DEVELOPMENT AND VERIFICATION OF A MODEL OF THE RESIN INFUSION PROCESS DURING MANUFACTURE OF FIBER METAL LAMINATES BY VARTM

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ABSTRACT: Fiber metal laminates (FMLs) are hybrid materials consisting of interleaved layers of metallic sheets and fiber-reinforced polymeric-resin composites. NASA Langley Research Center has developed a process which can be used to manufacture FMLs by vacuum assisted resin transfer molding (VARTM). A flow visualization fixture of the NASA FML, VARTM process was constructed and used to observe the resin infiltration process. The results of the flow visualization experiments are reported and compared with the predictions of a VARTM process simulation model.

KEYWORDS: Fiber Metal Laminates, VARTM, Simulation Model, Flow Visualization

INTRODUCTION

Fiber metal laminates (FML), such as ARALL™ and GLARE™, are fabricated by stacking alternate layers of metallic sheets and fiber-reinforced polymeric-resin prepreg plies [1]. The hybrid lay up is fabricated under elevated temperature and pressure to consolidate the layers and cure the polymer resin which bonds the fiber/resin prepreg to the metallic sheets. FMLs have superior mechanical and environmental properties compared with traditional metallic alloys or composite laminates.

FMLs are commonly manufactured from prepreg materials in a compression press or an autoclave. These manufacturing methods result in high quality structures, however, the cost is high and the part size is limited by the size of the press or autoclave. To overcome these limitations, a program is underway to investigate the manufacture of FMLs by the low-cost VARTM process.

NASA LaRC has developed a process for the manufacture of FMLs by VARTM [2,3]. A hybrid preform is created by stacking alternating layers of the metal sheets and dry woven fabrics. The preform is placed on the tool and bagged as shown in Figure 1. Resin is infused into the dry woven fabric and will bond the metal sheets to the reinforcing fiber layers when cured. A distribution medium is commonly incorporated on top the lay up to enhance the resin infiltration process. This variation of the

VARTM process is known as the SCRIMP® process [4,5]. With the addition of the highly permeable distribution medium, resin rapidly flows over the surface of the part and is pulled into the hybrid preform by the vacuum source. Since resin flow is primarily in the through-the-thickness or transverse direction, resin pathways must be inserted into the metal sheets to allow resin to infiltrate into the dry woven fabric layers as depicted in Figure 1. The size and shape of the pathways must be large enough to permit resin to flow into and wet-out the woven fabrics, but small enough as to not comprise the structural performance of the FML.

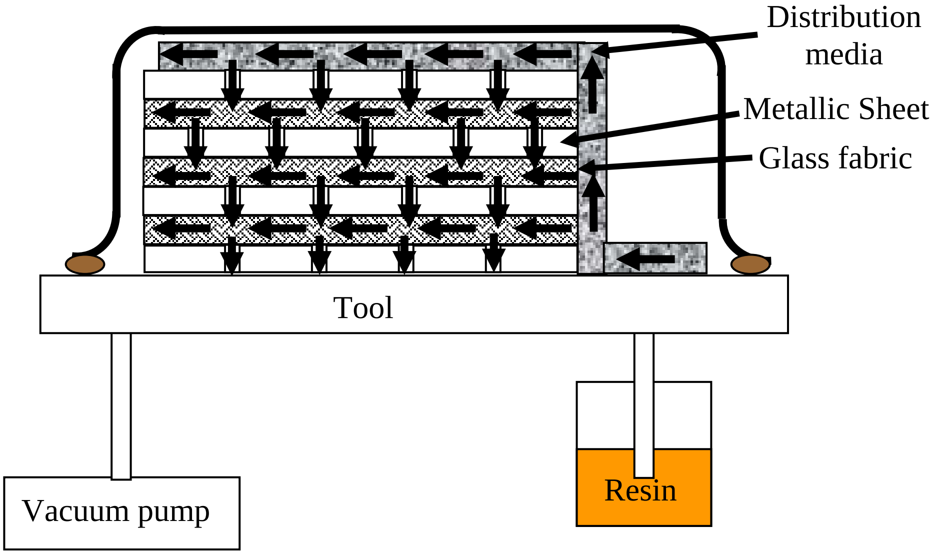

Fig. 1 Diagram of the FML VARTM process

A simulation model of the FML, VARTM process was developed using the commercial software package FLUENT. The model can be used to predict the resin flow behavior and determine if hybrid preform can be completely infiltrated with resin. In order to observe the resin infiltration patterns and verify the model predictions, a flow visualization fixture was constructed. The measured flow patterns will be compared with the predicted values and used to assess if FMLs can be successfully manufactured by the VARTM process.

EXPERIMENTAL

Flow Visualization Fixture

The visualization fixture, shown in Figure 2, is identical to the VARTM fixture currently used to manufacture FMLs except for the changes noted below which were necessary to observe the fluid during infiltration. A clear, scratch resistant, polycarbonate tool plate was used in place of the metal tool plate. The resin inlet tube is shown on the right and the vacuum outlet tube is shown on the left.

Acetate, clear plastic films, 0.381 mm thick, were used in place of the aluminum sheets. Resin pathways were machined into the acetate films to permit resin flow through the films during processing. The remaining components and all dimensions of the visualization fixture are identical to the VARTM fixture. Mounted below the polycarbonate tool was a mirror which was used to observe the resin flow along the bottom surface of the preform. Use of the mirror allows the video camera to simultaneously record the flow fronts on both the top and bottom surfaces of the preform.

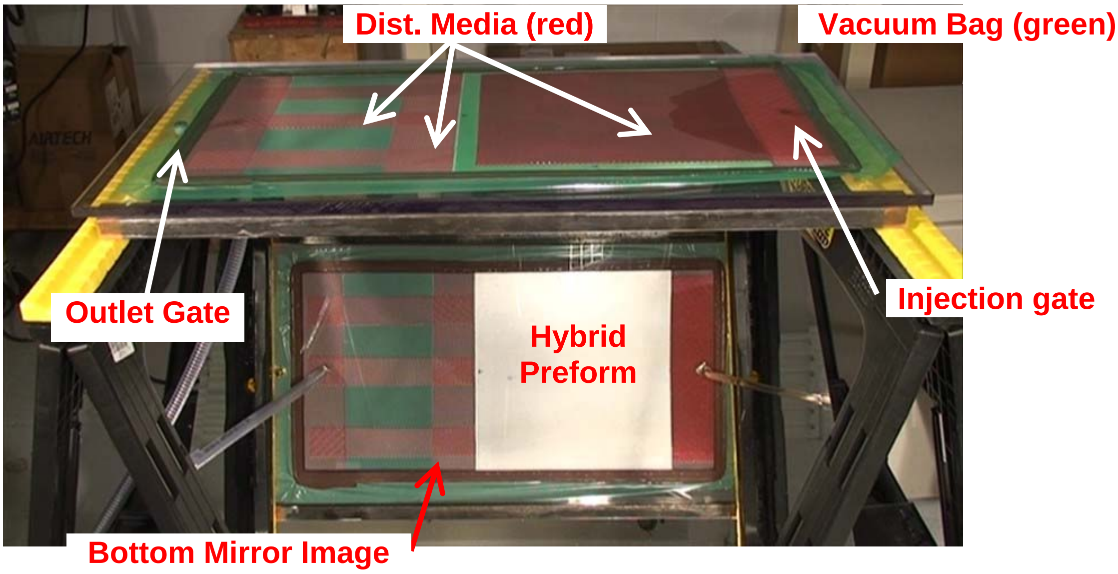

Fig. 2 Flow visualization fixture

Hybrid Preform

The preform consists of 5 sheets of the 0.381 mm thick acetate and 4 layers of S-glass fabric. The dimensions of the acetate sheets and S-glass fabric were 0.356 m by 0.356 m. The reinforcement was 8.9 oz, S-2-glass fiber, 8-Harness Satin Weave, Style 6781 biaxial fabric. The distribution medium placed on top of the preform consisted of 3 layers of polyethylene fabric. Circular resin pathways were machined into the acetate films using a precision drill fixture. The circular pathways were 0.83 mm diameter, drilled on 2.54 cm centers.

Test Procedure

The hybrid preform was vacuum bagged and held under a vacuum of 724 mm Hg for at least 30 minutes prior to infiltration. The infiltrating fluid was SAE 40 W motor oil with a viscosity of 0.24 Pa·s. The oil was degassed in a vacuum chamber for 30 minutes before the test. The fluid flow patterns on the top and bottom surfaces of the preform were recorded during infiltration using a digital movie camera.

SIMULATUION MODEL

A simulation model of the FML, VARTM process was developed using the computational fluid dynamics code FLUENT. A volume of fluid (VOF) multiphase model was adopted to model the filling process. The resin flow through the distribution media and glass fabric was modeled as a two-phase fluid flow through porous media. The permeabilities of the glass fabric and distribution medium were measured following the procedures in Grimsley et. al. [6]. Flow in the acetate films is limited to the transverse direction through the resin pathways that have been drilled into the sheets. The pathways are equally spaced holes that cover the entire length and width of the sheet. Each row of holes along the length of the film is modeled as a porous strip of width equal to the diameter of the pathways. Fourteen parallel porous strips are used to represent the flow pathways in each acetate film. The equivalent permeability of the porous strip is determined by equating the flow rate passing through the porous media to the flow rate passing through the holes [7].

RESULTS

The results of the infiltration experiments are shown in Figs. 3 and 4. The hybrid preform with 0.83 mm diameter flow pathways was successfully infiltrated using the VARTM process. The glass fabrics appeared to be completely wet-out with fluid and no significant dry spots were observed. The flow patterns in the distribution medium are shown in Fig. 3. Total wet-out of the distribution media was measured to be about 25 seconds (top). Beneath the photographs of the flow patterns are the results of the FLUENT VARTM simulation at the corresponding flow front positions. The scale bar beneath the simulation results represents the volume fraction of fluid in distribution

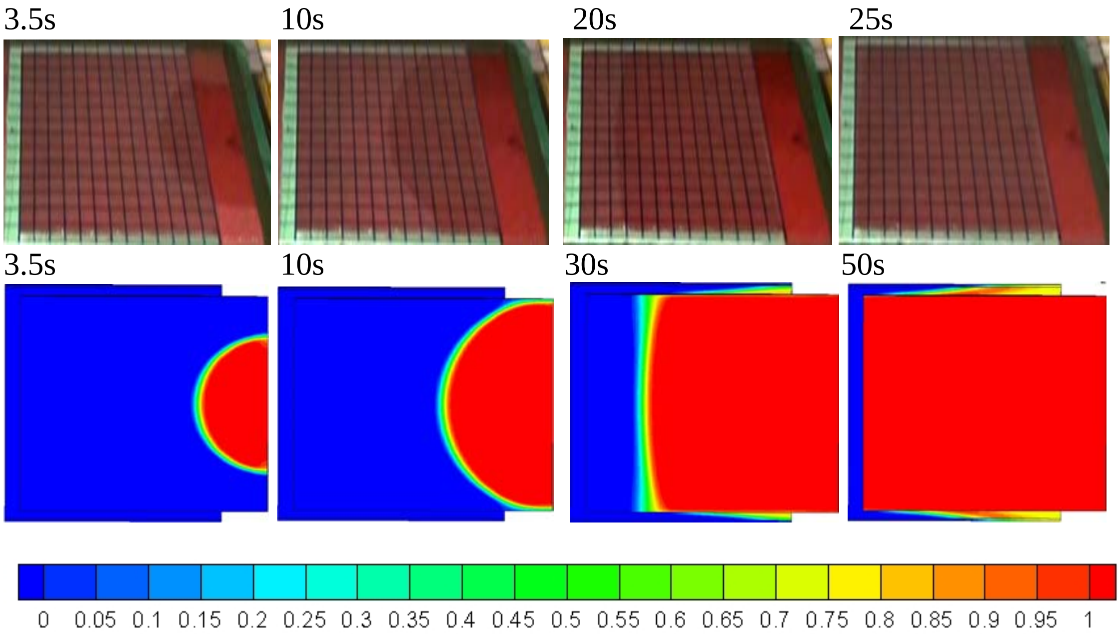

Fig 3. Flow patterns in the distribution media

media. The color red represents a volume fraction of fluid of 1, or fully saturated. The color blue represents a volume fraction of fluid of 0, or completely dry. Overall, the model was able to capture the shape of the flow patterns. At the beginning of infiltration, the predicted times agreed well with the measured values. However, later in the infiltration process the predicted times are longer than measured.

The flow patterns, at the bottom surface of the glass fabric next to the tool plate, are shown in Fig. 4. As expected, the circular flow pathways in the acetate films significantly affect the shapes of the flow patterns and the amount of time required to completely wet-out the hybrid preform. It appears the infiltration is dominated by the transverse flow through the acetate films.

Beneath the photographs of the flow patterns are the VARTM simulation results at similar times. The VARTM simulation, which represents the circular flow pathways in the acetate films as porous strips, captures the basic shape of the flow patterns and the progression of the flow front reasonably well. Obviously, there are differences since the flow pathways in the acetate films are not individually included in the model.

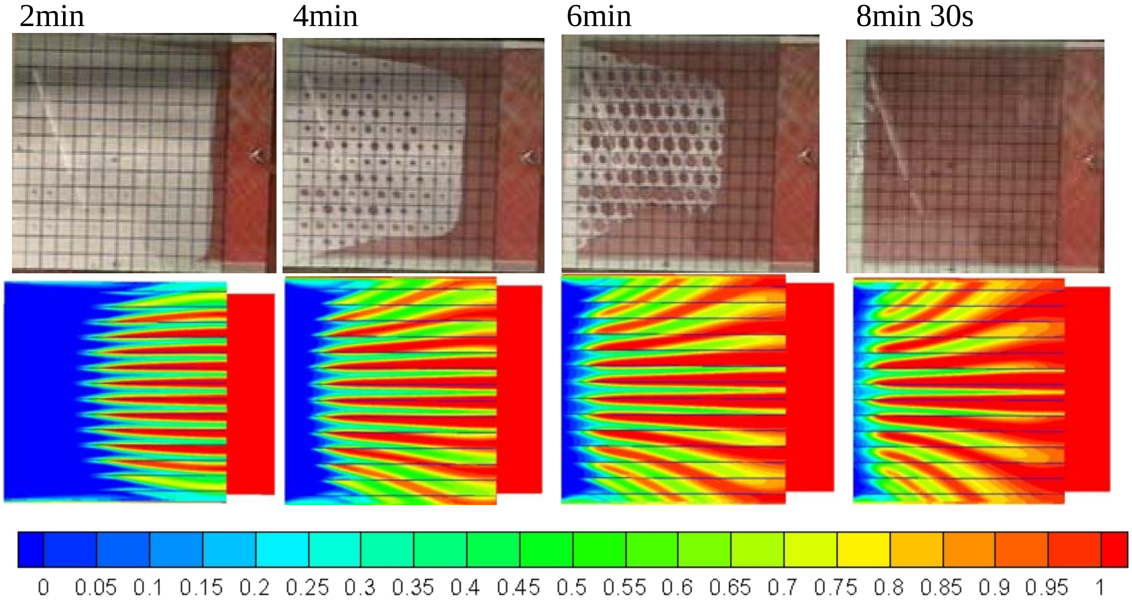

Fig.4. Flow patterns on the bottom surface of the hybrid preform.

SUMMARY AND CONCLUSIONS

A simulation model of the FML, VARTM process was developed using the commercial software package FLUENT. The time-dependent VOF formulation in FLUENT was used in tracking the interfaces between phases (flow fronts). The acetate films, with the flow pathways machined into them, were modeled porous strips.

A flow visualization fixture of the FML, VARTM process was constructed and used to observe the resin infiltration process. Results of the flow visualization experiments showed the complexity of the infiltration process due to the discrete flow pathways that are machined into the acetate films. The model was able to capture the basic shapes of the flow patterns. However, there are differences in the absolute times which are expected due to the simplified approach used to model flow through the acetate films.

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