Advanced Polylite composite laminate material behavior to tensile stress on weft direction

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Within this paper, basic mechanical properties have been experimentally determined on twelve layers glass fabric-reinforced polyester resin specimens subjected to tensile loads on weft direction until break. Glass fabric of type RT300 (300 g/m^2 specific weight) has been used to reinforce Polylite 440-M888 polyester resin. From a cured composite laminate plate, fifteen specimens have been cut on weft direction using a diamond powder mill to avoid introducing supplementary internal stresses in the laminate. Eight specimens have been tested with 1 mm/min test speed and seven have been tested with 2 mm/min test speed. Young's modulus, tensile strength, load at maximum load, extension at maximum load and other important features have been experimentally determined on a "LS100 Plus" Lloyd Instruments materials testing machine using Nexygen software.

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1. Introduction

Glass fabrics manufactured from unidirectional roving of type RT represent the second most used reinforcing material after chopped strand mats (CSMs). These fabrics present certain number of nodes on square centimeter, certain width and thickness, certain eye width, bending strength and feature certain surface aspect [1], [2]. The most used weaving methods are:

- Plain weave (in which warp and weft threads pass in a certain sequence one above each other);
- Diagonal weave (in which the fabric forms a characteristic pattern with diagonal lines on its surface);
- Satin weave (in which the fabric surface is formed either by threads belonging to warp or to weft).

The weaving method, threads thickness as well as their twist degree plays a significant role in mechanical characterization of a composite structure. In case of two-phase composite (e.g. matrix and reinforcement), the elastic properties can be quite easy computed using the basic elasticity properties of each compound in the rule of mixtures formula. Things are not so simple in case of three or more compounds. Here, homogenization and averaging methods can be used to compute elastic properties of such composite materials (e.g. pre-impregnated composites) [3]. Extended experimental researches have been carried out on glass-fiber-reinforced polymer matrix composites subjected to cyclic tensile-compression loadings with various numbers of cycles and load limits [4], [5]. Both experimental and numerical methods have been used to determine mechanical properties of various fiber-reinforced composite laminates, with and without fillers, subjected to off-axis loading systems, tensile and bending loads, biaxial loadings as well as thermal loads [6-11].

2. Material and method

The composite laminate used in tensile tests is a thermosett polymer (i.e. unsaturated polyester resin of type Polylite 440-M888) reinforced with twelve plies of glass fabric of type RT300 (300 g/m^2 specific weight). In general, the RT fabrics are manufactured from roving with cut margins and strengthened with Dreher threads (fig. 1). These fabrics are used to reinforce polyester and epoxy resins and present good impregnation properties.

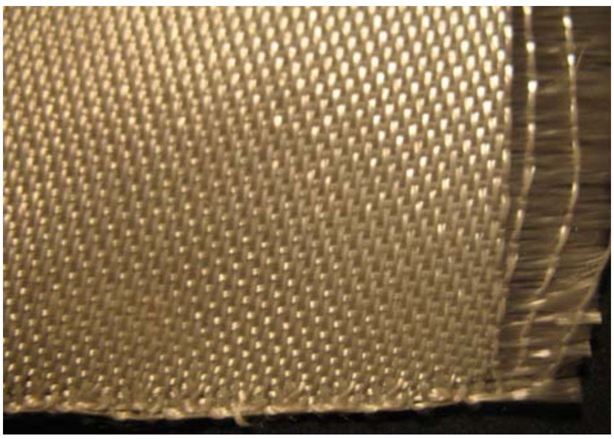

Fig. 1. RT300 glass fabric reinforcing material.

From a cured plate, fifteen specimens have been cut on weft direction using a diamond powder mill with added water to avoid introduce internal stresses and especially thermal stresses that can appear in the cutting process. The specimens have been tempered for 24 hours at a temperature of 20°C and then subjected to tensile loads until break according to SR EN 527-1: „Determination of tensile properties of fiber reinforced composite materials" (fig. 2). A "LS100 Plus" Lloyd Instruments materials testing machine have been used without extensometer to perform the tensile tests.

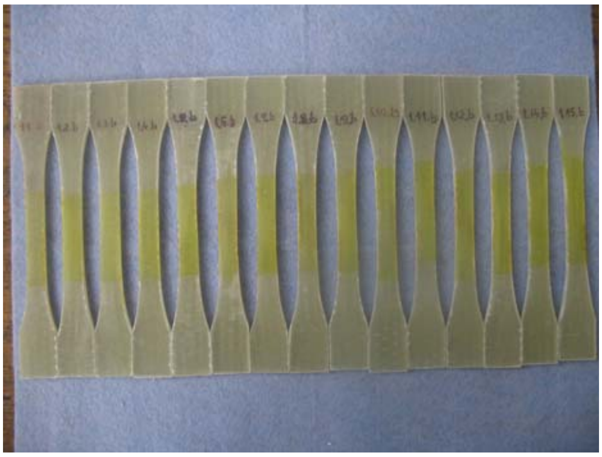

Fig. 2. RT300 glass fabric-reinforced Polylite 440-M888 polyester resin specimens cut on weft direction

Following main features have been experimentally determined:

- Stiffness (N/m);
- Young's modulus (MPa);
- Load/stress/strain at maximum load;
- Load/stress/strain at maximum extension;
- Load/stress/strain at minimum load;
- Load/stress/strain at minimum extension;
- Tensile strength;
- Load/stress at break;
- Work to maximum load/extension;
- Work to minimum load/extension.

Test and specimens features are:

- Test speed: 1 and 2 mm/min;
- Number of specimens: 8 for 1 mm/min test speed and 7 for 2 mm/min test speed;
- Specimens mean width: 9.63 mm for 1 mm/min test speed and 9.61 mm for 2 mm/min test speed;
- Specimens mean thickness: 3.65 mm for 1 mm/min test speed and 3.62 mm for 2 mm/min test speed;
- Mean cross-sectional area: 35.2 mm^2 for 1 mm/min test speed and 34.88 mm^2 for 2 mm/min test speed.

The materials testing machine allows determination of experimental results in electronic format by help of the NEXYGEN Plus software.

3. Tensile test results

Maximum mechanical properties of twelve layers RT300 glass fabric-reinforced Polylite 440-M888 polyester resin specimens cut on weft direction determined in tensile tests with 1 mm/min test speed are presented in table 1. For 2 mm/min test speed, maximum mechanical properties are presented in table 2. Both load-extension and stress-strain distributions have been generated for two test speeds (figs. 3-14).

Table 1. Specimens' maximum mechanical properties with 1 mm/min test speed

Feature	Value
Load at maximum load (kN)	11.57
Load at break (kN)	11.567
Young's modulus (MPa)	7446.2
Tensile strength (MPa)	312.74
Stress at break (MPa)	312.61
Strain at break (-)	0.077
Stress at minimum extension (MPa)	0.109
Strain at maximum load (-)	0.077

Table 2. Specimens' maximum mechanical properties with 2 mm/min test speed.

Feature	Value
Load at maximum load (kN)	10.778
Load at break (kN)	10.386
Tensile strength (MPa)	320.76
Stress at break (MPa)	309.11
Strain at break (-)	0.078
Stress at minimum extension (MPa)	0.104
Strain at maximum load (-)	0.077
Strain at maximum extension (-)	0.078

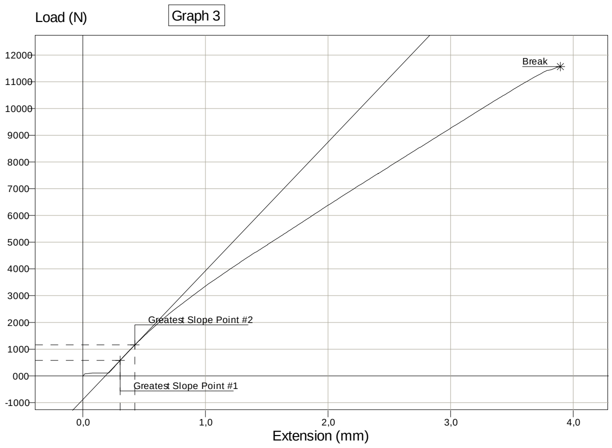

Fig. 3. Load-extension distribution of specimen 3 (1 mm/min test speed).

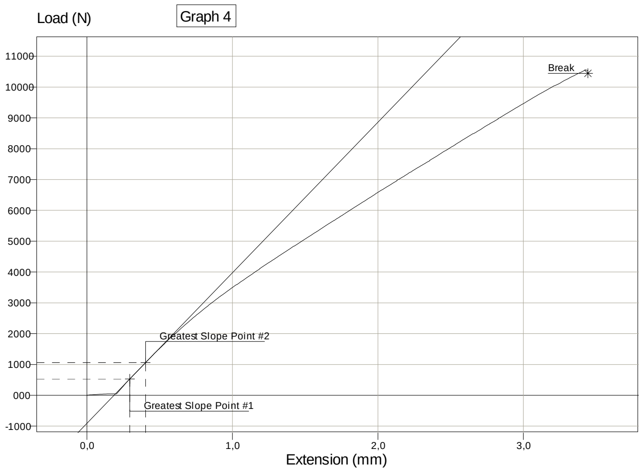

Fig. 4. Load-extension distribution of specimen 4 (1 mm/min test speed).

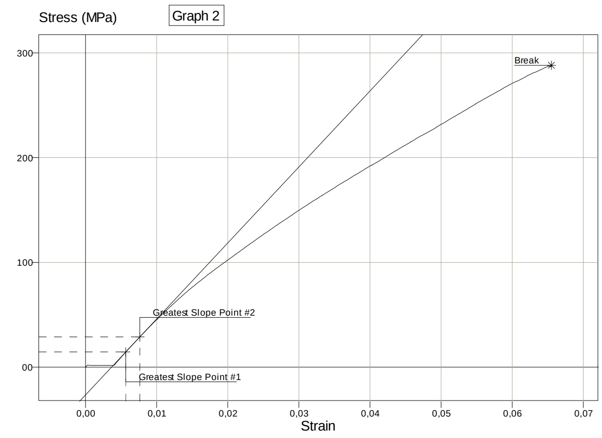

Fig. 7. Stress-strain distribution of specimen 2 (1 mm/min test speed)

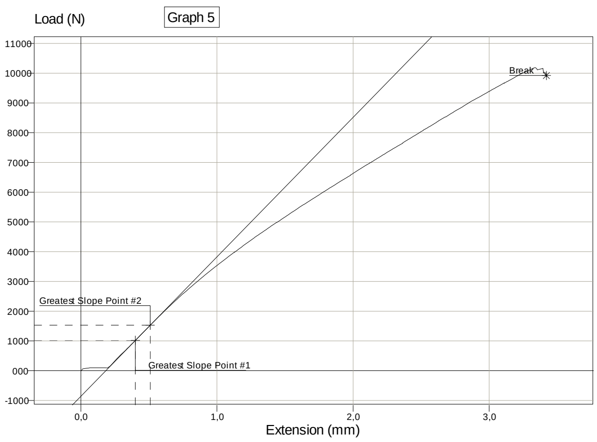

Fig. 5. Load-extension distribution of specimen 5 (1 mm/min test speed)

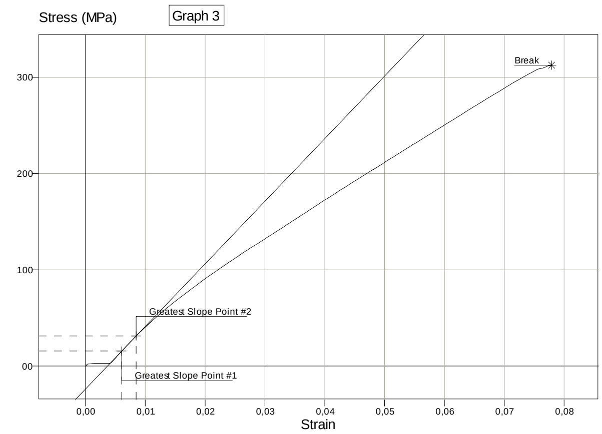

Fig. 8. Stress-strain distribution of specimen 3 (1 mm/min test speed)

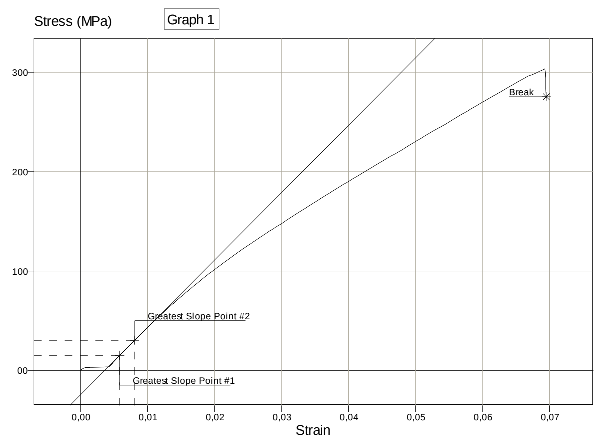

Fig. 6. Stress-strain distribution of specimen 1 (1 mm/min test speed)

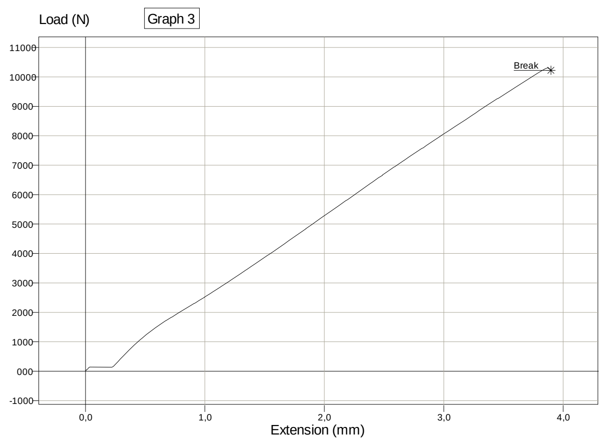

Fig. 9. Load-extension distribution of specimen 3 (2 mm/min test speed)

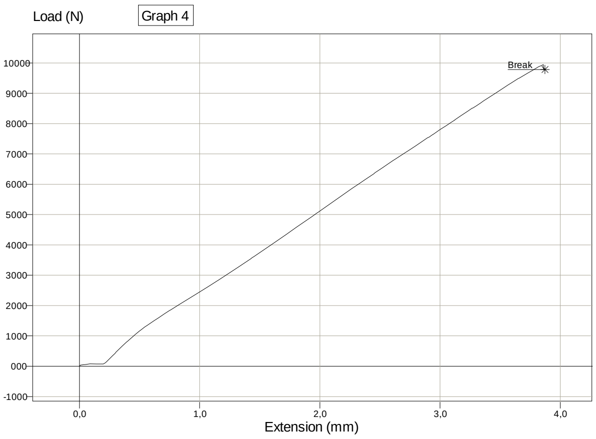

Fig. 10. Load-extension distribution of specimen 4 (2 mm/min test speed)

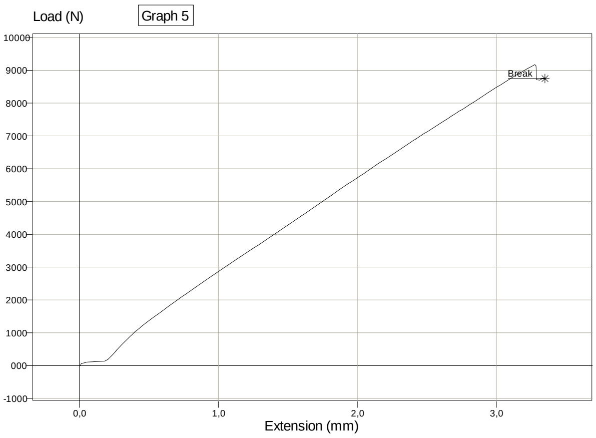

Fig. 11. Load-extension distribution of specimen 5 (2 mm/min test speed)

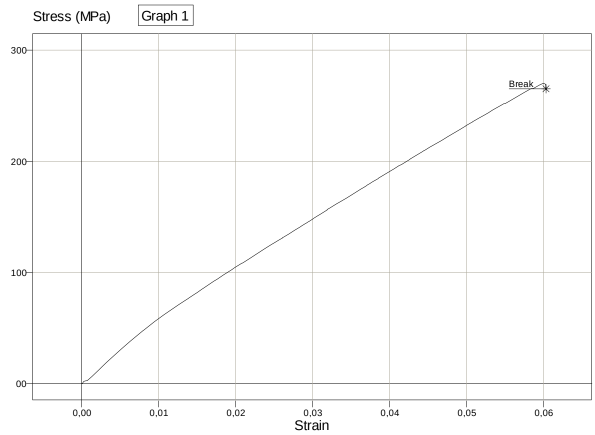

Fig. 12. Stress-strain distribution of specimen 1 (2 mm/min test speed)

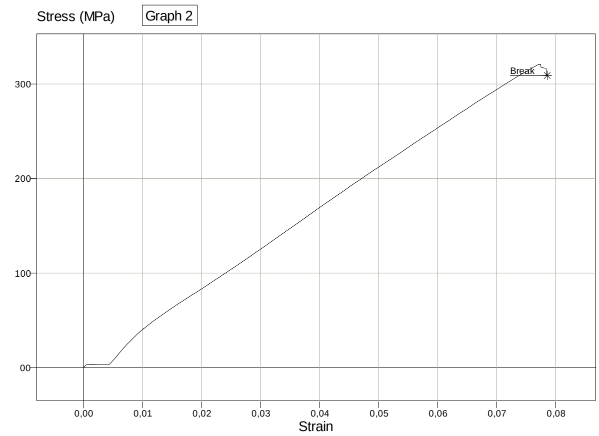

Fig. 13. Stress-strain distribution of specimen 2 (2 mm/min test speed).

In the distributions presented in figs. 6-8 and 12-14, the Young's modulus is computed between two points with the greatest slope belonging to the graph. These points are automatically generated at the end of each tensile test by the Nexygen software.

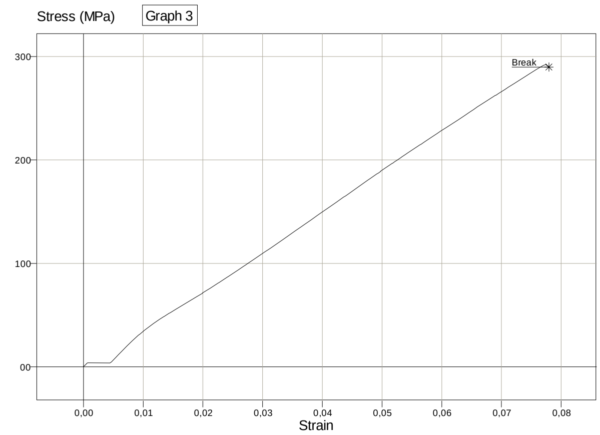

Fig. 14. Stress-strain distribution of specimen 3 (2 mm/min test speed).

Young's modulus distributions of twelve layers RT300 glass fabric-reinforced Polylite 440-M888 polyester resin specimens cut on weft direction are presented in fig. 15 as well as a distribution between Young's modulus and tensile strength (Fig. 16).

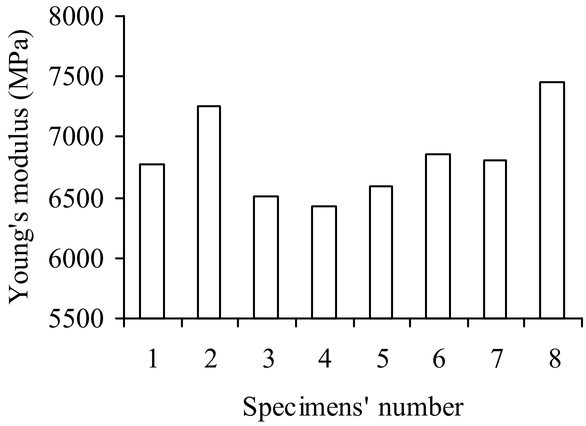

Fig. 15. Young's modulus distribution of eight RT300 glass fabric - reinforced Polylite 440 - M888 polyester resin specimens (1 mm/min test speed).

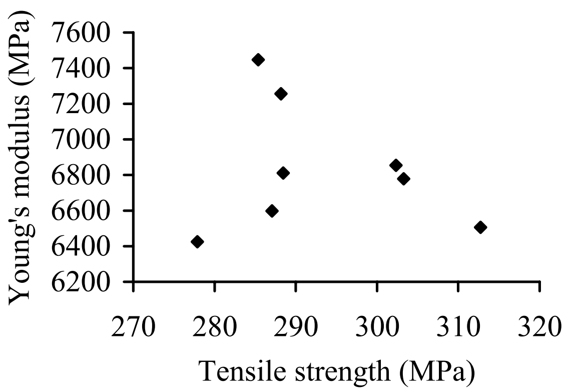

Fig. 16. Young's modulus distribution versus tensile strength of eight RT300 glass fabric-reinforced Polylite 440-M888 polyester res in specimens (1 mm/min test speed).

4. Discussion

Regarding the load-extension distributions of twelve layers RT300 glass fabric-reinforced Polylite 440-M888 polyester resin specimens cut on weft direction, all these behaviors shown in Figs. 3-14 present nonlinear distributions. This phenomenon is due to the nonlinear behavior of the Polylite 440-M888 polyester resin since is well known that glass fibers present perfect linear distribution in tensile test. The load-extension and stress-strain distributions for both 1 mm/min and 2 mm/min test speeds present close values. The Young's modulus distribution of twelve layers RT300 glass fabric-reinforced Polylite 440-M888 polyester resin specimens cut on weft direction presents a maximum value of 7446.16 MPa at specimen 8 and a minimum value of 6424.94 MPa at specimen 4 (Fig. 15). These values have been determined using the machine extensometer. Regarding the Young's modulus distribution versus tensile strength of twelve layers RT300 glass fabric-reinforced Polylite 440-M888 polyester resin specimens cut on weft direction presented in fig. 16, the eight values of Young's modulus are scattered between 277.86 MPa and 285.35 MPa tensile strength.

5. Conclusions

The first failures take place at a strain value of 0.025 – 0.035 for both test speeds. These failures appear due to delamination. The delamination is not so spectacular than in case of chopped strand mats reinforced polyester resin laminates. The crack that leads to break presents a development on a smaller length than in case of chopped strand mats reinforced polyester resin specimens. The tensile tests stopped at specimens' break. Due to good drape ability of RT300 glass fabrics, these reinforcing materials are widely used in most common polyester based composite structures.

Acknowledgements

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