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A NEW APPROACH TO MODEL NON-LINEAR SHEAR BEHAVIOUR FOR DAMAGE ANALYSIS OF COMPOSITE LAMINATES AND STRUCTURES

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ABSTRACT

It is well know that continuous fibre reinforced composite laminates display significant non-linear stress-strain behaviour when loaded in shear. To date, the Hahn-Tsai non-linear shear model [1] has been used extensively to capture this behaviour when modelling composite materials and structures [2, 3]. However, a drawback with this model is that it was designed to capture the non-linear *elastic* response and so does not provide a good fit for laminates that display non-linear shear behaviour to rupture. In addition, it also expresses shear strain as a cubic function of shear stress, which introduces unnecessary complications for implementation into finite element codes [4].

In this paper an experimental study is first carried out to characterise the shear response of both unidirectional carbon fibre and glass fibre reinforced epoxy laminates. It is shown that both material types display significant non-linear shear stress-strain behaviour to rupture and that it is not possible to capture this with the Hahn-Tsai model. A novel damage model is derived where the non-linear shear behaviour is captured exactly using a cubic spline interpolation method. The model can capture the non-linear stress-strain behaviour, the load/unload cyclic behaviour including damage and the rupture response, as shown in Figure 1. The model also provides an excellent fit to the experimental data.

Hashin's [5] failure criteria are used to predict damage in the laminates and this is incorporated within the framework of the material model. The model is three-dimensional and is implemented into the ABAQUS finite element code using the UMAT user defined material subroutine. The cubic spline equations are linearised, thus allowing them to be written in incremental form and so easily implemented into UMAT. The material Jacobian matrix is fully defined, thus allowing a full implicit material model to be derived. Hence, the model is suitable for both implicit and explicit codes. The paper will focus on the implicit implementation.

It is shown that the model accurately predicts the response of the laminates under longitudinal, transverse and shear loadings. By way of example, the model is also used to examine other off-axis tests such as a 67.5° and 22.5° laminates loaded in tension. In addition, the model is implemented into three-dimensional finite element models of open-hole cross-ply laminates loaded in tension and pin-loaded composite joints. The paper will present both the experimental and numerical findings.

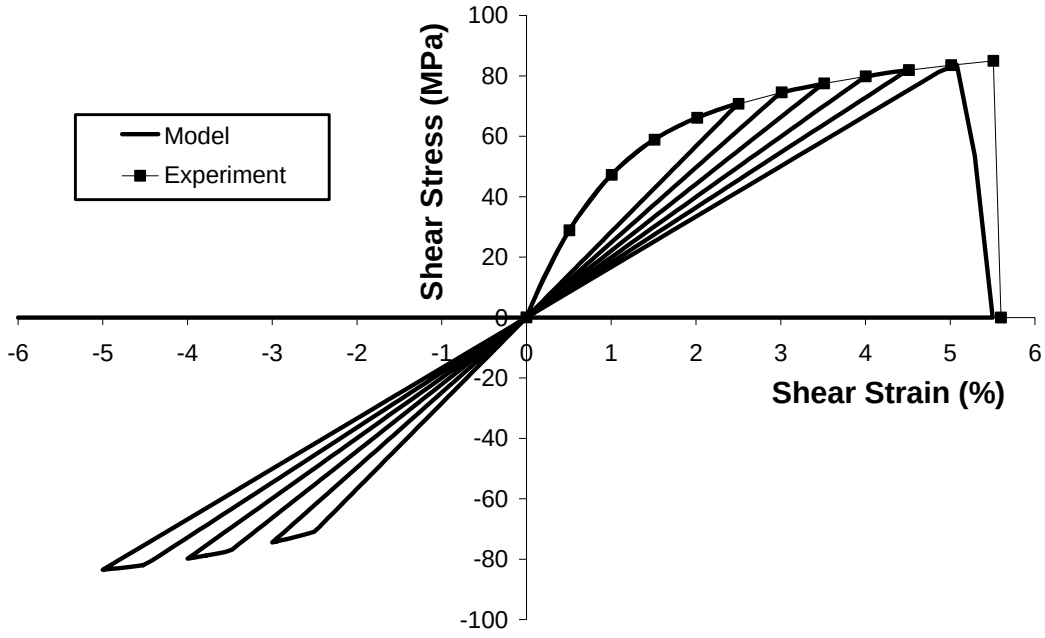

Figure 1 Cubic spline non-linear shear model under cyclic loading and corresponding experiment loaded monotonically until rupture

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