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Damage mechanisms in thin stitched laminates subjected to low-velocity impact

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Abstract

This study examines the influence of stitching on the structural and damage response of thin carbon/epoxy $[0_2/90_2]$s laminates subjected to low-velocity impact. Impact tests were carried out on unstitched and stitched laminates and the nature and extent of damage at various impact energies was characterized by radiographic analyses. The main results of the study are illustrated and discussed to highlight the role and the potential of stitches for improving the impact damage resistance of this class of laminated composites.

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Keywords: Composite Laminates; Impact; Stitching; Delamination; Damage

1. Introduction

The low resistance of laminated composites to out-of-plane low-velocity impact loadings, which is a direct consequence of the two-dimensional arrangement of fibres and of the lack of z-direction reinforcement, is one of the most critical issues concerning the use of these materials for structural applications. Delamination between layers is a particularly insidious form of damage, since its presence may substantially reduce strength and local stiffness of the material and seriously impair the structural integrity of the damaged components [1].

The insertion of localized through-thickness reinforcement (such as stitches or Z-pins) has proved to be an effective way to improve the resistance and tolerance to delamination of composite laminates [2,3]. However, despite the many advantages, stitching or Z-pinning techniques have yet to find widespread use in structural

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components. This is due not only to the detrimental role of defects introduced in the material during the stitching process (which can act as strain concentrators, leading to damage initiation and thus adversely affecting the static strength and the fatigue resistance of the laminate) but also to the presence of apparently conflicting experimental data on in-plane and out-of plane properties of stitched composite laminates [4].

As an example, while the majority of studies conducted on the impact performance of stitched laminates shows that the introduction of through-thickness stitches reduces the delamination area induced by impact loadings [5-10], some studies report comparable impact damage resistance [11,12] for unstitched and stitched composites. Moreover, very little attention has been devoted so far to the effect of stitches on the impact performance of thin laminates [7] and thus no reliable indications are yet available on the effectiveness of stitching in enhancing the damage response of thin laminates under impact.

This study examines the influence of through-thickness reinforcement on the impact performance of thin laminated composites. Low-velocity impact tests were carried out on unstitched and stitched $[0_2/90_2]$s carbon/epoxy laminates of 1.2 mm thickness and the nature and extent of damage at different impact energies was characterized by X-ray inspections. The main results of the analyses are illustrated and discussed to clarify the role of stitching in controlling the damage response to impact of this class of laminates.

2. Experimental

Cross-ply $[0_2/90_2]$s laminated panels were manufactured using unidirectional carbon/epoxy prepreg tapes (Seal Texipreg® HS160/REM). Before curing, some of the panels were stitched with twisted polyethylene rovings (3x200 dtex Dyneema® SK60) by an industrial sewing machine using a modified lock stitch. The panels were stitched perpendicularly to the 0° direction of the laminate, and both the distance between consecutive stitches along the stitching line (stitch step) and that between two adjacent stitching lines (stitch row spacing) were kept at 5 mm (Fig. 1a). A modified lock stitch, where the intersection between the upper needle thread and the lower bobbin thread occur at the surface of laminate (Fig. 1b), was adopted in order to reduce distortion within the laminate. The modified lock stitch was achieved by easing the tension of the needle thread.

Both base (unstitched) and stitched panels were vacuum bagged and cured in a hydraulic hot press under a pressure of 5 bar. The temperature curing cycle consisted of an initial 1.5 °C/min ramp followed by a 2 h hold at 125 °C and a ramp down to room temperature at a rate of 1 °C/min. The final thickness of cured panels was 1.2 mm. No significant difference in thickness was observed between unstitched and stitched panels after curing. Rectangular samples 65 mm × 87.5 mm in size (Fig. 1a) were finally cut out from the consolidated plates with a diamond wheel.

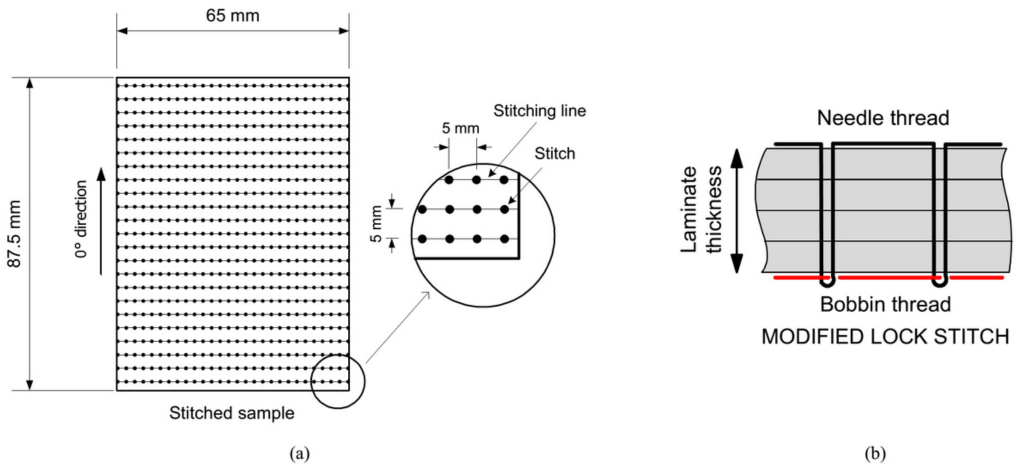

Fig. 1. (a) Stitching pattern; (b) Modified lock stitch.