INDUSTRIALIZATION OF LIQUID RESIN INFUSION PROCESSES (LRI) CONSIDERING TO THE STRESS TRANSFERRED INFLUENCES

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ABSTRACT:
Liquid Resin Infusion (RI) processes present specific characteristic compare to standard processes such as prepreg-autoclave processes. Regarding to the deformation induced by the process, specific to LRI processes deformation mechanism have been identified. This paper presents the main parameters of this mechanism due to the infusion equipment-part interaction. A simple model for the shape prediction is proposed. It introduce the virtual infusion equipment depth parameter, which is used for calculated the constraints responsible for deformation of the free composite part. A method is proposed to determine the virtual depth as function of the manufacturing configuration.

KEYWORDS: stress transfers, induced deformations, LRI processes

INTRODUCTION

Due to part-process-resources interactions, different deformation mechanisms can occur depending to part-process-resources characteristics. The focus is given on deformation mechanisms in case of symmetric balanced thin laminate. The warpage deformations result of stresses transferred into the part during the cure cycle by the different resources.

Investigations have showed the specific comportment of part manufactured by LRI processes for these both mechanisms [1].

The specific to LRI processes deformation mechanism is due to infusion equipment-part interaction. This work proposes experimental investigation for a better understanding of this phenomenon.

The industrialization of composite part manufacturing by LRI processes need prediction model to evaluate the impact of process / resource parameter on the part geometry. The prediction allows determining if the deformation can be neglected, minimized or if the tool or part design having to be modified.

EXPERIMENTAL SETUP

Specimen manufacturing

Specimens are manufactured by conventional Liquid Resin Infusion (LRI) process implementation. Parts are manufactured with a powdered fabric. Performs are compacted in a preliminary step. The process implementation is conventional (Cf. Fig. 1). The tool is treated for each part with an anti-adherent demould agent, Frekote NC44.

The injection point and the event are disposing at each extremity.

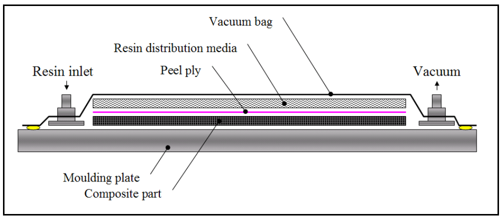

Fig. 1: Implementation of composite part manufactured by LRI process

The experiment resin is an epoxy resin with a low viscosity and a high reactivity. The used fibre material is a bi-directional 4H satin weave carbon fabric powdered with an epoxy resin.
An experimental tool was developed to manufacture flat composite part. The part geometry was designed with a high length/wide ration in order to isolate deformation in one dimension. For a highest flexibility; a self heating tool was developed. Heating ramp rate until 10°C/min are possible. The regulation temperature is given with thermocouples positioning on the tool surface. The top part is isolated by means of heat insulation cover.
The moulding plate is in aluminum with a conventional specified surface state.
PARAMETERS!

Specimen measurement
Due to the low rigidity of the part, a no contact measurement system is required. A scanner is used to measure the part shape. All parts are measured on the same ambient conditions (light, temperature…)
Parts are disposed on its side (Cf. Fig. 2) in order to prevent part deformation due to its own weight. The part surface in contact with the mould is scanned. The measured points are filtered and exported as coordinates.

Fig2: Shape measurement setup

The post treatment takes place in the software CATIA V5 module Digitalized Surface Edition (DSE). A middle plan called XZ plan is generated from the coordinate. The Z coordinate are projected on the XY plan. A second grad polynomial trend line is generated. The maximal warpage is given by the difference between the maximal and minimal Y-coordinates.

RESULTS

Deformation mechanisms
The resin distribution medium appears to be responsible for specific deformation [ESAFORM]. The infusion equipment have different thermal and cure properties as the composite part. During the cure cycle the expansion of the infusion equipment induced stresses at the infusion equipment-part interface from the resin gelation. These stresses are locked in the composite part after the resin cure and liberate after demoulding.
The influences of the infusion equipment can be highlighted using comparative experiments: one experiment with specimen manufactured by using conventional peel

ply and the second experiment by using perforated ETFE film as peel ply. The excellent demoulding properties of this film enable to considerate the suppression of the infusion equipment influences. The results are presented on the Fig. 3. By using a conventional peel ply the specimen warp on the infusion equipment side. Contrary to this result the specimen manufactured using the EFTE film present a warpage opposite to the infusion equipment side. The contribution to the deformation of infusion equipment-part interaction is significant. It major the deformation due to the tool-part interaction.

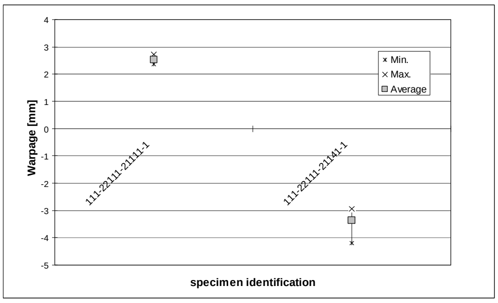

Fig. 3: Warpage with and without the infusion equipment influences

Infusion equipment-part interaction

The deformation due to infusion equipment-part interaction is non negligible regarding to the other deformation mechanisms. In order to identify her driver parameters, experiments are realized. Different type of infusion equipment, which have slight until large own properties differences are tested.

The first experiments allow a comparison between two different resin distribution mediums. The resin distribution media 1 is a 0,60mm thick polyester monofilament knitted infusion mesh. The resin distribution media 2 is a 0.9mm thick extruded nylon mesh. The results are illustrated on the Fig. 4. The warpage is strongly different depending to the resin distribution media. By using the media 1, the specimens warp on the resin distribution media side. Stress transfer due to the infusion equipment-part interaction is higher than the due to the tool-part-interaction. By using the media 2 the role are reversed: the specimens warp on the tool side. The tool part interaction effects major the due to infusion equipment-part interaction.

The manufacturing conditions such as the product-process-resources parameters are the same in both experiment except the resin distribution media, we conclude that the resin distribution media type have a strong influence on the deformation due to the infusion equipment-part interaction.

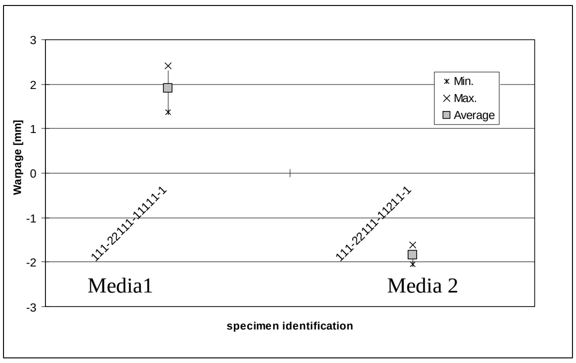

Fig. 4: Resin distribution media type influences

By analyzing the design of the two different medium and the resin-media manufactured composite fundamental difference are observed. By using the media 1 this manufactured composite have continues properties. The mono filament knitted architecture of this media behaves as a long fiber composite material. By using the media 2 the manufactured resin-media composite presents macroscopic heterogeneity. The media mesh is visible on his surface and there isn't resin continuity. In this case resin expansion and shrinkage have local impact. The stress transfer into the part is strongly reduced.

Infusion equipments contain a resin distribution media and a peel ply. The resin distribution types have a strong influence on the resulting specimen deformation. The peel ply is positioned between the part and the resin distribution media. In order to identify his contribution on the infusion equipment-part interaction, experiments are realized using different type of peel ply.
Peel ply choice is a compromise own to each part between peeling capacities, resulting roughness and global cost. We chose three peel plies different by the material or by the texture finesse. The peel ply A is 150µm, 92g/m² nylon weave, the peel ply B is a 114µm and 62g/m² nylon weave with a extra fine texture and the peel ply C is a 101µm and 64g/m² polyester weave with a fine structure. Specimens are manufactured using the same resin distribution media (media A). The results are illustrated on the figure 5. We observed a strong dependence of the peel ply type on the resulting deformation. The texture finenesses and the material appear to be influent factor to determine the transferred stress.

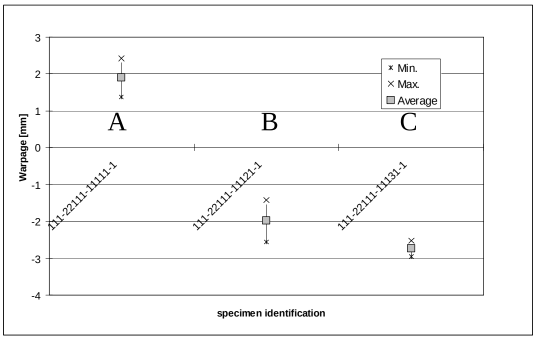

Fig. 5: Peel ply type influences

PREDICTION MODEL

Simple prediction method considering the infusion equipment-part interaction parameters

The stress transfer rate from the infusion equipment into the composite part could be determined experimentally on each manufacturing configurations. This solution will be too heavy to realize and to implant in a model. Experimental study has shown a strong dependence on process (ramp rate…) and resources (peel ply type…) parameters. We introduce the infusion equipment virtual depth parameter, which is own on each manufacturing configuration.

Using the classical laminate theory applied on the laminate infusion equipment/composite part is it possible to predict the part shape as function as intrinsic parameters such as the part length and depth [1]. The virtual infusion equipment depth ξ_{virtual} is used in order to calculate the virtual constraint applied on the free composite part corresponding to the experimental result.

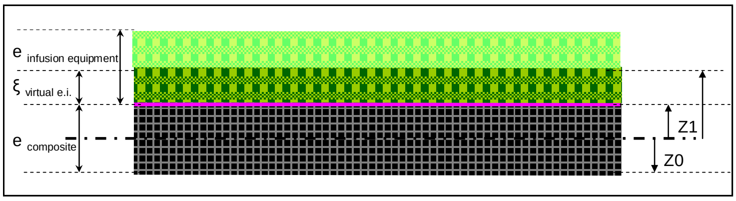

Fig. 6: Schematic view of the laminate

We propose a method to determine the virtual infusion equipment depth. The virtual depth is defined as the real depth factorize by coefficients depending to the resources parameters such as the resin distribution media type or the peel ply type (Cf. (1)). Each coefficient is determined experimentally.

$$\xi_{\text{virtual}} = e_{\textit{Infusion equipement}} \cdot C_{\text{resin distribution media}} \cdot C_{\text{peel ply}} \quad (1)$$

The prediction of deformation due to the tool-part interaction is performed using the method developed by [2-3]. The stress transfer is fit on experiment using an elastic shear layer.

This method allows the prediction of the warpage deformation as function of intrinsic parameters for different resources parameters. The robustness of the model is evaluated for varying intrinsic parameter with acceptable accuracy.

CONCLUSIONS

The deformation mechanism specific to LRI processes is dependant on process and resource parameters. Experimental investigations show the strong dependence of this mechanism on process and resource parameters.

A model is proposed for prediction of the part shape. A method has been developed for considering the manufacturing configuration as input parameters. The method evaluation show result with an acceptable accuracy. Process parameters such as the ramp rate and the temperature holds have to be integrate in the model in order to considerate the shrinkage rate

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