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BENCHMARK STUDY OF FINITE ELEMENT MODELS FOR SIMULATING THE THERMOSTAMPING OF WOVEN-FABRIC REINFORCED COMPOSITES

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ABSTRACT: Thermostamping of woven fabrics shows promise for being a viable means for making high-volume low-cost composites. A number of research teams around the world have been developing finite element methods for simulating this thermostamping process, and in an effort to understand the strengths and limitations of the different simulation methods, an international benchmark survey was conducted for a double-dome geometry. Comparisons were made by observing the resulting draw-in of the fabric and shear angles developed in the fabric after stamping. In this paper, simulations results as submitted by the various research teams are compared. Where possible, the simulation results are compared to experimental data. Forming parameters for a next round of simulations for comparison amongst the participating labs are presented.

KEYWORDS: Thermostamping, thermoforming, woven-fabric, composites, finite element

1 INTRODUCTION

Thermostamping of woven-fabric reinforced composites can produce high-volume low-cost composite parts. Having a well calibrated finite element model of the forming of such composites can assist in tailoring the manufacturing process to yield quality parts in the minimal time required and for prediction of the resulting mechanical behaviour. In an effort to understand the strengths and limitations of the different simulation methods that are being developed by various research teams around the world, an international benchmark survey was conducted. An earlier stage of the benchmark focused on experimental characterization of the tensile and shear responses of the Twintex fabric. A summary of the Round 1 results has been published [1]. For this first effort at benchmarking the models, several groups submitted simulation results for the thermostamping of plain-weave Twintex fabric using the double-dome geometry. Comparisons were made by observing the resulting draw-in of the fabric and shear angles developed in the fabric after stamping. Based on this information, a standard set of simulation parameters was developed for a second round of simulations. Initial comparisons from Round 2 show that orientation of the fabric blank and the type of material used had the greatest influence on simulation results. Other parameters, such as the friction coefficient and fabric blank size, were set at specific values and not varied, so the sensitivity of the resulting fabric deformation to these parameters could not be quantified.

This paper will summarize and compare the simulation results from four research groups that participated in a Round 2 of the forming-process modelling. From the analyses of these data, a set of forming parameters for a Round 3 of simulations are presented.

2 MATERIALS AND GEOMETRY

The tool selected for the benchmark program was the double-dome geometry as designed by Ford Research Lab (FRL) and shown in Figure 1. In 2004, FRL conducted an experimental program where composite double-dome parts were formed using the Twintex (commingled fibreglass and polypropylene (PP) fibres) twill-weave fabric. Draw-in and shear-angle measurements were recorded for these formed parts, and these experimental data can be used to evaluate the correlation of finite element simulation results to actual formed parts. However, to ensure that these data do not compromise the theoretical modelling efforts, the experimental data are not being disclosed at this time.

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All forming simulations of the double-dome geometry are to be conducted using this twill-weave fabric and a plain-weave fabric. The fabric properties, as reported by the material supplier and benchmark participants, are listed in Table 1.

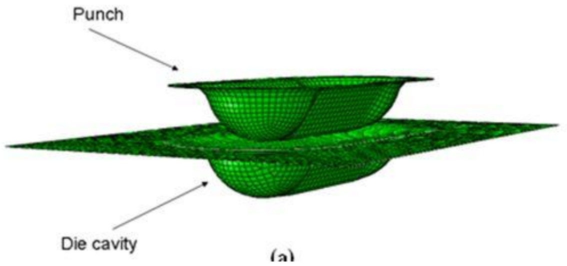


***Figure 1:** Double dome punch and die*

***Table 1.** Fabric parameters*

Mfgr's style	TPEET22XXX	TPECU53XXX
Weave type	Plain	Unbalanced Twill
Yarns	Glass/PP	Glass/PP
Weave	Plain	Twill 2/2
Area density, g/m^2	743	1816
Yarn linear density, tex	1870	2400
Thickness, mm	1.2	**2.3**

3 COMPARISON METRICS

Comparison of simulation results from each round of simulations relies on the same metrics being used in each round. These metrics include the amount of fabric draw-in at three specified points as well as the shear angles reported along the apex. The locations of the draw-in points are illustrated in Figure 2. All points of draw in are located on the edge of the material blank. Points D1 and D3 are located at the centre point of their respective sides. Point D2 is located at the corner of the material blank.

Shear angles are reported along the apex. The apex is defined as the line which passes through the points of greatest shear. Figure 3 illustrates the location of the apex with a white line. The line begins at the vertical axis of symmetry, passes through the location of greatest shear angle and ends at the edge of the material blank.

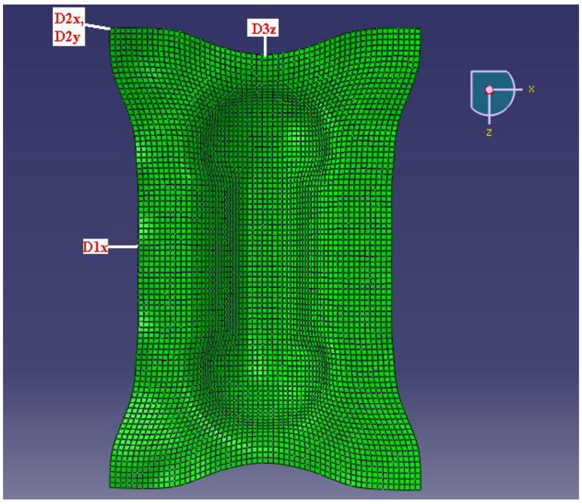


***Figure 2:** Location of reported draw-in for both 0/90° and ±45° orientations*

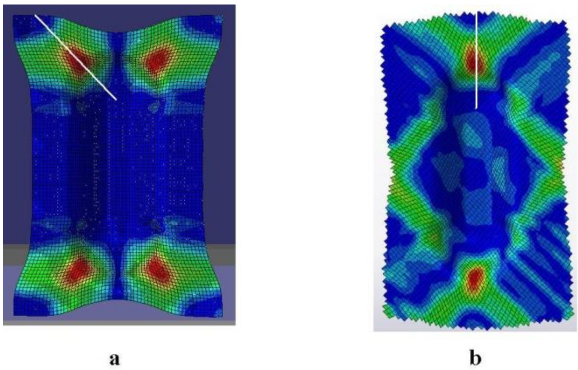

a
b

***Figure 3:** Shear angles measured along the apex line shown in white. (a) 0/90º fibre orientation (b) ±45º fibre orientation*

4 ROUND 2 RESULTS

Table 2 summarizes the draw-in and maximum shear-angle values reported by four research groups who reported data for Round 2. Figure 4 is a plot of the draw-in values. As can be seen in Figure 4, the draw-in amounts are fairly close at each location/direction for all of the groups. It can be seen that no group reports the largest or smallest draw-in across all four locations. Not all groups used the same binder force. However, it was concluded from the data that a greater binder force did not necessarily lead to less draw-in.

***Table 2:** Comparison of draw-in and maximum shear angle from different groups*

Institution	***Draw In (mm)***				***Max Angle (deg)***
	D1x	***D2x***	***D2y***	***D3y***	
UML	29.96	3.31	3.92	25.39	42.54
Northwestern	27.80	1.70	1.30	24.90	35.10
KU Leuven	25.50	3.59	3.06	29.10	40.71
INSA Lyon	28.72	3.63	4.21	25.79	43.45
Range =	4.46	1.93	2.91	4.20	8.35

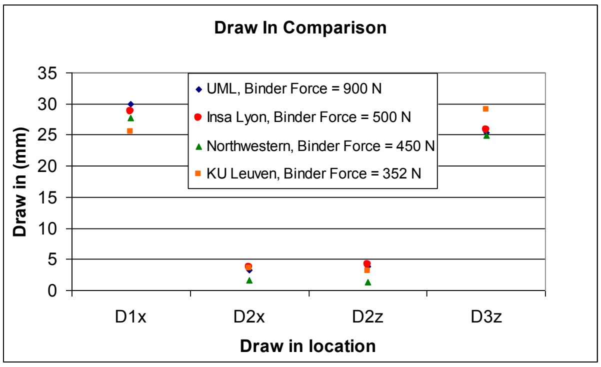


***Figure 4:** Comparison of draw-in from different groups.*

Some groups reported the shear angle along the apex, while others had specified a set of specific locations for reporting shear. Each group, however, did report the maximum shear angle observed whether it was recorded at one of the specified locations or not. As can be seen in Table 2, the maximum shear angle reported has a range of about 8° between the lowest and the highest.

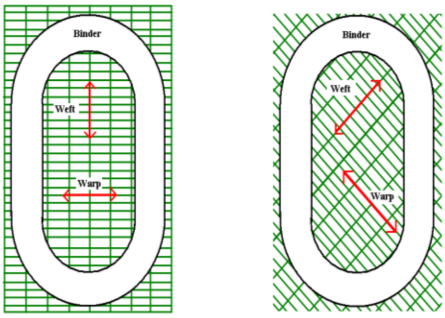
Not all groups used the same friction coefficient, shear/tensile behaviour from characterization tests, and binder force. Thus, direct comparison of stress distributions is not practical for the Round 2 simulations. In Round 3, these parameters will be prescribed so all groups use the same inputs and such a comparison will be meaningful.

5 ROUND 3 SIMULATION PARAMETERS

The Round 2 simulation data were used to develop a uniform set of Round 3 simulation parameters. These parameters include the orientation of the material blank, the amount of binder force applied, and the fabric. The orientation of the fabric blank will be specified as either the 0/90° or the ±45° orientation (Table 3). A standard is chosen for the orientation of the warp and weft fibres with respect to the binder, and this standard is shown in Figure 5.

The total amount of binder force applied will be varied between a very low binder force (close to 0) and a large amount of force (1000 N). If it is not possible to run a model with zero binder force, then it is acceptable to apply a small force greater than zero. The binder force should be distributed evenly across the binder.

The materials being simulated will be characterized by two different sets of tensile and shear stress curves which will be provided in an Excel data file. Other parameters classifying the material are also provided in this file.



a b

***Figure 5:** Blank orientations for the Plain-Weave and Unbalanced Twill-Weave fabrics*
(a) 0/90° fibre orientation (b) ±45° fibre orientation

The coefficient of friction and the size of the material blank were found to have little effect on the simulation results in Round 2 and will be set to specific values for all groups in Round 3. The coefficient of friction will be set at 0.3. The material blank size will be set at approximately 300 mm x 450 mm for the 0/90° and ±45° orientations.

The binder configurations, i.e. single-piece or segmented, varied between some groups in Round 2, and these can be left as they were in the previous rounds of simulations. The parameters for each simulation are presented in Table 3, and the standard parameter values are given in Table 4. Table 5 is a list of possible participating organizations for the Round 3 simulations.

Results from Round 3 of the benchmark will be summarized in a paper which will be circulated for comment and discussion before submission for a journal publication.

Table 3. Simulation parameter array

Simulation	Material	Blank Orientation	Binder Force (N)
1	PW	0/90°	0
2	PW	0/90°	1000
3	PW	±45°	0
4	PW	±45°	1000
5	UT	0/90°	0
6	UT	0/90°	1000
7	UT	±45°	0
8	UT	±45°	1000

PW Plain weave
UT Unbalanced Twill weave

Table 4. Constant simulation parameters

Coefficient of Friction	Blank Size: 0/90° Orientation (mm x mm)	Blank Size: ±0/45° Orientation (mm x mm)
0.3	380 x 540	380 x 540

Table 5: Potential Participants

Institution
Northwestern University, USA
University of Massachusetts- Lowell, USA
INSA-Lyon, FRANCE
University of Twente, NETHERLANDS
KU-Leuven, BELGIUM
University of Nottingham, UK
Hong Kong University of Science and Technology, HONG KONG
University of Glasgow, UK

5 CONCLUSIONS

The Round 2 simulation data as reported by four groups has been analyzed. While there was a range of forming parameters used, the draw-in values were relatively uniform among the four groups that participated in Round 2. The Round 2 results have been used to develop a uniform set of parameters for a Round 3 comparison of simulation results.

6 ACKNOWLEDGEMENT

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