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# Ultrasonic nondestructive evaluation of fibre-reinforced composite materials – a review

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**Abstract.** This paper reviews various ultrasonic nondestructive evaluation techniques applicable to fibre-reinforced composites. The techniques are briefly described and key references are cited. Methods to evaluate the reduced stiffness of composites due to micro-damage are described. Results show that for composites through-the-thickness attenuation increases and stiffness does not change due to transverse cracks, but in-plane stiffness and attenuation changes are substantial and can be measured by the Lamb wave techniques.

**Keywords.** Ultrasonics; nondestructive evaluation; composites; thin laminates.

## 1. Introduction

The excellent strength-to-weight ratio and the flexibility in tailoring the strength and stiffness of fibre-reinforced materials have made composites an indispensable structural material. Mixing of brittle but high strength fibres (e.g. graphite fibre, $\sigma_u = 2{\cdot}5\ \mathrm{GN/m^2}$) with viscoelastic and low strength (e.g. epoxy $\sigma_u = 0{\cdot}10\ \mathrm{GN/m^2}$) matrices, however, has created some very complex damage mechanism problems. Damage initiation and propagation are very different in composites from those in metals. The effect of mechanical, thermal or humidity loading is very complex in composites. Nondestructive evaluation (NDE) of in-service components is important because the damage initiation and growth mechanisms are not fully understood.

Various NDE techniques such as X-ray radiography, dye-penetrant tests, ultrasonics, thermography, acoustic emission, holography etc. have been successfully used to characterize damage in composites. This review is restricted to ultrasonic NDE of composites. It will also cover the technique of acoustic emission as well as the more recently developed method of acousto-ultrasonics.

In metals when damage is initiated, it becomes the nucleating site for further damage growth. On the other hand, Reifsnider *et al* (1983, pp. 399–420) have shown that in fibre-reinforced composites, a very different phenomenon takes place. Invariably, the first mode of damage in composites is matrix cracking. The fibres, being much stronger than the matrix, are able to carry the extra load due to the redistribution of stresses in