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# Geometrical effects in the low velocity impact response of GFRP

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**Abstract**

The suitability of damage–force maps for characterising low velocity impact damage in a glass fibre reinforced polyester composite has been investigated at low and intermediate energies. Tests were undertaken on circular plates with diameters ranging between 50 and 300 mm and on square plates with edge lengths of 75 and 200 mm. Damage took the form of delamination under the point of impact and more widespread matrix cracking. The translucent nature of the composites facilitated the determination and quantification of the extent of damage within each specimen. Plots of delaminated area against impact force yielded maps in which the experimental data lay within a narrow band over the range of conditions examined. For a given impact energy, the impact force was greater and damage was more severe in smaller coupons. The damage–force maps suggested that the impact force to generate delamination lay between 600 and 800 N in spite of the fact that largest structure was over 35 times larger than that of the smallest structure investigated. An energy–balance model was used to successfully predict the impact response of the circular structures and to predict the onset of damage within these composite plates.


*Keywords:* Impact; GFRP; Fracture

## 1. Introduction

Fibre reinforced composites such as carbon fibre reinforced epoxies and glass fibre reinforced polyesters are finding increasing use in a wide range of engineering applications. Work has shown that these lightweight materials offer superior properties over a wide range of loading conditions and exhibit an excellent resistance to cyclic conditions such as those associated with continuous fatigue loading [1–4]. It is now well recognised that many composite systems, particularly those based on thermosetting matrices, offer a relatively poor resistance to localised impact loading [5–7]. Indeed, previous work has shown that impact energies as low at 4 J are sufficient to reduce the load-bearing capacity of a composite coupon by over 50% [5].

Choi and Chang [8] investigated the mechanisms of damage initiation and development in a carbon fibre reinforced epoxy subjected to low velocity impact loading. They showed that there exists an impact velocity threshold below which no delamination occurs but above which significant damage is incurred [8]. They also showed that matrix cracking represents the initial failure mode in these composites, a failure mechanism that subsequently triggers delamination at neighbouring interfaces.

Griffin investigated the effect of varying the type of fibre reinforcement on damage development in composites based on the same matrix material. Here, it was shown that the threshold kinetic energy is strongly influenced by the properties of the matrix material and virtually independent of the properties of the fibres and the stacking configuration [9].

Wu and Springer [10] presented a method for calculating the locations and sizes of delamination in a composite plate subjected to low velocity impact loading. Initially, the stresses and strains in the plate were calculated using a three-dimensional transient finite element method. The size of the resulting delamination area was then calculated using a proposed failure criteria. Agreement between the predicted and experimentally-determined damage levels were

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within 20% for the cases considered. Liu [11] investigated damage development in composites by considering the mismatch of bending stiffness between adjacent laminae. He concluded that the delamination resistance of a composite plate could be enhanced by reducing the material property mismatching, decreasing the thickness of each lamina and increasing the number of interfaces.

Many workers have used plots of damage area versus impact energy to characterise the impact response of their composite structures [5,7,12]. Although such graphs can be useful for characterising and expressing the severity of damage within a structure, their overall applicability is limited since the data is only valid for the particular configuration(s) reported – changing the size of the structure will result in a different damage–energy plot [13].

A number of studies have shown that damage initiates in composite materials when the impact force reaches a critical value regardless of the incident energy [14,15]. Sjoblom [14] developed a simple model in which the transverse shear stress in the composite is assumed to be uniformly distributed over a cylinder or radius $r$ of height equal to the thickness of the laminate $h$. He showed that the critical force increases with $h^{3/2}$, a finding that was observed experimentally. Davies and Zhang described a strategy for predicting the extent of internal damage in a brittle carbon fibre reinforced plastic [13]. The authors conducted tests on four simply-supported and clamped structures and presented their data in the form of damage–force maps (plots of damage area versus impact force). They claimed that such maps are virtually independent of the size and dynamic response of the impacted structure and argued that a prima face case for predicting structural damage from the impact force signature had been presented [13].

Zhou [16] also used damage–force maps to characterise the low velocity impact response of a series of very thick GFRP plates. He concluded that damage initiation was dominated by delamination which could be predicted from the maximum interlaminar shear stress in the plate [16]. His work also suggested that the damage threshold in these impacted plates was dependent on its in-plane dimensions.

The aim of the present work is to investigate the potential of damage–force maps for characterising damage in relatively thin composite plates based on a glass fibre reinforced polyester resin. Here, a wide range of plate sizes is considered in order to investigate fully size effects in the development of damage in lightweight composite structures. The work is then extended to investigate the possibility of using a simple energy–balance model to predict the onset of delamination in fibre-reinforced structures of this type.

## 2. Experimental procedure

The composite panels tested in this research project were based on a woven glass fibre reinforced polyester resin. The laminates were manufactured via a hand lay-up technique by rolling liquid polyester resin into the woven glass fibres before allowing the composite to cure at room temperature. Three layers of plain woven E-glass fibre fabric were used in the manufacture of all panels. The final thickness of the manufactured panels was approximately 2.5 mm and the nominal fibre weight fraction was 55%. After manufacture, the test samples were removed from the plates using a circular slitting wheel.

Low velocity impact tests were conducted using the instrumented drop-weight impact tower shown schematically in Fig. 1. Here, a 2 kg steel carriage was dropped from a range of heights to generate impact energies up to 20 J. For most tests, a 10 mm diameter steel indentor was used, however, a limited number of tests were undertaken using a 20 mm diameter indentor in order to investigate the influence of identor size on damage development. The GFRP plates were supported on either circular or square supports

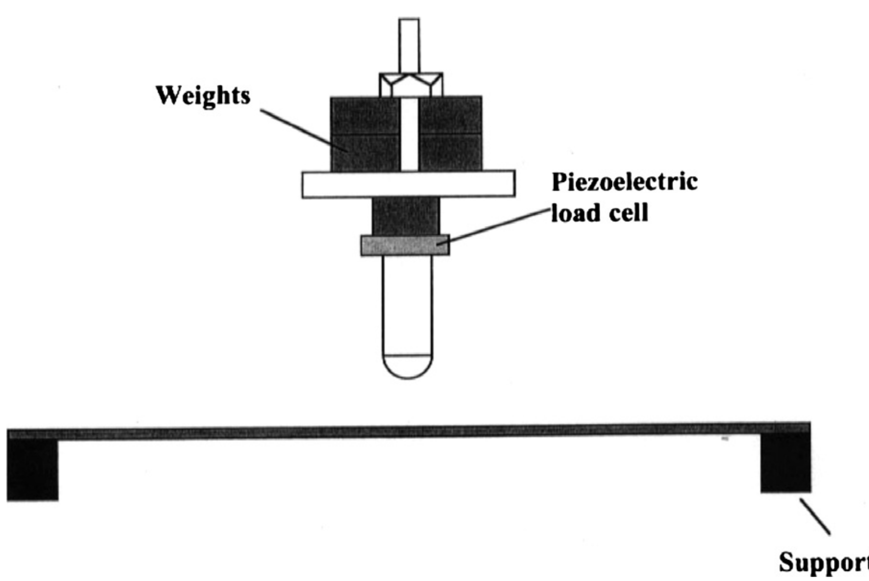


Fig. 1. Schematic of the drop-weight impact tower.