In-Mold Coating of Composites Manufactured by the Resin Infusion Between Double Flexible Tooling Process by Means of Co-Infusion

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SUMMARY: As composite materials gain wider acceptance within the transportation industry, it is pertinent to investigate the available coating processes with a view to reduce emissions and associated costs. This work aims to develop a methodology for in-mold coating components manufactured using the Resin Infusion between Double Flexible Tooling (RIDFT) process.

RIDFT is a neoteric two-stage manufacturing process that involves; 1) infusion of resin between two flexible silicone membranes until thorough wetting of the fibers is achieved, and 2) vacuum forming, where the membranes are pulled over a one-sided mold.
The viability of in-mold coating RIDFTed components was investigated. This work-in-process, reports on successes and challenges presented, during the co-infusion of a polyurethane enamel paint (DuPont Imron 5000) and a vinyl ester resin (Derakane 470-45).

KEYWORDS: Resin infusion, co-infusion, in-mold coating, composites

INTRODUCTION

Over the past four decades, polymer composites have been presented as the material of the future due to their advantages of high strength to weight ratios, corrosion resistance, and functional integration [1]. Nonetheless, the production economics of polymer composites tend to limit their application in the mass production sector. The lead times to manufacture are simply too high. Several production processes are available, with the liquid composite molding techniques being the most amenable to mass production.

Techniques such as resin transfer molding (RTM), vacuum assisted resin transfer molding (VaRTM), and their variants have been successfully implemented for the manufacture of polymer composite components. Once manufactured, composite components undergo a series of finishing processes to prepare the substrate for painting. Some of the current painting methodologies are not only laborious, time consuming and expensive, but may result in the release of materials that are harmful to the environment.

This work will assess the viability of in-mold coating composites made by the RIDFT process by means of co-infusion.

RIDFT is a two-stage process – resin infusion and wetting, followed by vacuum forming. As shown in Fig. 1, dry reinforcement is placed between two membranes. After securing the membranes, resin is infused under a vacuum. The next stage is vacuum forming, during which the membranes are drawn over a male mold (final product shape) by applying a vacuum. The use of a one-sided mold provides huge cost benefits when compared with the RTM process. A cost savings of 24% has been demonstrated when compared with SCRIMP [1].

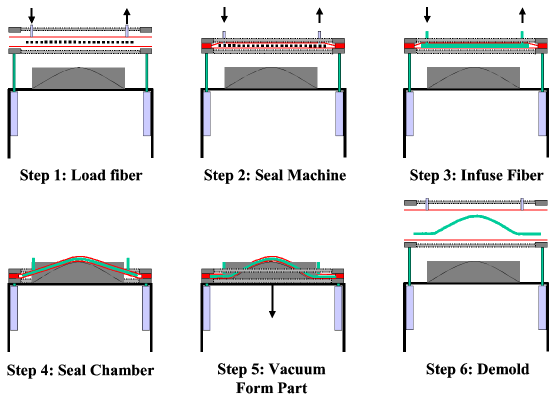

Fig. 1 The RIDFT process [1]

The automotive coatings market has been significantly influenced by the macroeconomic environment, the drive towards lower costs and higher efficiency, technology innovation and sound environmental practice [2]. Environmental concerns have led the trend to reduce solvent use in coating applications. The latest technology and materials development promise to lower assembly paint-line emissions, eventually eliminating solvents in paint, while improving scratch resistance and the overall durability of a vehicle finish.

It is imperative that methodologies are sought to reduce the costs associated with painting, as well as the negative environmental impacts. In-mold coating (IMC) of composite components may address these issues. IMC has been successfully used for many years for exterior body panels made from compression molded Sheet Molding Compound (SMC) to improve their surface quality in terms of functional and cosmetic properties [2]. When injected onto a cured SMC part, IMC cures and bonds to provide a paint-like surface. Another method for in-mold coating is the use of thermo-formable paint films.

Several forms of in-mold coating have been researched, including the metal plating of sheet molding compounds (SMC) [3], and in-mold coating of injection molded plastics [4]. McCarthy *et al* [5] discussed the effects of implementing paint films on different fiber structures. Castro *et al* [6] offered the process model for in-mold functional coating of thermoplastic substrates. Toro and Okoli [2] reported on the use of paint films on RIDFTed composite parts. They established the viability of the use of thermo-formable paint films with the RIDFT process.

This work describes the preliminary results of in-mold coating assessment studies of RIDFTed components. A room temperature cure vinyl ester resin was used with DuPont Imron 5000 paint.

APPROACH

Based on the work by Gillio *et al* [7], a simplified schematic of the co-injection setup is shown in Fig. 2. In the majority of cases, the flow of a polymer inside a mold filled with a stationary fiber bed is modeled using Darcy's law (Eqn. 1).

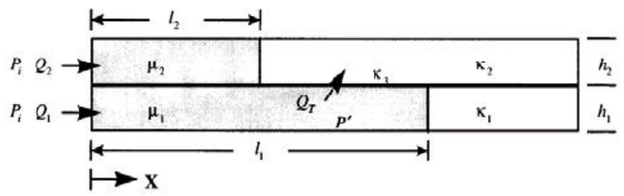

Fig. 2 Schematic of the one-dimensional flow model in CIRTM [7]

The macroscopic velocity, *u*, is given by:

$$u = \frac{k}{\mu}\frac{dP}{dx} \qquad (1)$$

where *k* is the permeability of the fiber preform, μ is the viscosity of the resin, and *dp/dx* is the pressure gradient in the flow direction.

In co-injection, the top and the bottom preforms could have different permeabilities and the resins injected could have different viscosities, leading to different resin velocities between the top and the bottom halves of the mold. The injection is assumed to be at the same pressure since this is the case in the majority of VARTM type processes [7]. In such a case the velocities of the two flow fronts will be given by:

$$u_1 = \frac{k_1}{\mu_1}\frac{P_i}{l_1} \qquad (2)$$

$$u_1 = \frac{k_2}{\mu_2}\frac{P_i}{l_2} \qquad (3)$$

The RIDFT set-up is illustrated in Fig. 3.

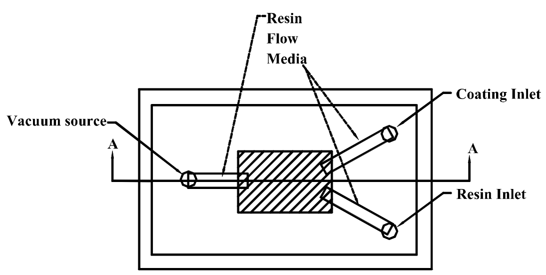

Fig. 3(a) RIDFT IMC (Top view)

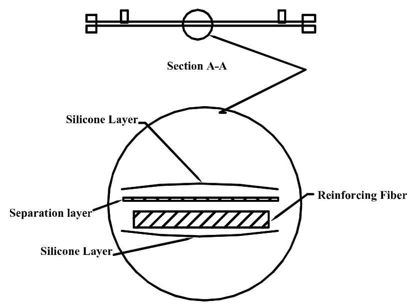

Fig. 3(b) RIDFT IMC (Detailed)

The resin and coating material were infused through separate flow media under vacuum. A layer of FERRO Prepak material was used to separate the paint and resin to prevent mixing during infusion. The paint is infused first followed by the resin, which dissolves the separation layer on contact.

RESULTS AND DISCUSSION

A series of experiments were performed. Initial tests used an impermeable vacuum bag as the separation layer. Resin Derakane 470-45 was co-infused successfully, demonstrating the viability of the experimental set-up. The bagging material was obviously unsuitable for a separation layer for IMC due to adhesive incompatibilities. Other materials were assessed including the FERRO # MCO8 Prepak material. Initial infusion with coating and resin showed promise. However, since the coating material is more viscous than the resin (30:1) and permeability $k_1 > k_2$, when infused concurrently, the resin filled the mold faster than the paint. Additionally, the resin depletes the separation material on contact. Therefore, it was necessary to first infuse the paint, and then infuse the resin.

Fig. 4(a) Non-coated and IMC RIDFTed components

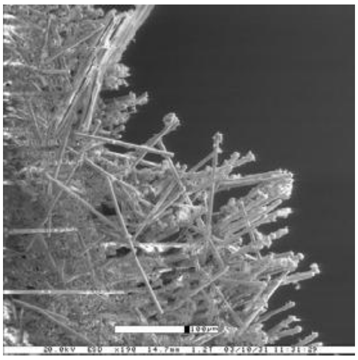

Fig. 4(b) Microstructure of IMC RIDFTed component showing poor interfacial bonding

As can be observed from the samples shown in Fig. 4(a), co-infusion was implemented. The resin and paint were co-infused into the flexible diaphragms. However, the separation layer did not perform as required, allowing the paint to seep through, and mix with the resin. This may have resulted in the paint interfering with the fiber-matrix interface. Fig. 4(b) is the microstructure of a failed IMC specimen. It shows extensive fiber pullout, which is indicative of a poor fiber-matrix bond. This poor interfacial bond may have resulted in the radical difference in storage modulii observed in the non-coated and coated parts. See Figs. 5 (a and b). Material selection is on- going to determine a more suitable separation layer material. Other paints will also be evaluated.

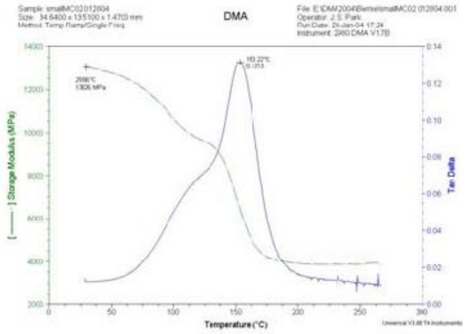

Fig. 5(a) DMA diagram showing composite storage modulus of 13026MPa and Tg is 153.22°C, for a RIDFTed composite part.

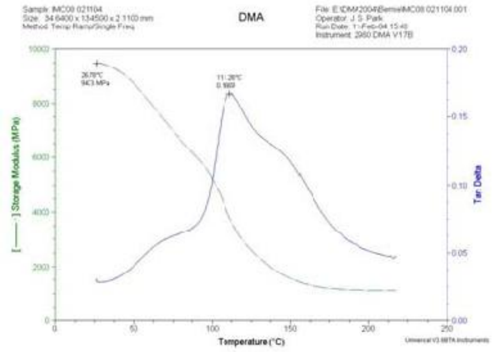

Fig. 5(b) DMA diagram showing composite storage modulus of 9473MPa and Tg is 111.28°C, for IMC RIDFTed part.

SUMMARY AND CONCLUSION

In this experimental study, co-infusion was implemented. The resin and paint were co-infused in-between the flexible diaphragms. However, the separation layer did not perform as required, allowing the paint to seep through, and mix with the resin. Material selection is on going to determine a more suitable separation layer material. Other paints will also be evaluated in future work.

The ability to in-mold coat a composite will certainly advance their manufacturing. Nonetheless, the methodology for sustaining or improving mechanical properties and appearance of products should be the premise of implementing IMC. In applying in-mold coating into the process today known as RIDFT, its unique approach to integrating flexible coatings with substrates is a natural fit for market segments such as automotive, agricultural, construction equipment, marine, lawn and garden, and aerospace.

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