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Fatigue mechanisms description in short glass fibre reinforced thermoplastic by microtomographic observations

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Abstract

Short glass fibre reinforced thermoplastics are promising materials for weight reduction of structures thanks to its very good specific mechanical properties. The current challenge is to provide experimental data concerning damage mechanisms and their kinetics in order to enhance micromechanical models for these materials with complex behaviour. The objective of this work is therefore to observe and explain damage mechanisms regarding spatial configuration of the microstructure. Fatigue tests have been running on reinforced polyamide specimens and interrupted at different levels of the estimated life. 3D pictures of the gage length of these specimens have been obtained by microtomography with high resolution (0.65 µm). This data presents damage location at different stages of lifetime. Thus, debonding, matrix damage and fibre failure have been identified as the three damage mechanisms for these materials. The analysis of the evolution of the damage markers quantity, volume and aspect ratio inform about the kinetic for each mechanism during the material life.

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1. Introduction

With increasing constraints of lightening in industrial fields, mechanical properties are now considered regarding material density. This trend ranks the short glass fibre reinforced polyamide 6,6 among very promising materials, whence emerges the need to describe its intricate behaviour. This complexity mainly comes from the microstructure

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of the material: the injection process, perfectly suited for high productivity and complex shapes, induces heterogeneous distribution and orientation of fibres. Furthermore, the mechanical performance of these composites results from a combination of the fibre and matrix properties and the ability to transfer stresses across the fibre–matrix interface as indicated by Thomason's works (Thomason 1999, Thomason 2008). In order to model its behaviour, one can use micromechanical approach which requires damage mechanisms knowledge and strain and stress thresholds values. The objective is then to observe and localise damage initiation and its development in the reinforced polymer. Despite significant work, there still is a lack of data about the link between spatial configuration of this microstructure fibres and damage mechanisms. Reference work in the field results from scanning electron microscopy (SEM) observations and analysis: a description of damage chronology has been made by Horst (Horst and Spoormaker 1996, Horst and Spoormaker 1997) for fatigue stress. Failure scenario in fatigue has been described by following steps: 1) Initiation of damage at the fibre ends. 2) Growth of this damage into voids, accompanied by debonding. 3) The voids grow into microcracks, which may remain bridged by either drawn matrix material or unbroken fibres. 4) The debonding relieves the constraint to which the matrix was subjected, which can therefore deform much more easily, forming bridges between the crack walls. 5) The bridged crack grows, until a critical size is reached, and the specimen fails. Two points have to be underlined about this work: firstly, the evolution of material process technology has to be considered. Then, this is a partial observation: SEM tool only enables surface observation. For this reason, it is maybe not representative of mechanisms proportions and kinetics in the whole material. In accordance to the objective of the study (i.e. spatial configuration of damage with respect to fibre organization), microtomography is the most suitable tool for 3D damage observation.
Here are presented the specific features of the material. Then, the procedure to manage to observe fatigue damage in the volume of the material is explained. This part is followed by a summary of preliminary results obtained with this method. Finally, results obtained for fatigue tests are shown and discussed.

2. Experimental

2.1. X-ray microtomography

X-ray computed microtomography is an observation technic based on the acquisition of a certain number of X-ray radiographs obtained for different angular positions of the sample with respect to the beam. These sets of X-ray radiographs are put together to obtain the three dimensional distribution of the linear X-ray attenuation coefficient μ within the sample. This distribution forms a 3D image where the elementary unit is called a voxel (volumetric pixel). For the reconstruction step, an analytical method was used. This method is faster than algebraic ones, but requires a complete set of radiographs during the rotation and cannot deal with missing views (Kak and Slaney 1988). X-ray computed microtomography can be performed using microfocus and synchrotron X-ray sources. Experiments presented in this paper were performed on ID19 beamline at the European Synchrotron Radiation Facility (Grenoble, France). A pink X-ray beam was used in mode 16 bunches, with a photon energy of 19 keV. A PCO edge camera with a 2048 x 2048 pixel sensor received 6000 X-ray radiographs during a rotation of the specimen over 180° along vertical axis. This experimental setup was optimized to obtain a voxel edge size of 0.65 μm. The acquisition of a complete scan lasts about 7 minutes. This first set of experiment were completed by additional imaging on Psyche beamline at the Synchrotron Soleil (Saclay, France). The filtered X-ray beam (2 mrad mirror, 0.5 mm aluminum and 0.25 mm silver) had an energy of around 26 keV. The CMOS detector with a 6.5 micron pixels, was associated to a x10 objective, leading to a voxel edge size of 0.65 μm. Specimen-sensor distance was 35 mm. 1500 projections were recorded per scan during a 180 degrees rotation of around 5 min, with 31 references pictures before and after scanning.

2.2. Specimen

The studied material is Technyl® A218V30, a commercial grade of polyamide 6,6 reinforced by 30wt% of short glass fibre supplied by Solvay Engineering Plastics-France. In addition to an intricate behaviour, the matrix of this material shows sensitivity to its conditioning. Indeed, effect of water content on polyamide 6,6 mechanical properties has been demonstrated (Barbouchi et al. 2007, Arif et al. 2014). For this reason, water content for