EXPERIMENTAL STUDY OF RESIN INFUSION UNDER FLEXIBLE TOOL (RIFT)

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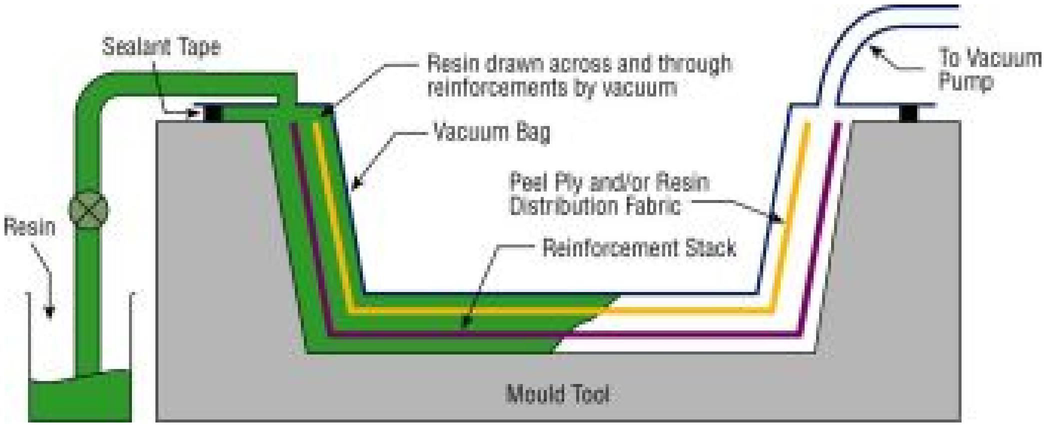
ABSTRACT

This study includes basic and processing experiments for the study of RIFT, using three types of resin distribution, highly permeable media. The basic experiments involve measurements of the in-plane and transverse permeability of individual or combined porous media to be used in RIFT experiments. The RIFT processing experiments involve measurements of the progress of the flow front during infiltration and measurements of the thickness of the manufactured laminates.

1. INTRODUCTION

RIFT is a composites manufacturing technique particularly suited for large structures often used in marine, construction, wind turbine blades, aerospace and biomedical instrument applications. In this, the assembly of fibre reinforcement is placed on one half of the mould and it is covered by a vacuum bag. The resin then is injected into the reinforcement under vacuum. In order to accelerate the filling stage, the resin flows through a highly permeable medium usually placed on one side of the reinforcement assembly. A diagram of the process is presented in Fig.1. The method is also known as Seemann's Composite Resin Infusion Moulding Process (SCRIMP®).



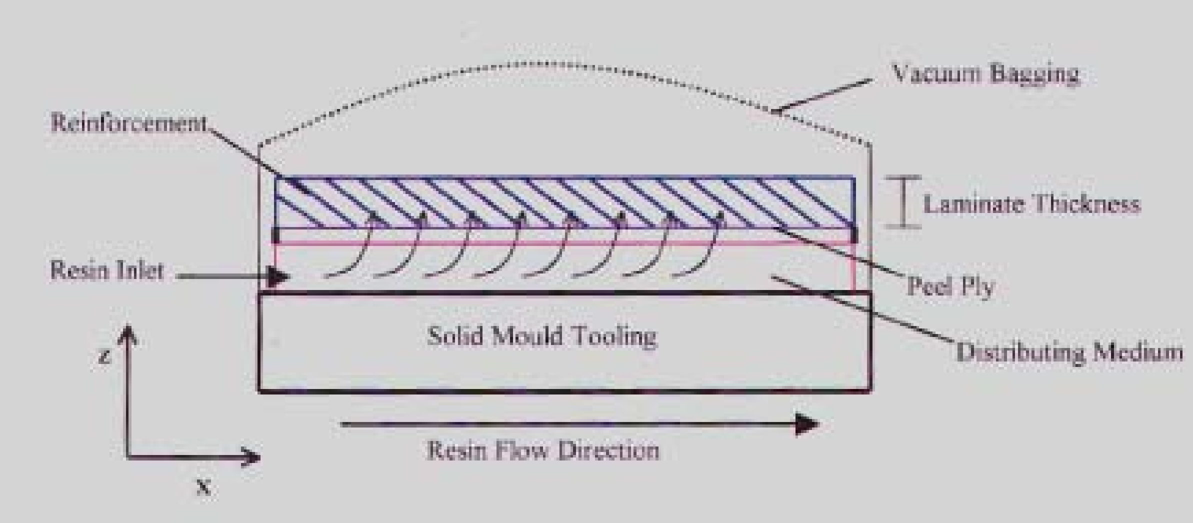
"**Fig. 1.** Diagram of a typical RIFT process."

The RIFT process is generally considered a low void technique although the thickness of the moulding is not as well determined as in a closed mould process such as resin transfer moulding (RTM).

2. THEORETICAL BACKGROUND

The experimental set up employed in this study had the highly permeable resin distribution medium under the reinforcement as illustrated in Fig.2. Darcy’s law is used to describe the resin flow through the combined porous media. The system requires a three-dimensional approach to the resin flow, i.e. in-plane and transverse flow. The large difference in the in-plane permeability of the resin distribution system and the reinforcement produces a lead lag in the resin front propagation and effectively a resin sink is created between the two components.

The peel ply serves only one purpose, to separate the cured composite from the distribution medium. However, the peel ply affects the transverse flow of the resin and its transverse permeability is therefore important. Generally, the peel ply is very thin of low porosity and low permeability.



“**Fig. 2.** Diagram of the experimental set up and resin flow in RIFT in this study.”

Another issue is the compressibility of the fibrous reinforcement and resin distribution medium. The fibre reinforcement is subjected to a compaction pressure, P_c, given by the relation

$$P_c = P_{atm} - P_{resin} \qquad (1)$$

where P_{atm} and P_{resin} are the atmospheric pressure outside the pressure bag and the local resin pressure, respectively. As the local resin pressure changes during filling, the compaction pressure changes leading to inhomogenities in the thickness of the fibre reinforcement. This also results in changes in the fibre volume fraction and permeability.

3. MATERIALS AND PROCEDURES

The fibre reinforcement consisted of layers of the E-glass satin woven fabric Y0736 supplied by Fothergill Engineered Fabrics. The peel ply was a 70 μm thick poly(tetrafluoroethylene) film. Four different types of highly permeable media were investigated as fibre distribution media: an E-glass unidirectional fibre mat (UF) [1] of an areal density of 0.22 kgm^{-2} and a nominal thickness of 0.37 mm; a random short fibre sisal mat (HHH1) of an areal density of 0.893 kgm^{-2} and a nominal thickness of 12 mm; a random short fibre sisal mat (HHH2) of an areal density of 0.862 kgm^{-2} and a nominal thickness of 12 mm; and a random short fibre sisal mat (FFF1) of an areal density of 0.727 kgm^{-2} and a nominal thickness of 11 mm.

In-plane (rectilinear flow) [2] and transverse permeability [3] experiments were carried out using two alternative model Newtonian liquids: silicone oil of an average viscosity of 170 mPas and corn oil of an average viscosity of 130 mPas. RIFT experiments were carried out using a mixture of a two part epoxy, Araldite LY564 and hardener HY2954 in a weight ratio 100:35.

4. RESULTS AND DISCUSSION

4.1 IN-PLANE PERMEABILITY EXPERIMENTS

This study involved rectilinear flow experiments in an RTM mould in three parallel assemblies of porous media: 9 layers of UF highly permeable medium; 5 layers of Y0736 reinforcement/peel ply/2 UF layers; 4x(peel ply/2 UF layers). The experiment is presented in Fig.3 where after a certain amount of time the UF highly permeable medium (on the left) is totally filled, the Y0736/peel ply/UF assembly (in the middle) has been filled by about one quarter of its length, and the peel ply/UF assembly (on the right) has been filled by about two thirds. In another rectilinear flow experiment in the RTM mould, the in-plane permeability of HHH2 and FFF1 sisal mats was determined in parallel.

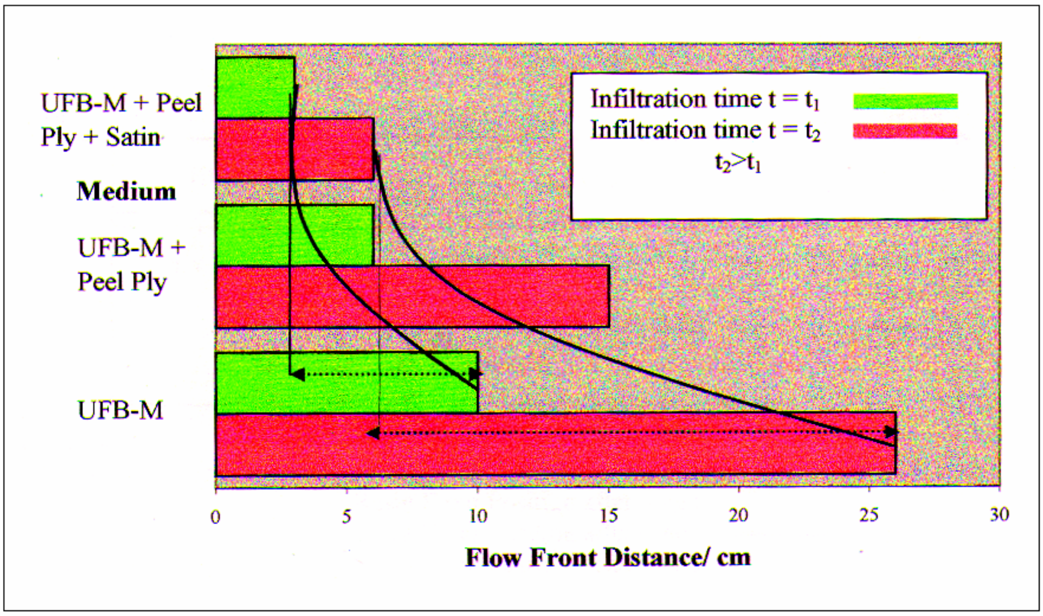
“**Fig. 3.** Flow progress in three parallel assemblies in an in-plane permeability RTM experiment.”

“**Table 1.** Experimental results of the in-plane permeability”

Porous medium	**Fibre volume fraction, V_f**	**In-plane permeability, k_p, (m^2)**
9 UF layers	0.23	$1.2x10^{-9}$
5 Y0736/peel ply/2 UF	0.62 (for the 5 layers of Y0736)	$6.8x10^{-11}$
4x(peel ply/2 UF)	0.30	$6.3x10^{-10}$
FFF1 sisal mat	0.17	$7x10^{-10}$
HHH2 sisal mat	0.20	$6.7x10^{-10}$

The results of the in-plane permeability experiments are presented in Table 1. k_p is similar for the two sisal mats and the small difference in the values is fully justified by the difference in the corresponding V_f values. The UF assembly has higher k_p which can be attributed to its large meso-channels. The presence of the peel ply lowers the effective in-plane permeability in the peel ply/UF system, whereas the combination of Y0736/peel ply/UF has the lowest global k_p. The latter system reflects the resin infiltration in RIFT although the RTM system has a well defined thickness.

Fig.4 illustrates the progress of flow front at two different times for the different components of the systems presented in Table 1 and it demonstrates the mechanism of creating a resin “reservoir” in the highly permeable UF component.



“**Fig. 4.** Diagram of flow front position after time t for different combinations of porous components.”

4.2 TRANSVERSE PERMEABILITY EXPERIMENTS

Table 2 displays the results of the transverse permeability experiments. The peel ply had a very low permeability which affected the transverse permeability of the combined peel ply/reinforcement system and is therefore expected to reduce the rate of filling in the reinforcement.

“**Table 2.** Experimental results of the transverse permeability”

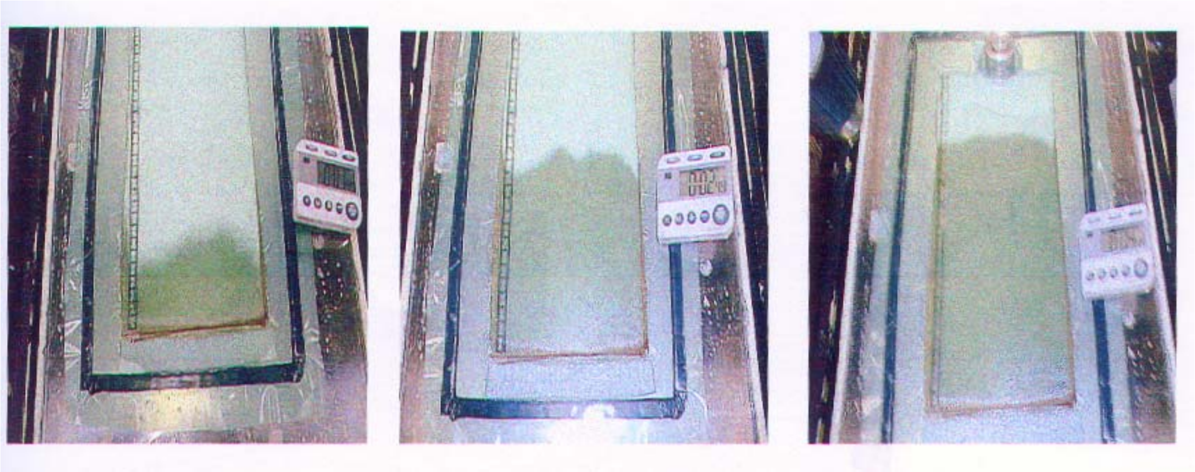
Porous medium	**Fibre volume fraction, V_f**	**Transverse permeability, k_T, (m^2)**
5 Y0736 layers	0.38	$1x10^{-10}$
Peel ply	0.98	$2.2x10^{-12}$
Peel ply/5 Y0736	0.40	$4.7x10^{-12}$

4.2 RIFT EXPERIMENTS

Table 3 presents the materials used in three different RIFT experiments, RIFT 1, RIFT 2 and RIFT 3. Besides measurements of the progress of the flow front (see Fig.5 for RIFT 3, for example), the cured epoxy composites were sectioned to assess the infiltration in both the longitudinal and transverse directions.

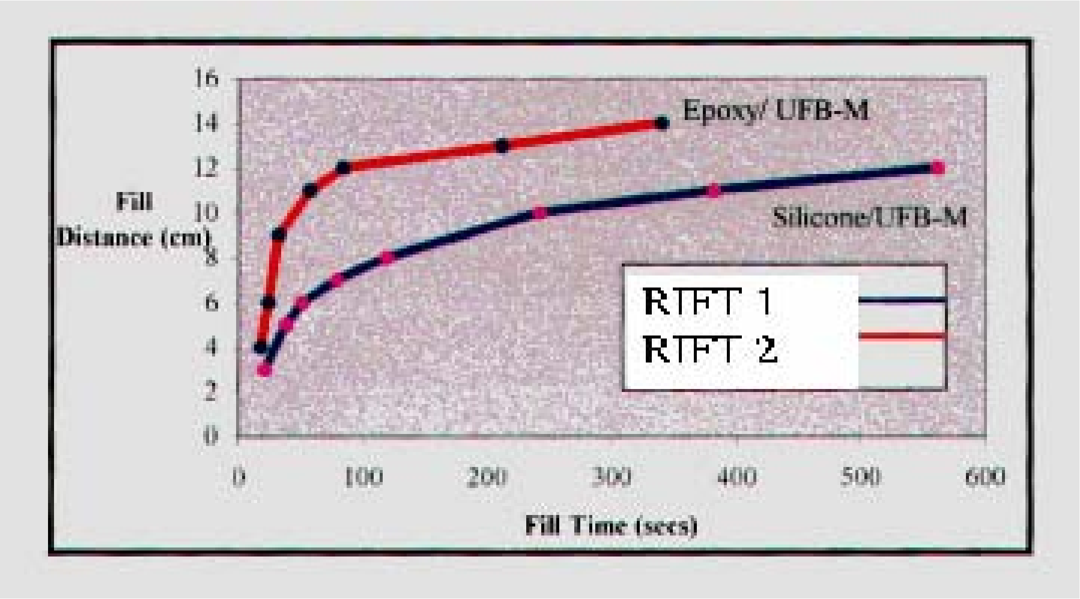
“**Table 3.** RIFT experiments: materials”

Experiment	System	Liquid
RIFT 1	2 UF/Peel ply/5 Y0736	Silicone oil
RIFT 2	2 UF/Peel ply/5 Y0736	Epoxy
RIFT 3	HHH1/Peel ply/5 Y0736	Epoxy



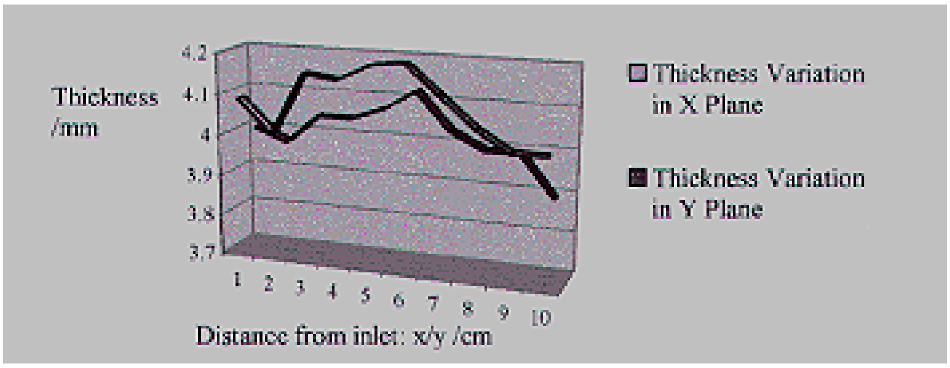
“**Fig. 5.** Resin propagation in RIFT 3.”

Fig.6 presents the filling length in the reinforcement as a function of time in RIFT 1 and RIFT 2. It is noticed that during infiltration in RIFT 1 the rate of infiltration was reduced. During the course of the experiment in RIFT 1, it was thought that a local vacuum was formed around the inlet preventing further infusion of the silicone oil. To avoid this problem, a thin breather layer was placed over the resin inlet port in RIFT 2. This resulted in a higher infiltration rate initially in RIFT 2, despite the fact that epoxy had a higher viscosity than silicone oil.



“**Fig. 6.** Progress of infiltration in the reinforcement in RIFT 1 and RIFT 2.”

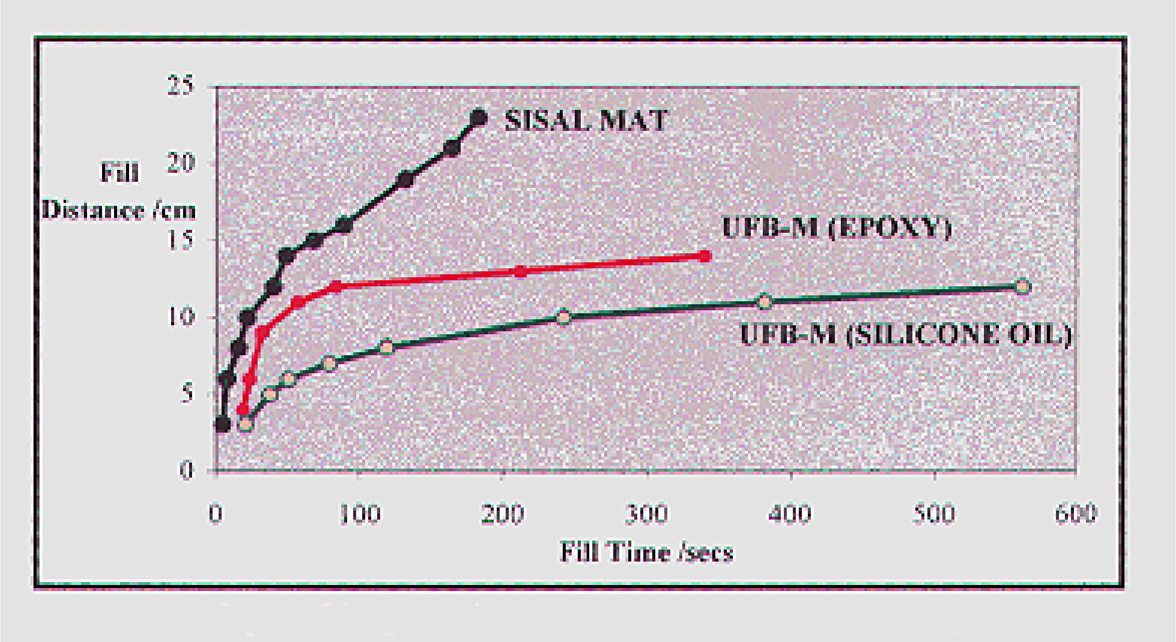
Fig.7 presents the thickness variation of the cured composite in RIFT 2.



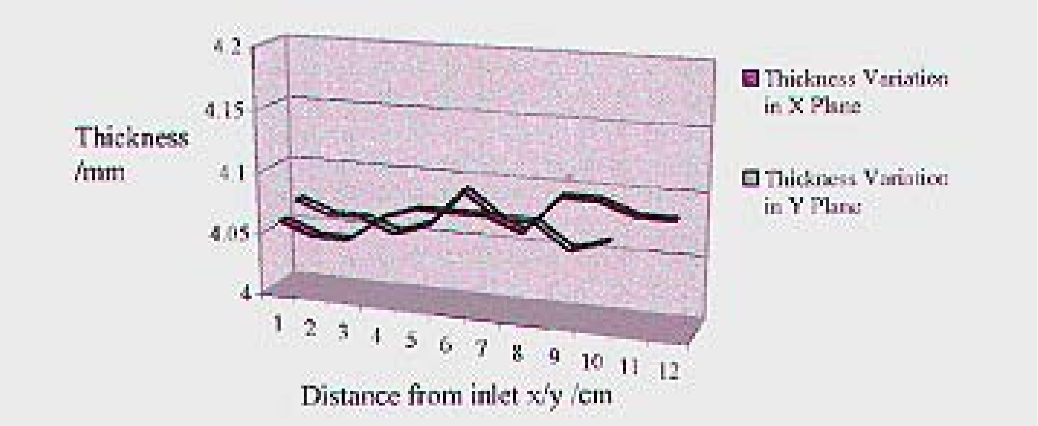
“**Fig. 7.** Thickness variation of the cured composite in RIFT 2.”

The thickness of the resin cured sisal mat in RIFT 3 was measured as 5.85 mm, which included a reduction of 6.15 mm from its original thickness when uncompressed. This corresponds to an increase in V_f from 0.06 to 0.12, caused by compaction of the sisal mat under vacuum.

Fig.8 presents a comparison of the progress of infiltration between the RIFT experiments. Whereas the rate of infiltration in RIFT 3 is similar to that in RIFT 2, it does not slow down so much in RIFT 3. This demonstrates that the effect of resin lagging may be reduced using the sisal mat as resin distribution system. Fig.9 presents the thickness variation of the cured composite in RIFT 3.



“**Fig. 8.** Progress of infiltration in the reinforcement in RIFT 1, RIFT 2 and RIFT 3.”



“**Fig. 9.** Thickness variation of the cured composite in RIFT 3.”

5. CONCLUSIONS

The RIFT experiments demonstrated that injection under vacuum in a mould with a flexible surface may produce various process problems, e.g. the bag under vacuum blocking the inlet port. The resin distribution, highly permeable medium needs to provide high infiltration rates not only initially but to maintain them during the whole course of the filling process. Initial studies proved that the sisal mat was a good choice as resin distribution medium. In a general case, though, experimental studies need to be coupled with process simulations to obtain a good insight about the suitability of a resin distribution system in relation to a particular reinforcement. This study has also provided data, such as permeability values, to be used in RIFT simulations which are planned as future work in this project. The obtained thickness variation in the laminates manufactured by RIM was within an acceptable range, especially in the case of RIFT 3.

ACKNOWLEDGEMENTS

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