Defining mechanical boundary conditions representatives of the frictional tool-part interaction when modelling the cure-induced deformations of thermoset-based composite parts

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Abstract

The polymerisation reaction of curing of the resin brings the material from the liquid to the glassy state. During this change of state, the part experiences deformations due to thermal expansion and chemical shrinkage of the resin. These deformations are constrained from developing freely due to the frictional tool-part interaction and internal stresses build up. Upon demoulding, those internal stresses are released and the part deforms. Previous studies have shown the important influence the frictional tool-part interaction during curing has on the final part deformation (1). Modelling the frictional interaction between the part and the mould increases dramatically the cost of the curing simulations. With the increase of the composite part and mould complexity, the curing simulation time explodes. However, the industry need is to shorten the restitution time in order, for instance, to include the computations in a mould compensation strategy which requires several iterations. This brings the interest of being able to predict the cure-induced distortions of complex composite parts while limiting the increase of computation complexity.
The present study aims at defining mechanical boundary conditions representatives of the frictional tool-part interaction in order to avoid the costly frictional contact interaction in numerical computation.

The numerical methodology consists in performing a first thermo-mechanical finite elements (FE) simulation on the mould using Abaqus. The temperature evolution applied is the Manufacturer Recommended Curing Cycle (MRCC) for the prepreg of interest. The node displacements evolution at the mould cavity surface is extracted, mapped on the composite part mesh and defined as mechanical boundary conditions on the node displacements of the composite part surface during the subsequent curing simulation. The curing simulation consists in performing coupled chemical-thermal-mechanical FE calculations using Abaqus and a user subroutine UMAT. The details of the model implemented in the UMAT follow the approach suggested by Svanberg and Holmberg (2) which considers a simplified linear viscoelastic behaviour of the material where time-temperature-degree of cure superposition is applied.

The geometry of interest for the present study is L-shaped part with a gusset in order to have a spring-in angle evolution along the part length (Fig. 1). The spring-in angle is the difference in angle between the nominal geometry (before curing) and the cured part.

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L-parts are 550mm long with 150mm long flangesand made of a symmetric stacking sequence of 10 plies of woven carbon fibres AS4/8552 prepreg

Experimental data was generated manufacturing the parts using SQRTM process in an aluminium closed-mould and measuring the angle evolution along the part length. The angle was measured using a Nikon MMx100 laser scanner mounted on a 7-axis Metrology-grade MCA II arm. The declared accuracy is 54μm which lead to an uncertainty of 0.1$\circ$ on the spring-in angle post-processed from the angle measurement.

The experimental measurements were compared to the spring-in angle predictions of different numerical models:

- the mould was modeled as a deformable body with aluminum properties and the frictional tool-part interaction was defined. The curing simulation of the part inside the mould was performed and the results, in term of spring-in angle, serve as a reference case to evaluate the accuracy of the "mapping" method;

- the mould displacement evolution extracted from the thermo-mechanical simulation was mapped on the composite part surface for the curing simulation until the part reached the glassy state from which a sliding contact was therefore considered.

Results have shown that the methodology set up allows to approximate the frictional tool-part interaction by mechanical boundary conditions on the node displacements. Further developments will focus on improving the method to better reflect the experimental behaviour during processing, especially the transition between sticking and sliding contact which strongly influence the mould deformation transferred to the part. Imposing a maximum shear stress the interface can carry before entering in sliding contact is a mean to account for the transition. The method will also be validated on larger parts where the computation time reduction is of great interest

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REFERENCES

(1) G. Fernlund, G. Twigg and A. Poursartip, Tool-part interaction in composite processing Part 1: experimental investigation and analytical model, Composites Part A: Applied Science and Manufacturing, 35, 2004, pp. 121-133.
(2) J.M. Svanberg and J.A. Holmberg, Predictions of shape distortions Part I. FE-implementation of a path dependent constitutive model, Composites Part A: Applied Science and Manufacturing, 35, 2004, pp. 711-772.