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Low velocity impact induced damage evaluation and its effect on the residual flexural properties of pultruded GRP composites

Z.Y. Zhang *, M.O.W. Richardson

Advanced Polymer and Composites (APC) Research Group, Department of Mechanical and Design Engineering, University of Portsmouth, Portsmouth, Hampshire PO1 3DJ, UK

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Abstract

Low velocity impact induced non-penetration damage in pultruded glass fibre reinforced polyester (GRP) composite materials was investigated using an instrumented falling weight impact test machine with a chisel shaped impactor. The characteristics of the impact event, force/time and force/deflection traces were determined. The internal damage was visualised and quantified by Electronic Speckle Pattern Interferometry (ESPI) in terms of the thickness, density and uniformity degradations of fringe patterns. There is a linear relationship between the impact energy and the identified damage areas. The post impact structural integrity of impacted specimens was evaluated by three point bending tests. It reveals that there is a significant reduction in flexural properties due to the impact-induced damage and that the residual flexural strength is more susceptible to damage than residual modulus.

Keywords: Polymer matrix composites (PMCs); Defects; Non-destructive testing; Impact behaviour

1. Introduction

Fibre reinforced polymer composites exhibit distinct properties such as high specific modulus and strength, lightness, high productivity, environmental degradation resistance and cost effectiveness [1,2]. They have found ever-increasing applications as engineering components and structures in the fields of transportation, aircraft, aerospace, marine, military weapon system and nuclear energy industries. However, polymer composites can be susceptible to impact damage during manufacturing and in service. Unlike traditional materials such as metals and ceramics, polymer composites exhibit unique damage characteristics. When they are subjected to impact loading, there might be no damage indication on surfaces by visual evaluation but internal damage may have already occurred. This damage can have an adverse effect on material performances and structural integrity. It is referred to as Barely Visible Impact Damage (BVID) [3–5]. This could potentially lead to catastrophic failure at any subsequent moment. Therefore, it is important to develop a good understanding of impact-induced damage non-destructively. Electronic Speckle Pattern Interferometry (ESPI) has made a significant contribution to engineering measurement and testing. It is capable of making whole-field and non-contact measurements of static and dynamic displacements with high sensitivity [6–9]. It can be extended to damage visualisation and quantification in non-destructive way [10–12]. The presence of either external or internal damage leads to mechanical degradations of GRP composite materials, which can be visualised by ESPI in terms of uniformity and continuity degradation and disruption of fringes. It is also important to establish a relationship between damage severity and residual properties by which the residual load bearing capabilities can be estimated [13–16]. The objectives of this study are to develop a good understanding of the characteristics of low velocity impact induced damage, including the damage formation and development features, to visualise and quantify the impact induced damage using ESPI and to evaluate the post impact load bearing capabilities.

* Corresponding author. Tel.: +44 23 92842360; fax: +44 23 92842351. *E-mail address:* zhong.zhang@port.ac.uk (Z.Y. Zhang).

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2. Experimental

The pultruded GRP panels were provided by Euro-Projects (LTTC) Ltd. They have been used for bridge floors, marine and chemical plant decking where they are subjected to low velocity and non-penetration impact events. The lay-up was confirmed to be symmetrical by deplying the specimen. It consisted of roving in the centre, sandwiched with random glass fibre mat with woven fibre fabric and surface veil placed symmetrically on both sides. The fibre volume fraction was approximately 50%. The panel was cut into rectangular specimens with overall dimensions of $150 \times 40 \times 4$ mm so that they could be accommodated into a purposely build fixture for ESPI testing.

Impact testing was implemented using an Instrumented Falling Weight Impact Test (IFWIT) machine. The general features of the equipment are schematically shown in Fig. 1. A controlled impact is achieved by dropping a chisel shaped striker which is attached to a weight in a defined manner from prescribed impact heights as shown in Fig. 2. The probe is equipped with a pizeo-electric transducer for measurement of velocity and load interaction between the probe and specimen. The velocity and load transducer provides a complete profile of the deformation response of the specimen during the impact process. Discrete values provided by the load transducer are collected and stored in a computer for post processing. A pneumatically operated mechanism switches on when the impactor bounces back to prevent the repetitive strike on the specimen. The specimen was pneumatically clamped between a 65 mm circular ring and anvil. Parameters such as energy, time duration, load, deflection and velocity are generated to characterise the impact events.

An ESPI system was based on a Helium Neon (He–Ne) continuous wave laser ($\lambda = 632.8$ nm) interferometer in combination with a frame store, monitor, video recorder, clamping jig and excitation apparatus which are schematically illustrated in Fig. 3. Theoretical aspect of ESPI and detailed descriptions of the testing system are documented elsewhere [17]. ESPI is capable of making whole-field and non-contact measurements of deformations with high sensitivity and perturbations to the fringe patterns are corre-

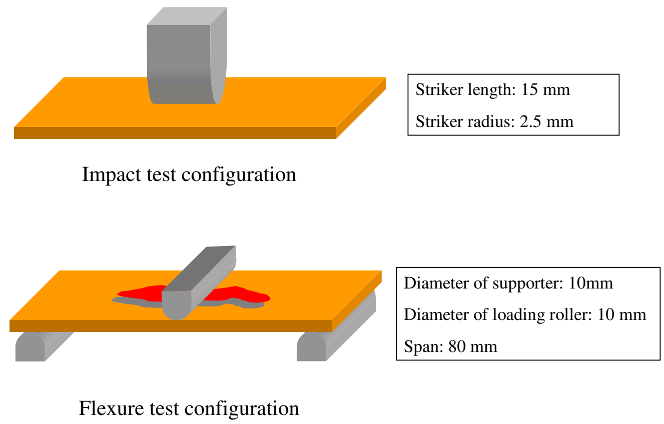

Fig. 2. Impact and flexure test configurations.

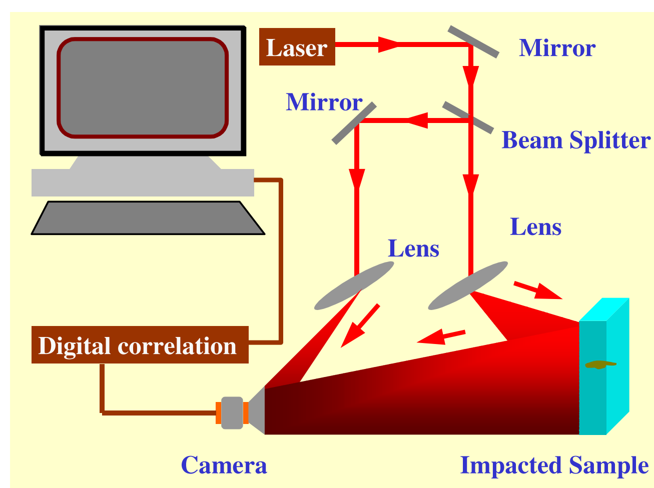

Fig. 3. Schematic of electronic speckle pattern interferometry (ESPI).

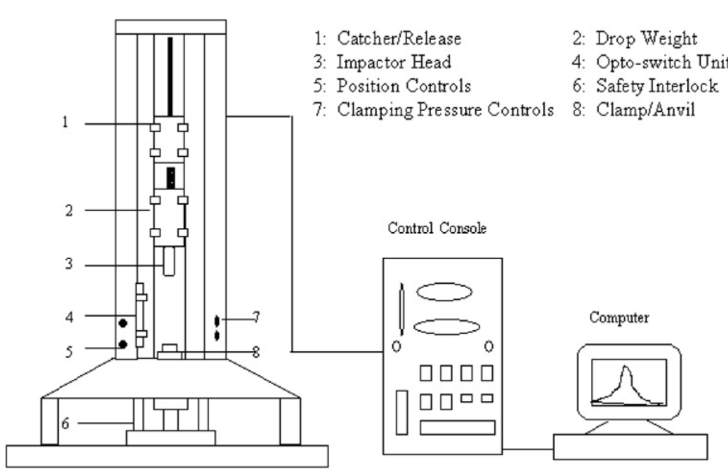

Fig. 1. Schematic of instrumented falling weight impact test machine.