Ply-orientation measurements in composites using structure-tensor analysis of volumetric ultrasonic data

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Ply-orientation measurements in composites using structure-tensor analysis of volumetric ultrasonic data

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Abstract

Ply wrinkling in carbon fibre reinforced polymer (CFRP) laminates is often geometrically complex and difficult to quantify using non-destructive techniques. In this paper, an ultrasonic technique for mapping ply wrinkling is presented. The instantaneous-phase three-dimensional dataset obtained from a pulse-echo ultrasonic inspection is processed using the structure-tensor image processing technique to quantify the orientations of the internal plies of a CFRP laminate. It is shown that consideration must be given to the wrapped nature of the phase dataset during processing to obtain accurate orientation maps. Three dimensional ply orientation and ply-location maps obtained from a test coupon are compared with true ply angles and locations by overlaying the ultrasonically-derived results on X-ray CT image slices, showing that accurate orientation maps can be obtained using the proposed technique.

Keywords: A. Layered structures, B. Directional orientation, D. Non-destructive testing, D. Ultrasonics

1. Introduction

1.1. Requirement

In advancing the design of carbon-fibre reinforced polymer (CFRP) laminate components to improve performance and reduce weight, particularly in the aerospace sector, components require precisely controlled and verified fibre and ply structures. For example, it is widely understood that tuning of structural performance is achieved by careful selection of a ply layup sequence, such as the +45°, -45°, 0° and 90° plies of a quasi-isotropic laminate. For clarity in this paper, this in-plane feature of the composite ply is termed '*fibre* orientation' and a local deviation from the desired fibre orientation is termed '*fibre* waviness', as illustrated in Fig. 1(a). Another important geometrical feature of the composite is the out-of-plane orientation of the plies themselves, the planar surfaces which exist as discrete layers on which the fibres are constrained, especially in the context of an out-of-plane wrinkle. This out-of-plane orientation is termed '*ply* orientation', with local deviations from the desired ply orientation referred to as '*ply* wrinkling', as illustrated in Fig. 1(b). The measurement of these ply orientations, and the characterisation of ply-wrinkling defects, together with the mapping of ply locations, are the focus of this paper.

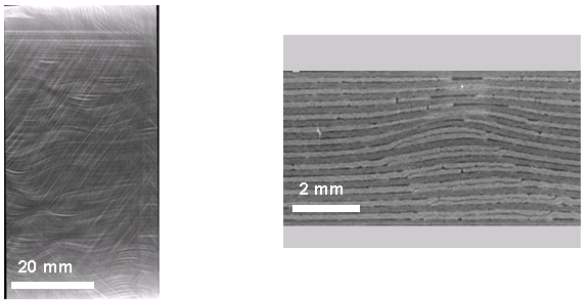

Figure 1: X-ray CT image slices from CFRP laminates showing (a) fibre orientation and evidence of in-plane fibre waviness on an in-plane cross-section, and (b) ply layers and evidence of gaps, overlaps and ply wrinkling on an out-of-plane cross-section.

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