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AN EXPERIMENTAL APPROACH TO PORT-BASED INJECTION IN VACUUM INFUSION PROCESSING

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SUMMARY: Vacuum Induced Preform Relaxation (VIPR) method provides a new approach to enhance resin flow for automated control of flow behavior during single sided molding processes. In this study, an injection port-based approach is developed and integrated with a VIPR chamber for the efficient manufacturing of composite parts made with vacuum assisted liquid composite molding processes. This new resin delivery technique consists of injection ports in the tooling surface and a rigid chamber that forms a seal with the vacuum bag directly above the port location. By applying a differential pressure in the chamber, one can relax the compaction of the preform increasing permeability temporarily. If the injection port is opened during this time, the resin can flow effortlessly through the thickness and in the plane of the part. When this differential pressure is removed, the flow through this port drastically reduces providing an enhanced level of control. The new port-based resin delivery process is compared with other standard vacuum infusion techniques in a series of experiments. The results compare the fill times of the various manufacturing techniques with the goal of emphasizing the ability of the port-based VIPR process to control the flow behavior and decrease the overall fill time.

KEYWORDS: VIPR, VARTM, SCRIMP, flow control, automation

INTRODUCTION

Liquid Composite Molding (LCM) is a composite manufacturing process in which a fibrous preform material is placed into a closed mold and a thermosetting resin with a relatively low viscosity is infused into the mold, filling the empty spaces between the fibers which make up the fibrous material [1]. LCM encompasses two main filling processes called Resin Transfer Molding (RTM) and Vacuum Assisted Resin Transfer Molding (VARTM), as well as a number of variations of those processes, such a Compression Resin Transfer Molding (CRTM) and the most common variant of the VARTM process, the Seemann's Composite Resin Infusion

Molding Process (SCRIMP) [2]. The RTM process is characterized by the use of a heavily constructed two sided rigid molding surface, and it is not cost effective for low rate production because of the high investment cost that goes into creating the mold [3]. VARTM is seen as the best solution to create large highly loaded structures for low rate production because the capital cost of creating the mold is significant less consisting of only a single lightly constructed net shaped molding surface [4]. A comparison schematic of the RTM and VARTM process is presented in Fig. 1, showing this difference.

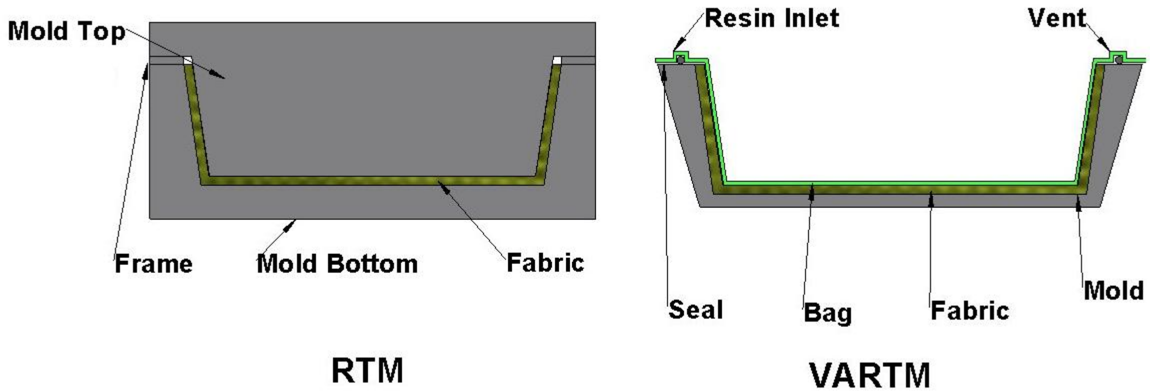

Fig. 1 A schematic comparison of the typical RTM and VARTM process molds. Left: An RTM mold consisting of a thick and heavy mold top and bottom. Right: A VARTM mold composed of only a single sided lighter mold.

In VARTM, fiber preform layers are placed on a single sided molding surface. A bag, which is a polymer film, encloses the preform and is attached to a double sided tape, adhered to the surface of the tool surrounding the preform to seal the assembly. Then a vacuum pump is attached to the vent to extract the air from the mold and compact the fibers. When the resin inlet is connected to a resin bucket, atmospheric pressure drives the resin into the mold since the mold is under vacuum. Once the mold is filled, the resin inlet is closed and the part is allowed to cure creating a viable composite structure.

The main issue with the VARTM process is that the mold filling times tend to be very high because of the limiting differential pressure of a single atmosphere which can be used to drive the resin through the mold. This limitation spurred the development of the now commonly used SCRIMP process which adds a resin distribution network to reduce the filling time significantly [5, 6]. The resin distribution network is often called Distribution Media (DM) and it is a highly permeability layer of material laid within the mold and allows a large amount of resin to quickly be driven into the mold along a large surface of the preform, from there the resin only needs to travel a short distance through the thickness of the part. In the SCRIMP process, the direction of the resin flow is dominated by the placement of the DM and since the DM can't be moved during the infusion, there is no way to manipulate the flow direction in the event of a unpredicted filling pattern due to variations in preform architecture or how the preform was laid into the mold. In this study we seek to improve the VARTM process in terms of filling time and better control with the introduction of the Vacuum Induced Preform Relaxation (VIPR) method coupled with the use of resin delivery ports in the mold.

VIPR PROCESS

The VIPR process introduces a vacuum chamber system into the VARTM process and is designed to accomplish three main goals. The first goal is to decrease the mold filling times relative to the VARTM process, secondly to increase flexibility in flow control relative to SCRIMP, and lastly to utilize tool side injection ports. The combination of the VIPR process and resin delivery ports was inspired by our recent work in the area of resin delivery called Flow Flooding Chamber (FFC) where an external rigid vacuum chamber is used to seal against the flexible bag surface of a vacuum infusion mold as shown in Fig. 2 [7].

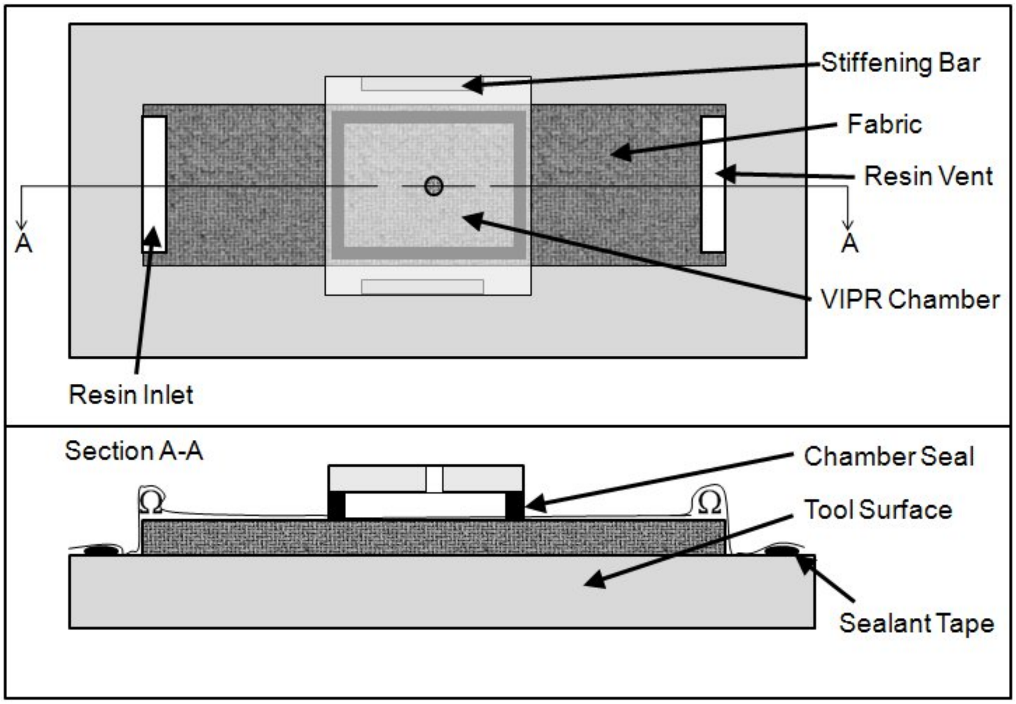

Fig. 2 Top: Schematic top view of the VIPR process set-up with stiffening bars. Bottom: Schematic cross-section view of the identical set-up.

The purpose of the FFC method of resin delivery is to stretch the bag within the sealing tape away from the fabric layers to create an extremely permeable gap by using a lower pressure in the chamber than in the mold. The VIPR process is similar in that it utilizes the same external rigid chamber, but the goal is to increase the preform permeability and affect the flow behavior *without* stretching the bag and creating a flow flooding gap. In the VIPR process, the chamber is placed over a selected region and the absolute pressure applied to the chamber is slightly lower than the pressure within the mold. During this process the bag never lifts away from the fabric layers but the pressure compacting the fibers is decreased while maintaining the maximum vacuum pressure driving the resin flow. This action causes the fabric layers to relax and have a higher permeability, and most importantly the effect is local and temporary until the pressure inside the chamber is discontinued. With this type of system, the filling pattern can be manipulated during the infusion to ensure a complete filling of the mold regardless of geometry and preform variations by applying the chamber to only the desired region of the mold, and further being able to turn that effect off when it is not needed.

Along with the ability to decide where the chamber is placed and for how long, the VIPR process also makes the use of tool side injection ports an effective means of resin delivery and control in vacuum infusion processes. Typically injection ports, which are simply holes drilled into the tooling surface, are not used in vacuum infusion processes because the resin has to overcome the fabric layers pressing against the hole due to the compaction pressure and hence the flow rate is too insignificant to influence the flow direction. This effect occurs even in the SCRIMP process because the transverse through thickness permeability of most fabrics is very low under full vacuum. The DM becomes ineffective because the resin entering the mold through a tool side port has to be forced through the thickness of the part before it can reach the DM, which is typically located on the top of the preform. In the VIPR method, when the chamber is placed above the injection port in the tooling the fabric region under the chamber relaxes allowing the resin to enter more easily and the in plane and through thickness permeability is substantially increased which enhances the flow significantly. This makes the use of injection ports an effective mode of flow control by controlling the vacuum in the chamber. The advantage of tool side injection ports as opposed to injection lines along the DM side is that they are permanently mounted to the mold surface and they are small. Tool side injection ports reduce the amount of work done while laying-up the preform and material used per part that is manufactured. Also the distribution of injection ports can be configured to create desired flow patterns for successful filling of a variety of preform geometries [8, 9].

EXPERIMENTAL COMPARISON OF FILL TIMES

These experiments focus on the ability of tool side resin delivery ports used in conjunction with the VIPR process to decrease the fill time in a vacuum infusion molding process. Since the SCRIMP process has been identified as the standard vacuum infusion technique, it will be used as the basis of comparison for the other techniques. Sequential injection was used during the experimentation to mimic the currently used commercial manufacturing practice for large scale structures. The goal of the experiments is to demonstrate the advantage of tool side ports and the VIPR process without the use of the distribution media as compared to VARTM and SCRIMP.

For the purpose of maintaining a consistent basis of comparison for all the experiments, the same base parameters were used for all the experiments. In each infusion, six layers of the same plain weave E-Glass were stacked onto a tooling surface. Each layer was cut to 0.6 meters long and 0.2 meters wide, where the thickness of each layer under full vacuum was 0.58 millimeters. Experiments dealing with the SCRIMP process would have the additional layer of distribution media stacked on top of the glass layers. The resin flow traveled in the length direction with sequential injection sites at 0, 0.24, and 0.48 meters. Initially the resin would only flow from the injection site located at the very edge of the fabric, the left hand side of Fig. 3. When the resin reached the sequential injection site, it would also be turned on until the part was saturated.

In the special case of the VIPR process experiment the chamber was placed directly across from each injection port and a vacuum of 127 mmHg was applied when the port was turned on. Once the region directly under the chamber was saturated, the chamber was removed and not used again until another injection site was ready to be initiated.

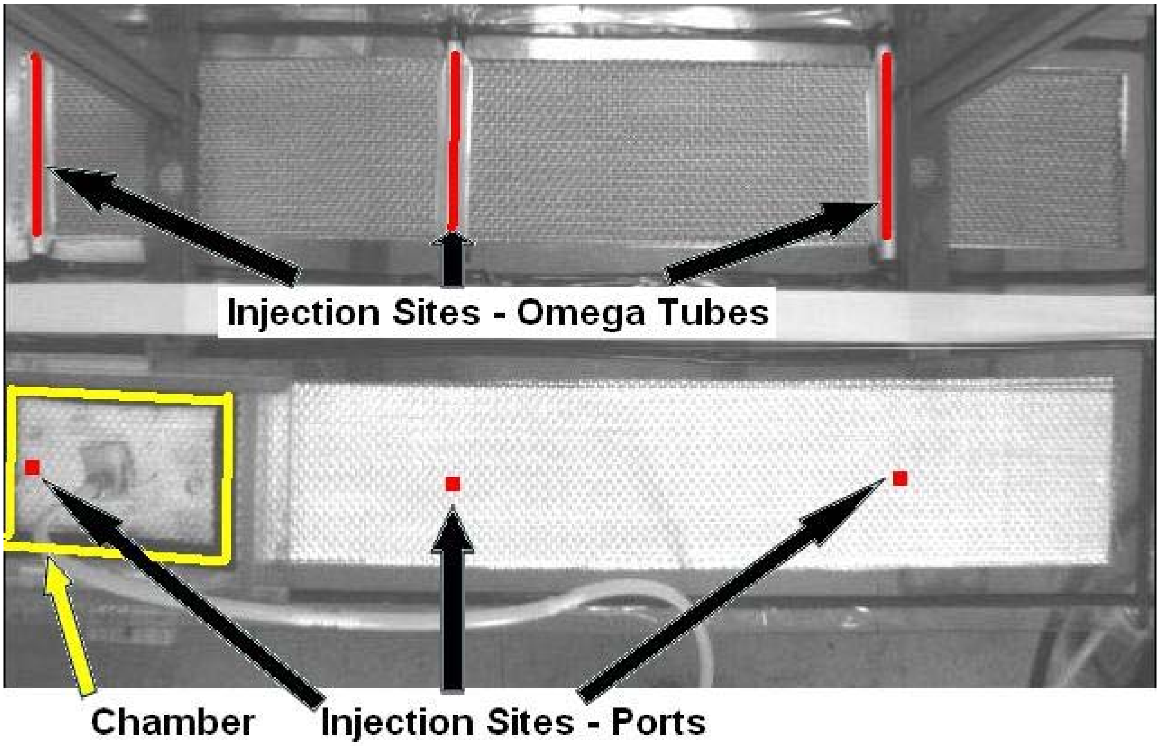

Fig. 3 A photograph of two experiments prior to beginning the infusion. On the top is an example of the SCRIMP process with omega tubing injection sites. Below is an example of the VIPR process, where the ports are in the tooling surface and covered by fabric and the chamber has been placed on the mold surface.

Both the VARTM and SCRIMP techniques were performed using injection ports and Omega Tubes, which distribute resin along the entire width of the mold. The VIPR process was only tested with tool side injection ports. The photograph in Fig. 4, shows the various resin delivery methods.

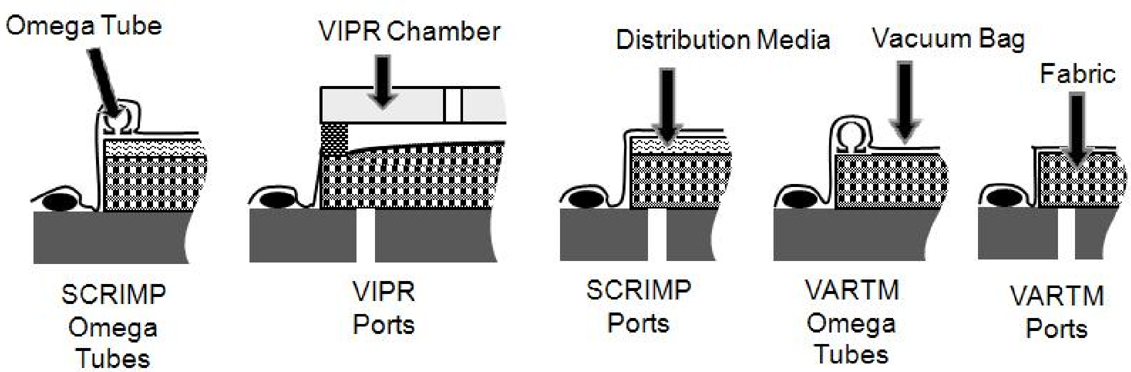

Fig. 4 Schematic representation of the various resin delivery methods presented in the order they are shown in Fig. 5. The resin source is connected to an Omega Tube or the port in the tooling surface of the mold.

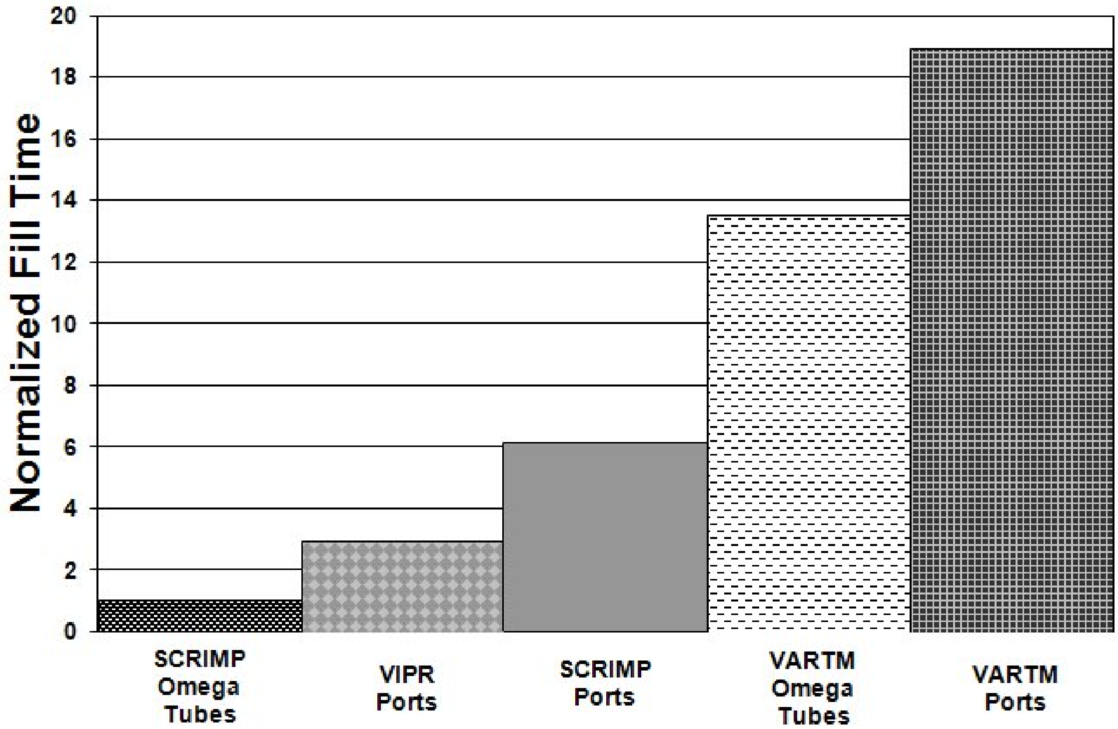

Fig. 5 The bar chart shows comparison of fill times between various resin infusions processes. The normalized fill time was calculated for each experiment with respect to the traditional SCRIMP experiment (labeled as SCRIMP Omega Tubes).

A total of five experiments are compared in the VIPR process with tool side ports and no distribution media with SCRIMP and VARTM with ports and omega tubes. As stated previously the fill-time results are normalized by using the traditional SCRIMP process as the baseline comparison and the results of normalized fill time are shown in Fig. 5.

The results displayed in Fig. 5, show that the VIPR process can significantly increase the resin flow rate into the mold as compared to the VARTM process. It is interesting that the fill time for the port-based VIPR process lies between the fill times of the SCRIMP process using omega tubes and ports. This results indicates that this resin delivery method is more suited for on-line flow control than the SCRIMP process since injection ports are the preferred instrument of spatially controlling resin flow into a mold. Also seen in the results is the trade-off of flow control and fill time between the port-based VIPR and SCRIMP methods using omega tubes. Though the use of ports with the VIPR process has a higher fill time for the same length of fabric, it has the additional advantage of flow control. Additionally, the VIPR process could be used with DM and omega tubes but such a change would lessen the degree of control the VIPR chamber would have on the infusion.

CONCLUSIONS

The experimental progress with the integration of tool side resin delivery ports and the VIPR process has shown that potentially one can add an element of control into conventional vacuum infusion processes such as VARTM and SCRIMP. Further this infusion technique takes another step in the ultimate goal of fully automating the VARTM process with on-line feedback control and flow correction. Advancements in the chamber design have resulted in the ability to use the chamber without undesirable effects on resin flow during infusion. The use of ports along with the VIPR process can be highly effective in reducing the filling time of large parts and offers many advantages over the standard SCRIMP process.

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