OPTIMISATION OF HOT-FORMING PROCESS THROUGH IN-PLANE CONSTRAINTS: NUMERICAL AND EXPERIMENTAL STUDIES

P. Bussetta[1], R. Gomes[1], S. Chen[2], O.P.L. McGregor[2], L.T. Harper[2], P. Harrison[3] and C. Correia[1]

[1]INEGI - Composite Materials and Structures
Institute of Science and Innovation in Mechanical and Industrial Engineering, Porto 4200-465, Portugal
Email: pbussetta@inegi.up.pt; rgomes@inegi.up.pt; ncorreia@inegi.up.pt
[2]Polymer Composites Group, Division of Materials, Mechanics and Structures,
Faculty of Engineering, University of Nottingham, Nottingham NG7 2RD, UK
Email: Shuai.Chen@nottingham.ac.uk; Lee.Harper@nottingham.ac.uk; Oliver.McGregor@nottingham.ac.uk
[3]School of Engineering, University of Glasgow
James Watt Building (South), University of Glasgow, Glasgow G12 8QQ, UK
Email: Philip.harrison@glasgow.ac.uk

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Abstract

The hot-forming process for thermoplastic composites is a very promising fabrication route for high volume applications. Reliable and fast numerical tools are needed to optimise the forming process and to support industrial exploitation. This paper presents the experimental validation of a finite element-based optimisation routine, which is used to minimise the local fibre shear angle by adjusting the in-plane constraints used to control material draw-in. A non-orthogonal constitutive model is used to simulate the behaviour of the thermoplastic composite material using a finite element approach, which is coupled with a genetic algorithm to optimise forming parameters, such as clamp location, clamp length and clamping force. A double-dome benchmark geometry is used to validate the finite element approach, using grid-strain analysis to compare local shear angles and the perimeter shape of the blank.

1. Introduction

Because of their high specific stiffness and low weight, the continuous fibre reinforced composite materials can be find in several applications (e.g. into the space and aeronautical industries). Nevertheless, the introduction into automotive industry is limited because of the high cost of fabrication and the low-volume manufacturing process. This limitation can be overcome thanks to the hot-forming process of composites with thermo-plastic resin. This resin is visco-elastic at the ambient temperature and visco-plastic at higher temperature. This forming process of continuous fibre reinforced composite panels is a low-cycle time, high-volume manufacturing process – taking typically less than two minutes to produce the final structure.

Usually, multilayer consolidated thermo-plastic composites are formed. First, the composite sheet is heated above the melting temperature of the resin. Secondly, the heated sheet is transferred to the forming tools. Then, the composite sheet is hot formed (stamped). The force applied to the composite stays constant during the cooling period. Finally, the formed structure is removed from the tool.

A good understanding of each step is key to control the properties of the produced material. A predictive numerical model is useful to reduce the trial and error strategy during the definition of the forming process. A review of the numerical models of this process is presented in [1]. The aim of this review is to guide the choice of the more relevant model regarding the desired aim. This review presents a classification of the numerical models versus the type of model and the understanding of the phenomena and the forming process modelled. In addition, the advantages and disadvantages of each kind of model are discussed to bring the future challenges and developments.

The aim of this work is to valid the numerical optimisation of the hot-forming process versus the in-plane constraints regarding the minimization of the shear angle developed in [2,3]. The experimental set-up developed in [4] is used to valide the optimisation of this numerical process.

2. Experimental set-up for high temperature press-forming of double-dome

The double-dome benchmark geometry has been manufactured at INEGI as a set of matched male and female steel tools (see Fig. 1). The experimental set-up used here is close to that of the benchmark set-up, though certain features have been changed to facilitate forming at high temperature. In particular, the blankholder boundary conditions and the initial blank shape have been modified (see [4]).

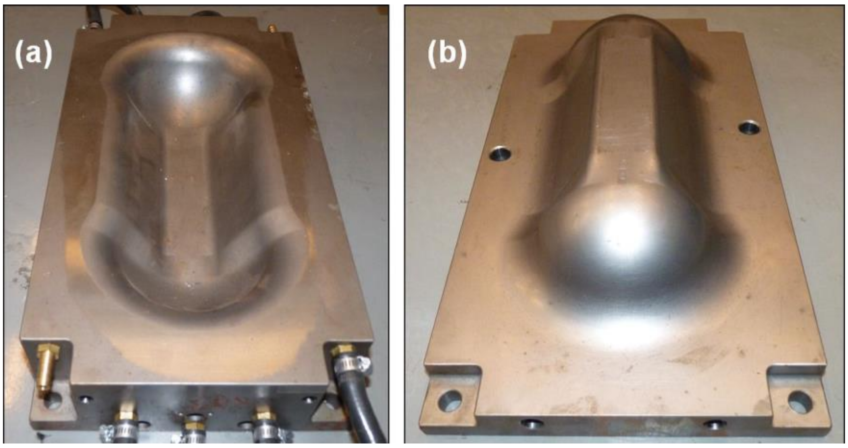

Figure 1. Double dome tooling [4]: (a) female die, (b) male punch.

The first step of the hot-forming process is the heating of the pre-consolidated sheet above melt-temperature of the resin. Then, the material have to be quickly transferred to the press for forming. An open-sided radiant heater oven (see Fig. 2, [4]) has been used to heat the pre-consolidated composite – 260ºC. The heater contained eight 1 kW radiant heating lamps (Elstein, FSR 1000–230 V), situated inside the top and bottom of the oven (Fig. 2a). Thus, a compressed-air driven shuttle system have been used to transfer the material from oven to press. The clamping system – clips and springs – as well as an example of the formed structure are presented in Fig. 3.

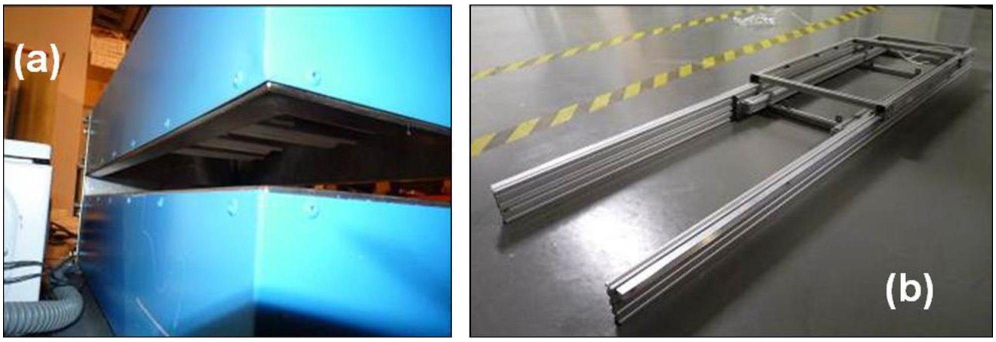

Figure 2. (a) Radiant heater used to heat blank. The upper heating lamps are visible, similar lamps are also positioned in the bottom of the oven [4]. (b) Shuttle system frame and blank-holder frame [4].

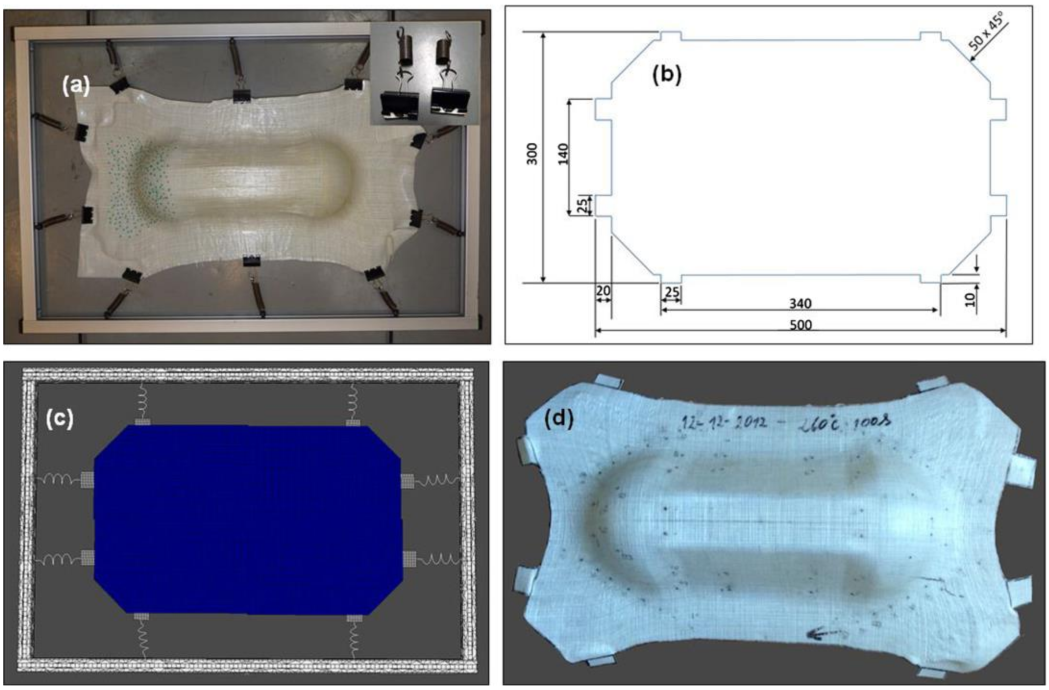

Figure 3. (a) Formed part after preliminary tests using springs and clips to apply tension, inset show the two different spring lengths used to induce tension in blank during forming [4], (b) dimensions of optimised blank shape in mm [4], (c) initial blank shape and spring locations used simulations [4] (d) example of 0/90 part using optimised blank shape (Case 1 in Tab. 1 of [4]).

3. Clamping optimisation

The clamping system is optimised into two step: the clamping arrangement and the spring stiffness [3] (see Fig. 3). First, a genetic algorithm has been developed to optimise the boundary conditions regarding the individual behaviour of each node of the boundary versus the minimal value of the shear angle after foming. Each node can be individually attached to a spring. Thus, the optimal boundary configuration has been used to determine the value of the spring stiffness value in order to minimise the shear angle after forming.

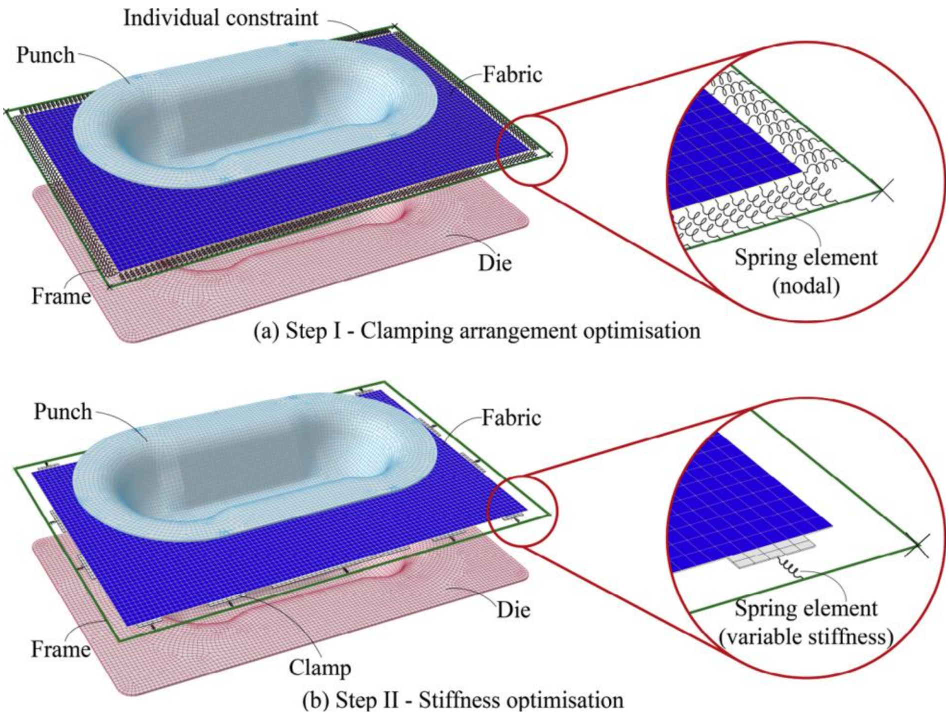

Figure 4. Finite element models for two-step in-plane constraint optimisation [3].

4. Final remarks

The numerical results show that the clamping conditions have an important influence over the values of the shear angle after forming. The shear angle restriction can be used to prevent defects of the formed structure (e.g. wrinkling). Moreover, the orientation of the fibres at the end of the process is the main characteristic of the mechanical properties of the final structure. Therefore, the control of the orientation of the fibres thanks to the clamping conditions is an important result regarding the wrinkling as well as the mechanical properties of the final structure. This work is still ongoing, the numerical results will be validated with experimental tests using the optimised boundary conditions considering the shear angle after forming.

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