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Technical Report

Aging-impact coupling based analysis upon glass/polyester composite material in hygrothermal environment

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ABSTRACT

The objective of this present paper is an investigation of aging-impact coupling upon the polyester matrix E-glass fibers composite materials in hygrothermal environment. In the first part of the study, laminate composite plates were aged in an artificial hygrothermal environment using a climatic chamber at 50 °C temperature and 95% of relative humidity. The gravimetric readings showed discrepancy with respect to Fick's law which indicates the non-Fickian character of the moisture absorption kinetics. The application of the Carter–Kibler's model confirmed the Langmuir's behaviour governing the absorption up to a lap time.

In the second part of the study, low energy impacts test were carried out on both aged and non-aged composite plates in a bending configuration on two metallic supports. The impact loads were applied using drop-mass tower. The mechanical responses of aged and non-aged plates such as impact force, bending, contact duration, energy dissipation and damage are highlighted and analyzed.

1. Introduction

The glass fiber reinforced plastic (GFRP) laminates are very often used as lightweight materials in a wide range of applications because of their high stiffness and low density. But during both operational and maintenance activities crashes, choc and low-velocity impacts may occur as tool drop, material handling choc and crash. It is well known that such a type of loading induces damage which degrades the strength of the material. Many works have been done on this topic. Guillaumat [1] designed an experimental apparatus and investigated the reliability of composite structure due to impact loading. Guillaumat et al. [2] made a worthy contribution using experimental design for probabilistic dimensioning of impacted composite. As well as the work made by Shah [3] on the impact resistance of a rectangular polycarbonate armor plate subjected to single and multiple impacts and by Ik-Hyeon Choi [4] on the low-velocity impact analysis of composite laminates under initial in-plane load.

Major investigations reveal that the main damages are matrix and fibers breakage and delamination. The accumulation of these internal flaws, often invisible by an optical inspection, can grow under a fatigue loading leading to failure of the apparently undamaged structure.

Another important factor for the safety is the environment in which a composite structure is used because it can be the source of deterioration of the composite too. Details on the subject are found in Springer Editor and Tsai [5–7].

Liao et al. [8] investigated the effects of environmental aging on the properties of pultruded GFRP. On other hand, Loss and Springer [9] studied the moisture absorption of graphite/epoxy composites immersed in liquid and humid air. Patel and Case [10] investigated the durability of hygrothermally aged graphite/epoxy woven composite under combined hygrothermal conditions.

The aging of composite materials under the environmental conditions of long years of service is one of the most relevant problems to which the engineers must face. Much works had studied the problem of environmental effects on composites materials and specially the diffusion of the moisture.

A comparative study of water absorption theories applied to glass/epoxy composites was made by Boniau and Bensell [11], Adda-Bedia et al. [12] investigated the moisture diffusion in polymer matrix composites with cyclic environmental conditions.

Han et al. [13] studied the humidity diffusion in composite plate subjected to cyclic environmental conditions. Verchery [14] had also investigated the moisture diffusion in polymer matrix with cyclic environmental conditions.

In this regards, the present study analyzes the aging-impact coupling of a laminate composite materials with polyester matrix reinforced with E-glass fibers. Despite the many works done in this field open questions remain. The main objective of this work is the investigation and analysis of the mechanical responses such as impact force, the bending of the plate and contact duration of aged

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and non-aged plates due to environmental effects by experimental and model fitness procedure.

2. Experimental procedure

2.1. Experimental devices

The plates tested are subjected initially to an artificial hygrothermal environment and impacted at different rates of absorbed moisture. Two main facilities were used for this work. The first one was an air conditioned chamber (Vötsch VC4034) to simulate the hygrothermal aging applied to the laminate. This apparatus was coupled to a balance (Mettler H6T DigCap 160 g) with 10^{-4} g accuracy to carry out regular weighing of the coupons.

The second one was an impact machine loading denoted drop tower that has been used by Guillamat [1,2]. This apparatus allows vertical drop of adjustable mass from any height up to three meters. The complete experimental apparatus is shown in Fig. 1. The machine is equipped with infrared sensors for drop height control and mass rising. Piezoelectric sensor is used to measure the contact force history between the impact of the striker and the plate. Laser sensors are used, the first located underneath the center of the specimen provides out-of plane displacement history. The second measures the sticker displacement and allows calculating the mass velocity before and after the impact. A high-speed camera Camsys + (2000–11,000 frames/s) is used to film the tests. Data was recorded using a plugging card in a P.C. especially designed with software developed in the laboratory for this purpose.

All the plates to be impacted were put on two steel supports and loaded at the center as a three point bending (Fig. 2). The span is 120 mm long. In our case, the impactor end has a hemispherical shape with 16 mm in diameter and a total mass of 1.85 kg. Two levels of energy have been considered by setting-up two different drop heights: 9 J (drop height: 0.5 m) and 13.6 J (drop height: 0.75 m). Three impact tests have been carried out for each case: the displayed results are obtained by the average of these three different tests. It is well known that the impact loading leads to scattered results and more especially when it is applied on composite structures.

2.2. Materials and specimens

The material investigated in this study is a glass fiber/isophthalic unsaturated polyester resin laminates. Each layer has 95% of the fibers in x direction and 5% in y direction to allow the handling of the dry fibers. The laminate was fabricated using hand lay-up process. The material is manufactured with the following stacking sequence: $0_3/90/90/0_3$. The average volume fraction of the material is about 60% and a total thickness of 4.5 mm.

Two types of coupons have been used according to the test to be performed. The specimens for impact were cut from large plate with the dimensions: (150 × 100 × 4.5 mm) which are dimensions generally used for specimens submitted to compression after impact as found in aircraft industries test method for fiber reinforced plastic [15] and advanced composite compression test [16] in order to evaluate the residual compression strength and the damage tolerance of the material.

For the aging test smaller coupons are generally used (4.5 × 50 × 50 mm) to only monitor the evolution of the mass of the sample and to estimate water absorption. All coupon edges were covered with a gel-coat to avoid longitudinal water absorption. Only transverse phenomenon is investigated as in real structures.

After treatment, all specimens are put in an oven during 24 h at a temperature of 40 °C for a complete polymerization.

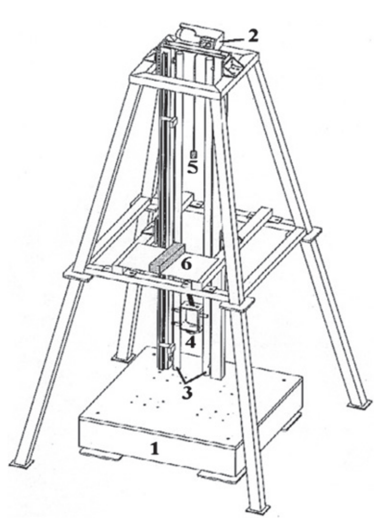

Fig. 1. Drop tower (impact loading machine).

2.3. Accelerated hygrothermal aging

Laminate composite plates were aged in an artificial hygrothermal environment using an air conditioned chamber at a 50 °C temperature and 95% of relative humidity.

The specimens were exposed for a period of 289 days (which is equivalent to 5000^2 s). This long period is due to the fact that the water absorption increased slowly and the saturation did not occur, then the test was stopped.

3. Identification of the water absorption model

The second objective of this study is to analyze the material response as well as to choose the model of water absorption that provides the best fit of the experimental results and that allows the calculation of various parameters.

The Carter–Kibler's model [17] and a cost function based on the least squares method [18] have been used for modelling experimental data and defined as:

$$q = \sum_i [M(t_i) - M_i]^2 \quad (1)$$

where $M(t_i)$ is the absorbed water weight calculated at time t_i from the Carter–Kibler's model, M_i is the absorbed water weight calculated experimentally,

The best curve fitting of experimental data points was carried out under MATLAB using algorithm of Gauss–Newton optimization type. Based on Carter and Kibler's study [17] and the so-called Langmuir-type a diffusion model was developed in which the initial portion of the curve describes well Fick's treatment [19] (constant diffusion coefficient). Carter and Kibler suggested a model involving bound water and mobile (free) water. Their model is expressed by:

$$M_t \cong M\infty\left\{\frac{\beta}{\gamma+\beta}\exp(-\gamma\cdot t)\left[1-\frac{8}{\pi^2}\sum_{i=1}^{\infty(add)}\frac{\exp(-ki^2\cdot t)}{e^2}\right]\right\} + M\infty\left\{\frac{\beta}{\gamma+\beta}(\exp(-\beta\cdot t)-\exp(-\gamma\cdot t))+1-\exp(-\beta\cdot t)\right\} \quad (2)$$

$$k = \frac{\pi^2\cdot D}{e^2} \quad (3)$$