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FLEXIBLE INJECTION: A NOVEL LCM TECHNOLOGY FOR LOW COST MANUFACTURING OF HIGH PERFORMANCE COMPOSITES. PART I - EXPERIMENTAL INVESTIGATION

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SUMMARY: High performance composites are used in a large number of applications in the automotive and aerospace industry. Because they combine high mechanical performance, low weight and good resistance to corrosion, an increase in the industrial usage of composite materials can be expected. In order to lower the cost of composite manufacturing, a new flexible patent pending injection technology [1] belonging to the family of LCM ("*Liquid Composite Molding*") processes was devised and is currently investigated by the NSERC – General Motors (GM) of Canada Industrial Research Chair at École Polytechnique de Montréal. It turns out that this approach is not only faster than rigid mold injection, typically known as *Resin Transfer Molding* (RTM), but if properly used it can also produce parts of high quality in terms of void content and mechanical performance. Since the resin flow in flexible injection combines features of RTM and resin infusion, these LCM process variants will be recalled in part II of this paper, which is focused on numerical simulation [2]. Part I will present flexible injection and then discuss the first experimental results obtained for random fiber reinforcements. This new approach consists of using a mold with two chambers separated by a flexible membrane. Experimental results for fabrics are also available in two related papers by Daqoune et al. [6] and Causse et al. [7] presented at FPCM-9.

KEYWORDS: Liquid Composite Molding (LCM), flexible injection, plan of experiments

INTRODUCTION

High performance composites are used in a large number of industrial applications ranging from structural automotive and aerospace parts to common consumer products. Because they combine high mechanical performance, low weight and good resistance to corrosion, further increase can be expected in the industrial usage of composite materials. In order to lower the cost of composite manufacturing, a new flexible injection technology belonging to the family of LCM ("*Liquid Composite Molding*") processes was devised and investigated by the NSERC – General Motors (GM) of Canada Industrial Research Chair. It turns out that this approach is not only much faster than rigid mold injection, typically known as *Resin Transfer Molding* (RTM), but if properly used it can also produce parts of higher quality in terms of void content and mechanical performance.

This new approach was first described in 2003 in Canadian patent application 2,434,447, followed by an international PCT application in 2004 [1]. It consists of using a mold with two chambers separated by a flexible membrane. This paper is focused on the analysis of the experimental behavior of flexible injection. Analyzing such a novel process is rather a complex task because of the number of parameters involved and the complex interactions between two coupled flows: Darcy's and Stokes.

Part I of this investigation presents the first experimental results obtained for random fibrous reinforcements (i.e, mats), while part II is focused on the numerical simulation of flexible injection. Successive plans of experiments were conducted with a transparent test mold [3, 4] to analyze the effect of the different processing parameters. Results show that flexible injection represents a promising new approach with improvements in fill times compared to RTM and VARTM by a factor of nearly 10 for mats and even larger for fabrics. The quality of composite parts can also be improved in terms of void content and mechanical performance. However, an efficient implementation of this new manufacturing technique for high performance composites requires a good knowledge of the effect of the main processing parameters. In the sequel, process performance will be evaluated by the time required to fill up a planar test mold by flexible injection as compared to standard unidirectional RTM injection.

DESCRIPTION OF FLEXIBLE INJECTION

The mold cavity is divided through its thickness by a flexible membrane or separation film: the lower part of the mold, the injection chamber, contains the fiber reinforcement and is filled with resin; a compaction fluid is injected in the upper part of the mold, or compaction chamber, so as to apply a uniform pressure through the thickness of the part and as a result, speed up the impregnation of the fibrous reinforcement. The schematic representation of Fig. 1 shows the different components of the mold.

The main idea of the flexible injection is to take advantage of several features present in the LCM process family. The basic principles of this new technology are illustrated in Fig. 1 to 4. The process is basically implemented in five successive stages:

1. Preparation.- Firstly, the reinforcement is inserted into the mold cavity, then a plastic film is positioned over the reinforcement and the mold is closed (see Fig. 1). Vacuum may then be applied through one extremity of the injection chamber, as illustrated in Fig. 2, causing the separating film to compress the fibrous reinforcement.

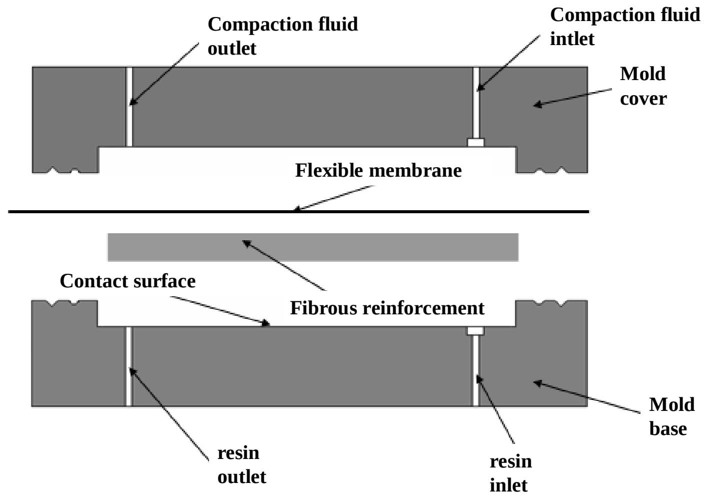

Fig. 1 Flexible injection mold components.

Fig. 2 Vacuum application.

2. Resin injection.- During the first stage of fabrication, a given amount of resin is injected under pressure into the mold cavity (see Fig. 3). Since the finished composite piece has a thickness smaller than the total height of the cavity, the resin only fills a fraction of the mold cavity. It is assumed that near the resin injection port the saturated reinforcement will reach the full thickness of the cavity, even if the reinforcement has been initially compressed by vacuum.

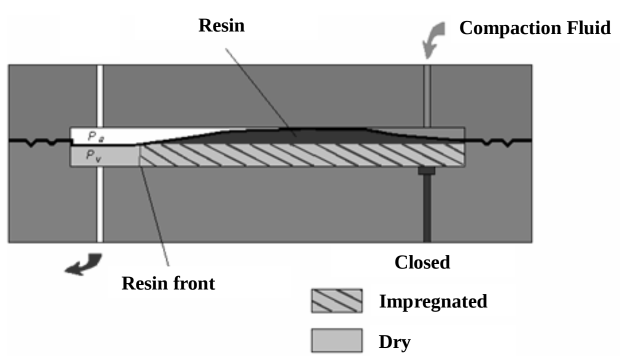

Fig. 3 Resin injection into the cavity.

3. Compaction.- A non reactive fluid is injected under pressure into the compaction chamber (above the separating film), in order to accelerate resin flow. This stage ends when all the reinforcement is impregnated by the resin. Note that this operation forces the impregnation of the dry portion of the reinforcement while ensuring the compaction of the saturated one.

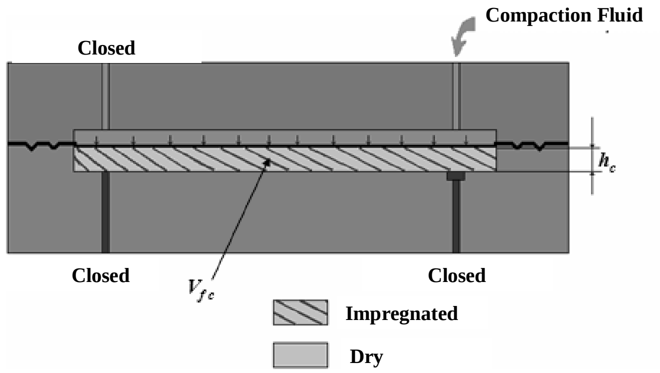

Fig. 4 Homogeneous compaction of impregnated fibers.

4. Consolidation.- When the reinforcement is completely impregnated, the resin vent is closed and the consolidation stage starts (see Fig. 4). Consolidation lasts the time necessary to ensure pressure equilibrium and obtain a uniform thickness of the composite. At the same time, the mold can be heated in order to polymerize the resin.

5. Demolding.- After the reticulation stage, the compaction fluid is drained out of the cavity while the mold is cooled. The mold is then opened and the separating film removed from the composite. The manufacture of the composite ends up with the removal of the finished piece from the mold.

EXPERIMENTS

A first set of 40 experiments was carried out at constant pressure using silicone oil to simulate the resin. The process parameters that were changed in these tests are the injection pressure of the resin, the gap of the cavity, and the viscosity and pressure of the compaction fluid. Details of the operating conditions and experimental results will be presented at the conference. The best results are obtained for a gap size twice that of the nominal thickness of the part. As expected, a higher resin and compaction fluid pressure accelerate mold filling that can reach a factor of ten compared to standard rigid mold injection (RTM process).

CONCLUSIONS

A new patent pending flexible injection process was presented that can speed up mold filling by one order of magnitude compared to RTM. A series of benefits can be derived from this approach:

1. The upper mold does not need to be as rigid as the lower one, thus a decrease in tooling costs can be expected.

2. A cyclic compaction of the reinforcement during stage 4 increases considerably the quality of the part.

3. Heating of the compaction fluid results in a more uniform cure of the part, thus allowing earlier demolding.

4. Excess heat can easily be removed from the mold by cooling and circulating the compaction fluid.

5. By maintaining a high compaction pressure during cure, an improved consolidation of the composite is obtained. This improves at the same time the surface finish on the face of the part in contact with the lower mold.

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