FAILURE AND IMPACT MODELLING OF TEXTILE COMPOSITES: ITOOL PROJECT

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1 SUMMARY

One key objective of the ITOOL project is to improve failure and impact modelling of textile composites and establish validated Finite Element (FE) tools for the analysis of 2D and 3D textile composites on a macro- scale. Furthermore, these tools are to be linked to the data exchange software being developed within the project so that information may be freely exchanged with other types of composites analysis codes. The work covering failure and impact has necessitated development of several new static and dynamic materials test procedures. An overview of the experimental and analysis work undertaken to date is given in this paper.

2 INTRODUCTION

The principle aim of the CEC Framework VI project ITOOL is development of a software tool to store and exchange data between arbitrary commercial composites Finite Element (FE) codes [1]. This paper is concerned with aspects of the project concerning macro-mechanical FE codes for analysis of ‘external loading behaviour’ covering, in particular, failure and impact/crash analysis. The project focuses on several composite material types including braid, woven and 2D Non Crimp Fabrics (NCF). The manufacturing process is dry textile performs using liquid infusion techniques with RTM6 resin. Due to recent strong interest in 3D reinforcements the 2D NCF is also investigated with tuft reinforcement in the through-thickness direction to enhance impact and damage tolerance.

In recent years new damage and delamination models have started to find their way into commercial FE codes, for example [2,3], to improve laminate composite failure and impact modelling. These models are demanding in terms of data input requirements and the tests needed to determine mechanical properties. In the ITOOL project further improvements to these models have been identified; these are notably test and modelling of through-thickness, compression and strain rate properties. These tests and some typical data obtained are briefly reviewed.

A further aspect of the work is calculation of macroscopic mechanical properties based on meso-mechanical FE models using homogenisation algorithms. The use of meso-mechanical textile models for virtual testing could significantly reduce the amount of experimental work needed for this basic data. So far the method has proven successful for prediction of elastic behaviour and is now being extended to consider failure and damage behaviour. A brief overview of the method is given.

3 TESTING THROUGH-THICKNESS PROPERTIES

The absence of crimp in NCF Composites provides good in plane material properties and, due to stitching of plies, does also offer enhanced through-thickness properties. Never-the-less inter-ply delamination and, moreover, delamination between the NCF blankets remains a weak link that can be greatly improved via full through-thickness stitching or tufting of the laminate. Appropriate standardised testing procedures are available for in-plane and delamination properties [4]; however, new tests are needed to determine failure criteria for through-thickness reinforcement.

Over the years numerous experimental tests have been used to characterise out-of-plane laminate properties. Most of these generate inter-ply shear failure using either three or four point bending of relative short thick specimens, the Iosipescu test, or double notched shear test, Figures 1a, 1b. These tests are relatively simple, however, only information on shear performance can be obtained and the non-uniform shear stress distribution generated makes them unreliable for accurate failure data. A test to open a curved laminate, Figure 1c, has been proposed for normal tensile failure at the mid-span, but this test does apparently produce a poorly defined tensile stress distribution at this location.

In order to obtain more reliable through-thickness failure data a test using waisted block specimens is proposed, Figure 1d, which can be loaded in tension or compression. Actually two independent material evaluations are required for the validation of the orthotropic three dimensional failure criterion [5]. These are; first, the determination of out-of-plane material properties and, second, a test with well defined combined loadings for validation of the criterion. Generally the above mentioned tests are unfavourable for combined loading since the loading is dependent on many parameters; e.g. specimen geometry, deformation and lay-up.

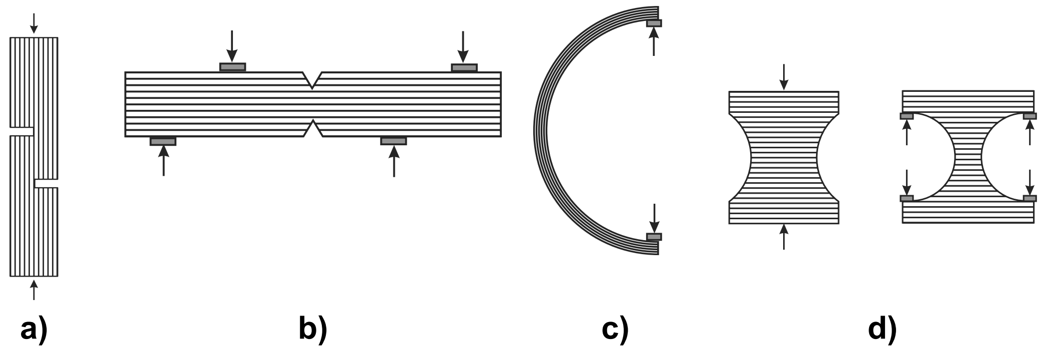
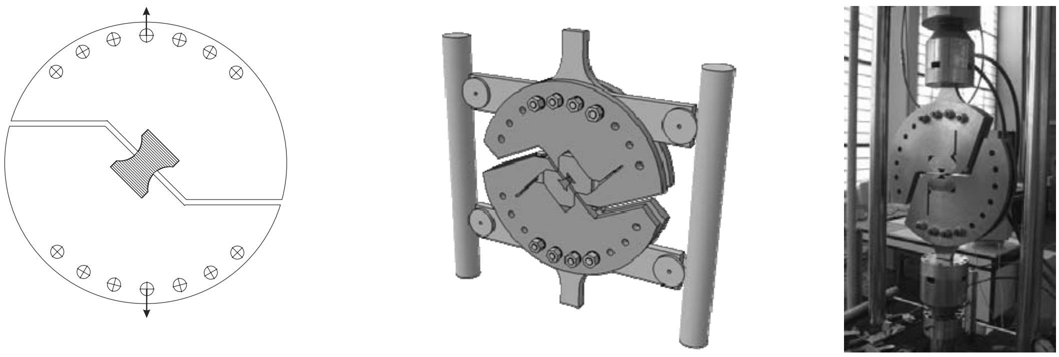


Fig.1. Potential test setups for through-thickness properties: a) Double notched shear test b) Iosipescu test c) Mode I tensile test d) Waisted specimens

A promising through-thickness test for pure normal (tension, compression), pure shear and mixed mode (tension-compression-shear) loading is the Arcan test [6] with a modified waisted block of the composite laminate, Figure 2a. The test is relatively simple and involves two halves of a disc which can be rotated and loaded in different directions to impose the required loading. Therefore this test provides the potential to determine both the pure out-of-plane material failure properties and to validate the failure criterion with a mixed mode loading.

A schematic drawing and view of the modified Arcan device in a hydraulic tensile test machine are shown in Figure 2b. The specimen is mounted in an inset in the centre of the rig; this facilitates the installation of different specimen geometries. The specimen geometry is restricted by the ability to produce three dimensional reinforcements in NCF materials. These reinforcements can only be applied to a moderate plate thickness of approximately 30 mm thick by the tufting process. This restricted plate thickness of tufted materials is a challenging problem to design feasible specimen geometries. Therefore different geometries were analysed by FE analysis and for each load case optimised specimen geometries have been defined.



a) b)

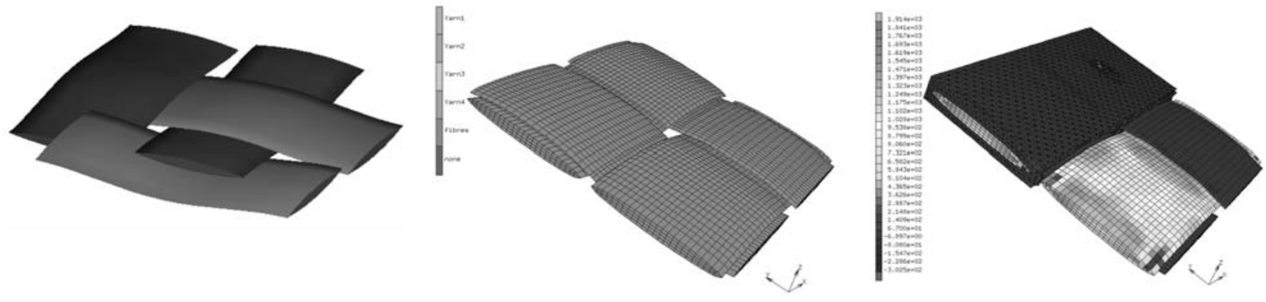
Fig. 2. The modified Arcan device: a) Principles of the test b) Schematic view of the tension-compression rig c) The prototype tension rig

4 CALCULATION OF MACROSCOPIC MECHANICAL PROPERTIES

The effort in ITOOL work package two provides, via the WiseTex pre-processor, a tool to build a geometrical model of a textile Representative Volume Element (RVE) and provide internal material description. This detailed description of the textile can be transferred, via the data exchange tool, to an FE model of the textile reinforced composite for use in a package such as ANSYS, Figure 3.

External loading of the Finite Element RVE model causes a complex internal stress distribution in the fibre and matrix parts. Using an averaging algorithm and homogenisation techniques the macro-mechanical elastic properties of the RVE can be calculated. This method typically requires six load cases where the RVE is loaded in the principal directions of the Cartesian coordinate system (three times tension and three times shear). The predicted elastic properties can than be used for a macroscopic (part level) analysis of the composite structure.

This method has proven successful for the prediction of elastic properties [7], and has also been a valuable method to determine mechanical properties that are hard, if not impossible, to obtain experimentally. In the ITOOL project these techniques are also being extended to damage behaviour of textile composites and will provide material failure data for macro-mechanical analysis.



a) b) c)

Fig. 3. Example construction (WiseTex – FE) of a woven fabric: a) WiseTex geometrical description b) Converted FE model c) The loaded composite for Exx (part of the matrix is removed for visualisation)

5 DYNAMIC TESTING OF COMPOSITES

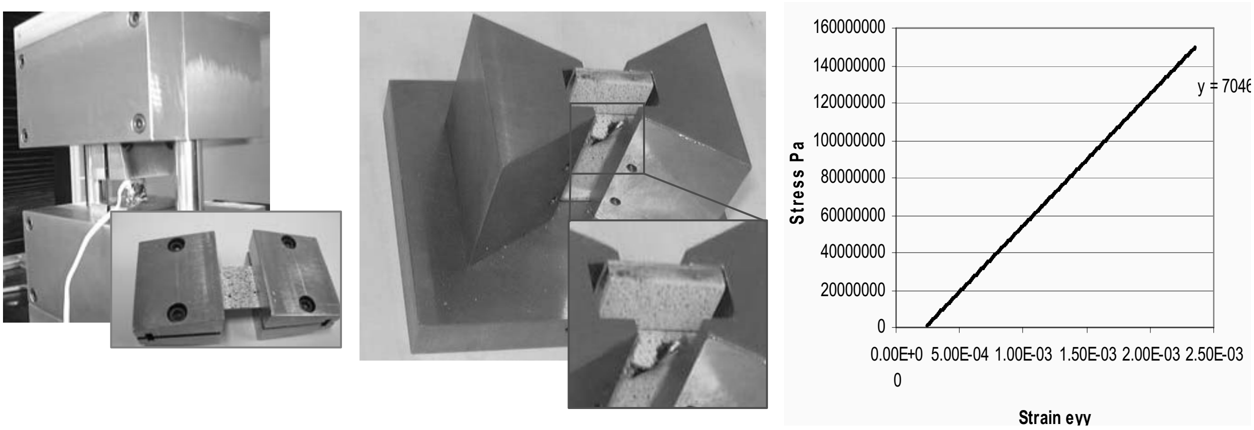
A full test program for static in-plane mechanical properties of 2D and 3D tufted NCF composite and Double Cantilever Beam (DCB) tests for delamination data has been undertaken. This data is respectively used for the Ladeveze ply [8] and inter-ply [9] failure models in PAM-CRASH. New work in ITOOL has focussed on extending these models into the dynamic regime. Currently two new tests are being specifically developed for dynamic compression and dynamic delamination testing; both of which are conducted in a drop tower. Future work will test materials at much higher strain rates, relevant to bird strike impact, using a Hopkinson bar apparatus.

4.1 Dynamic compression testing

Conventional compression testing uses the ASTM rig [10] with a short specimen to ensure axial compression, rather than buckling failure, Figure 4a. The test works well for UD composites, but is less successful for textile composites where wider specimens at least 2-3 times the textile unit cell size (total width ca. 25mm) should be used. This leads to poor stress distributions in the specimen due to the influence of end restraints; furthermore, the heavy weight of the rig limits its use to static testing. In order to overcome these limitations a new rig with side supports, Figure 4b, provides much greater testing gauge length (with improved internal stress distribution) that is appropriate for both static and dynamic drop tower compression testing. The main difficulties are measuring the dynamic strains and techniques using optical strain measuring and a high speed camera are proving successful.

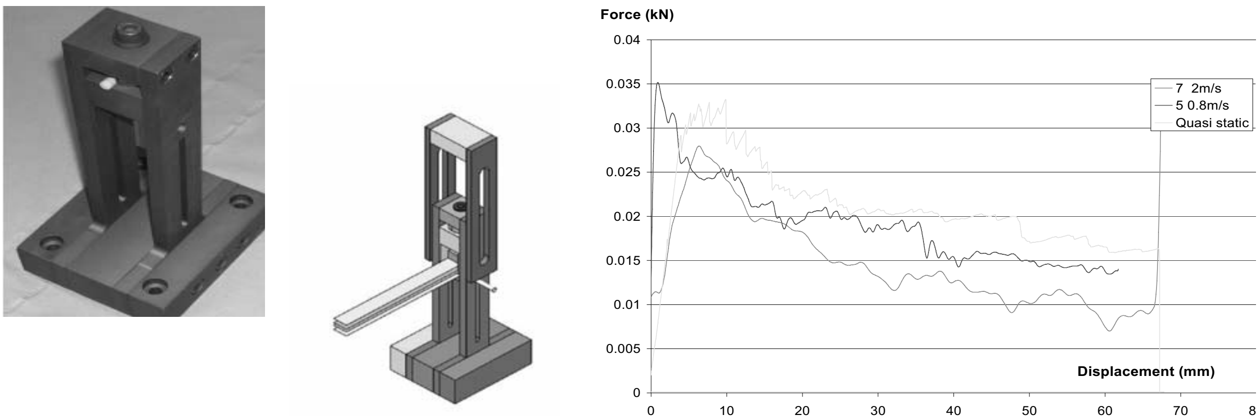
4.2 Dynamic delamination testing

Mode I delamination testing uses the conventional DCB test [11] which is performed under slow (static) loading. The concept of this test has been extended to dynamic rates of loading using the rig illustrated in Figures 5a, in which loading is now imparted dynamically via a drop tower impactor. Some early results, shown in Figure 5b, show that the force needed to drive a crack in 2D biaxial NCF reduces with the rate of crack propagation. Results for tufted NCF (not shown) indicate that the tufts, which dominate through-thickness strength and energy absorption, are less sensitive to rates of loading and crack propagation.



a) b) c)

Fig. 4. Compression testing: a) The conventional compression test b) The new dynamic test rig c) Example dynamic stress-strain curve

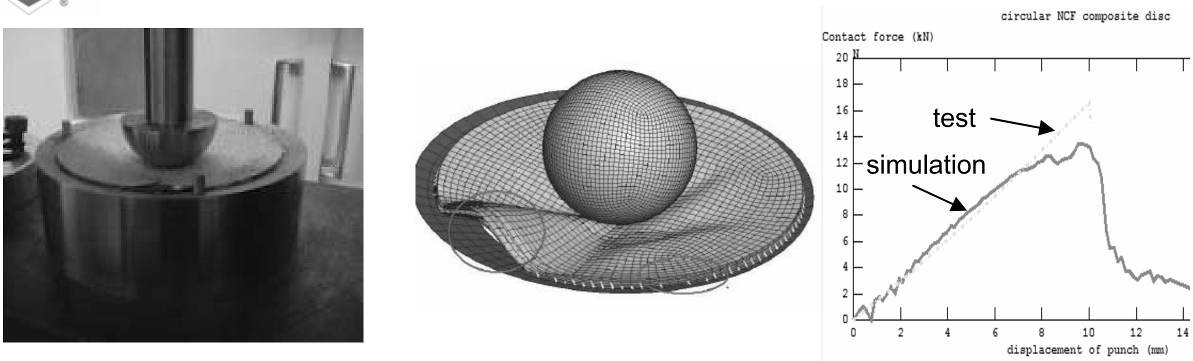


a) c)

Fig. 5. Dynamic delamination testing: a) The test rig b) Example results with impact velocities of 0, 0.5 and 2.0 m/sec

6 VALIDATION

During the latter stages of the ITOOL project several impact and crash validation studies are planned. Figure 6a shows a simple first validation study involving the loading of a simply supported circular disc by a central punch. In plane mechanical, damage and failure data has been obtained from experimental testing and used together with delamination facture toughness data. First results, as shown in Figure 6b, demonstrate an encouraging agreement between test and simulation for delamination growth and the loading force-displacement curve.



a) b)

Fig. 6. Validation of a simply supported bi-axial NCF composite disc under central punch loading: Comparison of test and simulation

ACKNOWLEGEMENTS

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