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Finite Element Analysis of Embedded Optical Fibre Sensors

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Abstract

Micromechanical Finite Element (FE) analysis was used to model stress and strain fields in and around embedded optical fibres (EOF's) in flexural test coupons of carbon fibre composite. The coupons were used in studies of EOF effects on macroscopic laminate properties[1]. The FE method allows complex material inhomogeneities, laminate boundaries and load conditions to be modelled.

Finite Element Analysis

Other researchers have modelled EOF's using FE analysis[2]. The work presented here goes further since: i) much higher element densities are used, allowing detailed resolution of the stress and strain fields in the OF core, ii) realistic representation of boundaries, plies and loads are used, iii) component stresses and strains (σ_x, σ_y, τ_{xy}, ε_x, ε_y) allow OFS response to be predicted, iv) all general types of local laminate disruption are considered.

The models are based on measurements from real microstructures. The laminate consists of 8 woven carbon plies (5-harness textile type). Each ply is approximated by two layers of orthogonal carbon fibres. Three microstructure types arise from details of laminate construction and EOF orientation. Fig 1 type shows the OF embedded between adjacent plies consisting of carbon fibres aligned orthogonally at 0° and 90° to the OF axis. If carbon fibres in adjacent plies are parallel, Fig 2 type results when carbon fibres are at 90°, and Fig 3 type when carbon fibres are at 0° to the OF axis. In the Fig 2 type microstructure a resin pocket exists either side of the EOF.

3-point bend tests were simulated where the model contained representative laminate boundary conditions and laminate dimensions, values and positions of applied loads, and position of the EOF. In the models presented here the EOF is in the mid-plane; models with the EOF in other positions will also be analysed. Tension, compression and shear test models are planned. Model accuracy is being checked by EOF Bragg grating measurements.

The OF and coating was modelled using triangular elements, with a mesh density which decreased with radial distance from the OF centre. The laminate was modelled using quadrilateral elements. An OF core region (diameter 10 μm) was defined. FE models (no loads applied) representing type 2 & 3 microstructures are shown in Figs 4-5 where shades are used to distinguish regions. Laminate properties are based on a mixture of uni-directional and woven fibre composite properties (both with AS4 carbon fibre in 3501 epoxy resin). The EOF modelled was a 125 μm o.d. silica OF with a 155 μm o.d. polyimide coating.

Shear stress is plotted in Fig 6 and corresponding shear strain is plotted in Fig 7. In both figures shades indicate relative values. A full set of results will be presented, but are not reproduced due to space limitations. Shear stress distribution in the laminate and the OF is modified by the EOF. Higher stresses exist in the OF and at localised points in the laminate.

1. Eaton, N. *Studies of Mechanical Effects of Optical Fibre Sensors Embedded in Composite Materials.* European Space Agency Symposium on Advanced Materials, Noordwijk, 1994.

2. Davidson, R, Roberts, S. *Finite Element Analysis of Composite Laminates Containing Transversely Embedded Optical Fiber Sensors* First European Conference on Smart Structures and Materials, Glasgow, 1992.

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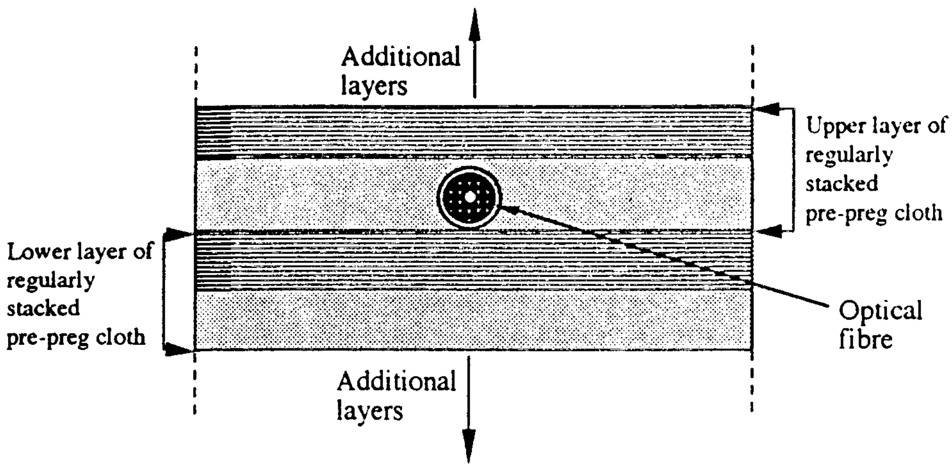

FIGURE 1

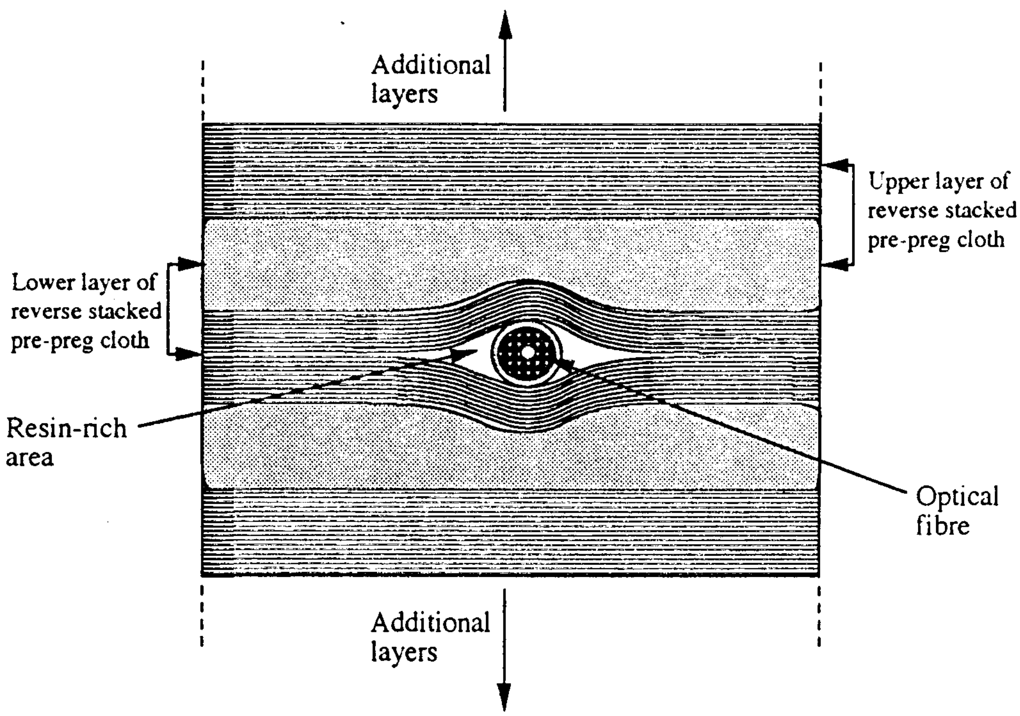

FIGURE 2

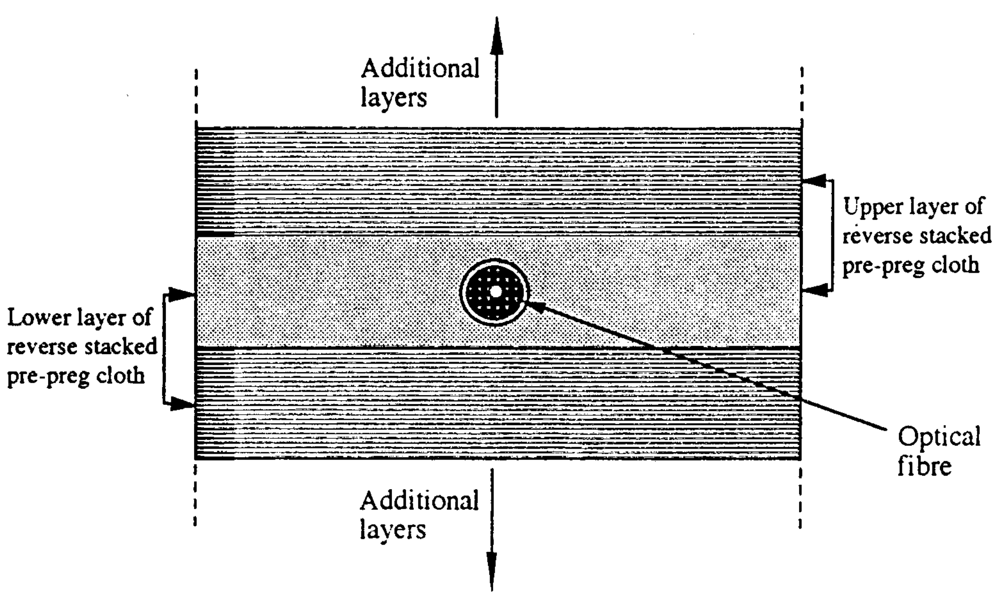

FIGURE 3

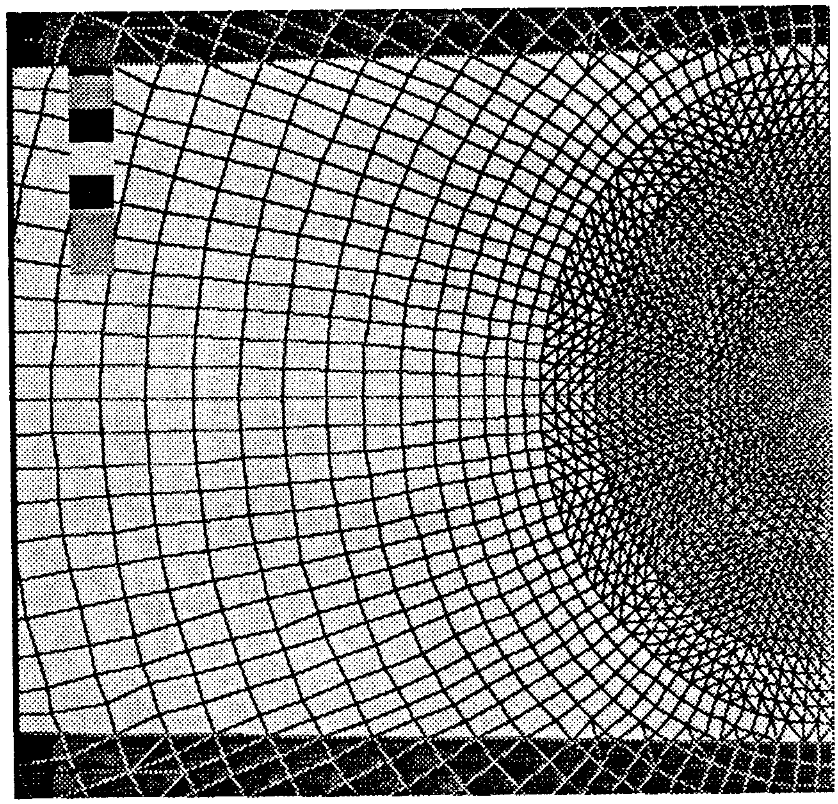

Fig. 4: FE model of type 2 microstructure

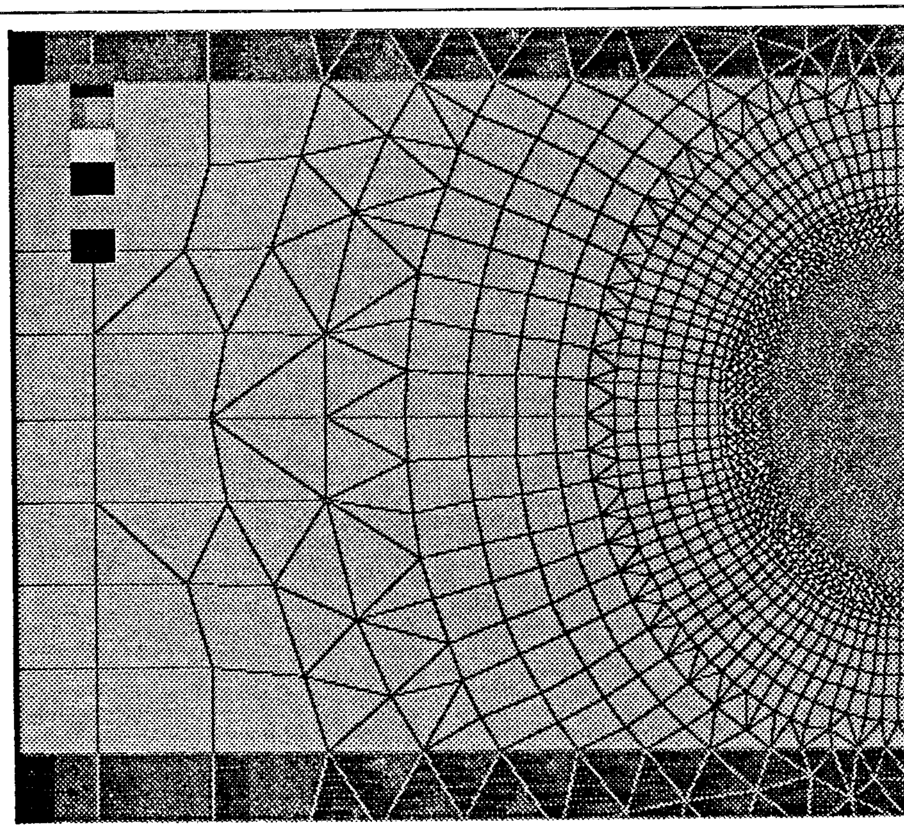

Fig. 5: FE model of type 2 microstructure

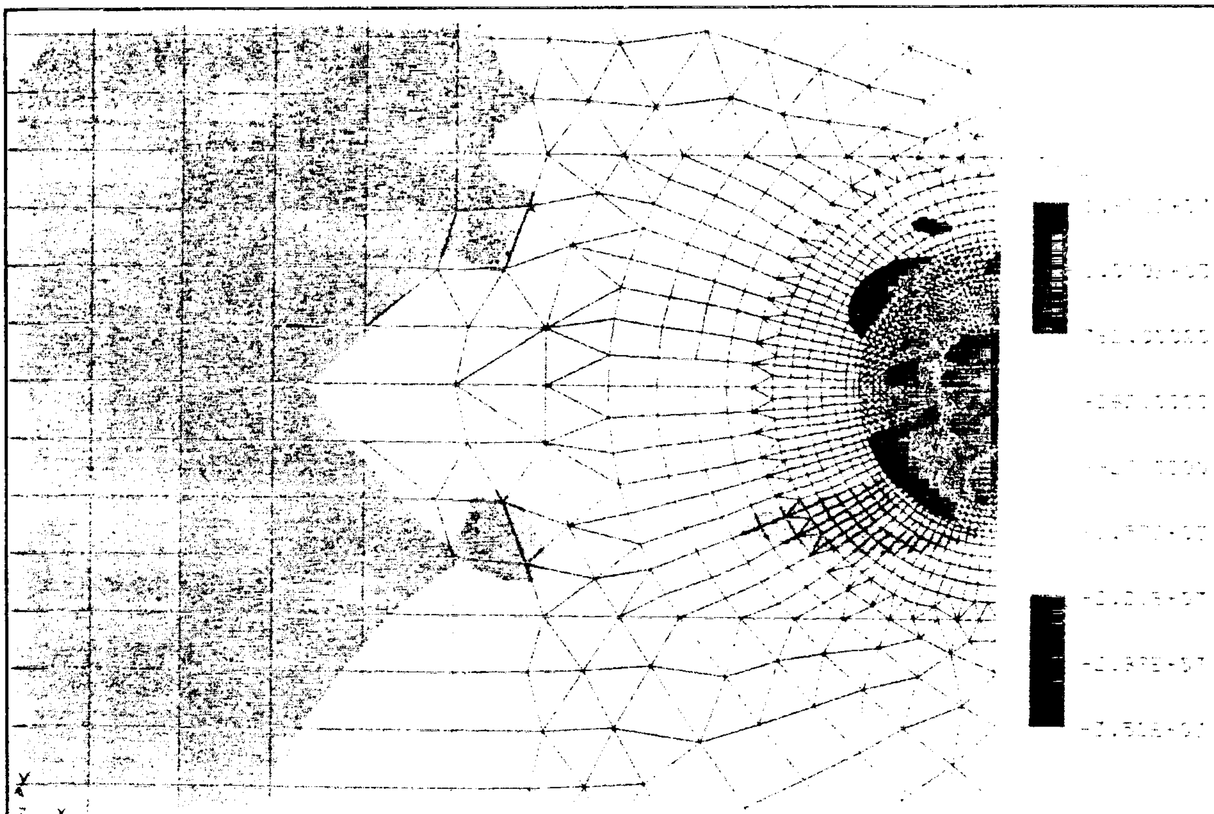

Fig. 6: Shear stress, type 3 microstructure

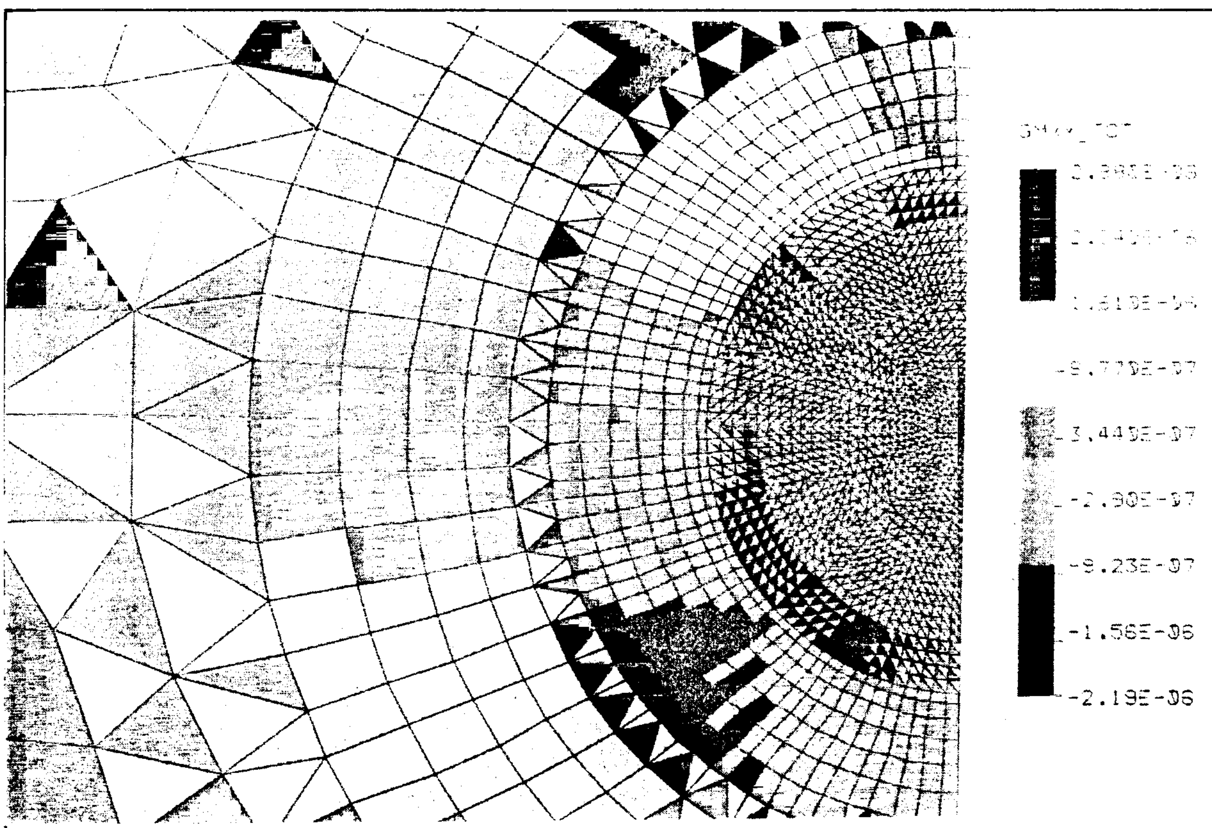

Fig. 7: Shear strain, type 3 microstructure