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COMPRESSION RESIN TRANSFER MOULDING UNDER MAGNETIC FIELD MODELLING AND NUMERICAL INVESTIGATION

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ABSTRACT:
Relaxation-compression resin transfer molding under magnetic field is a new variant of VARTM ("vacuum assisted resin transfer molding") process, which uses a flexible magnetic membrane controlled by a magnetic force, in order to govern the relaxation and compression phases by changing the permeability of the fabric preform. Thus permits to the resin to enter easily into the mold and to increase the resin impregnation velocity and the fiber volume fraction. This innovation is based on the application of the TRIZ theory ("the theory of inventive problem solving"), which allows us to answer to the shortcomings and the conflict links exist inside the VARTM processes. The objective of this paper is to present this new process and to study the effect of the current intensity and the separated gap between the flexible magnetic membrane and solenoid on the permeability of the preform.

Keywords: Liquid composite molding, Magnetic field, VARTM, Mold, Resin, TRIZ

INTRODUCTION

The conventional RTM processes usually have limitations in fabrication large parts due to the cost investments, pressure equipment, and the process time, that dramatically increasing proportional to the surface area of composite structures. The vacuum assisted resin transfer molding (VARTM) process was introduced to overcome these challenges. In this process a fibrous preform is placed into a mold cavity, and covers by a flexible polymer film, then a sealant tape is used to adhere it to the mold in order to avoid air-resin leakage. A vacuum pump is used to evacuate the air from the cavity, which leads to compact the preform. The inlet gate is opened and resin impregnates the preform under atmospheric pressure. The main disadvantages of the VARTM process are: First, the pressure gradient is limited to one atmospheric pressure so the mold filling is very slow and the filling time increasing proportional to the part's dimensions [1], along with the low permeability of typical fiber layers often leads the resin to not completely fill the mold cavity before the resin begins to gel. Second, as the VARTM uses only a single rigid side mold, the fabricated part has a low dimensional tolerances due to the non-uniformity of part thickness, and low fiber volume fraction. This process has still limited to non-aerospace applications.

Many processes have been proposed in order to overcome these shortcomings. The first variant of VARTM is SCRIMP (Seemann's composite resin infusion molding process), it aimed at reducing the fill time [2, 3], by adding a new highly permeable material called distribution media and a peel ply layer. In SCRIMP, the distribution media is inserted over the preform, allowing the resin to move and cover quickly the entire mold, as a result the resin impregnates the fiber layers through its thickness, which significantly reducing the fill time [4]. In order to separate and remove the distribution media from the preform in demolding phase, a peel ply layer is inserted between them. Alms and Advani proposed an FFC method that used a rigid chamber sealing on flexible bag.
A vacuum pump was used to evacuate the air inside the chamber and pull the bag away from the preform. After resin injection, an atmospheric pressure was applied on flexible film to compact the preform [5]. The main disadvantage of these

processes is that we couldn't govern and manipulate the resin flow dynamically, actively and temporarily for eliminating the dry spots regions and racetracking effect. These defaults appear due to the improper location of the inlet and outlet ports and bad cutting and draping of the preform. For solving these problems Alms developed a new process called vacuum-induced preform relaxation (VIPR) method that was similar to FFC method. In the VIPR, an external vacuum chamber is used that seals against the flexible molding surface of a VIP (Vacuum infusion processes) mold and applies a secondary vacuum to locally reduce the compaction pressure on the fibers, which increases the permeability of that region steering resin flow to that region [6,7]. This chamber is moveable which permits to control and guide the resin filling patterns. But this process adds a lot of equipment, which conduct to increasing significantly the cost investments. Ruiz proposed another process in 2003, called flexible injection. In this process, the lower and the upper sides of the mold are separated by flexible membrane. The resin enters into the mold base cavity through the inlet gate and impregnates the fiber reinforcement. The upper mold is filled with a compaction fluid, which apply a uniform pressure on the separation film, conducting to increase the resin impregnation velocity and compact the preform. This process present the advantages to increase the mold filling compared to RTM, also the upper mold does not need to be as rigid as the lower one, heating fluid can be used to speed up the polymerization reaction and cold fluid can also circulate in upper chamber to remove the excess heat in the mold [8, 9]. These several pros give a larger processing window, but they make at the same time the understanding and control of the fabrication process of flexible injection a complex task. The second disadvantage of VARTM is that low dimensional tolerances and low fiber volume fraction of the fabricated part .To solve this problem, the Boeing Corporation was developed another variant of VARTM called Controlled atmospheric pressure resin infusion (CAPRI). In this process the preform is debulked before the infusion stage take place which reduce overall thickness and increase fiber volume fraction. This advantage for enhanced performance and reduced the surface variability of the final product makes it a suitable infusion process for aerospace applications [10]. However, as the debulk stage decrease the permeability of the preform, the impregnation velocity will been slow and thus will increase the fill time. All these processes were tried to make the compromises between the part's dimension, fill time, time process, cost equipment, surface quality, dimensional tolerances and performance of the part. All these dictated conditions include the conflict links and contradictions that can't be solved by using only the compromises thinking. The objective of this paper is to propose and discuss a new variant of VARTM process that solves the conflict links between closing-compression force, fill time and the deformation of the mold wall, this process permits also to control the resin filling patterns by changing temporarily the permeability of the fabric preform. This innovation is achieved by using the TRIZ theory

TRIZ Theory TRIZ (the theory of inventive problem solving) is an innovation methodology, created and developed by the Russian engineer Genrich Altshuller in 1946. Over the past years, TRIZ has used in different sectors, including automotive sector [11] and mechanical field [12]. Due to these large scope of applications, nowadays TRIZ has become as one of the most powerful, popular innovative method. This article is first scientific paper that uses TRIZ in composites manufacturing using the LCM processes. In which, we use cause-effect analysis as a TRIZ tool to formulate the existing contradictions mentioned above, and to generate breakthrough creative solutions. Figure 1 illustrates the process of generating creative solutions by using cause-effect analysis.

Process Description Relaxation- compression resin transfer molding under magnetic field is a new variant of VARTM, belonging to the closed mold technique family. In this process, we only use a single side mold like as in the VARTM processes, that contains the fiber preform, and it covers by a flexible magnetic membrane, or by using a vacuum bag including a ferromagnetic sheet, gathered together by an effective glue. The magnetic field is controlled by the current intensity or by the separated gap between the coil and ferromagnetic membrane, so as to apply a magnetic force on the membrane and as a result

,move it up to relax the preform or down in order to compress the fiber reinforcement. Which leads to speed up the impregnation velocity and increase the fiber volume fraction. The main stages of the manufacturing cycle and the different components of the new mold are schematically illustrated in fig. 2 to 6.

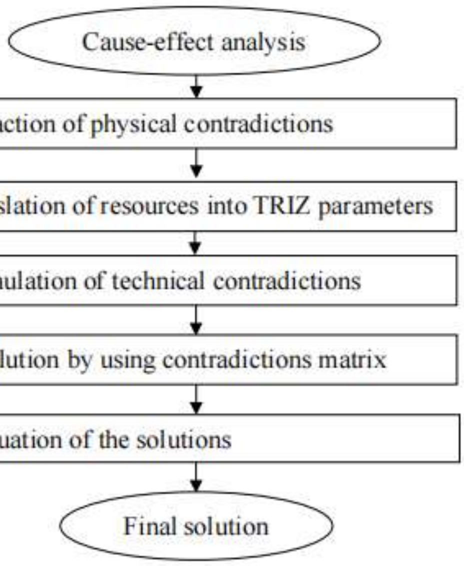


Fig. 1 The problem solving methodology by using cause-effect analysis

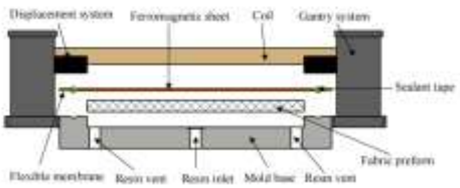


Fig. 2 Relaxation-compression resin transfer molding under magnetic field mold components

Mathematical Modeling of the Relaxation Stage During the relaxation stage a magnetic force is used to displace the membrane and to increase the permeability of the preform, it is controlled either by the current intensity or by the variation of the gap between the solenoid and the ferromagnetic sheet (Membrane). The instantaneous balance between forces depends on thickness hcc, in which the flexible magnetic membrane loses the contact with the fabric preform.

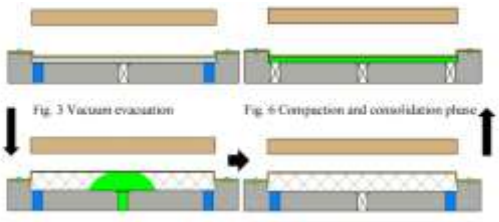


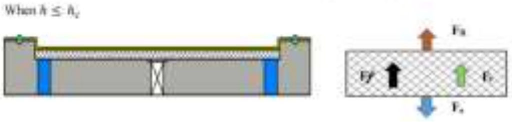
Fig. 3 Vacuum evacuation

Fig. 6 Compaction and consolidation phase

Fig. 4 Preform relaxation

Fig. 5 Resin injection

When $h \leq h_c$



In this case the instantaneous balance between forces is written as follows:

$$F_R = F_e - F_f - F_r \qquad (1)$$

Where F_R is the magnetic force generated by the coil in order to relax the preform, and it can be calculated by the following equation [13]:

$$F_R = \frac{(N \times I)^2 \times C_0 \times A}{2G^2} \qquad (2)$$

With N is number of turns, I is current intensity, C0 is magnetic constant, A surface of linear solenoid and G the separated gap between the solenoid and ferromagnetic sheet. $FFee$ is the evacuation force exerted in the mold, and $FFff$ is the force exerted by the fiber reinforcement [14]. Assuming the cases when the relaxation and injection phases are done separately, thus during this stage $FFrr = 0$. We also use the Toll-Manson model, which respectively relates the compressibility behavior of the fiber reinforcement [15] and the perform permeability K [16] with fiber volume fraction, these relation are formulated as follows.

$$\sigma\left(V_f(t)\right) = c\, V_f(t)^d \qquad (3)$$

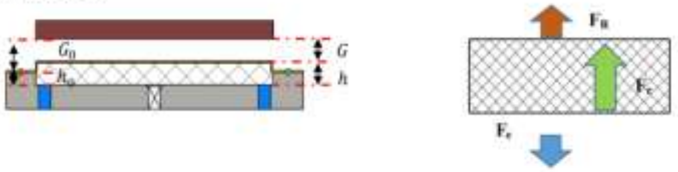
$$F_f = \int_0^W \int_{-\frac{L_0}{2}}^{\frac{L_0}{2}} \sigma\left(V_f(t)\right) dx\, dy = W L_0 c \left(V_f(t)\right)^d \qquad (4)$$

$$K_{xx}(V_f) = K_{yy}(V_f) = a V_f^{\,b} \qquad (5)$$

Combining equations (1)-(5) we obtain the relation between current intensity and permeability

$$\begin{cases} F_R = \dfrac{(N \times I)^2 \times C_0 \times A}{2G^2} \\ K_{xx}(I) = K_{yy}(I) = a\left(\dfrac{F_e - F_R}{W L_0 C}\right)^{\frac{b}{d}} \end{cases} \qquad (6)$$

When $h \geq h_c$



$$F_R = F_e \qquad (7)$$

$$G_0 - G = h - h_0 \qquad (8)$$

In this case the approximate in-plane permeability is described using the following equation [16]:

$$K_{xx} = K_{yy} = \frac{(h(t) - h_0)^2}{12} \qquad (9)$$

Combining equations (7)-(9) we get the relation between the current intensity and the permeability.

$$K_{xx} = K_{yy} = \frac{\left(G_0 - I\sqrt{\dfrac{N^2 \times C_0 \times A}{2 \times F_e}}\right)^2}{12} \qquad (10)$$

RESULTS AND DISCUSSION

This work aims to investigate the impact of the current intensity and the separated gap between the flexible magnetic membrane and solenoid on the permeability of the fibrous reinforcement.

L_q (m)	W (m)	h_0 (m)	C_q ($N.A^{-2}$)	N	I_q (A)	a (m^2)	b	F_r (KN)	c (Pa)	d	G_q (m)
0.5	0.1	0.015	$1{,}26\ 10^{-6}$	5000	2	$0{,}29\ 10^{-10}$	-2,377	250	$1{,}637\ 10^{7}$	3,58	0,01

The permeability of the preform increases considerably when the separated gap decreases between the ferromagnetic sheet and solenoid (see Fig. 7), also when the current intensity increases (see Fig. 8). As a result the resin impregnation velocity will increase and the fill time will decrease

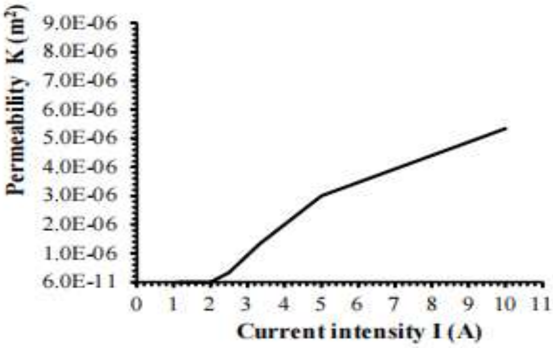


Fig. 8 Evolution of permeability as function of current intensity

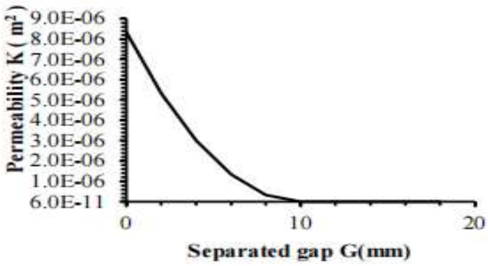


Fig. 7 Evolution of permeability as function of separated gap

.CONCLUSIONS

A new variant of VARTM process that uses a magnetic field was presented in order to control the relaxation- compression phases of flexible magnetic membrane process. This process allows to govern the resin flow dynamically and temporary for decreasing the cycle time and increasing the quality of the manufactured composite part.

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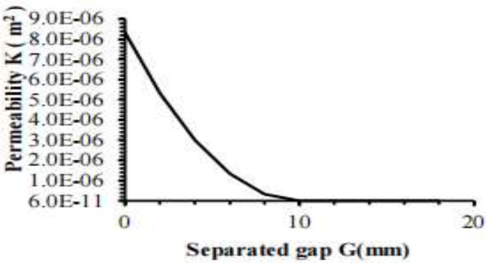

Fig. 7 Evolution of permeability as function of separated gap