BENCHMARK TESTING OF MODELLING METHODS FOR MULTIMATERIAL STRUCTURES

Peter Davies
Materials & Structures group, IFREMER, French Ocean Research Institute29280 Plouzané, France

Introduction

A major objective of the modelling cluster within the DOGMA project was to examine the reliability of modelling methods currently employed to predict the static stiffness and strength of multimaterial structures. Sandwich structures and adhesively bonded assemblies were identified by the cluster participants as being priority areas for current and future applications and three case studies were chosen:

- Sandwich beams under flexural loading
- Sandwich panels under uniform pressure loading
- Adhesively bonded composite/composite joints

The case studies were performed by up to 10 participants, listed at the end of this abstract, who were each provided with the same set of input material data and boundary conditions. Each ran calculations blind and provided results to a co-ordinator who compiled the results (A. Ferreira of INEGI for the beam flexural case and the author for the two other cases). The first case study was selected as it is being studied in a benchmarking round robin by Professor Meyer-Piening of ETH Zurich. The two other cases were based on experimental data available at IFREMER from previous work in a BRITE project (COMAST) and in PhD studies. The test configurations are shown schematically in Figure 1, materials are described in Table 1. In the limited space available here it is not possible to describe all the work performed on these case studies, so a brief overview will be presented and references given in each case to enable the reader to obtain more details. The DOGMA web-site [1] provides additional information.

1. Sandwich beams under four-point flexural loading

The details of the model input data are available elsewhere [2]. Two cases were examined, as shown in Figure 1, with either thin or thick facings and non-symmetric facings. This exercise was performed by several groups but represented a relatively small part of the overall benchmarking activity. The correlation between deformed shapes obtained by different models was reasonable.

2. Sandwich panels under uniform pressure loading

The loading of sandwich panels by uniform pressure has been proposed recently as a means of obtaining their two-dimensional flexural properties, as opposed to the one-dimensional simple bending of beam specimens. Such tests are attractive as they can simulate the hydrostatic loading conditions often encountered by marine structures, but in the configuration chosen here with two transverse stiffeners to react the applied pressure load the test is closer to a wide beam than a full panel test. It nevertheless provided an opportunity to compare different modelling methods, both analytical and numerical, and to then compare test results with measured values from tests performed at IFREMER. A first set of test data was available from the tests performed in a previous project [3], but further tests were carried out during the DOGMA project to check material properties, examine boundary conditions and to develop an image analysis method for measurement of core shear strains.

The models used are presented briefly in Table 2. These ranged from very simple beam theory analyses intended to give a first estimation of central deflections, through to very detailed finite element models including both large displacement and core material non-linearity.

An example of the central displacements predicted by the FE and higher order plate theory models and the comparison with measured values is shown in Figure 2. The correlation is quite good for central displacements, but the predicted deformed shape differs from the measured form and this is also reflected in differences between measured and predicted strains. At the pressure used for these comparisons, 0.1 MPa, there is core shear yielding. This was measured by image analysis, which revealed large core shear strains near the stiffener, and was predicted quite well by the FE models including non-linear core material behaviour. The boundary conditions imposed by the stiffeners have a strong influence on the local core response. The initial test results were from composite stiffeners and after discussion within the modelling cluster a new series of tests was run with steel stiffeners bonded to the sandwich panel, Figure 3. This did not significantly affect the central panel displacement but changed the deformed shape and the facing and core strains. More details of the modelling and test results were presented recently [7].

3. Adhesively bonded composite/composite joints

The assembly of components made from different materials is a critical part of the manufacture of multi-material structures. The development of reliable methods for the prediction of bond strength is essential if the benefits of adhesive bonding are to be achieved. The analysis of the failure of adhesively bonded composite adherends presents particular difficulties on account of the numerous possible failure modes and the controversy surrounding failure criteria for orthotropic materials [11]. This situation is further complicated when structural adhesives are employed, as these often show highly non-elastic behaviour. It was therefore appreciated from the outset that this case study would not be straightforward.

The range of models employed is shown in Table 3. Once again these varied from simple “back-of-an-envelope” calculations to detailed numerical analysis. A fracture mechanics model was also applied, using a fracture envelope available from previous work at IFREMER on these same materials [12]. Additional tests were performed during the project to check adhesive and composite input data.

Many results were obtained and these will be published in due course. When a relatively brittle adhesive was used predictions were reasonably close to measured failure loads. However when a ductile structural adhesive was used predictions were less satisfactory. Figure 4 gives an indication of some of the results for the latter adhesive. For this joint configuration the FE analyses tend to underestimate joint behaviour, analytical methods were a little closer and the fracture mechanics prediction overestimated the failure load. Clearly a more detailed discussion is needed than is possible here, to explain these differences and to detail the assumptions of the different models. The way in which the models treat singularities and the failure criteria employed differ considerably and extreme care is needed to avoid unrealistic predictions. Some attention was given to details of joint extremities during the project (tapering, fillets) and the critical importance of these “details” was clearly shown.

4. Some general conclusions

These modelling benchmark exercises have enabled some conclusions to be drawn and have highlighted a number of areas requiring further study.

- The analytical methods employed for the sandwich beam and panel generally provided a useful first indication of deflections.
- For more detailed analysis, and particularly in the evaluation of facing and core strains, more sophisticated models are required. The linear elastic FE predictions of deflections showed that there were not significant differences between the codes.
- In order to predict the correct deformed shape and hence to estimate core shear yielding of this panel, non-linear material analysis was required. When this was used a good correlation with measured core shear strains was obtained. Image analysis proved to be a useful technique to measure these shear strains.
- The modelling of composite/composite bonded joint failure is extremely complex due to the large number of possible failure modes.
- There is an urgent need to rationalise the available modelling approaches, both analytical and numerical, into a tool the designer can use to dimension bonded multi-material structures. This requires the limitations of existing methods to be clearly indicated, particularly when dissimilar adherend materials are involved.

References

[1] DOGMA web-site, address http://www.brookes.ac.uk/other/dogma/:
[2]. Ferreira AJM, Morais AB, "Benchmark test on a sandwich beam", Proceedings DOGMA Workshop on modelling of sandwich structures and adhesively bonded joints, September 1998, published by IDMEC Porto, 2000.
[3] Davies P, Choqueuse D, Bigourdan B, Jnl. Marine Structures, 1994, p345
[4] Allen HG, Analysis & Design of Structural Sandwich panels, Pergamon, 1969
[5] Adams RD, Weinstein AS, ASME Jnl. Eng. Materials & Tech., 1974, paper 75-Mat-K.
[6] Frostig Y, Baruch M, Vilnay O, Sheinman I, J. Eng. Mech., 118, 5, May 1992 p1026-43
[7] Davies et al., paper presented at 5th Sandwich Construction conference, Zurich September 2000.
[8] Adams RD, Comyn J, Wake WC, Structural Adhesive Joints in Engineering, 1997, Chapman & Hall.
[9] Jeandrau JP, Int. J. Adhesion, & Adhesives, 11, 2, April 1991 p71.
[10] Papini M, Fernlund G & Spelt JK, Int. J. Adhesion & Adhesives, 14, 1, 1994 p5-13
[11] McCarthy JC, "Failure criteria for adhesive joints, an industry briefing", AEA Technology May 1999.
[12] Ducept F, Davies P, Gamby D, Int. Jnl of Adhesion & Adhesives, 20, 2000, p233-244.

List of participants in modelling benchmark activities:

A. Ferreira, AA Fernandes (IDMEC), M.Mustakangas (FY-Composites), R. Gaarder (SINTEF), J. Sargent (BAE Systems), F. Carli (University of Pavia), I. van Straalen (TNO), M. Hentinen, J-P Karjalainen (VTT), M. Hildebrand, (VTT/ FY-Composites), P. Marchal (Hoogovens/CORUS), RD. Adams, (University of Bristol), J. Broughton, A. Beevers (Oxford Brookes University), B. Bigourdan, P. Chauchot, D. Choqueuse, P. Davies, S. Reynaud (IFREMER).

Case study	Materials	Loading
1. Sandwich beam	Not specified	4 point flexure, two facing thicknesses
2. Sandwich panel	Glass/epoxy facings PVC foam core	Uniform pressure on lower facing, reaction forces via two stiffeners (composite or metal)
3. Adhesive joint	Glass/epoxy adherends 3 and 6mm thick.	Tensile on single or double shear overlaps of 10, 20 and 30mm

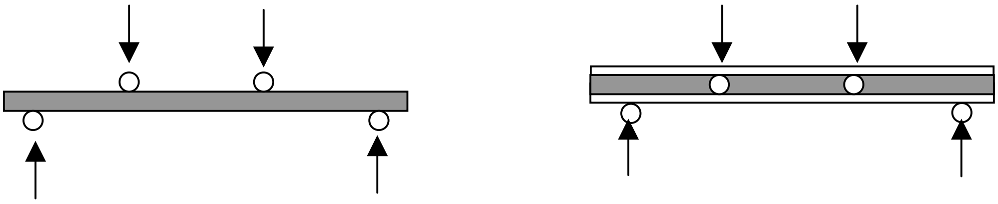
Table 1. Summary of case studies

Model	Brief description
SimpleAnalytical	Allen [4] and Adams[5] beam theories
Higher order analytical	Modified Frostig plate theory [6]
Linear Finite element	ABAQUS, ADINA, ANSYS, COSMOS, IDMEC, NISA, SAMCEF,
Non-linear large displacement FE	ABAQUS, ADINA, COSMOS, IDMEC
Non-linear material and large displacement FE	ABAQUS, COSMOS, IDMEC

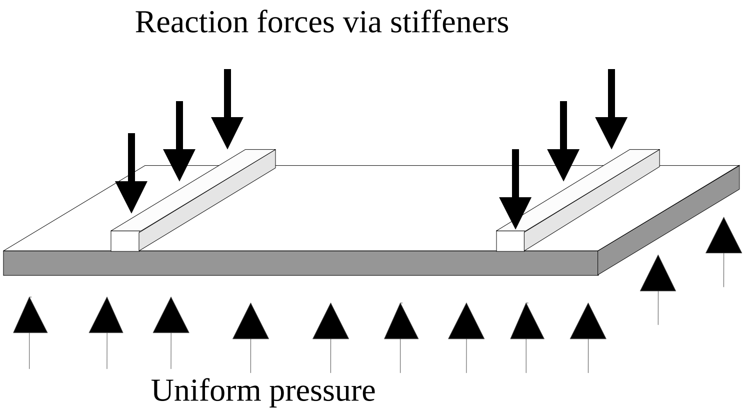
Table 2. Summary of models used to simulate uniform pressure loading of panel

Model	Brief description	Failure criteria Adherend/Adhesive
SimpleAnalytical	Adams[8]	5 criteria applied
Analytical elastic-plastic	CADIAC software [9]	Adhesive max. strain
Analytical fracture mechanics	Fernlund & Spelt analysis [10]	Adhesive mixed mode fracture envelope
Linear Finite element	SAMCEF,	Von Mises
FE Special joint element	IDMEC in-house	Max. strain/max. stress
Non-linear adhesive and large displacement FE	ABAQUS, ADINA, ANSYS, COSMOS, NISA	Adhesive: max strain for all Composite: max stress or Tsai Hill

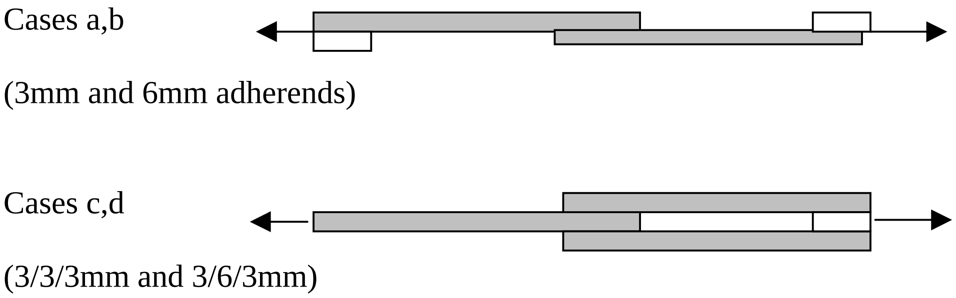
Table 3. Summary of models used to simulate adhesive joint behaviour



(1) Flexural loading of sandwich beams, thin and thick facings



(2) Uniform pressure loading of sandwich panel



(3) Adhesive bond composite/composite joints, single and double lap shear

Figure 1. Schematic presentation of the three case studies.

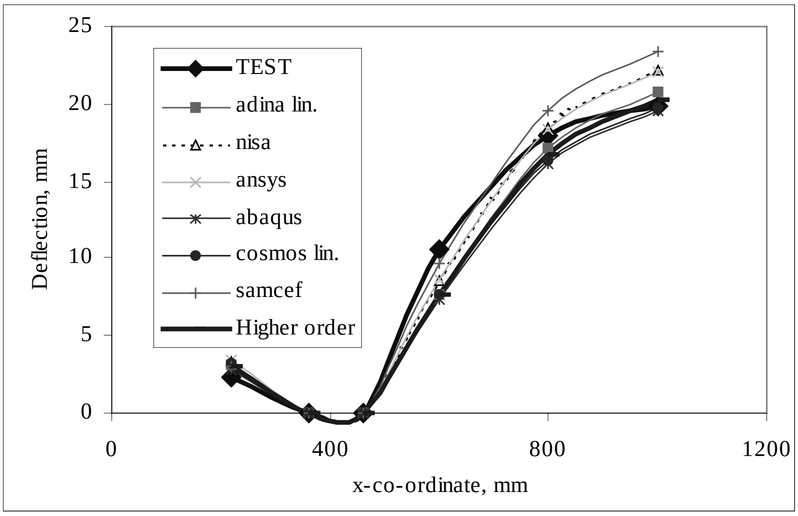


Figure 2. Uniform pressure test case study. Model predictions and test values of central out-of-plane displacements

Figure 3. Uniform pressure test panel stiffeners.

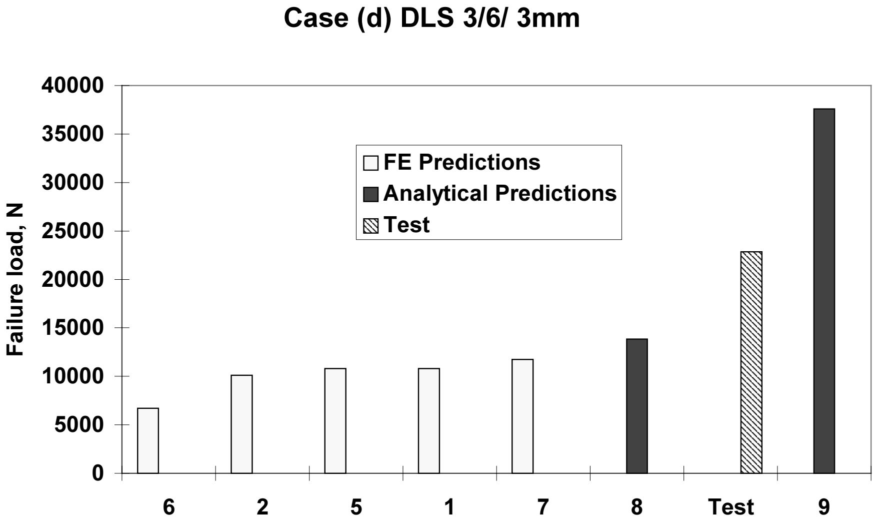


Figure 4. Composite/composite bonded joint case study. Predictions for double lap shear specimen failure load.