Gambling or Engineering? - Modelling of the ageing of components made of Short Fibre Reinforced Polymer Composites

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Abstract

This paper deals with numerical modelling of the ageing behaviour of Short Fibre Reinforced Polymer Composites (SFRPC) manufactured by the injection moulding process. First of all, en experimental program has been carried out in with the influence of the accelerated ageing cycling on mechanical properties of poly(butylene terephthalate) reinforced with 20% of glass fibres (PBT GF20) has been measured. Tensile, shear and compressive tests for longitudinal and transverse fibre alignment have been performed to obtain the elastic and strength response of the material. The nonlinear elastic, anisotropic, with asymmetrical tension and compression, rate and age dependent material model complemented by the failure criteria was implemented in user subroutine and validated by means of the finite element simulation of the performed characterization tests. Proposed methodology is applied to an injection moulded component with complex geometry. Results indicates that proposed procedure enables fairly accurate prediction of the durability of SFRPC components in FE Analysis.

Keywords: composites, failure, finite element methods, material properties, viscoelasticity

1. Introduction

In recent times, polymer composites, based on thermoplastics matrix are commercially more popular. It's related with, observed, replacing the more responsible elements, loaded dynamically, such as suspension components made of metals, by the plastic parts or their composites. The characteristics of reinforced plastics such as the ease and flexibility of moulding, affordability, strength ratio to weight, ease of colouring, good vibrations and noise damping, good insulation property (thermal and electrical), have led to very rapid growth in their production and their widespread commercial use. Prior to producing materials and components made of polymeric materials, however, remains the question of sustainability of such components. The polymer matrix and their composites, especially based on PBT matrix, are very sensitive to changing environmental conditions [2]. This implies a need to create tools to predict the durability of products including both the working conditions of the element and structure resulting from the production process. This is particularly important in the case of polymer composites reinforced with short glass fibres, which in the production process induce anisotropic properties which in turn affects the behaviour of the product during use.

2. Experimental

In order to determine the influence of fibre alignment, strain rate, stress state and the ageing time, which influence on material properties, the following tests were made:

- Transverse and longitudinal tensile tests for three different strain rates and ageing times
- Transverse and longitudinal compressive tests for three different ageing times
- Transverse and longitudinal shear tests for three different ageing times

Accelerated SFRPC ageing was done using Humidity-Temperature cycling acc. USCAR rev.5 class 3 – with temperature of 95°C set under conditions of increased (controlled) relative humidity (95%). The number of 40 and 80 cycles, each 8 hours' long, were programmed.

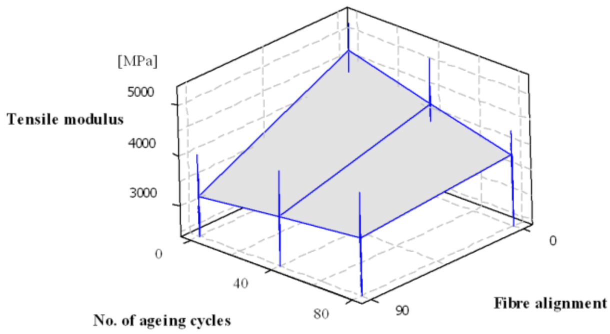

Figure 1: Surface plot of tensile modulus vs. ageing cycles and fibre alignment (0-Longitudinal, 90-Transverse fibre alignment)

Obtained results indicate that the number of the ageing cycles impacts on the Young modulus in different manners depending on fibre orientation (Fig. 1). The complete experimental results indicates that the following phenomena related with the SFRPC ageing process should be taken into account during material modelling:

- Decrease of Young modulus in longitudinal fibre alignment in tension and slight increase of Young modulus in transverse direction in tension

- Decrease of Young modulus with the strain rate for As Received (AR) materials
- Loss of the viscoelastic properties after H-T cycling
- Huge drop in tensile strength for both transverse and longitudinal direction in tension
- Increase of the shear modulus and decrease of shear strength
- Decrease of shear strength properties and equalisation of properties for transverse and longitudinal fibre alignment
- Decrease of compressive stress at break and strain at break

3. Material modelling and discussion

Based on experimental results, authors proposed extended computational procedure based on [1,3], presented in the Figure 2, taking into account described above phenomena. Material properties are defined as a N rational function (Eqn. 1).

$$z = (a + bx + cy + dxy)/(1 + fx + gy + hxy) \qquad (1)$$

where: z – tensile, compressive or shear strength in transverse or longitudinal direction, x – strain rate, y – ageing time

Fibre alignment import-geometrical mapping for different Finite Element (FE) position, local material orientation for each FE

Tensile, compressive and shear elastic and strength properties for longitudinal and transverse fibre alignment **surface function of ageing time and strain rate**

Determination of the dominant strain state
Tension: Long. / Transv.
Compression: Long. / Transv.
Shear: Long. / Transv.

Definition of material model: Transversely isotropic based user subroutine material model

- Damage parameter calculation - responsible for nonlinearity
- Strain rate dependent tangent modulus correction
- Stress based failure criteria calculation – determination of failure index and failure mode – FE stiffness reduction

Figure 2: Proposed computation diagram

As a result of implementation of proposed modelling procedure obtained very good agreement with experimental results with different impact of the ageing time dependently on fibre alignment (Fig. 3)

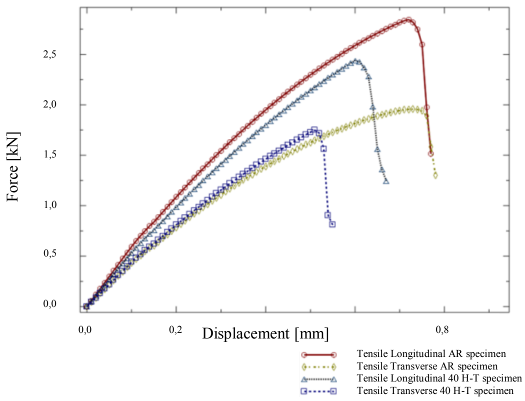

Figure 3: Comparison for AR material and specimens after 40 H-T cycling for tensile test

Computational diagram presented in the Figure 2, combined with failure models, were used to analyze the strength of the latch made of plastic reinforced with glass fibres presented in the Figure 4.

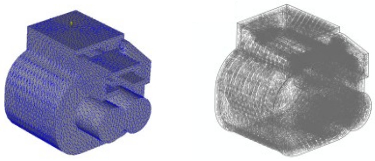

Figure 4: Fibre alignment - connector model
a) Calculated during mould filling analysis (left)
b) Imported to strength analysis (right)

The plastic latch was loaded by rigid pin providing displacement. The samples subjected to H-T ageing lose their viscoelastic properties what is visible in the Figure 5 in the form of a slight increase in reaction force during the 100 times increase in the speed test.

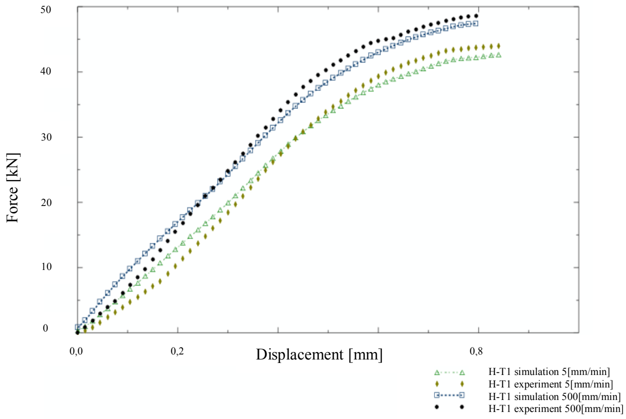

Figure 5: Comparison of different test speeds for simulation and experiment after 40 H-T cycling

These results are in agreement with experimental results. Comparison with laboratory tests shows that using material tests results and phenomenological material model which makes distinction between tension, compression and shear predominant stress state possible, complemented by material failure, produces very good results, close to laboratory tests. The error of the model is within 9%, which is located in the confidence interval changes of the short fibre reinforced injection moulded polymer composites material properties. The proposed approach enables a fairly accurate prediction of the durability of SFRPC parts in Finite Element Analysis.

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