10th International Conference on Composite Science and Technology
ICCST/10
A.L. Araújo, J.R. Correia, C.M. Mota Soares, et al. (Editors)

Thermal and mechanical modeling of thermoplastic composites during forming process

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Key words: CFRTP composites, Forming Process, Simulation, Thermostamping.

Summary: *CFRTP (Continuous Fibre Reinforcements and Thermoplastic Resin) composites are widely used in the aerospace industry because of its excellent mechanical properties, impact resistance and fatigue strength over its low density. Thermoplastic composites have many advantages over thermosets: a thermoforming cycle shorter than autoclave composite manufacturing, a higher impact resistance and the possibility to recycle the material. All these makes thermoplastic composites an appropriate material for mass production of high quality structures. In recent years, the automotive industry is increasingly interested in thermoplastic composites materials and in particular in two forming techniques: thermoforming and stamping of CFRTP. Both techniques can be easily automated and are based on the same technology that shaping metal sheets. The forming cycle consists of 4 phases in the case of thermoforming and 5 in the case of stamping: heating, transport (Stamping case), forming, consolidation and finally demolding and cooling phase.*

Modeling and numerical simulation of these processes is an important step in order to predict the final structure geometry and its mechanical properties which are mainly due to the position of the fiber reinforcements in final configuration. Forming simulation allows to determine the feasibility conditions of the structure and optimize the process. For this presentation we propose a new nonlinear visco-hyperelastic model for the simulation of thermoforming and stamping of CFRTP. The thermal dependence of the mechanical behaviour of the CFRTP is taken into account for this modelling.

1 INTRODUCTION

CFRTP (Continuous Fibre Reinforcements and Thermoplastic Resin) composites are widely used in the aerospace industry because of its excellent mechanical properties, impact resistance and fatigue strength over its low density. Thermoplastic composites have many advantages over thermosets: a thermoforming cycle shorter than autoclave composite manufacturing, a higher impact resistance and the possibility to recycle the material. All these makes thermoplastic composites an appropriate material for mass production of high quality structures. In recent years, the automotive industry is increasingly interested in thermoplastic composites materials and in particular in two forming techniques: thermoforming and stamping of CFRTP. Both techniques can be easily automated and are based on the same technology that shaping metal sheets. The forming cycle consists of 4 phases in the case of thermoforming and 5 in the case of stamping: heating, transport (Stamping case), forming, consolidation and finally demolding and cooling phase.

Modeling and numerical simulation of these processes is an important step in order to predict the final structure geometry and its mechanical properties which are mainly due to the position of the fiber reinforcements in final configuration. Forming simulation allows to determine the feasibility conditions of the structure and optimize the process.
In this paper we propose a new nonlinear visco-hyperelastic model for the simulation of thermoforming and stamping of CFRTR. This model is based on a non-linear viscoelastic model developed by Simo J.C. [1]. We consider a hyper elastic behavior associated to the dry reinforcement and it assumes that the viscoelastic behavior is mainly associated with the in-plane shear deformation.

2 IN-PLANE SHEAR BEHAVIOR OF CFRTP.

In-plane shear characterization is performed using Bias Test over different high temperature. Recent works have been conducted in LaMCoS-INSA Lyon to analyze [2] the in plane shear properties of mono-ply woven thermoplastics prepregs. In this work, the experimental set-up used in [2] has been improved and adapted to analyze the viscoelastic shear behavior of multi-ply CFRTP prepegs.

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3 CONSTITUTIVE NONLINEAR VISCOELASTIC MODEL FOR FORMING SIMULATION

At first, we consider a hyper elastic formulation to describe the mechanical behavior of woven reinforcement. The strain-energy density function is built under two principal assumptions: tension in warp and weft directions are uncoupled; tension and in-plane shear deformations are independent. In this way, the strain-energy function can be decoupled and formulated in term of three physical invariants [3].

Secondly, a non-linear viscoelastic model has been developed inspired by [2]. This model is based on the generalization of the Maxwell model and applied the concept of internal variables Q_i. After assume that viscoelastic behavior is mainly observed in-plane shear (sp) deformation, we consider that the stress response is given by the following expression:

$$\underline{\underline{S}}_{sp}(t,\theta) = \underline{\underline{S}}^{0}_{sp}(t) - \sum_{i=1}^{N} Q_i(t,\theta) \tag{1}$$

Where $\underline{\underline{S}}_{sp}$ is the in-plane shear contribution to the Second Piola-Kirchoff and Q_i are a set of internal variables of the system in function of time and temperature.

The evolution of internal variables involves the definition of material parameters $\gamma_i \in [0,1]$ associated with relaxation times τ_i which we assume as temperature dependent and the in-plane shear strain-energy W_{sp} function of the physical in-plane shear invariant I_{sp} .

The Second Piola-Kirchhoff tensor is obtained after integrating by parts the convolution form of equation (12) and adding the contribution of hyper elastic response due to the stretch in warp and weft directions.

The identification of viscoelastic and hyper elastic parameters is performed using the Levenberg–Marquardt algorithm [6] for fitting experimental results using the improved Bias test at different temperatures.

4 NUMERICAL EXAMPLES

The proposed model is implemented in PlasFib an explicit finite element code [4, 7, 8] using a three node shell element, the bending stiffness is taken into account within an approach without rotational degree [4, 9].

The finite element simulation of the forming of a glass/PA66 composite by a cylindrical punch is performed in order analyze the influence of the temperature and the speed of the punch displacement..

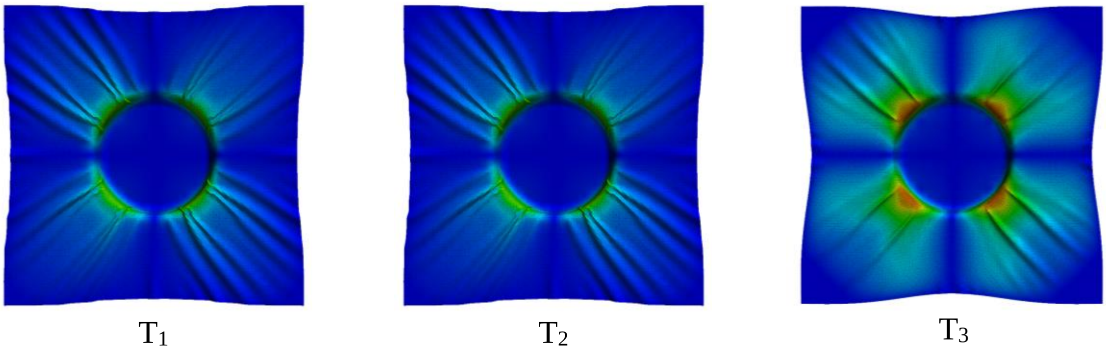

Figure 1: Simulation of a cylindrical forming at different temperatures (T1<T2<T3).

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