Predictive FE Modelling of Prepreg Forming to Determine Optimum Processing Conditions

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Abstract. In this study, FE simulations of the forming of viscous textile composite over a hemisphere and a helmet were conducted using a rate/temperature-dependent hybrid FE model in a commercial Finite Element code, Abaqus Explicit™. Optimum forming parameters such as the normal force distribution across the edges of a blank, blank size, forming temperature and forming rate, are predicted. Predictions are evaluated by a series of case studies of press-formed components. The results from the simulation and the experiments have good correlation and show that the forming performance of the viscous textile composite can be enhanced by optimizing the force distribution around the edge of the manufacturing tool and by careful choice of forming temperature and forming rate. The proposed model allows users to simulate all aspects of press-forming including mould geometry, processing parameters and evaluate forming performance including fibre orientation and forming defects.

Keywords: FE prediction, Prepreg forming, optimization.

INTRODUCTION

Virtual simulation is an important tool in improving efficiency in automated manufacturing processes. As such, deep drawing and press forming of viscous textile composites are prime candidates for virtual process development. This paper presents a full FE simulation to assess the effects of process variables such as material temperature and rate of forming, blank holder force distributions around the blank and blank size. The study can facilitate optimization of processing parameters; provide materials characterization data; and evaluate final products with a realistic representation of material and forming processing parameters.

EXPERIMENTAL METHOD AND MATERIALS

The materials used in this research were plain weave and 4x4twill weave carbon/epoxy prepreg. The plain weave prepregs were used in helmet forming experiments where the blank holder force and forming rate were varied. Twill weave samples were used in hemisphere forming experiments at different temperatures and with different blank sizes.
Forming experiments for a hemisphere were carried out using a dedicated up stroking hydraulic press with integrally heated tools. Components were formed either at room temperature or at the required temperatures (blanks were heated using infra-red heater). The pilot helmet forming was performed using a stamp-forming process with two matched moulds and a pressure blank-holder. The moulds were operated using a universal testing machine, so that forming rate could be controlled accurately. Draw-in of the prepreg was controlled using a segmented blank-holder, consisting of 16 spring-loaded feet mounted around a rectangular frame. A variable peripheral pressure profile was obtained by tightening 16 springs pressing on the holder plate through pressure pads.

**FE SIMULATION AND RESULTS**

In this study, numerical simulations of the forming of viscous textile composite over the hemisphere and helmet were conducted using a rate/temperature-dependent hybrid FE model in a commercial Finite Element code, Abaqus Explicit™. The textile composite was modelled as a two-phase material structure, i.e., truss elements represent the high tensile stiffness fibres, which are allowed to shear, and membrane elements model the shear properties of the viscous textile composite. The material properties of the truss elements follow an isotropic elastic model while those of the membrane elements are given using a user-defined Non-Orthogonal Constitutive Model [1] with material properties derived from a Multi-Scale Energy Model [2]. The latter predicts shear resistance from the textile structure and matrix rheology. Boundary conditions and tool/blank dimensions used in the simulation were same as the experiments. A detailed description of the model can be found in [3].

**Optimization of Forming Rate**

To verify the rate dependent behaviour of viscous textile composite, experiments and simulations were performed for forming rates of 5mm/min and 500mm/min at room temperature. The results are that for the slow rate less wrinkling can be observed in the formed part (Fig.1a) and slow forming results in less compressive stress (Fig.2a). The total compressive stress is reduced from 9.6GPa to 8.9GPa when the forming rate drops from 500mm/min to 5mm/min.

![FIGURE 1. Formed parts at 5mm/min (a) and 500mm/min (b).](image-url)
Optimization of Holding Pressure Profile

Experiments and simulations were performed for the two boundary conditions, i.e., uniform pressure and the optimized pressure profile determined by Skordos et al. [4] at a displacement rate of 500mm/min and room temperature. Fig. 3 shows that the wrinkling of the optimized part has been significantly reduced compared to the uniform pressure produced part. The predicted principal stress distributions along the fibres with uniform peripheral pressure for the optimized condition (where a plus sign corresponds to tension and a minus sign to compression) are shown in Fig. 4. The total compressive stress in the modelled parts is 7.7 GPa for the optimized case and 9.6 GPa for the uniform pressure case. Concentrated compressive stress exists near the ears in the two cases. However, the use of the optimized pressure profile achieves partial elimination of compressive stresses near the head and under the chin.

FIGURE 2. Simulated stress fields in fibres for (a) 5mm/min (a) and (b) 500mm/min.

FIGURE 3. Formed helmet components for (a) optimised force profile and (b) uniform force profile.
FIGURE 4. Stress distribution for (a) optimised force profile and (b) uniform force profile.

Optimization of Blank Size

The effect of changing blank sizes illustrated in Fig. 5, which is similar to that observed with increasing holding pressure [4]. The smaller size blank has severe wrinkles/folds in between the corners (Fig. 5b). Fig. 6 demonstrates that predicted maximum shear increases marginally with increasing blank size and the normalized total compressive stresses are lower at larger blank size and increase as the blank size reduces. The normalized compressive stress was calculated by summing stresses over all nodes with negative stresses and normalizing by the number of nodes of the corresponding blank.

FIGURE 5. Formed parts for two blank sizes
Optimization of Forming Temperature

Fig. 7 shows the effect of forming temperature between room temperature and 80°C with total blank holder force of 75N and a blank size 240x240mm. As expected, the room temperature formed part (Fig. 7a) was found to be slightly more wrinkled than that formed at higher temperature (Fig. 7b). The simulated parts also show the same effect, i.e., an increase in shear deformation from room temperature to 60°C and a decrease in compressive stress from room temperature to 80°C. Fig. 8 shows that the total compressive stress decreases with increasing forming temperature as a result of the increase in shear compliance of the material. The increase in the maximum shear at room temperature to 60°C is 6°. The corresponding variation in the total compressive stress is significant, in the range of 3.13x10^7 Pa.

CONCLUSIONS

This paper has described both experimental and numerical studies of forming for two complex components. The results of the modelling show that the outcome of the forming process can be influenced significantly by the choice of process parameters such as forming speed, forming temperature, blank holder force and blank size. Selection of appropriate processing parameters can allow wrinkling to be reduced.
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