Mechanical hydrothermal coupling behaviour of flax fibre composites

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Abstract. The long-term behaviour of flax fibre reinforced composites under real-life conditions is characterized by creep tests. The influence of three sources of damage (hydric, thermal and mechanical) was assessed by a coupled set-up: samples are immersed into water at constant temperature under mechanical solicitation. Flax composites immersed at 50°C and 70°C remained under stress for 115h and 23 hours respectively before breaking. No rupture was observed for composites immersed at 30°C during 900 hours. The comparison between thermo-mechanical and hydro-thermo mechanical tests highlights a composites coupling behaviour: samples exposed to thermo mechanical ageing break at about 0.7% of deformation while the composites exposed to hydro-thermo mechanical ageing presents a strain at break similar to values obtained for tensile tests (ε at break of 1.2 ± 0.1%). The elastic modulus decreases for about 50% in both cases but composites exposed to hydro-thermo mechanical conditions present a weaker time to fracture.

Introduction

The growing demand for bio-based materials needs a better understanding on their behaviour when exposed to environmental conditions. In real conditions, the different factors of damage act simultaneously, and their effects on biocomposites are coupled. Indeed, real conditions frequently couple simultaneously the action of temperature, humidity, mechanical loadings, and even other ageing mechanisms. [1]. The few studies on the plant fibre composites behaviour in aggressive environment highlight the lack of knowledge in this area (mainly under coupled conditions). Dhakal et al [2] studied the effect of water absorption on the mechanical properties of hemp fibre reinforced unsaturated polyester composites. It was shown a reduction in tensile modulus of 53% for hemp composites immersed aged into water at 25°C during 888 hours, while the strain at break increased by 22%. The work of McBagonluri et al [3] show a decrease of about 15% in modulus for a cyclically aged glass fibre reinforced composite exposed to water ageing at 45°C during 3000 hours. However the strain at break decreased for about 25% contrary to the increasing strain at break behaviour of flax fibre composites. Concerning the evolution of flax fibres into a composite, Le Duigou et al [4] observed a drop of about 55% flax fibre stiffness after water ageing at 23°C during 8 weeks. The tests were realised on dried samples which means that only irreversible degradation was measured and the plastification effect it is not apparent. In this work, the original feature consists in coupling hydro-thermo mechanical conditions in order to evaluate the influence of coupled ageing on the mechanical properties of flax fibre reinforced composites.

Unidirectional flax-fibre fabrics manufactured by Fibre Recherche Developpement (Troyes, France) were impregnated with an isophthalic unsaturated polyester resin and processed using vacuum infusion technique under controlled conditions (48%rh, 23°C). Composite sheets (300 mm x 250 mm) consisting of 4 layers of flax fabrics were vacuum infused with the resin. A vacuum pump was used to maintain impregnated fibres under a constant pressure of 100 mbar during 24 hours (curing at room temperature). Subsequently, a post-curing step take place in an oven at 60°C.

Samples were cut to size of 250 mm x 25 mm using a diamond cutter. Composites of 32% vol. of fibres were fabricated and were stored in a climatic room, at 23°C and 50% H.R., before testing.

A tensile creep tests is set up by applying a constant stress on a composites sample in order to determine the strain evolving behaviour of flax fibre composites. An experimental protocol based on regular stress releases enables to evaluate the evolution of the elastic modulus during ageing. A mechanical machine Dartec model 100 kN adapted with a LVDT sensor is controlled by a system developed by the Ecole des Mines d'Alès: Tema Concept®.

Results and discussion

The influence of the temperature on the creep behaviour of flax fibres composites immersed into water is presented in Fig. 1. We can note that the strain at break is not influenced by the water ageing temperature while the ageing time before breaking varies according to the temperature. Flax fibre composites remain under stress during about 23h and 115h (for water temperature of 50°C and 70°C) before break. No rupture was observed for flax fibre composites immersed into water at 30°C until 900 hours of ageing testing.

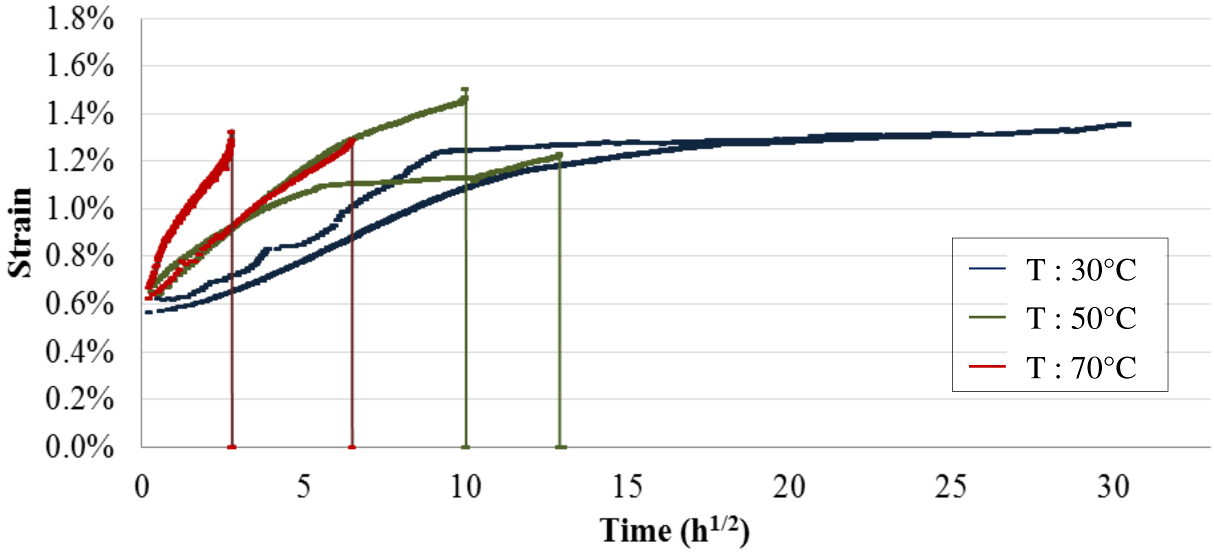

Figure 1 – Strain in function of ageing time for glass fibre composites immersed into water exposed to creep solicitation at 30°C, 50°C and 70°C. (applied stress : 60 MPa).

The strain and elastic modulus evolving behaviour in function of ageing time are show in Fig. 2 for flax fibre composites exposed to thermo-mechanical (T. M.) and hydro-thermo mechanical (H. T. M.) ageing (at 50° and 60 MPa of imposed stress). The influence of water ageing in creep behaviour is highlighted by an increase in strain at break. Indeed, flax fibre composites exposed to hydro-thermo mechanical ageing presents a strain at break similar (even higher) to values obtained for a monoaxial tensile stress test (ε at break : 1.2 ± 0.1%) while the flax composites exposed to thermo mechanical ageing break at about 0.7% of deformation. We observe a slight decrease in the ageing time before breaking: flax composites exposed to hydro-thermo mechanical conditions ruptures between 100 to 130 hours of ageing time while flax composites exposed to thermo mechanical conditions ruptures for about 220 hours of ageing time. The elastic modulus evolution during ageing shows similar behaviour in the two cases: a relative modulus decrease of about 50% is observed for flax composites before break. In this case, the water immersion at 50°C does not seem to influence the modulus degradation compared to the thermo-mechanical aged composites. Liang et al [5]observed a modulus increase of 2% when flax composites are exposed to fatigue solicitations at 0.8 UTS. This stiffening phenomenon is explained by the self-strengthening of the flax fibre related to the realignment of the flax microfibrils. However this strengthening behaviour is not observed here for flax composites exposed to creep solicitation.

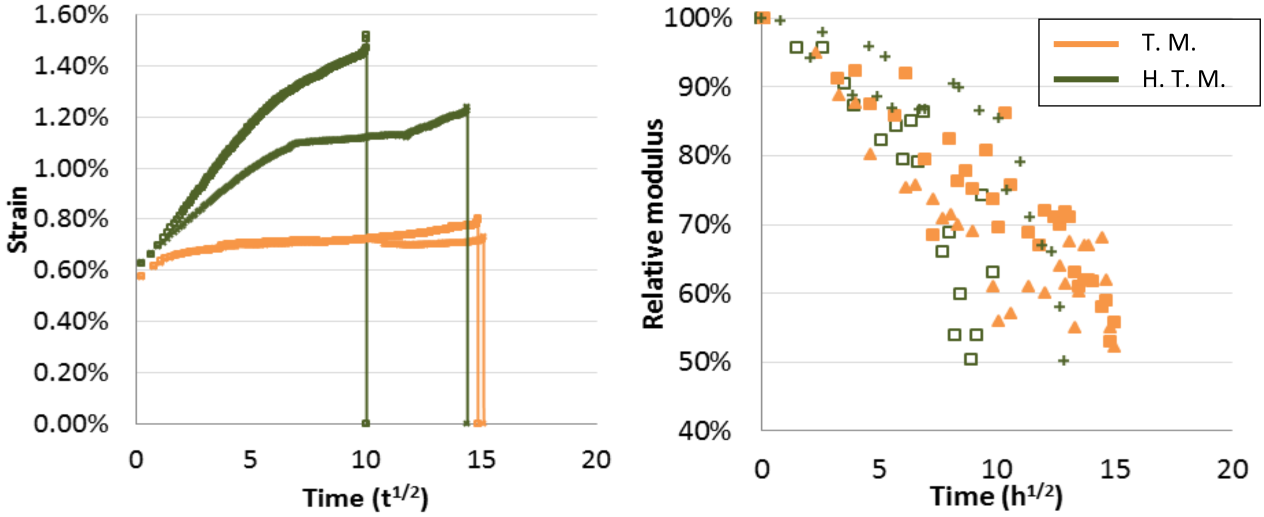

Figure 2 – Strain in function of ageing time for flax fibre composites exposed to thermos-mechanical and hydro-thermo mechanical degradation (at 50°C and 60 MPa).

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