EVALUATION OF IN-PLANE SHEAR FAILURE IN COMPOSITE LAMINATE WITH HIGH PERCENTAGE OF 90^o PLIES

S. Vali-Shariatpanahi

Durability Group Leader Airbus-UK, New Filton house Filton Bristol BS99 7AR

Professor S. Noroozi, Professor J. Vinney

School of Design, Engineering and Computing, Bournemouth University, Poole House, Talbot Campus, Fern Barrow, Poole, Dorset. BH12 5BB

Introduction The first step in the analysis of composite joints is to establish a correct and appropriate definition of properties of the materials used. The effect of fibre orientation, and the interaction between them in the laminated composite, play a key role in determining the laminate characteristics, the laminate mode of failure as well as the overall mode of joint failure. In order to study the failure of a new generation of composite laminate joints, sets of material properties are needed in three directions. This paper presents the study of the in-plane (interlamina) shear properties and the behaviour of a specific CFRP with a particular balanced lay-up under compression load. This paper presents the continuation of a previous investigation by the author to study shear in a specific CFRP Ref [1].

Methodology This study involved a detailed experimental programme to determine the material properties of a specific composite laminate, which were required in order to analyse the failure of a new type of fastener joint for composite laminates. Twenty shear tests were carried out using a minimum of six specimens for every lay-up. Although some thickness tolerances issues were caused by using different laminate lay-ups, all other geometric parameters were kept at nominal values. Ply failures were observed for $45^o/90^o$, 45^o, 90^0 specimens. A simple Finite Element (FE) model was also developed for each particular lay-up and results were compared against the test data. The FE model was used to explain why each coupon failed in a particular way. The FE model used 2D unsymmetrical material properties with shell elements representing the thickness. In terms of boundary conditions the model was constrained at one end with a compressive load applied at the other end.

The double notch shear test followed ASTM D 3846 method Ref [2] for this experimental programme. The results of this study and the previous work in Ref [1] show that, the laminate with high percentage of 90^o fibre orientation (with no supporting fibre in 0^o direction) will experience failure due to compression under the shear test.

Experimental Approach In-plane shear strength is measured by applying a compressive load to a notched specimen of uniform width. The specimen is loaded edgewise in a supporting jig, shown in Fig1and Fig2. Failure of the specimen was expected to be shear between two centrally located notches. Notches were machined halfway through specimen's thickness and spaced at fixed distance on two opposite faces Ref [2].

Test specimens Test panels were prepared in accordance with EN 2565 method B Ref. [3] each panel was made using 12 plies of pre-preg Cytec material (CFRP 977-2 HTS). All panels were hand lay-up and cured. The variation in thickness between all laminates, were within 2% of nominal thickness. The panels were subjected to NDT (C-scan) to find any preliminary damage, delamination or imperfection Ref. [4]. Three different panel lay-ups were used for this experiment.$45^0/90^0$, 90^0 and 45^0 .All panels were cut into specimens as shown in Fig1 and Fig2. A testing machine capable of controlling constant-rate-displacement was used. The load-indicating mechanism was set up to show the total compressive load carried by the test specimen during the test.

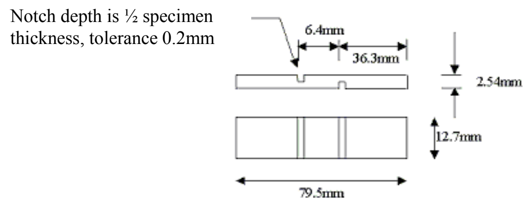


Fig1- specimen

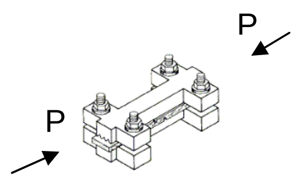
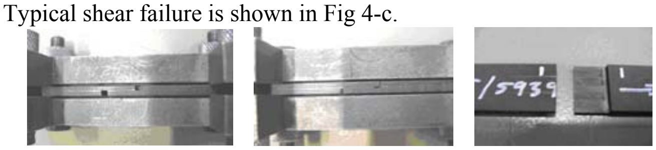


Fig 2-Jig Fig3- test machine test setting

A supporting jig (Fig2) was used to hold the specimens in line with direction of load within the test machine. This jig secured the specimen from buckling by using a small suitable tightening torque. To find the in-plane shear or interlamina strength, the maximum shear load carried by the specimen during the test, was divided by the width of the specimen and the length of the failed area.

Test definition The nuts used in the jig were tightened to a torque of 0.113 + 0.000, − 0.028 N·m before placing the coupons in the compression machine. The speed compression rate was set at 1.3+/-0.3mm/min. All tests were done in RT and normal humidity conditions. The average RT is 23^oC and normal humidity about 15%. Based on the direction of the load, the deflections were measured using cross head displacement via an inbuilt LVDT Ref.[1,2]. Typical shear failure is shown in Fig 4-c.



a) b) c)

a) Specimen in side jig b) failed Specimen inside jig
c) Interlaminate shear after failure
Fig4- typical specimens before and after testing

During the testing of the $45^o/90^o$ laminate lay-up the specimens failed in compression modes Fig 5. This is an unexpected mode of failure. In order to discover the reason for this unexpected failure a further set of specimens with UD $45^o$and UD 90^o laminates were made and tested to destruction.

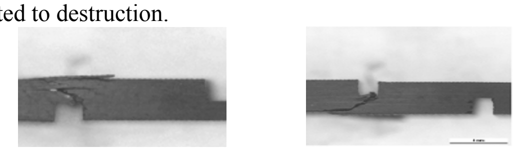


Fig5- the unexpected failure of the $45^o/90^o$ laminate

FE Modelling A 2-D finite element model was built using Patran and solved using MSc Nastran for each particular lay-up. The FE model used the nominal geometry of the test. Shell elements were used with orthotropic material properties and with corresponding ply lay-ups. Each ply was represented by a row of shell elements. Shell elements are oriented on xz plane where x is parallel to load direction and z is lying through thickness of the laminate. This assumption is made considering the infinite direction of the shell represents the in-plane direction of the specimen.The model is constrained in two directions at one end and loaded at the other end similar to the test configuration Fig6. The FE model was built on PATRAN and solved by NASTRAN using linear static analysis Ref [5]. Maximum and minimum shear stresses and displacement were read for each ply by using the corresponding row of shell elements.

Fig 6- FEM mesh with BC and direction of applied load

Results and discussion Specimens with a 45°/90° lay-up unexpectedly failed in a compression mode, as shown in Fig 5. FEM results showed the stress concentration around the notches for 45°/90° laminates Fig 7. This result has been discussed in a previous paper by the Author Ref [1] which covers the in-plane shear failure and ply stress plots for expected shear failure.

Fig7 also shows the shear stress plot for multi-directional 45°/90° laminate. In this plot, each row of shell elements represents one ply. A different colour for each ply in the stress plot shows how the different ply-direction has a different shear stress distribution. The crack is initiated at the corner of the notch; the notch being located at the high stress concentration area. It was expected that the high stress paths grow through the weakest link, which is the region lying between the two notches. The stress distributions are shown in Fig7. The high stress area does not stay between the notches in the same way as the other laminates Ref [1]. In this case, the crack has jumped to the different plies in order to find the lowest energy path. The failure mode is no longer the in-plane shear failure. This type of failure is observed during the in-plane shear testing for the 45°/90°specimens and quoted as unexpected failure Ref [1]. Further tests for UD 90° and UD 45° were carried out to analyze this type of the failure. In UD 45° shear stress plot Fig 8 each row of shell elements represents one ply. Specimens of this type UD- 45° fail due to interlaminate (in-plane) shear failure mode. In contrast the specimens with UD 90° laminate did not fail in a shear mode Fig 9. In the stress result for UD 90° laminate, it appears that the cracks initiated in the region of stress concentrations around the notches. The lower energy path is the driving path failure and therefore the failure mode. In this case the lower energy path does not lay in the link between the notches (Fig 10-b). Having 90° fibres against the direction of the force does not resist crack growth. Therefore the crack will find the minimum energy path, which appears to be in the next ply and the resin between plies so it jumps into that area and causes micro failure and fibre breakage. Then, it continues to jump ply by ply damaging the fibres and growing to the edge of the laminate. In the case of the UD 45 the lower energy path is the weakest link between the two notches, this leads to the failure due to in-plane shear failure as shown in Fig 8 and Fig 9. In this case, fibres resist against the crack growth through the plies. Therefore the crack can only grow in the resin between plies lying and between the two notches. It is similar to the in-plane shear behaviour of all other laminates lay-ups with no 90° ply or having a percentage of 0°plies aside of 90° plies Ref [1]. The non 90° plies provide the resistance and redirect the crack growth path through the resin area between the plies.Fig10 is the comparison between a typical displacement plot occurring at the in-plane shear failure mode (UD 45°specimen) and the displacement caused by the compression failure (UD 90° specimen).

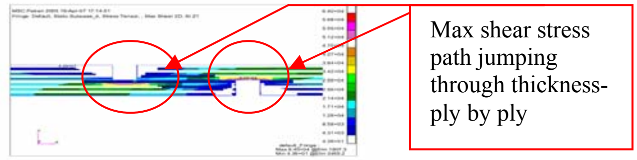
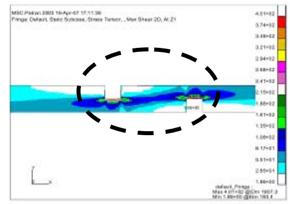


Fig7-the shear stress plot for 45/90 compression failure



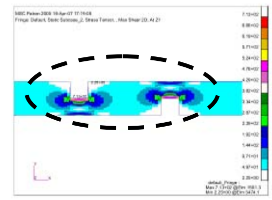
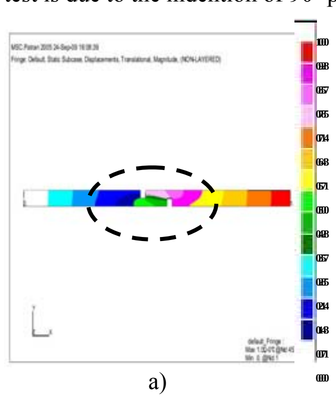
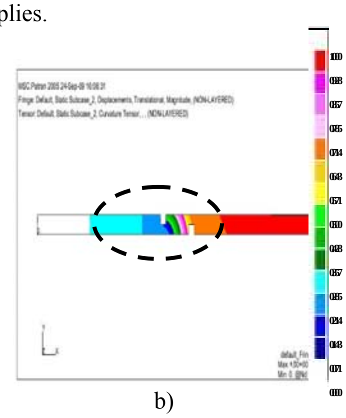


Fig 8- shear stress for UD-45° Fig 9- stress results for UD-90°

The results show that FE model prediction of the high stress paths is similar to the failure paths resulting from in plane shear test. It can be concluded that the compression type failure during the in-plane shear test is due to the indention of 90° plies.



a)



b)

a) UD–45° Failure in shear b) UD-90° failure in compression

Fig 10-Normalised Displacement

The interaction between the 45° plies and 90° plies configurations or any configuration of laminate with 90° (where there is no 0° fibre) leads the shear test to exhibit compression failure. The material property determined from these three lay-up configurations are listed in Table 1.

Laminate lay-up	UD-90	UD-45	Lay-up 45/90
Normalised Modulus*	0.149	0.183	0.171
Failure mode	Compression	In plane shear	Compression

Table 1- modulus for specimens under compression (*not to be considered as conventional shear modulus)

Reference:

1- S.Vali-shariatpanahi "Evaluation of in-plane shear failure in composite laminates", AIAA conference Illinois, 7-10 April 2008, 49th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference

2- ASTM D3846 –02 American Standard test method for In-Plane shear strength of Reinforced Plastics 2001.

3- AECMA Standard prEN 2565 edition 2 May 1993, Aerospace series preparation of carbon fibre reinforced resin panels for test purposes.

4- BS EN ISO 2818 British standard 1997, plastics preparation of test specimens by machining

5- Patran/ Msc Nastran (the McNeal –Schwendle cooperation) 2005