Advanced Pultruded Glass Fibers-Reinforced Isophtalic Polyester Resin

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Within this paper an experimental analysis of an advanced composite U-beam pultruded profile based on isophtalic polyester resin reinforced with unidirectional glass fibres and overlay veil has been carried out to determine its most important mechanical properties. Tensile tests have been accomplished on specimens cut from the pultruded profile along and transverse to the fibers direction. Over thirty mechanical properties including Young's moduli, stiffness, load-extension as well as stress-strain distributions determined at maximum load, maximum extension and at break have been determined on a Lloyd Instruments LS-100KPlus materials testing machine. Typical failure mechanisms such as fibres pull-out and delaminations have been noticed. The tests show that this kind of unidirectional glass fibers-reinforced isophtalic polyester resin with overlay veil obtained in the putrusion process is suitable for a large range of applications from the automotive and aerospace industry and put into evidence its strong anisotropy.

Keywords: Pultrusion, Isophtalic polyester resin, Mechanical anisotropy, Tensile tests, Stiffness

In general, the pultrusion process is used at the manufacture of any continuous composite profile. In this process, fibers are pulled out from a beam creel, passed through a resin bath and pulled at constant speed through a heated drawing die [1]. In this heated drawing die, the uniform impregnation is accomplished and the curing process begins [2, 3]. The curing temperature is situated between 120 and 150°C. The curing speed depends on the hardeners' quantity from the resin mixture as well as on the disposal of the heating and cooling zones within the drawing die. The cured profile is then cut at the desired length. Except the fibers with orientation at 0°, in the drawing die can be introduced fabrics also. While the pultrusion process is a continuous one obtaining profiles with constant cross sections, nowadays a variant of this process known as "pulforming" allows the introduction of a certain variation in the profiles cross section [4, 5]. The pulforming process allows materials pulling through a drawing die to be impregnated, the resulted profiles being then clamped into a mould for the curing process. Typical applications for the pultruded profiles are beams and struts used in bearing structures like roofs, bridges, decks as well as profiled panels. These profiles are outstanding alternatives to concrete, aluminium, steel and aluminium. The advantages of the pultruded profiles are:

- Very fast and economic method to impregnate and cure a polymer matrix composite material;
- the resin content required for impregnation can be controled very accurately;
- the mechanical properties of the laminates are very good since the profiles present straight unidirectional oriented fibres and high fibres volume fractions can be obtained;
- the impregnation with resin can be accomplished into a closed zone so that volatile emissions can be limited.

Two main disadvantages of the pultrusion process may be mentioned as following:

- the process is limited at the manufacturing of profiles with constant or almost constant cross sections;
- the costs involved in the heating of the drawing die may increase the overall products costs.

Experimental part

Materials and method

The composite materials characterization is accomplished on a pultruded U-profile manufactured from following compounds:

- unidirectional E-glass fibres;
- isophtalic polyester resin;
- overlay veil.

The pultruded profile presents up to 60% fibers volume fraction. From this pultruded profile, five specimens along and perpendicular to the fibers direction have been cut. For tensile tests, the specimens have been cut according to ISO 527-5:2009 (Plastics – Determination of tensile properties – Part 5: Test conditions for unidirectional fiber-reinforced plastic composites). To avoid the specimens' degradation during the cutting process as well as to avoid to introduce residual internal stresses, a diamond cutting disc has been used at high speed rotation using a water cooling system. In figures 1-3, some glass fibers-reinforced isophtalic polyester resin profiles obtained in the pultrusion process at Fiberline Composites are presented. The tensile tests have been accomplished on a materials testing machine type LS-100KPlus. A detail of the tensile test is presented in figure 4.

Fig. 1. Glass fibers-reinforced isophtalic polyester resin pultruded T-profiles

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Fig. 2.. Glass fibers-reinforced isophtalic polyester resin pultruded hollow square profile

Fig. 3. Glass fibers-reinforced isophtalic polyester resin pultruded hollow tubular profile

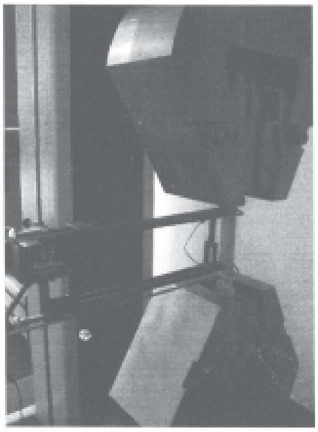
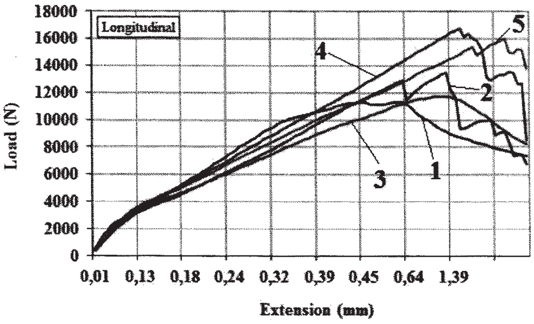
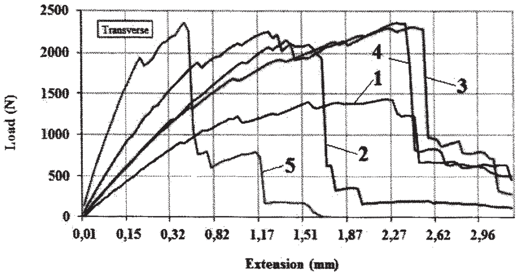


Fig. 4. Tensile test detail of an advanced pultruded glass fibers-reinforced isophtalic polyester resin



a.



b.

Fig. 5. Load-extension distributions of five specimens: a - cut along fibers direction; b - cut transverse to fibers direction

Results and discussions

One of the most important mechanical features of any material is represented by the Young's modulus. In tensile tests carried out on an LS100KPlus materials testing machine the experimental data have been recorded using special software called NEXYGEN Plus. The Young's modulus has been determined as chord modulus between two defined percentage strain points, namely between 0.05 and 0.25%. In tensile tests, the specimens have been subject to a test speed of 1 mm/min and the length between extensometer's lamellae is 50 mm. Load-extension as well as Young's modulus-tensile strength distributions are presented in figures 5-8.

In case of specimens cut along the fibers direction, the loads values are compact until the extension of 0.18 mm. From this value, they become scattered until break (fig. 5.a.). For specimens cut transverse to the fibers direction a significant anisotropy can be noticed, the loads values being up to eight times smaller than those recorded transverse to the fibers direction (fig. 5.b.). In the transverse direction, the fracture appears for the same values of load about 2300N...2400N and load-extensions are very different which shows the material anisotropy. Young's modulus-tensile strength distributions of all specimens present quite compact values especially those determined transverse to the fibers direction Young's moduli determined along fibers direction are only two times greater than those recorded transverse to the fibers direction (fig. 8). A comparison between the load-extension distributions at maximum and medium loads of specimens cut along and transverse to the fibers direction is presented in figures 6 and 7 .

The similar tests were performed by Pizhong (1996), Ahmadi (2009) and Pourladian (2010) on pultruded fiber glass reinforced with epoxy resin [6-9]. The average values of Young's Modulus obtained in present work recorded similar values (fig. 9).

Analyzing the failure modes, it can be noticed that the samples cut along fibers direction are characterized by delamination and a creep rate longer than the creep rate

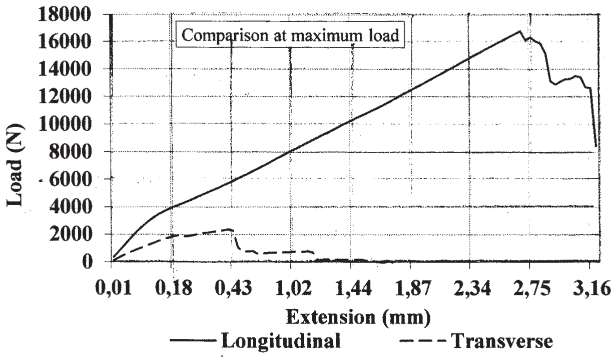


Fig. 6. Load-extension distributions at maximum load

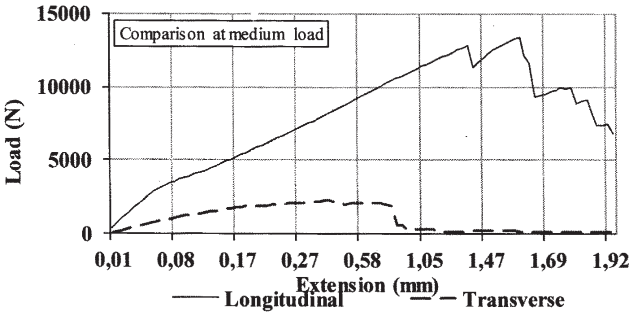


Fig. 7. Load-extension distributions at medium load

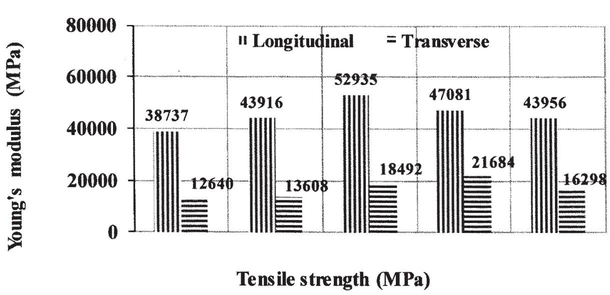


Fig. 8. Young's modulus-tensile strength distributions of all specimens

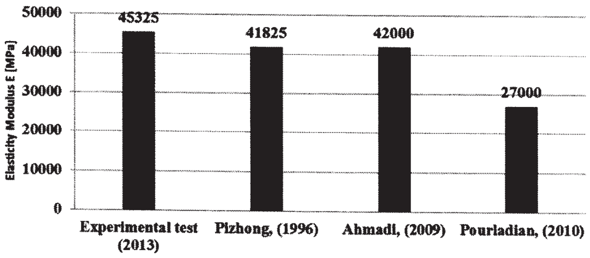


Fig. 9. Comparison of Young's modulus obtained with references

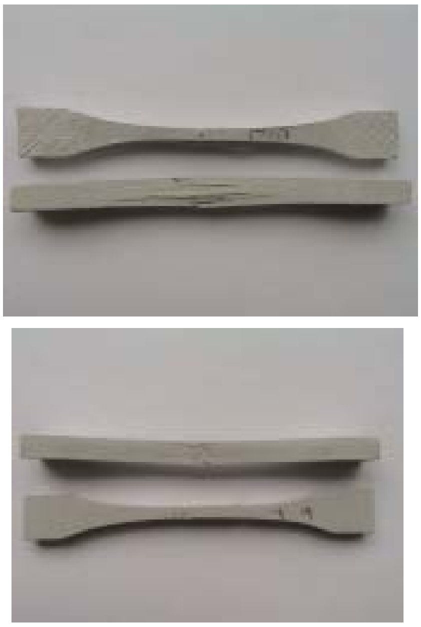


Fig. 10. Fracture modes of samples: a – cut along fibers direction; b - cut transverse to fibers direction

of samples cut transverse to fibers direction. The last one presents a ductile fracture at fracture force by six times lower than fracture force for samples along fibers direction (fig. 10).

Conclusions

The pultruded profiles are used in many interesting applications due to their constant cross-section, stiffness, high weather and corrosion resistance as well as high tensile strength. The tensile tests accomplished on specimens cut from a U-beam pultruded profile based on glass fibers-reinforced isophtalic polyester resin along and transverse to the fibers direction put in evidence some of the main advantages of this kind of composite material:

- Young's moduli up to 45000 MPa determined along the fibers direction;

- tensile strengths up to 350 MPa determined along the fibers direction.

The mechanical properties determined transverse to the fibers direction show a significant decrease from that determined along the fibers direction, so that the unidirectional glass fibers-reinforced isophtalic polyester resin pultruded profiles present a strong anisotropy.

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