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Technical Report

Efficient computational modelling of carbon fibre reinforced laminated composite panels subjected to low velocity drop-weight impact

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ABSTRACT

This paper reports on the actual and virtual low velocity impact response of carbon fibre composite laminates. It utilises the contribution of through-thickness stresses, in the prediction of the onset of internal damage created by this type impact scenario.

The paper focuses on the damage imparted by the flat nose impactor since this induces a different type of damage and structural response compared to that of the standard test method of using a round nose impactor.

Vulnerability of the fibrous composites to vertical drop-weight impact can result in premature failure which is a major concern in their widespread usage. The topic has been of intense research to design more damage tolerant and resistant materials. However, due to materials' anisotropic and three-dimensional nature and complicated damage mechanisms no standard model could have been achieved. Designers predict consequences of a local impact within the global structural context without full-scale testing.

Majority of the existing simulation models neglect through-thickness stresses that are regarded as the major cause of catastrophic failures. Efficient and reliable investigations are required to reduce testing and include through-thickness stresses. Drop-weight impact simulation models were developed herein using ABAQUS™ software. Simulations were carried out to compute in-plane stresses subjected to flat and round nose impacts on laminates of differing thicknesses. These stresses once computed were numerically integrated employing the equilibrium equations to efficiently predict through-thickness stresses. The predicted stresses were then utilised in failure criteria to quantify the coupled and embedded damage. This provides a quick insight into the status and contribution of through-thickness stresses in failure predictions. The computed values were compared to the experimental results and found to be in good agreement.

1. Introduction

Many typical aerospace structures are fabricated from strong and stiff carbon fibres at various angles embedded in a polymer matrix to form a lamina and replicated to form laminated laminate as shown in Fig. 1. The state-of-the-art commercial aeroplanes such as the Boeing™ 787 Dream Liner and Airbus™ A380 XWB use these materials in similar forms in significant quantities. The market for these composites is also growing in transport and sports industries due to their superior in-plane properties when compared to metallic structures.

However, fuselages, tails, and wing skins are vulnerable to foreign object impact that inflicts internal damage that can reduce residual strength as much as 60% [1,2] below and could cause catastrophic failures. Such impacts are common from: tools (tool box) or hammer drops, debris or flying fragment during maintenance and the service life of an aircraft. Therefore, knowledge of impact response of these laminated composites is essential for safer and more economical design. Considerable experimental and analytical work has been reported on various aspects of the vast subject in the literature. Selected and relevant are references presented here. Four mathematical impact models: spring mass, energy balance, complete model, and impact on infinite plate for the analysis of quasi-static and dynamic response of composite structures. Experimental investigations on impact response of carbon fibre reinforced composite are reported in [1–3]. Results suggested that the spring mass and energy balance model be suitable in the quasi-static cases. They have investigated the delamination threshold load for low velocity impact for the number layers ranging from 6 to 96. Influence of different nose shape impactors using drop-weight impact tests on composites can be found in [4–7]. Efficient computational finite difference and finite element solutions are given in [8–10]. Useful experimental and computational works are described in Refs. [11,12]. Derivations and simulations of interlaminar shear stresses reported in [13–15]. References on damage

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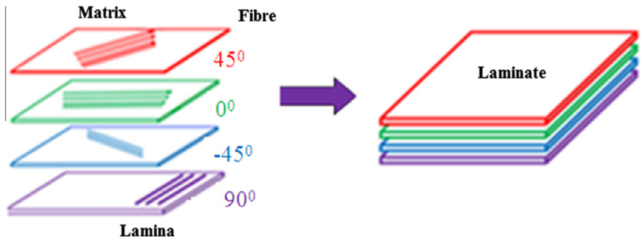

Fig. 1. Schematic of 8-ply symmetric quasi-isotropic laminate.

and failure analyses of low velocity impacted composites can be found in [16–20].

Mode-based failure criteria composed of fibre-fracture mode due to tensile-flexure coupling and quadratic stress criteria for delaminations have been proposed in [21]. Effects of various parameters were investigated using explicit finite element simulations. The results consistently showed that at lower impact velocities, the damage size and residual strength reduction increased with increasing impact velocity. Interactive failure criteria and a general failure criterion in terms of the stress invariants were proposed in [22].

Most of the recent experimental studies found in the literature [23] on low velocity impact of fibre composites have followed the American standard test method (ASTM: D7316). However, due to the material characteristics such as: anisotropy, heterogeneity, and distinctive failure modes cause the complex behaviour of these materials. Designing composite materials for commercial use requires a large number of experimental tests. Similarly, most of the numerical studies consist of finite element analysis as in [24] utilising explicit/implicit routines of ABAQUS™ software [25]. However, computational models are based on three-dimensional analyses consuming huge computing resources. Analyses are over-simplified consisting of load–deflection analysis and neglecting the contribution of the through-thickness stresses. The through-thickness stresses can have a considerable influence on the impact performance of composites. Particularly, high stress gradients in regions local to the round nose impact. Similarly, analyses of the internal damage: induce delamination, de-bonding and back-face splitting of plies scenarios attributed to the flat nose impact requires through-thickness stresses.

Continued progress is being made in understanding the impact event; however, knowledge of the internal barely visible impact damage (BVID) is still limited. In the present work, contributions from through-thickness stresses have been considered. In-plane (2-D) stresses were computed for round and flat nose impacts of the laminates and a damage analysis was then carried out using the mixed failure criteria. Subsequently, the predicted in-plane stresses were numerically integrated utilising the equations of equilibrium to evaluate through-thickness (3-D) stresses. The integration developed three-dimensional ply-level stresses from two-dimensional in-plane stresses. The predicted stresses were then utilised in advanced failure criteria to quantify and efficiently predict the embedded ply-by-ply damage and failure.

2. Analysis of flat and round nose impact of composites

Experimental and computational damage and failure evaluations of impacted fibrous composite are performed through load–deflection and stress–strain based methods. Since experimental techniques may not be able to detect all of the damage modes present in an impacted laminate, it is a frequent practice to incorporate numerical predictions with experimentally produced data values. In addition, most techniques give relative rather than absolute indications of damage, so that a comparison between results obtained using different techniques on the same set of laminates

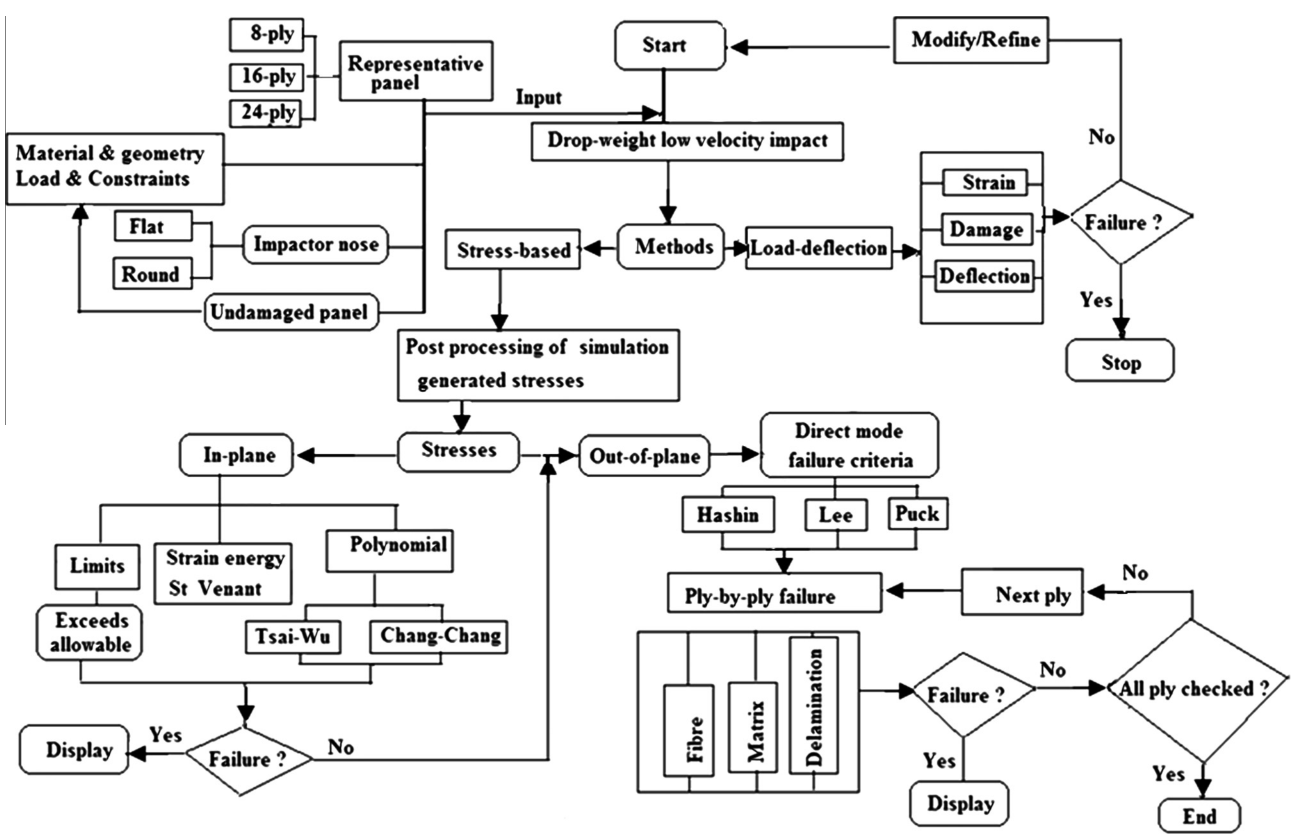

Fig. 2. Flowchart of drop-weight impact analysis.