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On the life time prediction of repeatedly impacted thermoplastic matrix composites

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ABSTRACT

Impact-fatigue properties of unidirectional carbon fibre reinforced polyetherimide (PEI) composites were investigated. Low velocity repeated impacts were performed by using pendulum type instrumented impact tester (Ceast, Resil 25) at energy levels ranging 0.54–0.94 J. Samples were prepared according to ISO 180 and subjected to repeated low velocity impacts up to fracture by the hammer. Results of repeated impact study are reported in terms of peak load (F_{max}), absorbed energy (E_{max}) and number of repeated impacts. An analytical model to describe the life time of composite materials subjected to repeated impact loadings was presented.

1. Introduction

Continuous fibre reinforced polymer composites with a high specific modulus and specific strength compared to other conventional materials have been used in large-scale structures such as aerospace, marine, automotive etc. [1]. Structural composites should be tested and analyzed under extreme loading conditions in order to determine their ultimate properties, such as static, impact and fatigue strengths etc. The composites may be subjected to low energy impact loadings during the service life [2]. These loads such as the drop of a handling tool, small impacts during the maintenance etc. may result in initial deformations and reduce the strength and life time of composite material.

There are many studies in literature report that material properties such as type of matrix and fibre, fibre orientation, volume fraction of fibre and matrix, interfacial properties, type and frequency of loading and service environment etc. closely affects the impact strength of the composites [3–5].

Because of their anisotropic nature, characterization of fracture behaviour and morphology of polymer composites are more complicated compared to conventional materials [6]. Fibre and/or matrix breakage, fibre debonding, fibre pull-out, shear failure of matrix and fibre and delaminations are common events not found on monolithic materials, and that can precede the ultimate failure of a composite [7–11].

Although many researchers have made efforts to analyze the impact behaviour of composite structures, there are limited studies about damage and life time prediction of composite laminates which are subjected to repeated low velocity impacts [12–15]. Azouaoui et al. [16] have presented the damage of a glass/epoxy laminated composite under impact-fatigue loading at low velocity and various incident energies. They have found that the damage history can be evaluated in three stages. In the first stage, the initiation and multiplication of delaminations are reported. The phenomenon of delamination saturation has been seen in the second zone and in the last zone an acceleration of the damage is observed by the failure of fibres and cracking of the last layer. Hosur et al. [17] have investigated the impact-fatigue response of woven S2-glass/SC-15 stitched and unstitched composite laminates under single and repeated low velocity impact loading. They showed that under repeated impact loading, at lower energy levels peak load did not change significantly with number of impacts but at higher energy levels, peak load dropped suddenly after a certain number of impacts and absorbed energy also showed similar trend with respect to the number of impacts. Another impact-fatigue study have been designed to assess the behaviour of E-glass fibre reinforced vinylester composite material under repeated impact loads and to demonstrate the existence of a fatigue curve with an endurance limit by Roy et al. [8]. They have found that the composite samples showed progressive endurance with decreasing applied impact energy below the threshold fracture energy. Fernandez-Canteli et al. [18] were explored the possibility of applying the instrumented Charpy impact technique in order to determine the dynamic fracture toughness, K_{Id}, in carbon and glass fibre fabric composites for comparison with the corresponding static value, K_{Ic}. The registered impact force and displacement at the specimen hammer contact point were used to evaluate Mode-I fracture energy and dynamic fracture toughness. The changes in fracture toughness due to impact velocity, crack size and stacking sequence of the specimen were investigated with different degrees of aging conditions. The results of the experiment showed that the dynamic and

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the static fracture toughnesses were increased with the crack growth for the two composite materials considered. Hosur et al. [19] determined the response of four different combinations of hybrid laminates to low velocity impact loading using an instrumented impact testing machine. The results of the study indicated that, there was considerable improvement in the load carrying capability of hybrid composites as compared to carbon/epoxy laminates with slight reduction in stiffness. The effect of repeated low energy impact on the performance of carbon–epoxy composites with three different stacking sequences was evaluated by de Morais et al. [2]. From the experimental results obtained, it was shown that the cross-ply and non-symmetric laminates have a better endurance against low impact events than unidirectional laminates. Dear and Brown [20] investigated the impact toughness of two grades of sheet moulding compound (SCM) and one grade of glass mat thermoplastic (GMT) material. Notable in the findings was that, the onset of through thickness damage occurred before there was visual evidence of surface damage at the point of contact between the striker and the specimen. Reis and de Freitas [21] determined the limit loading capacity and the damage growth mechanisms of impacted carbon fibre reinforced epoxy resin matrix composites when subjected to compression after impact. They had found that unstable damage growth was obtained by compression after impact due to a buckling mechanism in the delaminated area which was a function of the impact energy.

In this study, the composite material is subjected to low velocity repeated impact loadings with different impact energies. The main aim is to investigate the effect of the low velocity repeated impacts on the fatigue-impact properties of the continuous carbon fibre reinforced thermoplastic polyetherimide (PEI) matrix composites and to understand the impact-fatigue lifetime of this material. Results of low velocity repeated impact study were reported in terms of peak load, absorbed energy and number of impacts to failure.

2. Experimental procedures

Unidirectional carbon fibre reinforced Polyetherimide (PEI) composites were kindly supplied by TenCate Advanced Composites (Nijverdal/Netherlands) in the form of hot pressed plaques. Fibre volume content was 60%. Plaques manufactured from 14 plies with a ply thickness of 0.14 mm and the areal weight of ply was 222 g/m^2. The commercial code of the laminate was CD5150.

Impact tests were performed by pendulum type instrumented impact tester (CEAST-Resil 25). The test samples were prepared according to ISO 180 standards. Un-notched samples were used with the dimensions of 10 × 2 × 65 mm Fig. 1 illustrates the sample insertion procedure.

Preliminary experiments were performed in order to find the optimum drop angle. This angle was found as 70°, which has minimum inertial oscillations in the contact load between striker and sample during the impact. The sample was fractured with single impact at 70°. The maximum available impact energy of the striker was 2.65 J for 70°. Hammer length and mass were 0.327 m and 1.254 kg, respectively. Sampling time was chosen as 8 μs. At an angle of 70° (2.65 J) the hammer hit the sample with the velocity of 2.05 m/s.

Instrumented impact test parameters are shown in Fig. 2. Results of low velocity repeated impact study were reported in terms of peak load, absorbed energy and number of impacts. It is important to understand the approach used in the analysis of force–time curves, which is critical in determining the impact characteristics of materials. Upon impact of the pendulum, the force rises sharply to a maximum value (F_{max}) and gradually decays to zero due to catastrophic failure (fracture). The total area under the force–time curve gives the impact energy of the system (E_{max}). These curves can be divided into two regions. The 1st region is the crack initiation and the second is the crack propagation regions. The areas under each region give the energy for these processes, which are defined as energy for crack initiation (E_i) and energy for crack propagation (E_p). The spikes in the 1st region are due to inertial oscillations of the sample. The amount of deformations (X.e.v.) is illustrated in Fig. 1, which corresponds to the maximum deformation of the composite sample.

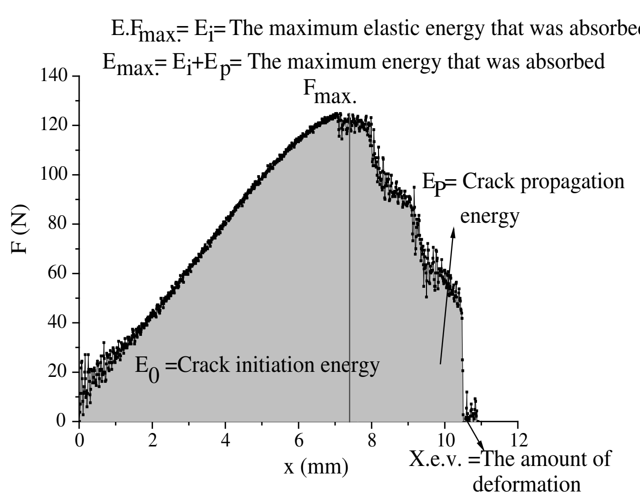

Fig. 2. Instrumented impact test parameters.

3. Results and discussions

At first step of this study, preliminary observations were done in order to understand the impact response of the composite samples. Fig. 3 represents the instrumented impact test results of these

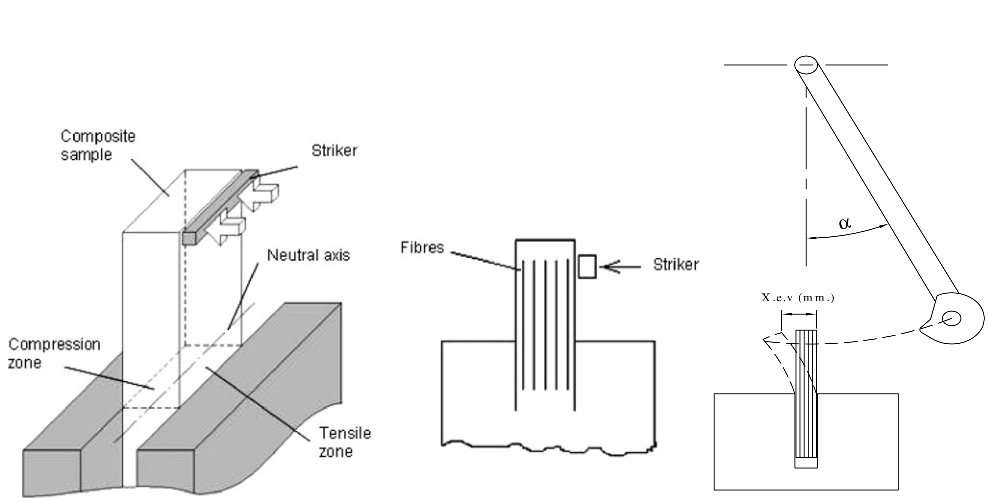

Fig. 1. The illustration of sample geometry, insertion and testing procedure.