EXPERIMENTAL STUDIES AND COMPUTER SIMULATIONS OF THE DRAPING OF WOVEN FABRICS

U.Mohammed, C.Lekakou and M.G.Bader

School of Mechanical and Materials Engineering
University of Surrey
Guildford, Surrey GU2 5XH

ABSTRACT

Extensive experimental and theoretical analyses of the draping of woven fabrics have been carried out. The mould set up consists of a hemispherical dome sitting on a flat surface in order to investigate the double-curvature draping. Four types of woven fabrics were tested: a loose plain weave, a tight plain weave, a twill and a satin weave. The draped shape was photographed and image analysed to evaluate the local fibre orientation. The fabrics were compared in terms of formability and wrinkling. The draping was also modelled by using the solid mechanics theory of forming, the assumption of elastic shear deformation, experimental data for the material properties of fabric and a finite element analysis (LUSAS FEA software package). The interactions between the fabric and the mould were modelled by considering a 'soft air' volume between the two bodies.

1. INTRODUCTION

In the process of producing composite components using resin transfer moulding (RTM), woven fabrics are draped onto mould surfaces of varying geometric complexity before being infiltrated with liquid resin. The draping process results in changes of the local fibre orientation, fibre volume fraction, permeability as well as properties of the final product. This is an important reason for devoting research effort towards producing a methodology that explains and predicts the deformation of fabrics during draping.

There have been several experimental[1,2] and numerical studies focusing on the diaphragm forming of thermoplastic composites. The numerical studies follow either the kinematic approach [3-5] or a viscoelastic model [6]. Bickerton et al [7] and Laroche and Khanh [8] employed the cone mould geometry to assess drapability of fabrics. A third approach based on a continuum, solid mechanics model has also been adopted in the simulation of the draping of fabrics [9].

The aim of the current study is to present draping experiments for four types of woven fabrics draped over a hat mould geometry, in combination with a solid mechanics, finite element analysis of draping. Data of wrinkling and local fibre orientation are included. Other studies by the same authors [10,11] include data for the shear deformation and shear locking in picture frame type of shear tests. This data is used in finite element simulations of draping.

2. MATERIALS

In this study four E-glass woven fabrics were tested: a loose plain weave (LPW), a tight plain weave (TPW), a twill (TWILL) and a 5 harness satin weave (5HSW). Their details are presented in Table 1.

Table 1. Specifications of the tested woven fabrics

Weave type	LPW	TPW	TWILL	5HSW
Coding	basket weave	Y0212	Y0185	Y0227
Thickness (mm)	0.58	0.48	0.28	0.23
Areal density ($kg\ m^{-2}$)	0.529	0.546	0.331	0.297
Ends/10mm	1.1	6.7	11.8	22.4
Picks/10mm	1.2	6.3	11.8	21.3

3. DRAPING EXPERIMENTS

Double curvature draping of fabrics was carried out in the mould presented in Fig.1. The mould consists of two parts: a lower aluminium platen with a centrally located, hemispherical dome of 97 mm radius, and an upper transparent block, from poly(methyl methacrylate) with a centrally located, hemispherical cavity.

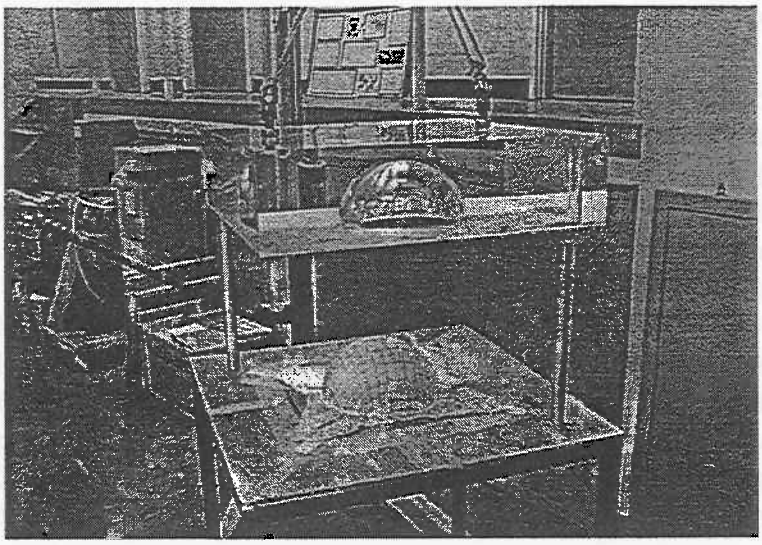


Fig.1. Mould used for the draping of fabrics.

First a fabric piece of 360 x 360 mm was cut and had inscribed a 20x20 square grid. The fabric was draped over the hat mould geometry, smoothed over manually and then the upper half of the mould was lowered and the mould was closed. The aims of the draping experiments were: (a) to observe wrinkling (see for example Fig.2), (b) to take photographs of the profile of the draped fabric and (c) to measure the angle between gridlines, taken as representing the angle between fibres after draping.

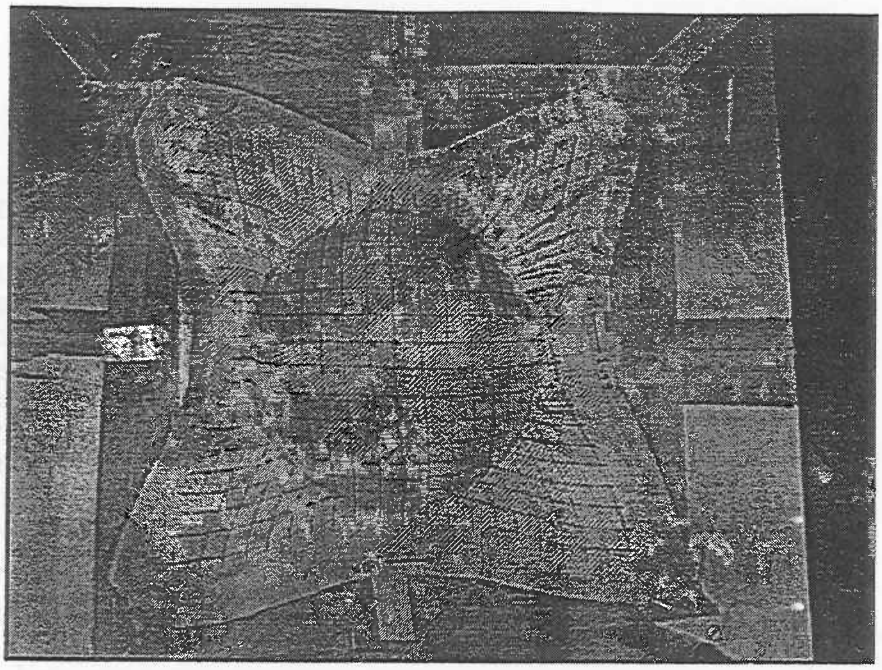


Fig.2. Wrinkling in the draping of TWILL.

3.1 DRAPING EXPERIMENTS: RESULTS AND DISCUSSION

Wrinkling as presented in Fig.2 is caused by in-plane compressive stresses induced during forming, resulting in gross buckling deformation of the fabric. The buckling is observed when the fabric is sheared beyond the "locking angle" which is characteristic for each fabric and has been measured for all four fabrics [10,11].

Fig.3 presents top viewed, boundary profiles of each fabric draped over the hat mould geometry. The four-ray star shape is common in the profile of all draped fabrics. The observed profiles are close to each other although the extent of wrinkling differed in the various fabrics [10]. The profile of the draped satin weave seems to have a lower degree of rotational symmetry than the profiles of the other three draped fabrics.

Fig.4-6 present shaded contours of the angle between gridlines at different locations across each draped fabric where the angle between gridlines is considered to represent the angle between sheared fibre yarns. Starting from the apex, fibre yarns are almost orthogonal, which means that there are not sheared in this region. The minimum shear is observed within the central region often of a diamond shape (LPW) or cross like shape (TWILL and TPW). Small shear is also observed locally just at the corners of the initially square fabric pieces for the densely woven TPW and TWILL. The maximum amount of shear is observed around the diagonals of the initially square fabric piece, at the flat part mostly just after the dome edge. An important observation in Fig.4-6 is that although the angle contours of the various fabrics have general similarities, they also have distinct differences which depend on the shear characteristics of each fabric. The authors have also studied the shear behaviour of these fabrics in picture-frame type of shear tests [11].

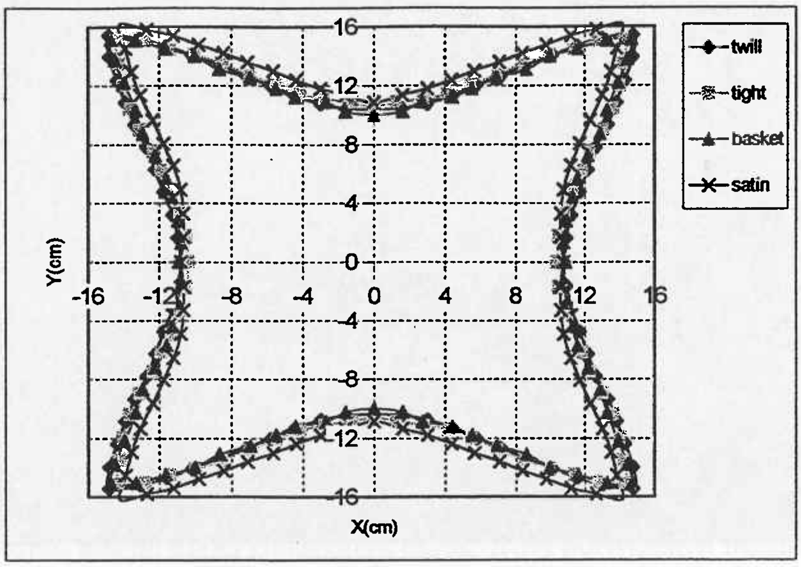


Fig.3. Boundary profiles of the draped fabrics.

4. FINITE ELEMENT SIMULATIONS OF THE DRAPING OF FABRICS

This section includes the mathematical modelling and computer simulations of draping by using the continuum solid mechanics approach. In this approach the fabric is represented by a solid surface or a thin solid body with a numerical finite element mesh. The mesh should be sufficiently fine to model accurately local features of draping, such as wrinkles, but may not reach the fabric micro-scale. The finite element analysis for static or quasi-static cases is based on the principle of conservation of virtual work which includes body forces, concentrated loads and surface forces. The displacement in each element, $u^{(e)}$, is derived from the interpolation of the nodal element displacements, $a^{(e)}$, by using the shape function matrix, $N^{(e)}$.

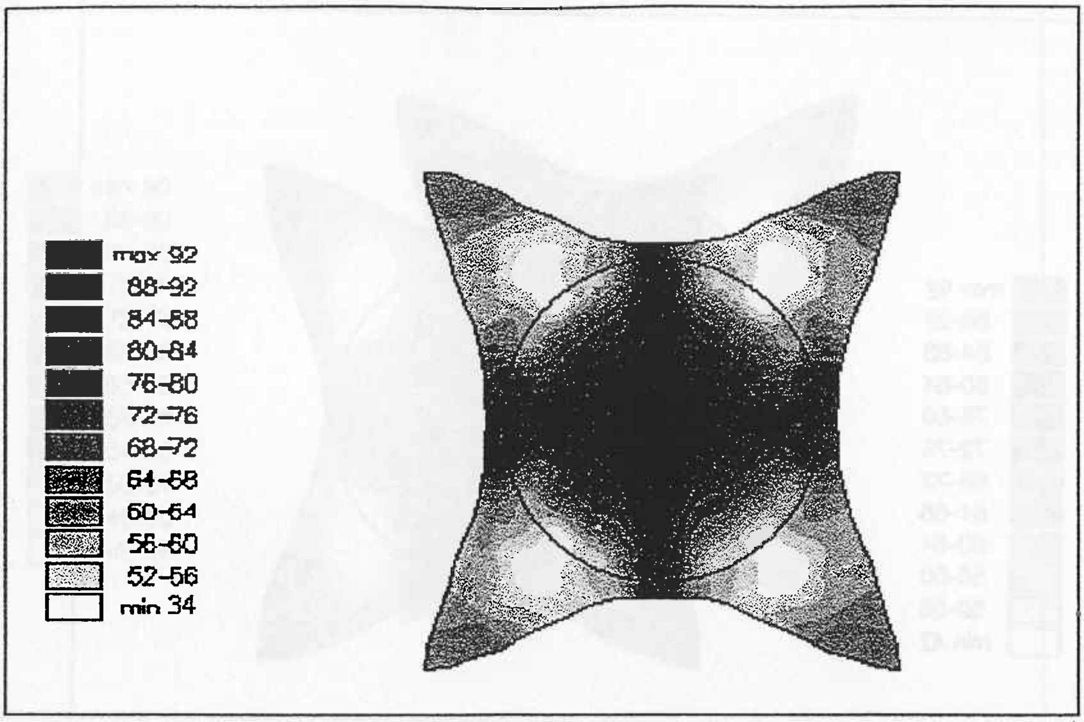
$$u^{(e)} = N^{(e)} a^{(e)} \tag{1}$$

The strains in each element, $\varepsilon^{(e)}$, are related to $a^{(e)}$ via the strain-displacement matrix

$$\varepsilon^{(e)} = B^{(e)} a^{(e)} \tag{2}$$

Constitutive relationships are used between stress and strain where the mechanical/viscous material properties feature. By using the virtual displacement theorem, the equilibrium equations of the assembly of elements are derived:

$$R = Ka \tag{3}$$



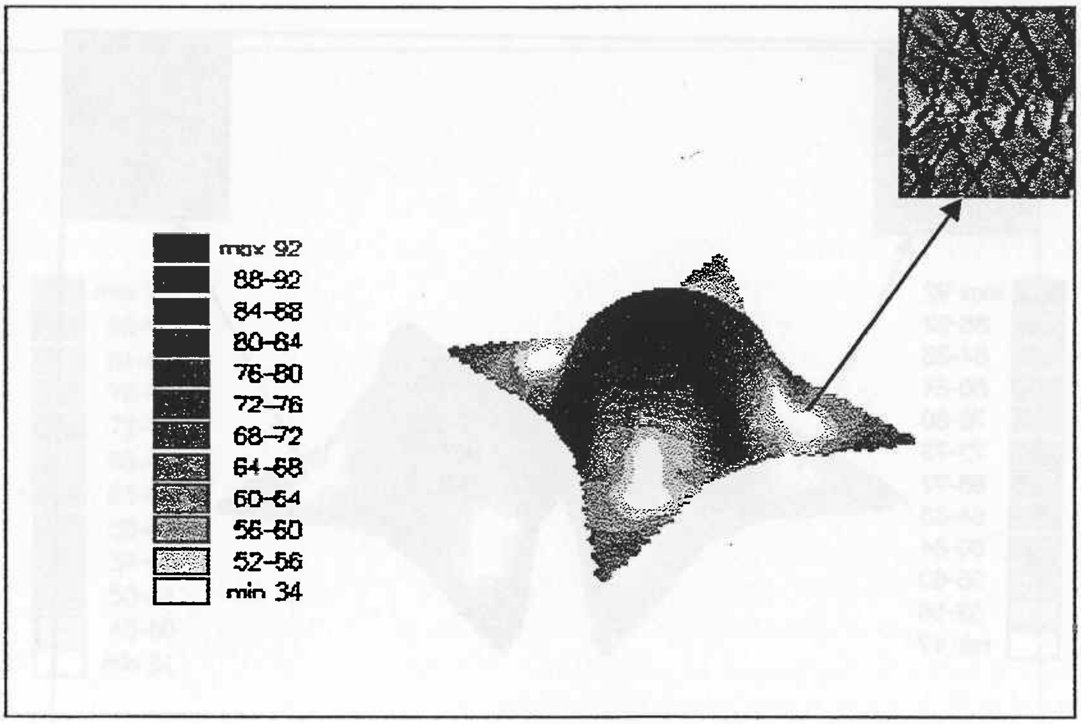
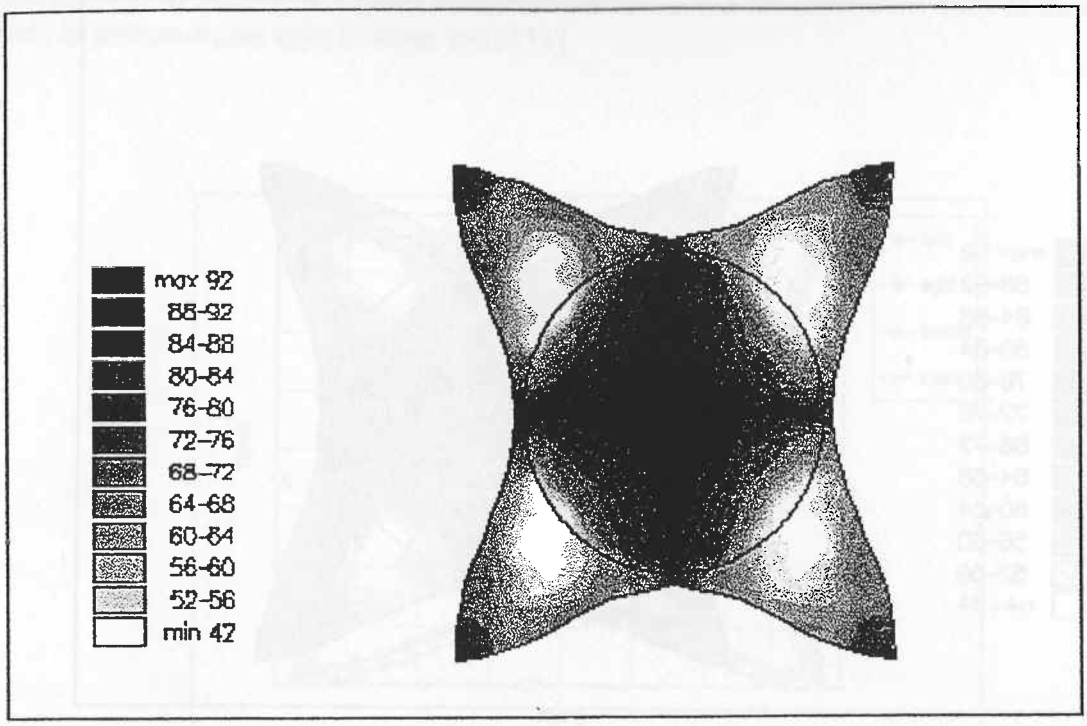


Fig.4. Shaded contours of the local angle between crossing gridlines in the draped loose plain weave (LPW)



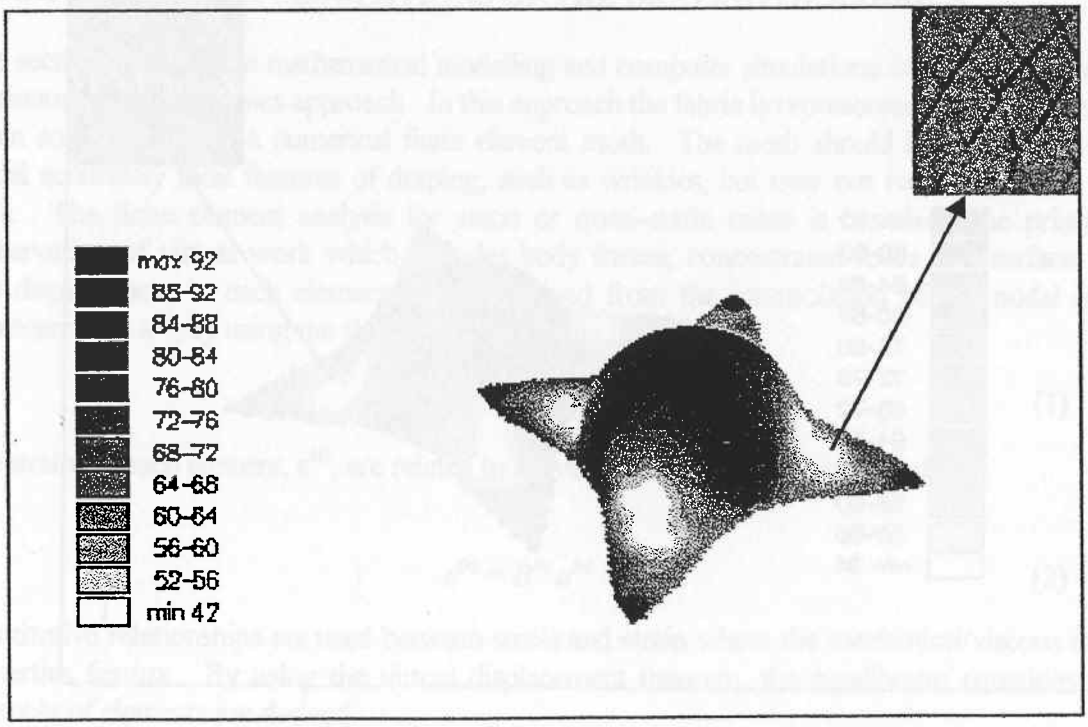
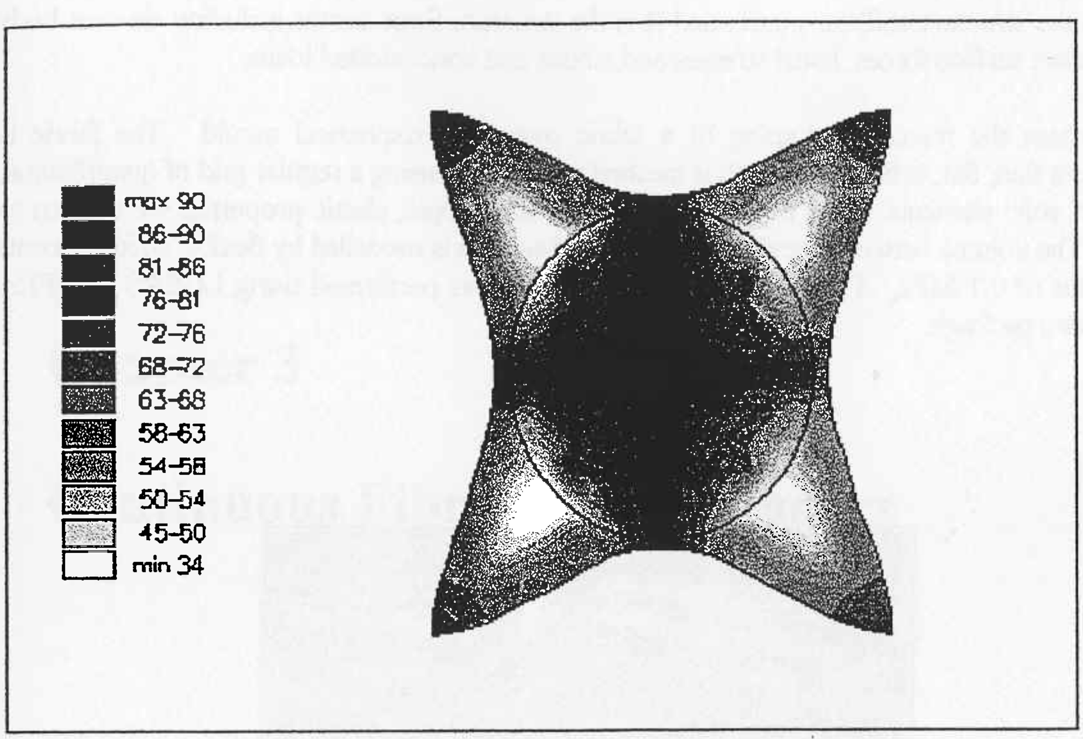


Fig.5. Shaded contours of the local angle between crossing gridlines in the draped tight plain weave (TPW).



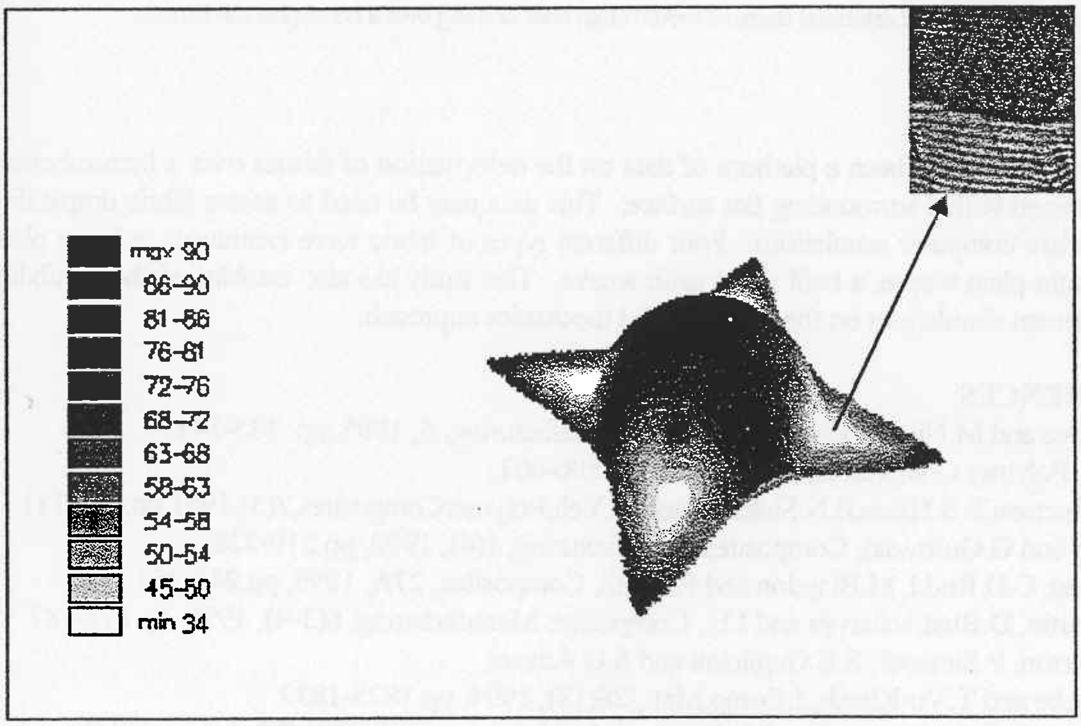


Fig.6. Shaded contours of the local angle between crossing gridlines in the draped twill weave (TWILL).

where K is the structure stiffness matrix and R is the structure force vector including element body forces, element surface forces, initial stresses and strains and concentrated loads.

Fig.7 illustrates the numerical draping of a fabric over a hemispherical mould. The fabric is modelled as a thin, flat, solid sheet which is meshed numerically using a regular grid of quadrilateral, orthotropic, solid elements. As a first approximation, orthotropic, elastic properties were given to the sheet. The volume between the sheet and the solid surface is modelled by flexible solid elements of a modulus of 0.1 MPa. The finite element simulation was performed using LUSAS 11, (FEA Ltd.) software package.

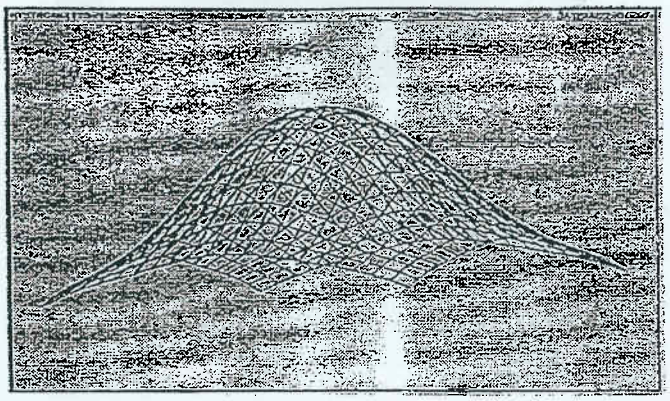


Fig.7. Predicted deformed shape of woven cloth after draping over a hemispherical surface.

5. CONCLUSIONS

In this study, there have been a plethora of data on the deformation of fabrics over a hemispherical dome combined with a surrounding flat surface. This data may be used to assess fabric drapability and to validate computer simulations. Four different types of fabric were examined: a loose plain weave, a tight plain weave, a twill and a satin weave. This study has also established the feasibility of finite element simulations on the basis of solid mechanics approach.

6. REFERENCES

1. S.Delaloye and M.Niedermeier, Composites Manufacturing, 6, 1995, pp. 135-144.
2. M.Hou, Polymer Composites, 17(4), 1994, pp.596-603.
3. R.E.Robertson,E.S.Hsiue,E.N.Sickafus and G.Yeh,PolymerComposites,2(3),1981,pp.126-131.
4. S.Albert and G.Gutowski, Composites Manufacturing, 1(4), 1990, pp.219-228.
5. A.C.Long, C.D.Rudd, M.Blagdon and P.Smith, Composites, 27A, 1996, pp.247-253.
6. T.A.Martin, D.Bhattacharyya and I.F., Composites Manufacturing, 6(3-4), 1995, pp.177-187.
7. S.Bickerton, P.Simacek, S.E.Guglielmi and S.G.Advani,
8. D.Laroche and T.Vu-Khanh, J.Comp.Mat., 28(18), 1994, pp.1825-1839.
9. H.Sabhi, J.C.Gelin, P.Boisse and A.Cherouat, 2nd Int.Symp. TEXCOMP2, Leuven, 1994.
10. U.Mohammed, C.Lekakou and M.G.Bader, ECCM-8, Naples, 1998.
11. U.Mohammed, C.Lekakou and M.G.Bader, submitted to Composites A.