Evaluation of the Vibration Assisted RTM Technique in the Production of Real Parts

Nikos G. Pantelelis

National Technical University of Athens, Department of Mechanical Engineering, Building M, Zografou Campus, 15773, Athens, Greece, pande@mail.ntua.gr
and
Synthesites SA
POBox 64078, 15710, Athens, Greece, synthesites@freemail.gr

SUMMARY: To promote the intermixing between micro and macro resin flows through fibers using dynamic means few ideas have been proposed such as the audio frequency vibrations applied to the injection pressure and the VIARTM technique. In the latter the mold and the preform are vibrated together during and/ or after the filling process by applying external mechanical vibrations to the mold eliminating air traps and improving wetting. For the evaluation of the VIARTM technique and the identification of the flow phenomena an improved test rig has been developed to explore the repeatability of the process and the dependence of the performance on the frequency that the mold is vibrated at. Trials indicate that vibrations contribute towards the balancing between the capillary and the channel flow resulting in improved fiber impregnation and elimination of racetracking. Moreover the filling time is reduced maintaining the injection pressure or lower injection pressure is required for the same filling time with respect to the classic RTM case. The use of VIARTM to a real geometry composite part reveals its advantages.

KEYWORDS: RTM, vibrations, flow

INTRODUCTION

The main characteristic of liquid composite molding is the flow phenomena that take place during the filling stage where the resin impregnates the dry fibers. The void formation during the filling process is one of the major problems of Resin Transfer Molding especially when the tendency is to increase the fiber volume fraction and decrease the filling time. Many studies have dealt with the mechanisms of void formation where the air (as well as gases that are produced during the chemical reactions) are entrapped in the fiber preform structure, thus small or large voids are formed in the composite part, deteriorating part quality significantly [1]. Unfortunately, in practice variability in the preform placement and uneven compaction of the fibers may alternate significantly the theoretically calculated flow paths and, consequently, to increase voids and air-bubbles.

In order to eliminate these problems, the vibration assisted resin transfer molding (VIARTM) has been proposed [2], based on the application of external mechanical vibrations to the mold and the fiber preform during and/ or after the filling cycle transforming the “static” RTM process to a “dynamic” one. For the evaluation of the VIARTM technique a new improved test rig has been developed to perform a new round of trials with the aim to explore the repeatability of the process and the dependence of the performance on the vibration frequency. Furthermore, VIARTM is evaluated for a real RTM part geometry.

Void formation mechanism

In Liquid Composite Molding the problem of the formation of small (air-bubbles) and/ or large (dry spots) voids occurring during fiber impregnation is well known. For an acceptable composite part from RTM process the targets are to eliminate completely dry-spots which destroy the quality of a composite part and to minimise significantly the size of the remaining air-bubbles in the part. In all dry fabrics' impregnation the existence of two different flow paths is evident: the macro flow or inter-tow flow is developed through the micro channels that are formed in random manner by the compaction of the fabrics in the cavity, dominated by the hydrodynamic pressure and the micro flow or intra-tow flow, which is formed when the resin impregnates the fiber bundles, governed by the capillary pressure. When the flow rate is high, air bubble generation can be observed inside the fiber tows whereas the opposite phenomenon (air-bubbles are formed at the micro- channels) occurs when the flow rate decreases.
For the reduction of the void generation the proposed technique is employed for the balancing enhancement of these two simultaneous flows towards a homogeneous flow. The idea of enhancing the intermixing between micro and macro flows using dynamic means is not new. Baig and Gibson [3] and Song and Ayorinde [4], introduced audio frequency flow vibrations to enhance the productivity and the quality of the process. Both teams developed mechanisms that generated high-frequency vibrations to the resin entering the cavity at the inlet gate. Although advantages of these techniques were claimed to be a significant decrease of the filling time, the reduction of voids and a more effective resin impregnation of the fibers these were not confirmed in practice as flow-induced vibrations at the inlet port vanish at the flow front, together with the hydrodynamic pressure.
On the contrary, in the VIARTM technique the mold and the preform are vibrated together during the filling process by applying external mechanical vibrations to the mold. Parameters that could affect the process and need to be studied are the frequency, the magnitude and the direction of the external vibrations with respect to the cavity shape.

Results

For the evaluation of the VIARTM technique a test rig has been built with a flat circular cavity with 340 mm diameter and 3 mm nominal thickness. The cavity was formed using a 3mm spacer between an aluminium and an acrylic flat plates of 25 mm thickness, each.
The transparent acrylic plate has been used as the upper tool in order to track continuously the flow behavior of the resin during the filling cycle using a digital video camera. The resin enters into the cavity from a central inlet gate and overflows from a single outlet gate at the perimeter of the cavity when the filling cycle is concluded. The materials used for the trials were a polyester resin (Norpol 4190) with a rather high viscosity (700 cps @ room temperature) and 7 plies of a plain weave thick glassfiber fabric. To eliminate the deformations from fiber compaction and injection pressure the acrylic plate was reinforced with steel beams, maintaining

a uniform part thickness. The trials were repeated several times in order to ensure the repeatability of the obtained results.

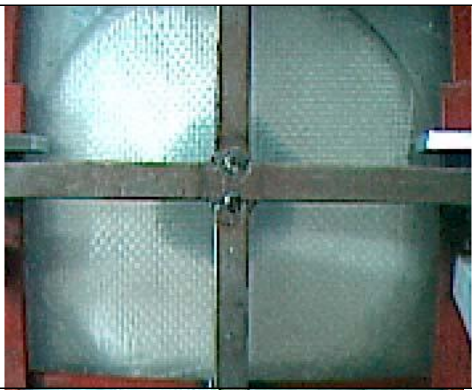
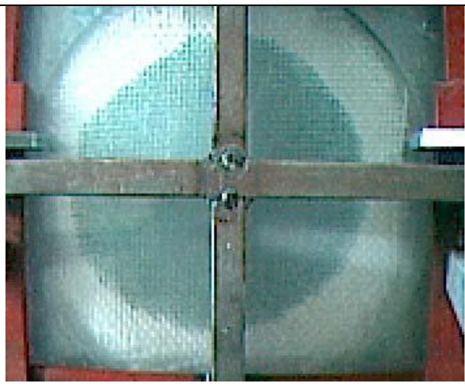
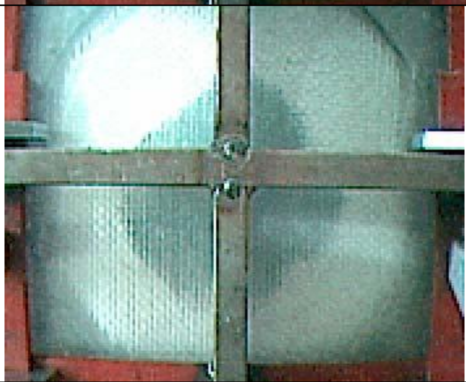
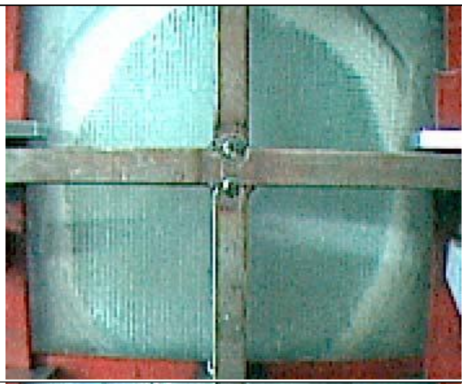
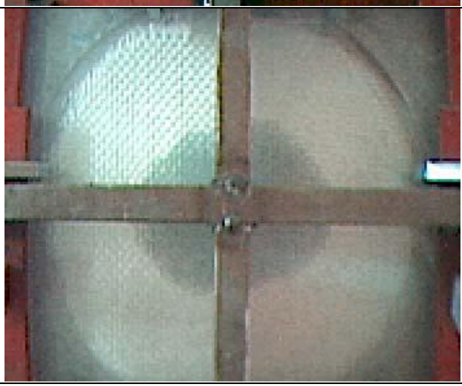
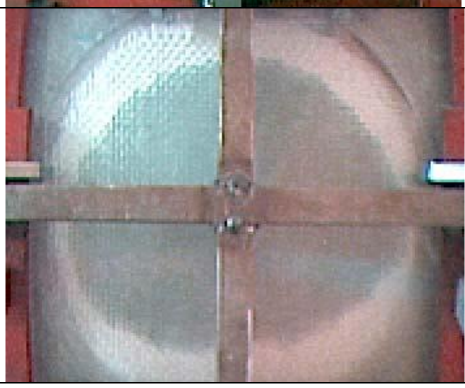
Min	1	5
Case 1 (RTM)		
Case 2 (VIARTM 15 Hz)		
Case 3 (VIARTM 17 Hz)		
Case 4 (VIARTM 30 Hz)		

Figure 1. Filling patterns with RTM and VIARTM during a corresponding filling cycle.

At the present study the mechanical vibrations were generated using a conventional AC motor coupled with a cam mechanism creating a 2 mm vibration magnitude where the excitation frequency may vary from 1 to 60 Hz. To study the effect of different vibrations' directions with respect to the horizontal plane of the cavity, in the 15 Hz case (case 2) in-plane vibrations were applied, in the 17 Hz case (case 3) random vibrations and perpendicular vibrations at the 30 Hz case (case 4). Regarding the snapshots at figure 1 which were taken from the corresponding video captures for each test case some very useful observations can be made. The 15 Hz case 2 proves the faster test case having a difference of more that 2 minutes from the total 7 minutes filling time of the classic RTM case 1. The 17 Hz case 3 seems to be slightly slower than case 2 and as can be seen in the snapshots, at the 5th minute the resin has the same pattern as in the 7th minute in the classic RTM. The 30 Hz case 4 (perpendicular vibrations) was marginally faster than classic RTM. With respect to the full filling cycle, as can be seen in table 1, a significant reduction of 33% of the filling time for the VIARTM case 2 has been attained with respect to the classic RTM test case 1 whereas for the other two VIARTM cases the filling times presented no significant differences comparing to case 1.

Table 1. Experiments for the circular cavity varing the vibration frequencies.

Case	Vibration (Hz)	V_f (%)	Thickness (mm)	Filling time (min)	Flexural modulus (MPa)	Flexural Strength (MPa)
1	-	36.8	3.60	12.15	2016	457.0
2	15	35.6	3.80	8.07	1830	469.9
3	17	36.0	3.75	10.50	1847	452.8
4	30	35.8	3.75	12.56	1753	490.5

In order to explore the effects of vibrations to the mechanical properties of the composite part, five coupons (25x80) from each composite disc were cut and tested in accordance to the ASTM D790 standard. Comparing the flexural strengths of the coupons cut from each disc, the coupons produced in the classic RTM (case 1) and in case 3 (random 17 Hz) presented the lowest values, coupons of case 2 (15 Hz) presented rather higher value whereas coupons of case 4 (30 Hz) presented a 10% increase with respect to the classic RTM (case 1). Comparing the flexural modulus (table 1) a 10% decrease is apparent for the coupons of all the VIARTM cases with respect to the RTM case.

Figure 2. The geometry of the composite part

Figure 3.a. No racetracking was observed

Figure 3.b. No racetracking was observed (right side).

	(right side).	

In order to further explore the behavior of the VIARTM in real geometry parts a long flat part (750 mm) with variable width (from 70 mm to 190 mm) and thickness in the longitudinal direction was selected (fig. 2). The thickness varied from 1.0 mm at the widest edge to 2.5 mm at the narrowest edge resulting in a variable fiber volume fraction from 24% up till 60% using two layers of biaxial (0/90) carbon fiber NCF from Saertex and an epoxy resin heated at 40^{o} C for reducing its viscosity to 200 cps. A central gating and one outlet gate at each narrow edge were used. This specific set-up was chosen as the longitudinal flow was also unbalanced: the most difficult region for impregnation was on one end and the easiest at the other end. To make things worse the fabrics were deliberately cut randomly narrower allowing enough space for racetracking. As the injection pressure was set to 0.4 MPa it was impossible to fully impregnate the part without using vibrations. The resin reached only the easiest outlet gate after 5 minutes and went halfway towards the other direction. On the contrary, using vibrations it took 2 minutes for the resin to reach the easiest outlet gate and 5.2 minutes the second gate. Moreover, no racetracking was observed (figures 3.a and 3.b). Although the mold was made from aluminium no problems were encountered for the installation of the vibration mechanism (at 40 Hz and a magnitude of 1 mm).

Conclusions

An alternative technique was tested in depth for the enhancement of resin impregnation through the fiber preforms in RTM. Applying vibrations at the mold and the preform, resin impregnation is improved especially in the case of high volume of fraction (V_f) and woven fabrics where most of problems in the classic RTM occur. However, further experiments are essential in order to study the resin impregnation in higher V_f (up to 65%) as well as to introduce measurements techniques to get a better insight of the effects of vibrations at the inter and intra fiber tow resin impregnation.

Results indicated that there is an obvious change in the flow of the resin through the fibers indicating that vibrations contribute towards the increase of the capillary pressure and as a result effective resin impregnation through the fibers is attained. However, further studies are essential in order to explore in details the effects of mold vibrations in the mold filling, the resin curing and the final mechanical properties of the composite part.

Acknowledgements

This research was partially funded by the Greek General Secretariat for Research and Development under contract No. 01-PRAXE-107. The author would like to thank also S. Pavlidou, D. Asvestas and T. Vrouvakis for their support on the test rig, the trials and the mechanical properties measurements.

References

1. M.K. Kang, W.I. Lee, H.T. Hahn, "Formation of microvoids during resin-transfer molding process", Composites Science and Technology, 60 (2000), 2427-2434.
2. N. G. Pantelelis and A.E. Kanarachos, Vibration assisted resin transfer molding (VIARTM), 13th International Conference on Composite Materials, China, 2001. (Reprinted as a Society of Manufacturing Engineers Technical Paper, EMO 1-343).
3. B.S. Baig and R.F. Gibson, "Vibration Assisted Liquid Composite Molding", Proc. 11th Annual ESD Advanced Composites Conference, 1995, Dearborn, USA, pp.645
4. F. Song, and E.O. Ayonrinde, "Model development in the simulation of vibration assisted liquid composite molding", Proc. 11th Annual ESD Advanced Composites Conference Dearborn, USA, (1995), pp.203-212.