COST 526

"Automatic Process Optimization in Materials Technology"

(APOMAT)

Half-Yearly Report

To be sent to **V.Tesch@access.rwth-aachen.de** until **February 28, 2004**

1. Reporting Period	**28.2.2004 – 27.08.2004**
Project title	Optimisation of properties and dimensional stability of composites by controlled fibre placement
Project leader	Dr. Martyn Wakeman
Organization	Laboratoire de Technologie des Composites et Polymères (LTC) Ecole Polytechnique Fédérale de Lausanne (EPFL) CH-1015 Lausanne, Switzerland
Main collaborators involved	Dr. Niklas Jansson, Dr. Martyn Wakeman

2. Funding Situation

Amount of money received specifically for COST 62 000+59 000=121 CHF (received 2002-06-24, 2003-09-03)

Other resources partially used for the project kEuros

3. International Collaboration

(mention group and type of work done in collaboration during the reporting period)

Participation in the Working Group Meeting in Angers + project progress report

☑ YES

☐ NO

4. Industry participation

(mention name of companies and work done in collaboration during the whole project)

The project will to some extent be carried out in collaboration with DaimlerChrysler, Research and Technology, Ulm, Germany

5. Meetings, visits, exchange of scientists, short-term scientific	**Location, date**

missions	

6. Progress within the reporting period

(Not exceeding 3 pages, including tables and figures)

The aim of this research project is to develop the techniques and tools necessary to optimise the amount, material and location of the tow in order to reach the maximum mechanical performance in relation to weight or cost of structures manufactured by using integrated processing. One important building block includes the development and validation of finite element modelling strategies to allow efficient but accurate stress and stiffness analysis of fibre-tow reinforced thermoplastic structures. Efficient and accurate finite element analysis forms the basis and is a prerequisite for a subsequent successful coupling with the to-be developed optimisation tools and routines.

As a starting point detailed 3D finite element analyses have been performed and shown to compare favourably with available experimental data. However, one conclusion that can be drawn from the results of the detailed 3D modelling is that the effects of stable cracking in the matrix (experimental observation) and the non-fatal transverse failure of the tow (from the simulations) are very hard to incorporate in a finite element analysis. That means that the advantage of a good resolution of the stress state in the detailed 3D models is counteracted by the inability to model the progressive damage occurring in the structure. Hence, in an attempt to decrease the complexity and computational cost of the finite element models substantially with only a minor loss of accuracy, 2D models have been developed.

Two different 2-D models have been developed and tested, the beam and the composite shell model. In both models, the matrix is represented by shell elements whereas the tow is modelled either by beam elements or composite shell elements. In the latter, the area covered by tow is meshed with layered shell elements where the tow is an orthotropic layer in the middle with matrix layers top and bottom. The models has been evaluated in both tension and flexure against a detailed 3-D analysis and against experimental data.

The first main conclusion that can be drawn from the comparison between experiments and simulations is that the modelling of the compressive behaviour need further attention. In the 3-point flexure test, compressive failure is predicted to occur already at a mid-point deformation of 7-8 mm. However, in the miscroscopy examinations of the flexure specimens, no signs of buckling failure could be found even for a maximum displacement of 16.5 mm. The second conclusion is that the results from the 2-D models compare favourably with the ones from the 3-D model. Hence, it is fully viable to use the more effective 2-D models for the optimisation simulations.

The work undertaken during the current reporting period has been directed towards investigating the applicability of the routines in the commmercial finite element program Ansys to optimization of tow reinforced structures. As a test problem, a U-beam reinforced with cross-ribs was chosen. Design variables were the thicknesses of the bottom and sides of the U, the thickness of the ribs and the amount of tow in the top and bottom of the side walls and in the top of the ribs. Of the algorihtms available in Ansys, the so called sub-problem approach was used. This is a response surface method where the optimization problem is solved by a gradient based algorithm. It has the advantage that the gradients don't have to be numerically calculated for each iteration but can be obtained from the response surface. The method also allows for general non-linear behaviour of the structure which is desirable for the current type of structures.

Several optimisation runs were performed to test the influence of starting point, number of initial runs before commencing the actual optimization and the number of design variables. It turned out that neither the number of design variables nor the number of initial simulations had a clear influence on the convergence behaviour of the optimization. It should be noted though that enough simulations were always performed to form the response surface. Another result, as described already in the manual, is that the results from the optimization algorithm are dependent on the starting position. This has the implication that one has to perform the optimization several times, and more times for more design variables, to be reasonable sure that a good solution has been found. This can prove expensive as the solution algorithm performs one FE model evaluation for each iteration. Another drawback related to this is that the optimization has to be performed several times with different combinations of tow locations in the structure. This is due to the fact that the tow has a lower strain to failure than the matrix. Hence, for low tow content where the tow can't limit the deformation enough, the maximum strain constraint for the tow is exceeded. But for zero tow content this could still be an admissible state as the tow strain constraint is not active.

7. List of publications

a) Published

Below are publications that have been generated within the IPPC project, which as mentioned, is related to the APOMAT project:

MECHANICAL ANALYSIS OF MULTI-MATERIAL COMPOSITES MANUFACTURED BY INTEGRATED PROCESSING
P.-O. Hagstrand, M. D. Wakeman, F. Bonjour, P.-E. Bourban and J.-A. E. Månson
Proceedings of SAMPE 2002
Long Beach, California, USA, May 12-16 2002.

COST MODELLING OF A NOVEL INTEGRATED COMPOSITE MANUFACTURING CELL FOR INTEGRATED COMPOSITE PROCESSING
M.D. Wakeman, F. Bonjour, P.-E. Bourban, P.-O. Hagstrand, J.-A. E. Månson
Proceedings of the 23rd International SAMPE Europe Conference
Paris, France, April 9-11 2002.

ROBOTIC TOW PLACEMENT FOR LOCAL REINFORCEMENT OF GLASS MAT THERMOPLASTICS (GMTS)
M. D. Wakeman, P.-O. Hagstrand, F. Bonjour, P.-E. Bourban and J.-A. E. Månson
Composites Part A. 33 1199-1208 (2002)

MECHANICAL ANALYSIS OF THERMOPLASTIC POLYMERS REINFORCED WITH ROBOTICALLY PLACED CONTINUOUS FIBRE TOWS
P.-O. Hagstrand, N. Jansson, M. D. Wakeman, F. Bonjour and J.-A. E. Månson
Proceedings of the 14th International Conference on Composite Materials (ICCM-14)
San Diego, California, USA, July 14-18 2003.

b) Submitted for publications

FINITE ELEMENT MODELLING AND TESTING OF A GENERIC TOW REINFORCED STRUCTURE
N.E. Jansson, P.-O. Hagstrand, M. D. Wakeman, J.-A. Månson
Submitted to Composites part B: Engineering (Elsevier)

c) In preparation