Composite Structures 203 (2018) 696–708

Contents lists available at ScienceDirect

Composite Structures

journal homepage: www.elsevier.com/locate/compstruct

Low-velocity impact response of carbon fibre composites with novel liquid Methylmethacrylate thermoplastic matrix

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ARTICLE INFO

Keywords:
Impact
Carbon fibre
Thermoplastic
MMA
Elium®

ABSTRACT

Experimental investigations were carried out to determine the low-velocity impact behaviour of carbon fibre composites with novel liquid Methylmethacrylate (MMA) thermoplastic matrix, Elium®. The load, deflection and the energy attributes under impact are studied in detail and the baseline comparison is carried with the carbon fibre composites with epoxy matrix. The quasi-isotropic non-crimp carbon fabric (NCCF) laminates were impacted at 25 J, 42 J and 52 J impact energies and the material response of both the composite configurations were studied. The composite laminates have shown less catastrophic damage at a high energy level (52 J) and around 10% higher peak load was observed. Structural integrity as measured from the load-deflection curve demonstrated up to 53% increase for Thin NCCF Elium composite compared to their counterpart composites with epoxy matrix. Significant energy absorption (56%) before the onset of major failure mostly through elastic-plastic deformations was observed for thin NCCF Elium® composite. Impact results at different energies showed the strain sensitivity of Elium® microstructure with the improved performance with increasing impact energy. From the detailed fracture and damage analysis of the impacted samples, the failure mechanisms were deduced for the novel Thin NCCF Elium® and epoxy composites.

1. Introduction

Composite materials are widely used in many industrial applications due to increased specific stiffness and the tremendous weight savings offered by them [1–3]. Thermoplastic composites have gathered significant attention due to their recyclability, impact absorbing and damage tolerance properties [4–8]. In general, the thermoset matrix material is brittle in nature and hence increases the susceptibility of delamination in composite materials [9]. Carbon fibre with epoxy matrix system is a preferred solution in wide engineering applications as they offer a tremendous weight saving as well as excellent performance in two dimensions, but they severely lack the desired properties in the thickness direction due to low interlaminar fracture toughness associated with the epoxy matrix.

Major damage modes during an impact event includes matrix cracking, fibre/matrix debonding, delamination, inter-laminar failure and fibre breakage [10–14]. Impact damage is a serious concern as it significantly deteriorates the structural integrity of the component [15]. Impact damage is a function of the resin type, fibre reinforcement, orientation and the thickness [16–21]. Thermoplastic matrices and toughened epoxies are competitive solutions to brittle epoxy matrices for improving the out of the plane response of composite laminates [22]. Vieille et al. [23] studied the effect of matrix toughness under the low-velocity impact. Bell et al. [23] compared the impact response of epoxy and thermoplastic (PPS and PEEK) composites and deduced the presence of fibre breakage, interlaminar and inter-ply cracks as the dominant failure mechanisms for all the composite configurations. They concluded from C-scan observations and fractography that thermoplastic-based laminates experience less delamination than the thermoset counterparts. It was also inferred that local matrix plasticisation in matrix rich areas, greater interlaminar fracture toughness and fibre bridging helped to resist ply separation and opening in Mode-I. These failure mechanisms contributed to the improvement offered by the thermoplastic composites. In another work [24] CAI tests showed that matrix toughness is not the primary parameter governing the damage tolerance. Though, matrix ductility helped to slow down the propagation of transverse cracks during compression. P. Russo et al. [25] studied the flexural and an impact response of Polypropylene (PP) based laminates reinforced with woven glass fibre fabric. Bending test on compatibilized laminates system showed the increase in flexural strength while low-velocity impact test showed opposing dependence on interface strength. Higher energy absorption was noticed for non-

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https://doi.org/10.1016/j.compstruct.2018.07.066
Received 20 May 2018; Received in revised form 27 June 2018; Accepted 16 July 2018

compatibilized composites [25]. P. Russo et al. [26] carried out impact study with thermoplastic polyurethane/woven glass fabric composite at various temperature ranges and showed higher performance at a higher volume fraction of the reinforcement. Davoodi [27] e al. carried out the work on PBT toughening with hybrid kenaf/glass epoxy composite and shown a 54% increase in impact energy absorbing capability compared with toughened epoxy systems. Bondy et al. [28] carried out the work on compounded PA6/CF long fibre thermoplastic and shown the puncture energy increased an average of 0.5 J with 1% increase in the fibre weight fraction. Recently Sonnenfeld et al. [29] proposed a new way to improve the damage resistance by utilizing the thermoplastic/thermoset interlayer approach. It was shown that a compatibility layer can increase the adhesion energy/critical energy release rate by the factor of 15. Boria et al. [5] studied the impact performance of fully thermoplastic composite (both the reinforcement and the matrix are made in polypropylene) at different energy levels. It was deduced from the tests that the plastic deformation without the crack tip and the yarn sliding were the major failure mechanisms.

Above mentioned composites with conventional thermoplastic polymers offer attractive solutions compared to epoxy matrix composites [30–32]. The thermoplastic matrices are available either in film or pellet forms and require very high-temperature processing and costly equipment, like autoclave and hot press [33]. So, there is a growing need of time to have a thermoplastic resin which can be processed at room temperature and imparts excellent impact and mechanical properties. Current research is focused on investigating the impact benefits offered by the novel room temperature cure reactive liquid Methylmethacrylate (MMA), Elium® thermoplastic resin composite. Already the processing [34], vibration damping [33] and the fracture toughness (Mode I) [35] attributes of the composite system manufactured with this novel resin is investigated in detail. This paper highlights the improvement offered by this novel composite system under low-velocity impact environment and the results are compared to its counterpart composite manufactured with epoxy resin. This also serves as a baseline study for various comparisons in current research.

2. Low-velocity impact (LVI) test

2.1. Important parameters

Before proceeding to discuss the results obtained for the Low-velocity impact tests laminates for various configurations, first, the important terminologies related to impact will be elaborated in the subsequent section.

2.1.1. Load bearing capability of the laminate

In the current research, there is the impetus to understand both the material and the structural response of the composite laminates which undergone LVI tests. The LVI test is dissimilar to High-Velocity Impact (HVI) tests in regard to the larger contact duration between the impactor tip and the laminate in LVI test. So, in the case of LVI tests, the evolution of load-time curve can generate greater details to understand the structural response of the composite laminate. Fig. 1 shows the sample Load vs. Time curve recorded in one of the impacted composite laminate. Two important characteristic values are highlighted in the load-time curve, L_i and L_m. L_i is the point in the load-time curve where the first noticeable load drop is noticed whilst the point corresponding to maximum load is termed as L_m. L_i indicates the initiation of damage within the laminate while after reaching the point L_m, laminate will not sustain any further load and it is the maximum load value sustained before the event of a major failure. As can be seen from the Fig. 1, after attaining the maximum load, there is a massive load drop in the curve, which is indicative of damage formation and propagation in the impacted laminate. Also, two different types of load-time curves can be observed from the Fig. 1, viz. subcritical and supercritical impact. Impact events which are carried above the damage threshold of the material are termed as supercritical impact and lead to extensive damage. On the contrary, subcritical impact events are performed below the damage threshold of the composite laminate. In general, the target laminate undergoes barely visible damage in case of sub-critical impact. Subcritical impacts follow the sinusoidal trend, and there is no sharp load drop observed in this type of impact loading.

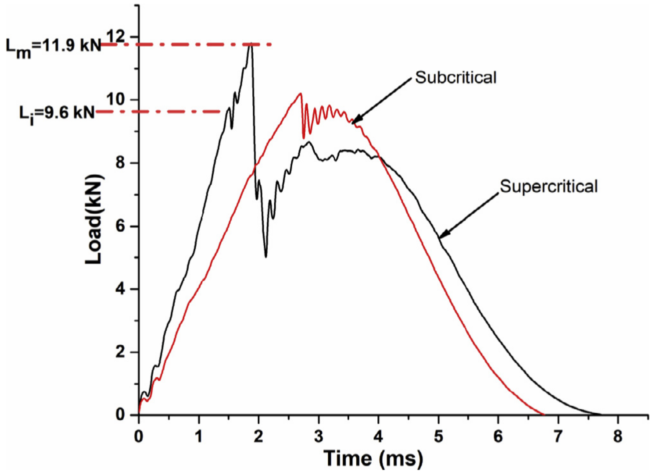

Fig. 1. Sample Load vs. Time curve to explain associated parameters.

2.1.2. Laminate deflection characteristics during impact

Fig. 2 shows typical load-deflection curve in case of an impact event showing both loading and unloading phases. The area enclosed by the curve is indicative of the total energy absorbed by the target laminate during an impact. Both the laminate deflection as well as the deflection arises due to the local indentation of the projectile sums up the total projectile displacement. Two important terminologies as shown in Fig. 2 are PD_u, (overall laminate displacement or maximum projectile displacement) and PD_m (projectile displacement corresponding to the peak load). "PD_u– PD_m" is a parameter which indicates the structural integrity of the laminate with the lower value suggests the lower loss in the structural integrity.

2.1.3. Energy characteristics during an impact event

The analysis of the impact test results in energy perspective in the current study is based on the important parameters as shown in Fig. 3.

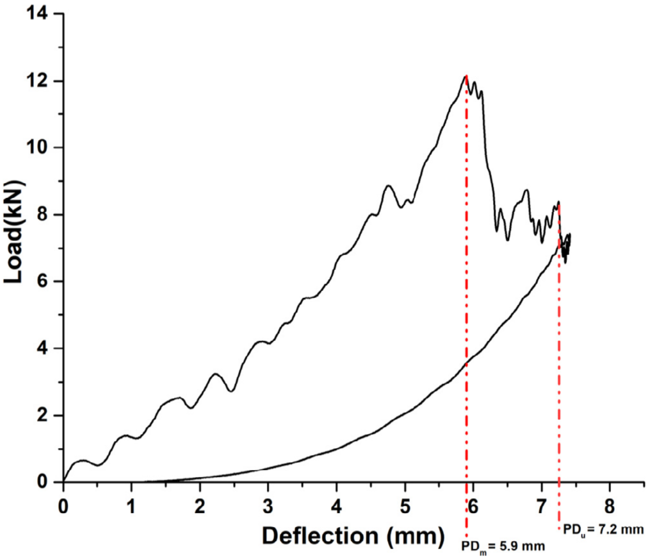

Fig. 2. Sample Load vs. Deflection curve to explain associated parameters.