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Experimental Compare of the Mechanical Properties of Pultruded Glass Fibre Reinforced Plastic Based on Polyester and Vinylester Resin

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***Abstract* - The main purpose of this study is an experimental investigation and comparison of the mechanical properties of pultruded glass fibre reinforced polymer composite based on polyester and vinylester resin. For this purpose, the specimens were cut from the walls of square tube pultruded profile along to the fibres direction. The mechanical properties of the pultruded composite such as ultimate tensile strength and ultimate bending strength, tensile modulus and flexural modulus were obtained. It was observed that using of vinyl ester resin in pultruded composite instead of polyester resin enhanced the ultimate tensile and flexural strength from ~13% to ~24% in dependence of composite specimen's thickness.**

Keywords - Pultruded unidirectional GFRP lamina, tensile testing, flexural testing

I. Introduction

Modern composites are widely used now in different engineering constructions due to their high stiffness-to-weight and strength-to-weight ratios [1], [2] and high dissipative properties [3], [4]. The mechanical properties of composite materials are estimated in most cases by using conventional fracture methods [5]-[6], ultrasonics [7] and inverse technique based on low-frequency vibrations [8]–[10].

Pultrusion is one of the fastest growing manufacturing processes within the composites market. It is a continuous and cost-effective technology and is widely used for a production of high strength fibre-reinforced polymer composite profiles with different cross-sections [11].

During the manufacturing process, the reinforcement materials (fibres in the form of roving and mats) are pulled through an impregnation bath, containing a resin, and then fed into a heated forming where shaped into the geometry of pultruded profile. Finally, the profile is pulled out of the heated mould and cut according to desired length [12].

In literature, many different numerical and experimental techniques are carried out to design pultrusion processes. Mostly, thermo-chemical modelling in transient and steady state analyses are developed for a better understanding of pultrusion processes to analyse the distributions of temperature and degree of cure inside the die, using the finite element methodology [13]-[15] finite difference methodology, based on the nodal control volume method [16], [17].

Modern pultruded fibre reinforcing polymer (FRP) are becoming significantly important for the production of a large variety of products due to their light weight, higher tensile strength, good environmental resistance, high durability and electromagnetic neutrality [18], [19]. These characteristics ensure extensive application in civil engineering. Pultruded profiles are widely used as main structural component in bridge and building construction instead of the traditional materials [20]-[22].

The most common pultruded FRP composites used continuous fibres in the form of rovings, mats, woven fabrics and various type resin materials, including polyester, epoxy and vinyl ester. Combinations of these materials allows obtain the necessary mechanical properties of composite used for construction purpose [23]. The knowledge about mechanical properties of various pultruded GFRP composites significantly grow in last few years. Many researchers reported advantageous of pultruded composites by means of mechanical properties. A systematic study on material properties of pultruded GFRP composites is very important for extend application these materials in civil engineering [24]-[26] and simulation on mechanical behaviour of structures under

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loading. Characterization of mechanical behaviour is not only an important study for entire structures under loading, but also for the separate parts in time of their production, since stresses and deformations caused by the process may occur [27]- [29].

One of the main component in pultrusion is a type of resins. Polyester resins is the most widely used type of resin used in manufacture of pultruded composite. This resin can be used in the manufacture of anything composite and has an excellent resistance to corrosion in aggressive environments. Disadvantage of this polyester resin in compare to the vinylester resin is low long-term durability. In addition, the vinylester resin faster in cure and offers exceptional moisture resistance. The strength of vinylester is higher than polyester resin but polyester resin is the cheapest [30], [31].

The main aim of this investigation is an experimental determination the mechanical properties of pultruded GFRP composite based on polyester and vinylester resin and their comparison. Mechanical characteristics include tensile and flexural modulus of elasticity and ultimate tensile and bending strength. Specimens with two thickness and different structures used in this study.

II. Materials and methods

The pultruded GFRP specimens involved in this study were manufactured by COMPOR Company. They cut off from E-glass/polyester and E-glass/vinylester sheets with 6.3 mm and 3 mm thickness, respectively. The sheets cut off from walls of square tubes. GFRP square tube were fabricated with unidirectional glass fibre yarn (4800g/1000m) and continuous filament mat (CFM) layers embedded in polyester or vinylester resin matrix through pultrusion process. Wall with thickness of 6 mm consist of outer and internal middle layer of CFM with density 600 g/m^2 and inside layer with density 450 g/m^2. The wall with thickness of 3 mm consist of two CFM as outer and inside layer with density 450 g/m^2. It can be note that difference in construction of specimens can lead to distinction in mechanical properties.

The tension tests were carried out according to ASTM D3039 [32] in order to determine the ultimate tensile strength and longitudinal elastic modulus. Specimens were tested using a universal testing machine ZWICK100 with a capacity of 100 kN and crosshead movement speed of 2 mm/min. The dimension of specimens are 250 mm long in the direction of roving fibres and 25 mm wide. Gauge length of extensometer in tensile testing was 50 mm. The resulting average values of tensile test results were taken by repeating nine tests.

The ultimate tensile strength (σ_T) and longitudinal tensile modulus (E_T) were calculated using Equations (1) and (2).

$$\sigma_T = P_{max}/A \quad (1)$$

$$E_T = \Delta\sigma/\Delta\varepsilon \quad (2)$$

where, P_{max} is the force that caused failure (N); A is the cross-sectional area (mm^2); $\Delta\sigma$ is the difference in applied tensile stress between the two strain points (MPa); $\Delta\varepsilon$ is the difference between the two strain points

The flexural properties of pultruded GFRP composite specimens were determined according to ASTM D790 [33] using an Instron E3000 testing machine. The three-point bending flexural test were carried out to determine values of elastic modulus and ultimate flexural stress. Flexural tests were carried out at crosshead speed of 5 mm/min and using a 3 kN load cell. The dimension of flexural specimens for thickness 6.3 mm are 120 mm long in direction of roving fibres and 23 mm wide. The span was chosen according to recommendation of ASTM D790 standard. Span-to-thickness ratio, *L/t*, must be 16:1. Thus span between two supports is 100 mm. Specimens with 3 mm thickness has 60 mm long and 11 mm wide. Span between two supports is 48 mm. The resulting average values of bending test results were taken by repeating seven tests.

The ultimate flexural stress (σ_f) and flexural modulus (E_f) were calculated using Equations (3) and (4).

$$\sigma_f = 3P_{max}L/2bt^2 \quad (3)$$

$$E_f = L^3\Delta F/4bh^3\Delta s \quad (4)$$

where: P_{max} is the failure force (N); L is the support span (mm); b is the width of specimen (mm); t is the thickness of specimen (mm); Δs is the difference in specimen mid-point deflections (mm); ΔF is the difference in loads at Δs respectively (N).

III. Fresults and discussions

A. *Tensile and Flexural Strength*

Table 1 and Table 2 represent the comparison between tensile and flexural average strength for two pultruded composite with two type of resins and two thickness, respectively. The largest value in the tensile and flexural strength of the pultruded composites were obtained for composites with vinylester resin.

Replacement of a polyester resin (PE) by vinylester resin (VE) increases ultimate tensile strength of pultruded composites (Table 1). The maximum tensile stress reached 448.6 MPa and 353.7 MPa for pultruded composites with thickness 6.3 mm and 3 mm. The replacement of a polyester resin (PE) by vinylester resin (VE) gives an increase of ~18% and ~16%, respectively.

Table 1 Tensile strength

Specimen	Number of tests	Aver	Standard Deviation	Coefficient of Variation
		GPa	GPa	%
VE t=6.3 mm	9	448.6	21.58	5.07
PE t=6.3 mm	9	367.5	23.10	6.62
VE t=3 mm	9	353.7	24.99	7.45
PE t=3 mm	9	295.9	22.97	7.76

A similar increase is observed for the flexural strength in the pultruded composites (Table 2). Differences of the maximal stress between two resins achieve ~13% for specimens with thickness 6.3 mm and ~24% for specimens with thickness 3 mm.

TABLE 2 FLEXURAL STRENGTH

Specimen	Number of tests	Mean	Standard Deviation	Coefficient of Variation
		GPa	GPa	%
VE t=6.3 mm	7	506.0	20.24	4.00
PE t=6.3 mm	7	439.0	18.24	4.16
VE t=3 mm	7	268.6	21.80	8.12
PE t=3 mm	7	203.0	15.10	7.44

Averaged tensile stress-elongation curves of pultruded composites with two type of resins is plotted in Fig. 1. The stress-elongation curves for both type of resins were linear up to break. It can be observed that elongation at break for pultruded composite with polyester resin less than for composite with vinylester resin.

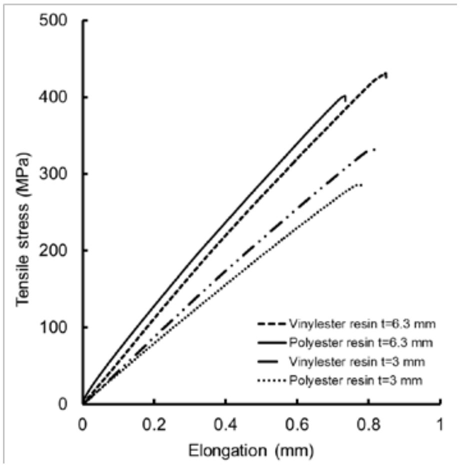

Fig. 1. Tensile stress-elongation curves of pultruded GFRP specimens with different thickness and resin.

Fig. 2. shows average flexural stress-displacement curves of pultruded composites with two type of resins. The displacement at failure had similar values for the pultruded composite with polyester and vinylester resin with the same thickness. The stress increased linearly until failure. The local destruction of the specimens begins on the lower surface in the middle of the span.

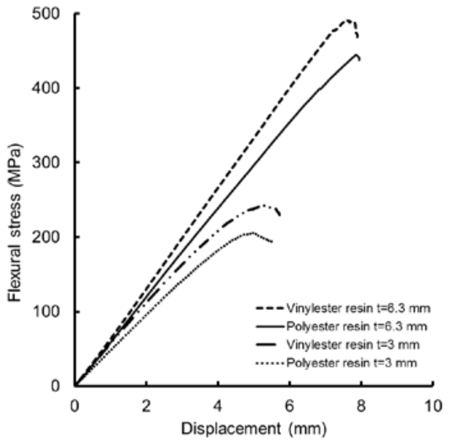

Fig. 2. Flexure stress-displacement curves of pultruded GFRP specimens with different thickness and resins.

B. *Tensile and Flexural Elastic Modulus*

The average results obtained for the tensile and flexural modulus with two type resin of the pultruded composites are presented in Table 3 and Table 4, respectively.

TABLE 3 TENSILE ELASTIC MODULUS

Specimen	Number of tests	Mean	Standard Deviation	Coefficient of Variation
		GPa	GPa	%
VE t=6.3 mm	9	28.36	3.41	12.04
PE t=6.3 mm	9	29.25	1.46	4.97
VE t=3 mm	9	22.60	2.34	10.36
PE t=3 mm	9	22.84	2.25	9.84

The pultruded composite with polyester and vinylester resin have approximately the same results in tensile modulus (Table 3). Percentage difference between polyester and vinylester resin does not exceed ~3% and ~1% for composites with thickness 6.3 mm and 3 mm, respectively.

Comparing the flexural modulis of the pultruded composite with two type of resin when thickness of specimens is 6.3 mm no significant differences were observed between them ~3%.

TABLE 4 FLEXURAL ELASTIC MODULUS

Specimen	Number of tests	Mean	Standard Deviation	Coefficient of Variation
		GPa	GPa	%
VE t=6.3 mm	7	19.78	1.37	6.90
PE t=6.3 mm	7	19.14	1.75	9.15
VE t=3 mm	7	9.90	0.96	9.68
PE t=3 mm	7	7.23	0.66	9.08

The replacement of a polyester resin by vinylester resin had the negligible influence on the flexural modulus of elasticity for composites with thickness 6.3 mm (table 3). The greatest increase of flexural modulus was obtained only for composites with thickness 3 mm and achieves ~27%. The flexural modulus of elasticity increased from 7.23 to 9.90 GPa.

The pultruded composite with thickness of 3 mm has a lower tensile and flexural modulus in compared to the corresponding values of composites with thickness of 6 mm. Different number of continuous filament mat in construction of pultruded composite may explain this difference.

IV. CONCLUSIONS

In the present research, the mechanical properties of pultruded GFRP composite with combination of two resin were studied. The knowledge about mechanical properties of pultruded glass fibre reinforced polymer composite based on polyester and vinylester resin are important because this product is relatively light and can be used in specific places. The experimental testing and analysis of pultruded GFRP composite were performed with the aim to investigate the influence of vinylester resin and polyester resin on the ultimate tensile and flexural strength, elastic and flexural modulus. For this reason, the composite specimens with two thickness and two type of resin were investigated experimentally. The results obtained allow us to conclude:

- The ultimate tensile strength was obtained for the pultruded composite with vinylester resin. The ultimate tension strength increase by ~18% and ~16% for pultruded composites with thickness of 6.3 mm and 3 mm, respectively.
- The ultimate flexural strength of pultruded composites with thickness 6 mm was increased by ~13% from 439.0 to 506.0 MPa. Composite with thickness 3 mm had the greatest percent increase in strength ~24%.
- The pultruded composite with polyester and vinylester resin have approximately the same results of tensile modulus.
- The replacement of a polyester resin by vinylester resin had the neglible influence on the flexural modulus of elasticity for composites with thickness 6.3 mm. The greatest increase of flexural modulus was obtained only for composites with thickness 3 mm and achieves ~27%. The flexural modulus of elasticity increased from 7.23 to 9.90 GPa.

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REFERENCES

[1] E. Barkanov, E. Eglitis, F. Almeida, M. C. Bowering, G. Watson, "Optimal Design of Composite Lateral Wing Upper Covers. Part I: Linear Buckling Analysis," Aerosp Sci Technol, vol. 38, pp.1-8, 2014. https://doi.org/10.1016/j.ast.2014.07.010

[2] E. Barkanov, E. Eglitis, F. Almeida, M. C. Bowering, G. Watson, "Optimal design of composite lateral wing upper covers. Part II: Nonlinear buckling analysis," Aerosp. Sci. Technol. vol. 51, pp. 87-95, 2016. https://doi./org/10.1016/j.ast.2016.01.020

[3] W. Hufenbach, L. Kroll, C. Holste, O. Täger and E. Barkanov, "Design of Dynamically Loaded Fiber-Reinforced Structures with Account of Their Vibro-Acoustic Behavior," Mech. Compos. Mater., vol. 37(2), pp. 145-152, 2001.

[4] Y. Koutsawa, W.L. Azoti, S. Belouettar, R. Martin and E. Barkanov, "Loss Behavior of Viscoelastic Sandwich Structures: a Statistical-Continuum Multi-Scale Approach," Compos. Struct., vol. 94, pp. 1391-1397, 2012. https://doi.org/10.1016/j.compstruct.2011.11.003

[5] R.F.S Hearmon, Introduction to Applied Anisotropic Elasticity, Oxford: Oxford University Press, 1961.

[6] V. Lusis, A. Krasnikovs, O. Kononova, V. Lapsa, R. Stonys, A. Macanovskis, A., Lukasenoks, "Effect of short fibers orientation on mechanical properties of composite material - fiber reinforced concrete," J. Civ. Eng. Manag., vol. 23(8), pp.1091-1099, 2017. https://doi.org/10.3846/13923730.2017.1381643.

[7] L. Filipczynski, Z. Pawlowski, J. Wehr, Ultrasonic Method of Testing Materials, London: Butterwoths, 1966.

[8] E. N. Barkanov, M. Wesolowski, P. Akishin and M. Mihovski, "Techniques for Non-Destructive Material Properties Characterisation," in Non-Destructive Testing and Repair of Pipelines, E. N. Barkanov, A. Dumitrescu, I. A. Parinov, Eds. Springer International Publishing, 2018, pp. 191-207.

[9] E. Barkanov, M. Wesolowski, W. Hufenbach and M. Dannemann, "An Effectiveness Improvement of the Inverse Technique Based on Vibration Tests," Comput. and Struct., vol. 146, pp. 152-162, 2015. https://doi.org/10.1016/j.compstruc.2014.10.006

[10] M. Wesolowski and E. Barkanov, "Improving Material Damping Characterization of a Laminated Plate," J. Sound Vib., vol. 462, 114928, 2019. https://doi.org/10.1016/j.jsv.2019.114928

[11] E. Barkanov, P. Akishin, R. Emmerich, M. Graf, "Numerical simulation of advanced pultrusion processes with microwave heating," in: Proceeding of the VII European Congress on Computational Methods in Applied Sciences and Engineering, 2016, pp. 7720-7738. https://doi.org/10.7712/100016.2368.5953

[12] N. Uddin, Developments in Fiber-reinforced polymer (FRP) Composites for Civil Engineering, Woodhead Publishing, 2013.

[13] E. Barkanov, P. Akishin, N.L. Miazza, S. Galvez, "ANSYS-based algorithms for a simulations of pultrusion processes, "Mech. Adv. Mater. Struc., vol. 5, pp. 377-384, 2017, https://doi.org./10.1080/15376494.2016.1191096

[14] E. Barkanov, P. Akishin, N.L. Miazza, S. Galvez, N. Pantelelis, "Experimental validation of thermo-chemical algorithm for a simulation of pultrusion processes, " IOP Conf. series: Journal of Physics:Conf. series, vol. 991, 2018, https://doi.org/0.1088/1742-6596/991/1/012009

[15] E. Barkanov, P. Akishin, E. Namsone, A. Bondarchuk, N. Pantelelis, "Real time characterization of pultrusion processes with a temperature control," Mech. Compos. Mater., vol. 56(2), pp. 135-148, 2020. https://doi.org/10.1007/s11029-020-09868-4

[16] Y. R. Chachad, J, A, Roux, J. G. Vaughan, E. S. Arafat, "Thermal model for three-dimensional irregular shaped pultruded fiberglass composites," J. Compos. Mater, vol. 6, pp. 692-721, 1996. https://doi.org/10.1177/002199839603000604

[17] I. Baran, C.C. Tutum, J. H. Hattel, "The effect of thermal contact resistance on the thermosetting pultrusion processes," Composites: Part B, vol. 45, pp. 995-1000, 2013, https://doi.org/10.1016/j.compositesb.2012.09.049

[18] A.S. Mosallam, A. Bayraktar, M. Elmikawi, S. Pul, S. Adanur, "Polymer composites in construction: an overview," vol. 2, p. 25, 2015. http://dx.doi.org/10.15226/sojmse.2014.00107

[19] A. Vedernikov, A. Safonov, F. Tucci, P. Carlone, I. Akhatov, "Pultruded materials and structures: A review," J. Compos. Mater., vol. 54(26), pp. 4081–4117, 2020. https://doi.org/10.1177/0021998320922894

[20] L.C. Bank, "Composites for Construction: Structural Design with FRP Materials, " John Wiley & Sons, 2006.

[21] A. K. Gand, T.-M. Chan, J. T. Mottram, "Civil and structural engineering applications, recent trends, research and developments on pultruded fiber reinforced polymer closed sections: a review," Front. Struct. Civ. Eng., vol. 7(3), pp. 227–244, 2013. https://doi.org/10.1007/s11709-013-0216-8

[22] H. Xin, Y. Liu, A.S. Mosallam, J. He, and A. Du, "Evaluation on material behaviors of pultruded glass fiber reinforced polymer (GFRP) laminates," Compos. Struct., vol. 182, pp. 283–300, 2017. https://doi.org/10.1016/j.compstruct.2017.09.006

[23] R.W. Meyer, Handbook of Pultrusion Technology. Springer-Verlag, NJ, 1985

[24] J. R. Correia, M.M. Gomes, J.M. Pires, F.A. Branco, "Mechanical behaviour of pultruded glass fibre reinforced polymer composites at elevated temperature: Experiments and model assessment," Compos. Struct., vol. 98, pp. 303–313, 2013. https://doi.org/10.1016/j.compstruct.2012.10.051

[25] E. Madenci, YO.. Özkılıç, L. Gemi, "Experimental Experimental and theoretical investigation on flexure performance of pultruded GFRP composite beams with damage analyses," Compos. Struct., vol. 242, pp. 112-162, 2020. https://doi.org/10.1016/j.compstruct.2020.112162

[26] A. Landesmann, C.A. Seruti, E.M. Batista, "Mechanical Properties of Glass Fiber Reinforced Polymers Members for Structural Applications," Mat. Res., vol. 18(6), pp. 1372–1383, 2015. https://doi.org/10.1590/1516-1439.044615

[27] E. Barkanov, P. Akishin, E. Namsone, J. Auzins, A. Morozovs, "Optimization of Pultruzion Processes for an Industrial Application," Mech. Compos. Mater., vol. 56(6), pp. 697-712, 2021, https://doi.org/10.1007/s11029-020-09868-4

[28] V. Antonucci, A. Cusano, M. Giordano, J. Nasser, L. Nicolais, "Cure-induced residual strain build-up in a thermoset resin," Composites: Part A, vol.37, pp. 592-601, 2006, https://doi.org/10.1016/j.compositesa.2005.05.016

[29] O. Kononova, A. Krasnikovs, G. Harjkova, V. Lusis, "Numerical simulation of mechanical properties for composite reinforced by knitted fabric," in: Proceeding of the 11th World Congress on Computational Mechanics (WCCM) / 5th European Conference on Computational Mechanics (ECCM) / 6th European Conference on Computational Fluid Dynamics (ECFD), 2014, pp. 2925-2932.

[30] A.M. Fairuz, S.M. Sapuan, E.S. Zainudin, C.N.A. Jaafar, "Polymer composite manufacturing using a pultrusion process: a review," Am J. Appl. Sci., vol. 11, pp. 1798–1810, 2014. https://doi.org/10.3844/ajassp.2014.1798.1810

[31] J.M. Sousa, M. Garrido, J.R. Correia, S. Cabral-Fonseca, "Hygrothermal ageing of pultruded GFRP profiles: Comparative study of unsaturated polyester and vinyl ester resin matrices," Composites Part A: Applied Science and Manufacturing, vol. 140, 106193, 2021. doi:10.1016/j.compositesa.2020.106193

[32] ASTM D3039. Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials, ASTM International, West Conshohocken, PA (2017).

[33] ASTM D790. Standard Test Methods for Flexural properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials, ASTM International, West Conshohocken, PA (2017).