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Zouhaier Jendli, Ali Akrouit, Abderrahim El Mahi, Mohamed Haddar, Mondher Haggui. Damage identification in flax fibre composite with thermoplastic matrix under quasi static loading. International Conference on Advanced Materials, Mechanics and Manufacturing A3M'2016, Dec 2016, Hammamet, Tunisia. hal-04584500

HAL Id: hal-04584500

<https://hal.science/hal-04584500>

Submitted on 23 May 2024

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Damage identification in flax fibre composite with thermoplastic matrix under quasi static loading

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Abstract – The use of natural fibres has recently become an alternative reinforcement for fibres reinforced polymer composites. Due to their eco-friendly, bio-degradability characteristics, good mechanical properties, they are exploited as a replacement for synthetic fibres, such as glass, aramid and carbon. The present study focused on the manufacturing and mechanical characterization of an eco-composite based on flax fibre associated to a thermoplastic matrix. The composite prepared by liquid infusion was subjected to quasi static tensile loading and cyclic tensile test to investigate its mechanical behaviour. Macroscopic observations were used along the tensile test. The aim of this experimental characterization was to identify the failure mechanisms occurring under the load, and to correlate their effects with the tensile behaviour of the material. The cumulative of damage mechanisms induces a non-linear response of the flax composite.

Key words: Flax fibre / Thermoplastic/ Damage mechanisms / Eco-composite / Tensile Test

1. Introduction

The application of polymer composites reinforced with natural fibers has substantially increased in the last few years, especially in sectors such as the automotive, aerospace, sport and leisure, where their reduced cost, eco-friendly and higher biodegradability may represent important incentives for use[1].

Many factors can influence the performance of natural fiber reinforced composites. The effect of fibre content and interfacial characteristics on the properties of natural fiber reinforced composites is particularly significant. It is often remarkable that the increase in fiber strength leads to an increase in tensile properties [2].

The present study focused on the manufacturing and mechanical characterization of an eco-composite based on flax fibre associated to a thermoplastic matrix. The composite prepared was subjected to quasi static tensile loading and cyclic tensile test to investigate its mechanical behaviour. Macroscopic observations were used along the tensile test. The aim of this experimental characterisation was to identify the failure mechanisms occurring during the load.

2. Experimental details

2.1. Materials

The composite used in this work is based on continuous unidirectional flax fibres 200g / m² FLAXTAPE © developed by the company LINEO. And thermoplastic liquid resin called Elium made by ARKEMA. This resin is an acrylic activated by peroxide. Its fluidity makes it particularly interesting for implementation by infusion technique.

2.2. Preparation of composite

Flax fibres were manually cut and then dried in an oven for about 1 hour at 110 ° C [3]. The various dried plies are positioned manually to the desired stacking sequence directly on a plane and previously waxed smooth mould. The infusion is then performed at a 0.4 bar depression.

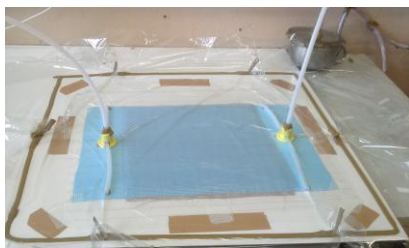


Figure 1. Technique of infusion

All prepared specimens are composed of 4 plies of flax fibres: UD-0°; UD-90°; [+45/-45]_s; [0/90]_s

2.3. Tensile test

The tensile tests were carried out with a tensile machine equipped with a 100 kN load cell. The strains in the tensile direction were measured by mean of an extensometer with a gauge length of 50 mm. The specimens have rectangular geometries (25 mm x 250 mm). All prepared configuration were tested under uniaxial loading, according to the standard test method ASTM D3039/D3039M [4].

3. Results and discussion

3.1. Mechanical properties

The flax/Elium composite volume fraction is estimated about 40%. The tensile tests carried on have allowed identifying the mechanical elastic and strength proprieties.

Table 1. Mechanical properties of the UD composite.

Elastic properties		strength proprieties	
component	Value	component	Value
E _L (GPa)	23.10	Σ _{Lrupt} (MPa)	210.46
E _T (GPa)	3.18	Σ _{Trupt} (MPa)	7.46
E _{LT} (GPa)	13.3	Σ _{LTrupt} (MPa)	115.51
v _{LT}	0.35		

3.2. Tensile test Analysis

The macroscopic stress-strain response presented in figure 2 is developed in three consecutive phases: first linear phase corresponds to elastic and reversible behaviour of the composite material, and then a second, non-linear phase, is associated with the initiation of damage mechanisms and the last phase linear and relatively inelastic, is conditioned by the intensification and spread of damage phenomena preceding the end of test.

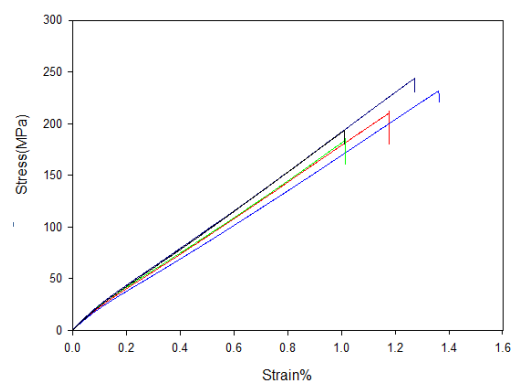


Figure 2. Tensile test stress-strain curves for UD-0° specimens

For each category of broken specimens in tensile test, macroscopic analyses of the failure modes and mechanisms were performed. The aim was to identify the main damage mechanisms such as delamination or fibre pull-out on the different types of specimen.

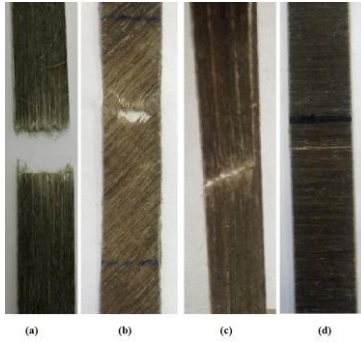


Figure 3. Damaged specimens under tensile test: a)[0/90]_S; b)[+45/-45]_S; c)UD-0°; d)UD-90°

The UD-0° specimens break for a high level of loading. The damage initiation occurs transversely in the middle area of the specimen and it propagates longitudinally. The [+ 45 / -45]_S specimens shows a high delamination. However, in the [0/90]_S specimens, the damage occurs and propagates mainly in the transverse direction due to fiber breakage. The UD-90° specimens shows a clearly break at the transverse direction unlike other test the damage takes place in the matrix part and then propagates to failure.

3.3. Damage propagation

In order to quantify the macroscopic damage, cyclic tensile tests (charge-discharge) was carried on the Flax/Elium composite. Figure 4 presents the stress/strain response with periodic amplification of the stress.

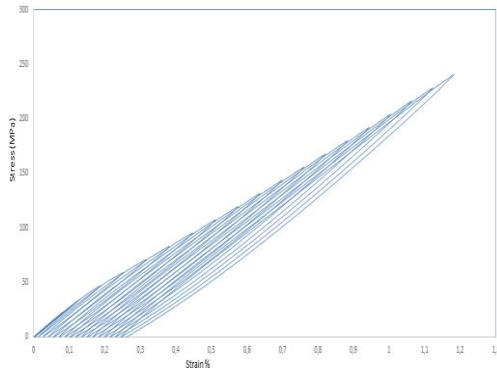


Figure 4. Stress/strain response under cyclic tensile test on UD-0°

The hysteresis loops slope after each cycle charge-discharge until the breaking of the material, this induces damage of the material, the area of the hysteresis loops increases progressively, indicating the presence of the viscosity within the material, The macroscopic damage is given by:

$$D_{macro} = 1 - (E_d / E_0) \quad (1)$$

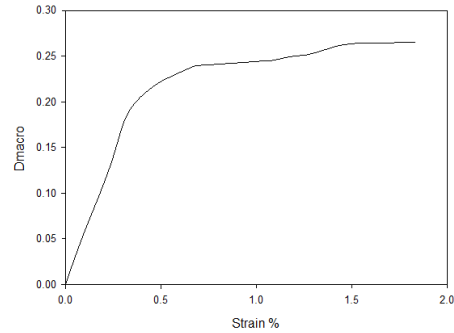


Figure 5. Stiffness degradation.

The damage under cyclic tensile test takes place in a high rate in the first cycles and then becomes slowly in the end of test .This behaviour reveals the visco-plasticity characteristic of the composite.

4. Conclusion

The present study highlights the manufacturing of an eco-composite based on thermoplastic liquid resin and flax fibres. The infusion technique allows preparing multiple samples during a very short time compared to a thermo compression. Mechanical tests carried on different configuration of specimens show a non linear response, this due to many damage mechanisms which take place along loading to failure. Thanks to its important mechanical strength, the flax/Elium composite could be a good candidate for many industrial applications.

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