Can it be made?
Predicting the Formability of Textile Composite Components

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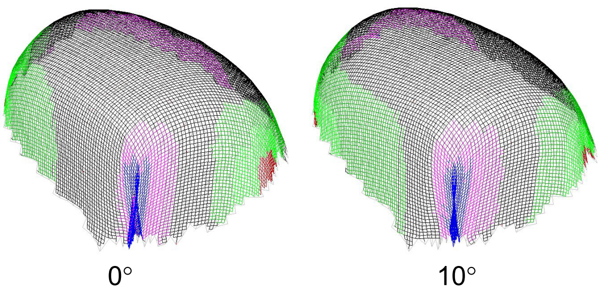
Extended Summary

There are many ways of forming components from composite materials. These include injection moulding, hand lay-up, diaphragm forming, stamping, pultrusion, resin transfer moulding, filament winding, and vacuum forming [1]. In recent years, attention has been focused on optimising the structural properties of composite components by using continuous fibres. Producing materials that can be formed with minimum force to produce high quality components is a challenging task.

In order for a textile composite material to form a given shape, various deformation mechanisms may occur. The most important and widely studied of these is intra-ply shear. One simple approach to predict the formability of components - kinematic draping - is to idealise a textile as a pin-jointed net, and to compute deformed fibre paths via a geometric algorithm [2]. The algorithm has been implemented commercially (e.g. MSC Laminate Modeler) and can provide a rapid solution. The kinematic approach can be used by designers to optimise the shape of components to minimise shear deformation and to predict mechanical properties, but since the algorithm takes no account of material properties, it cannot provide material manufacturers with any assistance in designing conformable textiles or recommend one material over another for production. In many cases, designers do not have the luxury of reshaping parts, and so compromises have to be made such as inserting cuts or splits into the fabric. Inevitably, these modifications reduce performance (strength, stiffness).

It has been shown that many shapes cannot be formed without inserting cuts into an idealised woven textile composite. One simple example is the cube [3]. Rapid changes in curvature also produce difficulties. Figure 1 shows a car wing mirror holder being draped by a 0/90 woven textile. Whatever initial fibre orientation is chosen, the algorithm fails to completely cover the surface without fibres crossing over each other, forming folds and wrinkles.



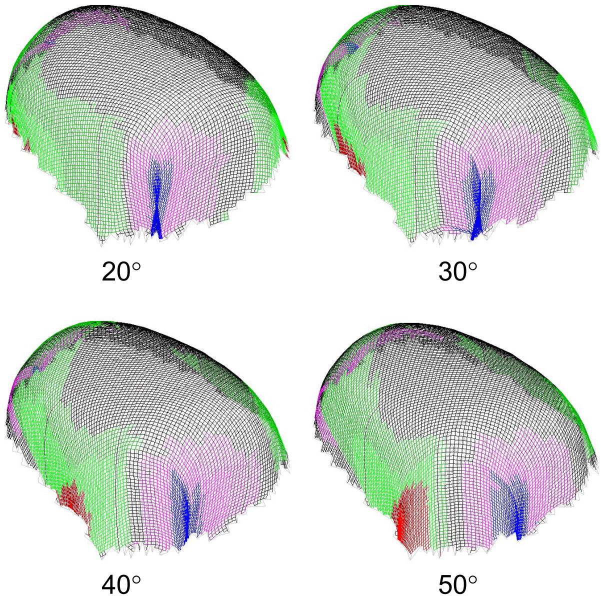


Figure 1: Drape simulations for car wing mirror holder at various initial fibre orientations.

Fortunately for manufacturers, textile composites can deform by modes other than shear. These include inter-tow slip and fibre extension or uncrimping [4]. Figure 2 shows a car wing mirror holder produced from Twintex (a glass/polypropylene woven thermoplastic composite) via vacuum forming. Before the component was formed, a grid was marked on the material to indicate the fibre directions. In the region where the kinematic algorithm predicted a fold, there is considerable shear deformation, but the component is formable due to other deformation modes coming into play.

Figure 2: Car wing mirror holder formed from Twintex.

More sophisticated algorithms have been devised that take into account material properties and additional deformation modes such as fibre extension and un-crimping. Explicit finite element codes (eg. ESI PAM-FORM) can represent material behaviour and processing conditions, but take much longer to compute and require significant material property data [5]. An alternative has been developed by the authors, based on the kinematic model described above implemented within an iterative scheme. In this approach, the appropriate mapping of fibres onto the surface is chosen to minimise shear strain energy. This can utilise data either from experimental shear testing or from constitutive modelling, thus enabling the effects of material construction to be considered [6].

For manufacturing processes that require textile composites to be shaped to a component's surface by hand, an additional limitation on forming is the energy required to deform the material. Various experimental test methods such as the bias extension and picture frame shear tests can be used for existing materials, but a large number of costly tests are required to fully characterise each material at a range of forming conditions (rate, temperature, etc). However, a constitutive model for intra- and inter-ply shear behaviour, based on constituent properties (fibre architecture, matrix rheology) has been developed and validated for both thermoset and thermoplastic prepregs over a range of processing conditions [7]. The model is entirely predictive, and requires a small set of input data including matrix rheology characterisation, fibre volume fraction, and tow properties, all of which should be relatively easy to obtain from manufacturers' data sheets or from a small number of additional tests. The advantage of the constitutive modelling approach is that the sensitivity of materials to changes in matrix viscosity or other variables can be assessed, providing material manufacturers with design information, which can be used to manufacture more conformable textile composites.

A forming limit diagram can be constructed by considering the energy required to form a given component from a woven textile composite material. Figure 3 shows such a diagram. The graph was constructed by computing the energy required to form the helmet from a fibre reinforced composite with a range of fibre volume fractions at various forming temperatures via the energy draping algorithm. It is assumed that the operators can apply a given amount of energy. When the energy is exceeded, the component is unformable.

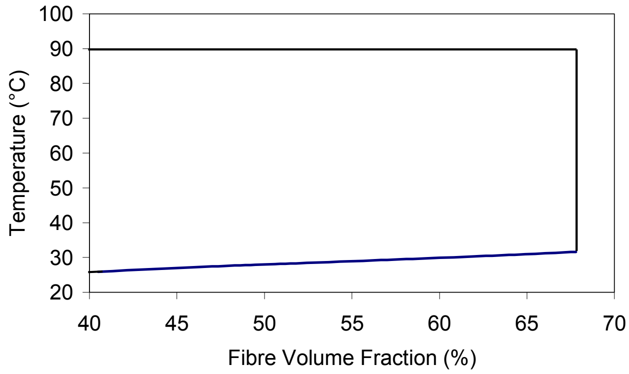


Figure 3: Forming limit diagram for a helicopter pilot helmet.

References

1. Hull, D. An introduction to composite materials. Cambridge University Press, 1996.

2. Long A.C. and Rudd C.D., A simulation of reinforcement deformation during the production of preforms for liquid moulding processes. Proc Inst Mech Engrs 208 (1994), pp. 269–277.

3. Robertson RE, Chu T-J, Gerard RJ, Kim J-H, Peterson RC. Three-dimensional fiber reinforcement shapes obtainable from flat, bidirectional fabrics without wrinkling or cutting. 1. A single four-sided pyramid. Compos, Pt A, Appl Sci Manufact 2000;21:703–715.

4. Potter, K. D. (1979), The Influence of Accurate Stretch Data for Reinforcements on the Production of Complex Structural Mouldings, Composites, pp. 161-173.

5. De Luca P., et al., Development validation and first industrial numerical results of a finite element code to simulate the thermoforming process, in: Proceedings of the Fourth International Conference on Automated Composites (ICAC'95), Nottingham, UK, 1995.FEA.

6. De Luca, P., Lefebure, P., Pickett, A.K. Numerical and experimental investigation of some press forming parameters of two fibre reinforced thermoplastics: APC2-AS4 and PEI-CETEX. Composites Part A, 29A, 101-110, 1998.

7. Harrison, P., Clifford, M.J., Long, A.C. and Rudd, C.D. A constitutive model for pre-impregnated viscous textile composites. Composites Part A (in press), 2004