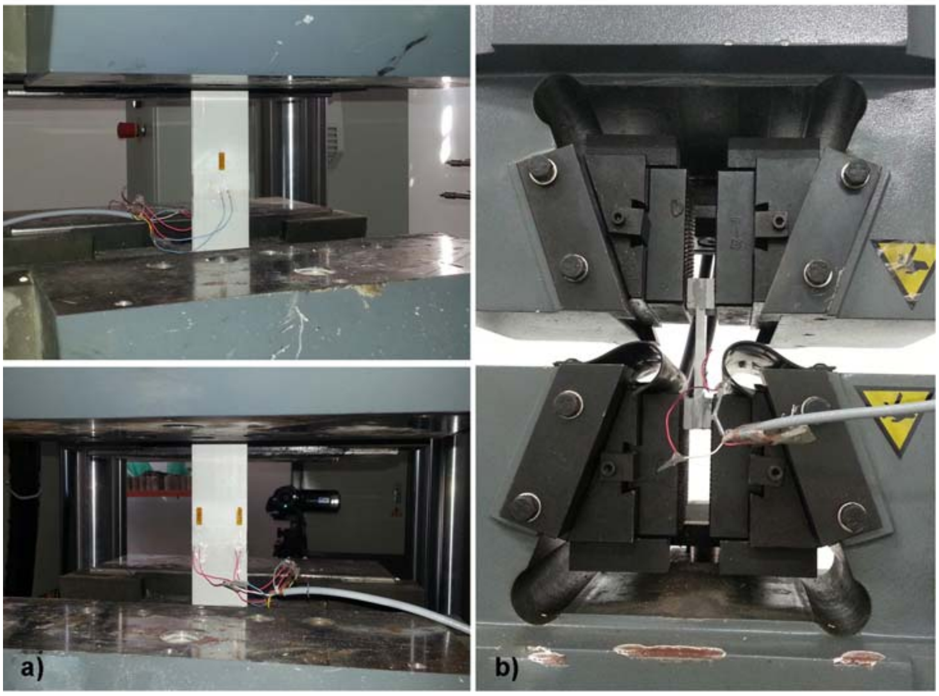


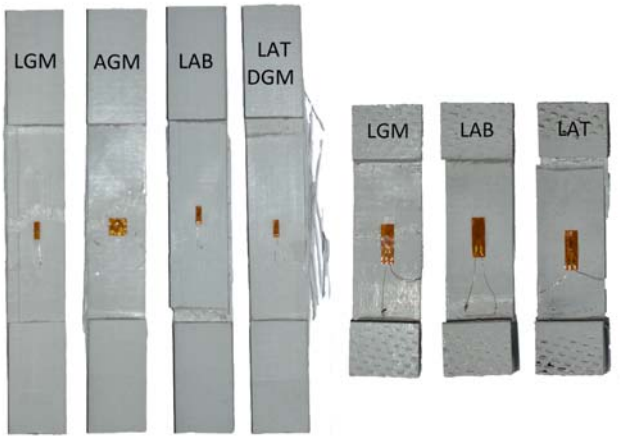
Fig. 3 – Specimens positioning in the testing machine clamps:
a – 0^0 specimens; *b* – 90^0 specimens.

The axial forces and the displacements in the tested specimens have been recorded by a universal testing machine and for strains an external USB-2401 DAQ board wired in half-bridge by using U-Test software has been employed (ADLINK Technology, 2013).

2.3. Experimental Results

The instrumentation of the specimens with strain gauges, linear variable differential transducers, and load cell provided data for determining the ultimate strengths, ultimate strains and displacements, moduli of elasticity, and the Poisson's ratio.

The failure modes identified on the tested specimens are in accordance with ASTM D3039/D3039M-08 being presented in Fig. 4. The dominant failure modes occur by lateral failure in the gauge region and by lateral failure in the grid/tab region.



a *b*

Fig. 4 – Identifying the failure modes in accordance with ASTM D3039/D3039M-08: *a* – longitudinal direction 0^0; *b* – transversal direction 90^0. LGM – lateral gage middle; AGM – angled gage middle; LAB – lateral at grid/tab bottom; LAT – lateral at grid/tab top; DGM – edge delamination gage middle.

The force vs. displacement curves and experimental results values are presented in Fig. 5 and Table 1, respectively. The ultimate strength values obtained for specimens with a 0^0 angle orientation of the fibres (direction of pultrusion) are 5.83 times higher than for the 90^0 samples.

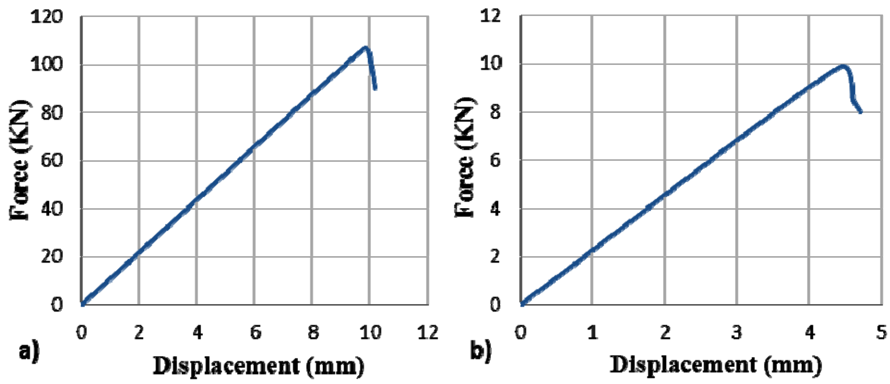


Fig. 5 – Force *vs*. displacement curves: *a* – longitudinal direction 0^0; *b* – transverse direction 90^0.

Table 1
Experimental Results for 0^0 and 90^0 Specimens. Force vs. Displacement

Specimen	Ultimate force kN	Ultimate displacement mm
Longitudinal direction	106.55	9.77
Transverse direction	9.506	4.21

The stress–strain curves and the statistical processing of the experimental results are presented in Fig. 6 as well as in Tables 2 and 3, respectively.

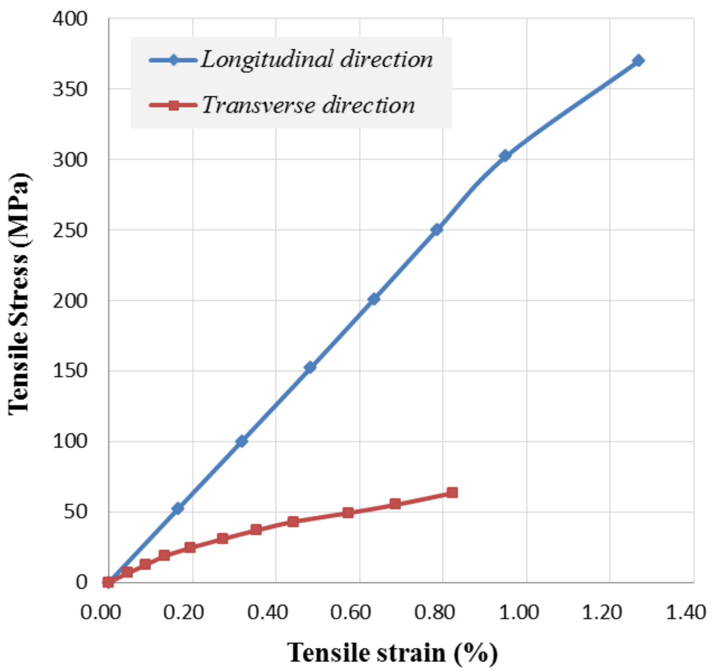


Fig. 6 – Stress – strain curves for 0^0 and 90^0 specimens.

Table 2
Experimental Results for 0^0 Specimens

	F^{tu} MPa	ε^{tu} µm	E^{chord} GPa	$\nu_{0,90}$
Average values	369.97	12,693	32.157	0.263
Sample standard deviation	13.76	475	1.021	0.064
Coefficient of variation, [%]	3.72	3.74	3.17	2.45

Table 3
Experimental Results for 90^0 Specimens

	F^{tu} MPa	ε^{tu} µm	E^{chord} GPa
Average values	63.37	8,232	10.135
Sample standard deviation	4.64	1,730	0.25
Coefficient of variation, [%]	7.32	21.01	2.47

For the calculation of the tensile chord modulus of elasticity and the Poisson's ratio, eqs.

$$E^{\text{chord}} = \frac{\Delta\sigma}{\Delta\varepsilon}, \quad (1)$$

$$v = \frac{\Delta\varepsilon_t}{\Delta\varepsilon_l}, \quad (2)$$

have been used according to ASTM D3039/D3039M-08, where: E^{chord} is the tensile chord modulus of elasticity; $\Delta\sigma$ – difference in the applied tensile stress between the two strain points; $\Delta\varepsilon$ – difference between the two strain points; v – the Poisson's ratio; $\Delta\varepsilon_t$ – difference in lateral strain for a specified stress increase; $\Delta\varepsilon_l$ – difference in longitudinal strain for the same stress increase.

For the 0^0 specimens, the values of $\Delta\sigma$ and $\Delta\varepsilon$ obtained at 3,000 µm and 1,000 µm, respectively, there resulted $\Delta\sigma$ = 64.12 MPa with $\Delta\varepsilon$ = 1,994 µm, respectively $\Delta\sigma$ = 20.81 MPa with $\Delta\varepsilon$ = 2,054 µm for the 90^0 specimens.

When calculating the Poisson ratio values, a strain gage range interval between 1,000 µm and 3,000 µm has been considered ($\Delta\varepsilon_t$ = –525 µm and $\Delta\varepsilon_l$ = = 1,994 µm).

3. Numerical Modelling

For the numerical modelling two finite element models have been selected for use with the ANSYS software. The type of finite element used in linear analysis, named Solid 185, is defined by eight nodes having three degrees of freedom at each node.

Composite coupons have been introduced in simulations as orthotropic materials with elastic characteristics determined experimentally through the testing program.

The discretization models consisted of 3,516 elements for the longitudinal direction, and 581 for the transverse direction, respectively. The contour conditions have been chosen in order to simulate as closely as possible the experimental model by introducing a fixed support in the bottom extremity and applying the ultimate experimental force at the opposite end. The stress and strain maps of the specimens are presented in Figs. 6 and 7.

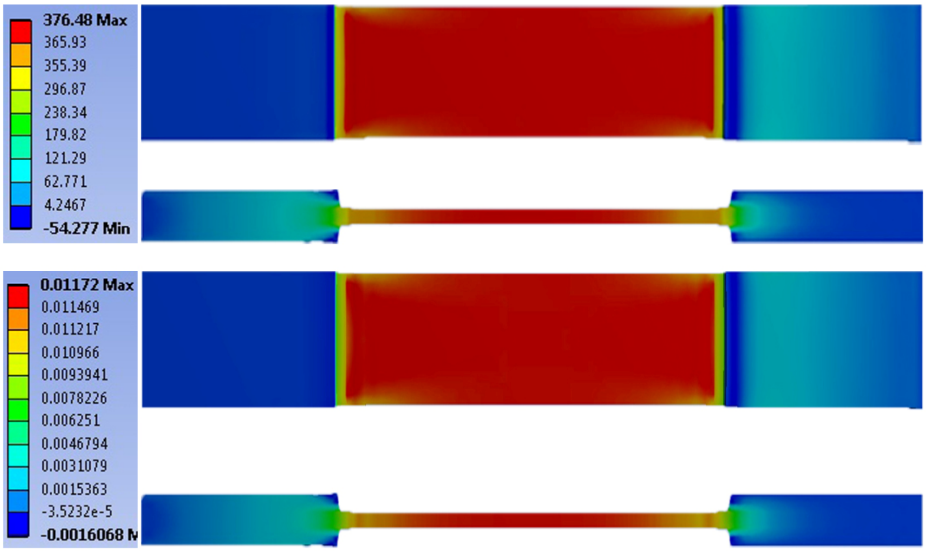


Fig. 6 – Stress–strain maps for longitudinal direction model.

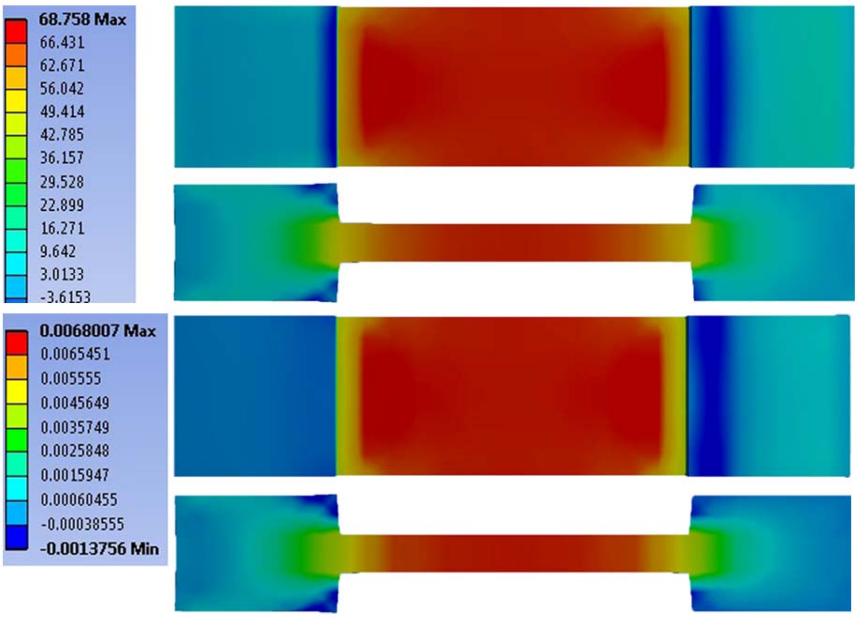


Fig. 7 – Stress–strain maps for transverse direction model.

4. Discussions

The comparative study of the experimentally results with those obtained by numerical modelling or analytical calculation is an essential step in the knowledge of the behavior of a material.

Comparative stress – strain curves are presented in Fig. 8 and Table 4.

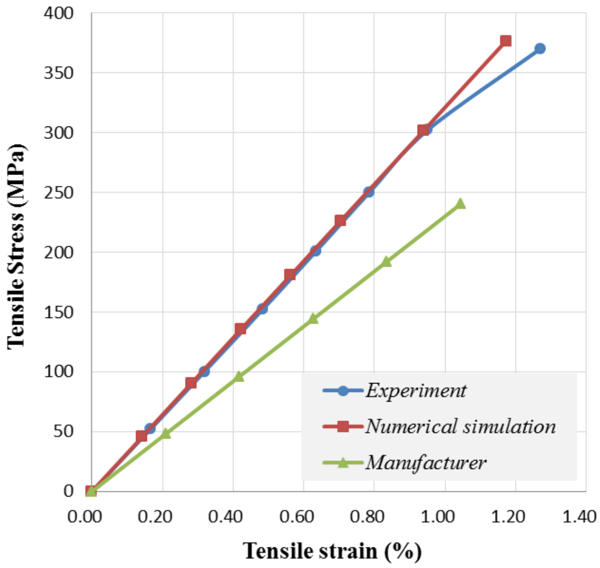


Fig. 8 – Stress *vs*. strain curves for longitudinal direction 0^0 specimens; results comparison.

The values obtained by numerical simulation for the longitudinal model are in agreement with the experimental results, having an insignificant difference in case of the tensile chord modulus of elasticity, 1.76% in terms of the ultimate stress and 8.3% for the ultimate strain.

Table 4

Results Comparison for 0^0 Specimen.

	F^{tu} MPa	ε^{tu} µm	E^{chord} GPa	$\nu_{0.90}$
Experiment	369.97	12,693	32.157	0.263
Numerical simulation	376.48	11,720	32.122	–
Manufacturer	240.00	10,430	23	0.230

In the case of the 90^0 specimens, a difference of 8.5% in terms of ultimate strength and 21% in terms of ultimate strain has been obtained. The comparison of results values is presented in Table 5 while the stress–strain curves are plotted in Fig. 9.

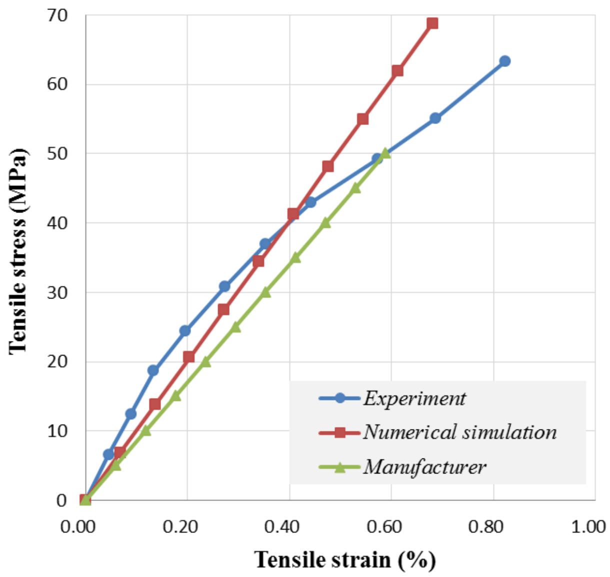


Fig. 9 – Stresses *vs*. strains curves for transverse direction 90^0 specimens – results comparison.

Table 5

Results Comparison for 90^0 Specimens

	F^{tu} MPa	ε^{tu} µm	E^{chord} GPa
Experiment	63.37	8,232	10.135
Numerical simulation	68.76	6,800	10.110
Manufacturer	50.00	5,880	8.50

A nonlinear model is required for modelling in the transverse direction in order to obtain better results.

5. Conclusions

The tensile properties are the most important parameters required in designing of an element or structure. Manufacturers often avoid providing all data about the products.

Experimental testing is the best tool used by researchers to evaluate the elastic and mechanic characteristics of a material. The accuracy of the experimental results is proportional with the precision of the samples preparing and instrumentation by using various transducers.

In this work the tensile properties of pultruded GFRP coupons have been evaluated both experimentally and by numerical simulation. The tensile ultimate strengths in the longitudinal direction obtained experimentally are with 583% higher than for that determined in the transverse direction while the tensile chord modulus of elasticity is 317% higher

The values provided by manufacturer for the modulus of elasticity are with 40% lower than those obtained experimentally in the longitudinal direction, and with 19% lower in the transverse direction, due to applying the safety factors for long term behaviour.

If the experimental values are compared with the values obtained through numerical modelling, the values of the ultimate tensile strengths are with 1.76% higher for the 0^0 specimens, and with 8.5% for the 90^0 ones. For a better accuracy of the results, a nonlinear model is required for the samples loaded in the transverse direction.

REFERENCES

* * * *Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials*. ASTM D-3039/D3039M-08.

* * * *Standard Guide for Testing Polymer Matrix Composite Materials Materials*. ASTM D-4762-11a.

* * * *I Profiles and Plate: Pultruded Glass Fibre Reinforced Polyesters Profiles and Plates*. Fiberline (2013).

* * * *Adesilex PG1: Two-Component Trixotropic Epoxy Adhesives for Structural Bonding*. Mapei, 2013.

* * * http://www.kyowa-ei.co.jp/eng/product/strain_gages/gages.

* * * *User's Manual, USB-2401, DAQ Module,* ADLINK Technology, 2013, 31.

EVALUAREA PROPRIETĂŢILOR LA TRACŢIUNE ALE UNOR CUPOANE PULTRUDATE DIN POLIESTERI ARMAŢI CU FIBRE DE STICLĂ

(Rezumat)

Se prezintă evaluarea proprietăţilor la tracţiune în direcţie longitudinală şi transversală pentru un material compozit pultrudat fabricat din poliesteri isoftalici armaţi cu fibră de sticlă (CPAFS). Au fost tăiate la dimensiunile dorite zece probe pentru fiecare direcţie din platbande cu secţiunea 100x6 mm şi testate în concordanţă cu prevederile din ASTM D3039/D3039M-08. Instrumentarea epruvetelor cu o varietate de traductoare ca extensometre, traductoare liniare variabile diferenţiale, mărci tensometrice şi celulă de forţă a asigurat înregistrarea datelor necesare pentru determinarea forţelor ultime, deformaţiilor şi deplasărilor, modulilor de elasticitate la întindere şi coeficientului lui Poisson. Valorile rezultatelor experimentale au fost comparate cu valorile obţinute prin modelare numerică utilizând programul ANSYS, observându-se o concordanţă bună.. Dacă sunt comparate cu datele furnizate de firma

producătoare, valorile modulului de elasticitate obţinut pe cale experimentală este mai mare cu 40% pe direcţie longitudinală şi cu 19% pe direcţie transversală. Explicaţia derivă din aplicarea de către producător (furnizor) a unui coeficient de siguranţă care asigură valori acoperitoare pentru încărcarile de lungă durată.