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THE OPEN HOLE TENSILE TEST – A CHALLENGE FOR VIRTUAL TESTING OF COMPOSITES

***Stephen R. Hallett and Michael R. Wisnom**

Advanced Composites Centre for Innovation and Science
University of Bristol, Queens Building, University Walk, Bristol, BS8 1TR, U.K.
stephen.hallett@bris.ac.uk, www.bris.ac.uk/composites

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ABSTRACT

The open hole tensile test is important in deriving allowable stress levels for use in component design since open hole strength can be a limiting factor. It is also one of the simplest tests that combines unavoidable geometrical interaction with material properties. Thus it is on the border between a true materials test and a simple or small scale structural test. For this reason it is also sometimes used for material ranking to give an early indication of a material's structural performance. Although standards exist for open hole tensile strength[1], results are strongly dependent on both layup and testing configuration e.g. the well known hole (notched) size effect[2]. This creates difficulties for designers and modellers alike since small changes in parameters will affect data values produced. There is thus an increased requirement for virtual testing to avoid expensive tests but paradoxically many predictive techniques require empirically derived calibration factors.

Work at the University of Bristol has investigated a number of the different factors causing variations in strength. A finite element modelling technique has been developed which has been able to capture variations both in terms of the failure mechanisms and the absolute values of strength. This paper summarises a number of these effects which have been tested and characterised as well as predicted using finite element analysis.

A comprehensive experimental programme investigated the scaling of open hole tensile strength[3]. This kept the ratio of hole size to specimen width and length constant. Three scaling routines were applied to a quasi-isotropic layup; thickness (1D), in-plane (2D) and thickness and in-plane combined (3D). In the thickness direction the stacking sequence was defined as either "sublaminate level scaled" i.e. repeated [45/90/-45/0] elements or "ply level scaled" i.e. plies of the same orientation blocked together. This formed a baseline data set from which a number of variations have been tested.

Two other quasi-isotropic stacking sequences have been tested and these were scaled in the thickness direction by both sublaminate and ply level scaling. This resulted in constant strength and a change in failure mechanism for one stacking sequence and a significant drop in strength and change in failure mechanism for the other.

Two alternative layups with a fibre dominated and matrix dominated configuration have been tested i.e 50/40/10 and 10/40/50 using the conventional 0/±45/90 percentage notation. For these tests only a single thickness (5mm) laminate was used and scaled in the in-plane (2D) directions only with the fibre dominated layup showing a pronounced size effect but the matrix dominated laminate showing an almost constant strength

In the baseline tests the specimen width was increased whilst keeping the ratio of hole size to width constant i.e. constant finite width correction factor. In addition tests were carried out in which the width was increased, keeping the hole size constant. These tests highlighted the role of sub-critical damage which occurs prior to ultimate failure. In the narrower specimens damage at the hole could join up more easily with damage at the free edge whilst in the wider specimens this occurred at a higher stress thus increasing the ultimate strength of the specimens, even after the finite width correction had been applied. This effect is less pronounced in the sublaminate scaled specimens where the more dispersed plies restrict the growth of the subcritical damage (Figure 1).

It has been found to be crucial to capture the progressive failure process in the finite element analysis. The method developed models the laminates on a ply-by-ply basis using hexahedral elements. Interface elements with a stress based initiation criterion and fracture based propagation criterion are used to model the matrix failures[4]. These elements are inserted between each ply to predict delamination and within each ply, as potential cracks, parallel to the fibre direction, starting at the hole boundary. Fibre failure is predicted using a statistical criterion based on Weibull strength theory. Good agreement has been obtained for all of the configurations analysed using this method.

The variety of failure mechanisms and trends in strength with changes in test parameters shown here is indeed a challenge for virtual testing. One for which the current finite element method in use at the University of Bristol has shown promising results.

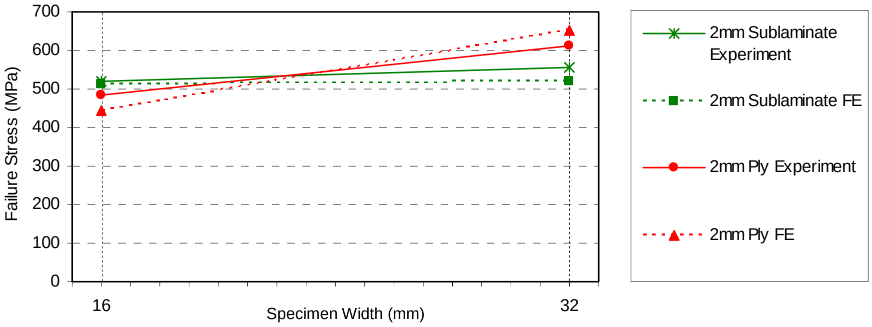

Figure 1 Experimental and finite element results for 1/8" dia. hole (finite width corrected)

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