Pores Parameters Influence on Composites Infusion from both Inside and Outside at Same Time

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***Abstract*-Impregnation quality is critical to the whole composite part. To improve it in a novel way, the infusion from both inside and outside at same time is introduced. Pores parameters are valuable during process for its special structure. To determine pores factors influence on cycle filling time, different strategies of pores depth along the tube, the tubes location and arrangement with pores in the preform are analyzed and studied. Conclusions showed that with greater depth of pores in the preform, the cycle filling time will be shorter. Comparison of filling time of tubes with pores situation strategies indicated that distance from resin source is a key factor to filling process. If the assembly makes the fibers in the preform nearest to the resource or pressure gradient field distribution uniform, the cycle filling time will be shorter.**

Keywords- Impregnation Quality; the Infusion from Both Inside and Outside at Same Time; Pores Parameters, Pores Depth; Tubes Location and Arrangement with Pores

I. INTRODUCTION

As a typical denotation for a family of manufacturing process of composite parts, nowadays LCM is gaining more and more popularity. The quality of the composite component mainly depends on successful filling and cure of the resin within the mould. Many defects exist in large or high thickness parts for it is difficult to permeate. Many researchers have performed some ways to improve it. Such as VARTM (vacuum aid resin transfer molding process), which includes groove type and high-permeable medium type. When placed high permeable medium on the preform, the filling time can reduced some for its assistance in impregnation [1-4]. But as the thickness is larger than a certain value, the medium can do nothing. The grooves on the molds make the flow velocity higher than the permeable medium type [5], but they only carry resin outside the preform, the highness inside the preform cannot be reached. So spots will be leaved in the part. The sandwich materials are utilized to meet some requirements for high thickness, even some grooves or tubes are made on the sandwich to raise the flow rate. But connect of sandwich core with the upper and the lower is not tact, they cannot form a whole part easily. The needled material [6] will be formed into a part via needling, carburization, and resin permeation, etc. It can be used in some special fields for the complex process. So the difficulty in high-thickness part forming is not overcome.

To avoid the likely formation of voids and dry spots, the infusion from both inside and outside at same time (IIOS) is introduced. Due to tubes with pores into the preform, as indicated in Fig. 1, they can provide additional channels for resin flowing [7] and finally improve impregnation efficiency. Resin flow area divided into some subareas, the impregnation is implemented quickly. At same time it can offer fast cycle times and relatively low dry fiber content and void. Moreover, it may overcome the limitation on the large thickness part via traditional infusion. Some complex and large preforms fast permeation and homogeneous preform permeability distribution can be achieved through this method.

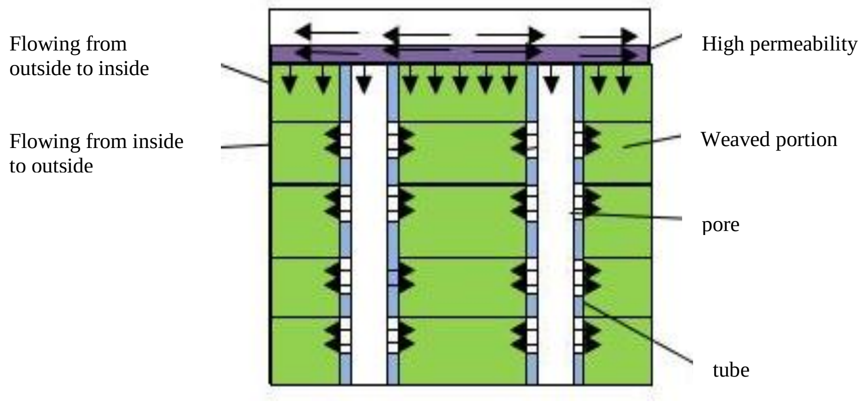

Fig. 1 Diagram of architecture of IIOS

The preform of IIOS is presented in Fig. 2. Tube with pores used in preform and scenario of resin flowing from pores is indicated in Fig. 3.

Fig. 2 Preform of IIOS

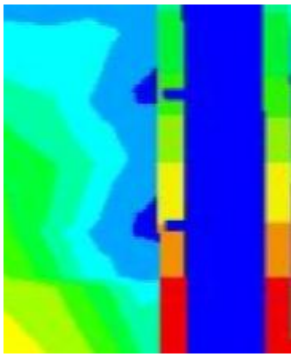

Fig. 3 Scenario resin flowing from pores

From both Fig. 2 and Fig. 3, in presence of pores resin flowing paths diversified, the process of IIOS has good advantage over others especially for part integration capability on large thickness work pieces.

IIOS is a novel way with many parameters influence on the impregnation, such as the permeability of the porous medium, resin viscosity and injection pressure gradient etc. as same as conventional infusion methods. However, different from others, pores parameter is a key factor during IIOS impregnation. They can reduce the filling cycle time and increase the infusion, in particular, in the high depth into preform. On the other hand, the filling cycle time plays an important role in judging the process. The objective of mold filling is to impregnate the whole preform before curing whatever the inner structure design is. More area of fibers saturated within same or less time is valuable [5]. The relationship between pores parameters-pores depth among the tube and tubes with pores arrangement in the preform, and mold filling time is focused on in this article.

Computer simulation, which can predict cavity filling due to its results closely related with the experimental results, can give some effort for constructing and designing different case studies with the most efficient filling strategy. It has great potential to reduce the trial and error times and obtain the accurate and appropriate data for the process to optimization [8, 9, and 10]. Some research studies proposed to address the relationship between pores parameters and mold filling time during impregnation based on PAM-RTM developed by ESI. PAM-RTM is a numerical code based on non-conforming finite element methods. This code was used to study the position of flow front through fiber reinforcement for 3D isothermal flow and reasonable agreement was obtained with experimental results.

II. SIMULATION CONDITIONS

IIOS utilizes a highly permeable layer to quickly distribute resin across the surface, then the resin flows through the thickness of the preform partly and others will be delivered to the tube position. The tube is a cylinder with some pores on its wall. And moreover, its permeability should be higher than the high permeable medium. Therefore resin will fill the tube firstly as soon as it reaches to the tube gate and some of it will permeate from the pores and be invasive near fibers.

Taking fiber content fraction into account, the tube inner radius should be suitable, and only the permeability value needs to be greater than the medium.

Simulation conditions are as follows:

The preform size is 36x36x17 mm^3, 9 tubes with 4 mm inner radius and 6 mm outer radius. And the space between two tubes is 12 mm. Pores were preset along the tube. Five pores layers arrangement were performed and four pores with 1 mm radius in every layer. Distance from the top to the first layer is 2.5 mm and between every two layers there is a 3 mm gap. Four gates were located in the middle of every four tubes and four vents were placed in four corners. The model is shown in Fig. 4:

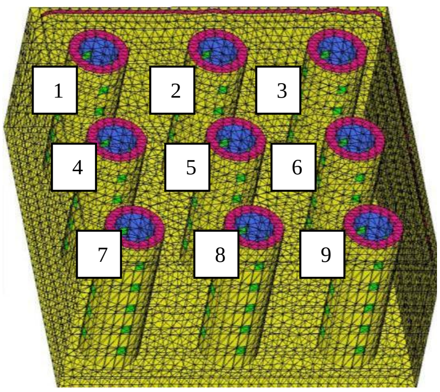

Fig. 4 IIOS simulation model

And the permeability value and process parameters are presented in Table 1:

TABLE 1 PERMEABILITY AND PARAMETERS

Items			infusion
Permeability (m^2)	Weaving fiber	thickness	3.2E-11
		area	1.5E-10
	medium	thickness	1E-9
		area	1.3E-8
	tube		5E-7
	pore		1.25E-8
porosity	medium		0.85
	Weaving fiber		0.4
Viscosity of resin(Pa s)			0.1
Pressure Difference(MPa)			0.1

Boundary conditions are [11]: (1) fixed pressure at the injection inlet; (2) atmosphere pressure along the flow front curve; (3) no slippage at the mold surface.

And some assumptions are as following [12]:

(1) the weaving is isotropic; (2) the viscosity of the resin is constant; (3) all is done under isothermal atmosphere; (4) no solidification occurs; (5) no deformation takes place during molding filling phase.

The permeability of tube and pore can be calculated by cylindrical equivalent permeability equation:

$$K_t = R^2 / 8 \tag{1}$$

$$K_p = R^2 / 8 \tag{2}$$

Where, K_t, K_p is permeability of tube and pore, R, r is inner radius of tube and pore respectively.

III. RESULT

A. *Influence of Pores Depth Distribution along the Tube on Mold Cycle Filling Time*

1) Single Layer Pores Depth Distribution on Single Tube:

Only single layer pores were preset on the central tube (No. 5) and no pores on other tubes. Five strategies were indicated in Fig. 5.

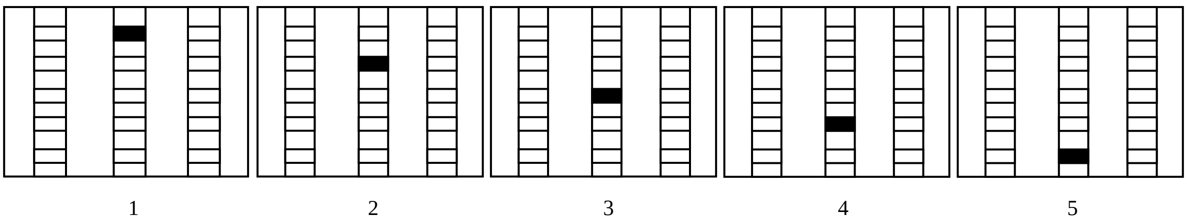

Fig. 5 Schematic of single layer pores on single tube

The resin flow molding cycle graph of five strategies can be obtained in Fig. 6.

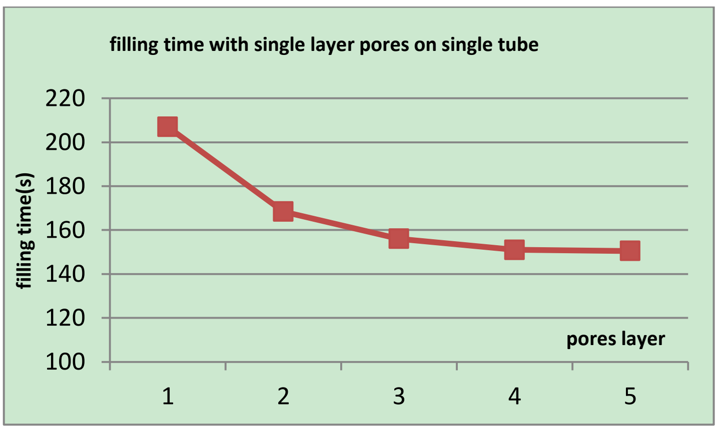

Fig. 6 Diagram of resin flow molding cycle with single layer pores depth variation

In Fig. 6, it is clear that the mold filling time decreased from 208 s to 149 s with increasing single layer pores depth. On the upper tube, pores location deeper, the filling time curve fell sharply. But on the lower tube, pores location deeper, the filling time curve fell gradually.

2) Single Layer Pores Depth Distribution on Some Tubes:

Place single layer pores of all the tubes, five strategies were shown in Fig. 7.

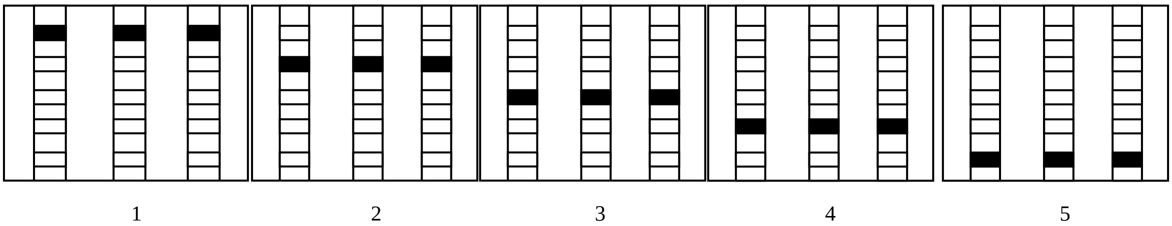

Fig. 7 Schematic of single layer pores on all the tubes

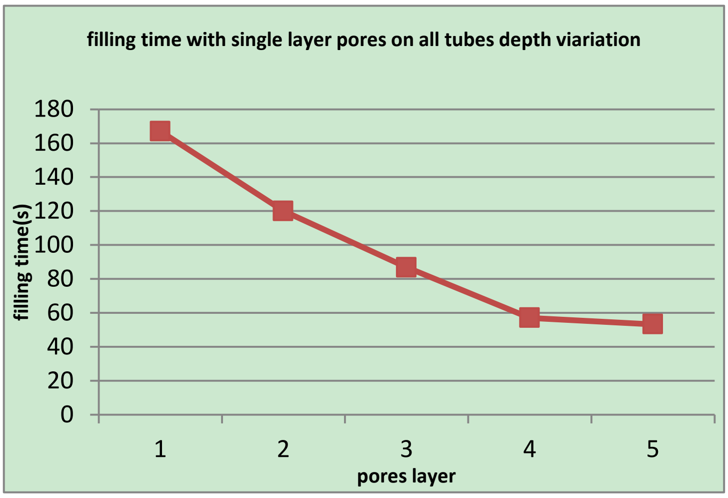

Fig. 8 Diagram of resin flow molding cycle with single layer pores depth variation

The resin flow molding cycle graph of five strategies can be obtained in Fig. 8.

In Fig. 8, the graph shape is similar as Fig. 6, which is apparent. When the pores location depth increased, filling time declined from 165 s to 52 s. And on the upper tube, it dropped rapidly, while on the lower tube, it dropped slowly.

B. Tubes Arrangement with Pores in the Preform

Pores preset on the tube wall, the resin can flow from the pores to be invasive near fiber. Therefore, the pores can be regarded as resin resource. And in case of pressure gradient, the pores changed the pressure variation even the whole pressure field distribution. Different arrangement of tube with pores in the preform will lead to different flowing situation. Some simulation researches were carried out about influence of different tubes arrangement with five layer pores in the preform on the filling time.

1) Relationship between Single Tube with Pores Location in the Preform and Mold Filling Time:

There are three position considered among all the tubes for only single tube with pores. One is in the centre of the whole preform-No. 5, one is in the corner-No. 1 selected and one is on the edge-No. 4. Three test cases are shown in Fig. 9:

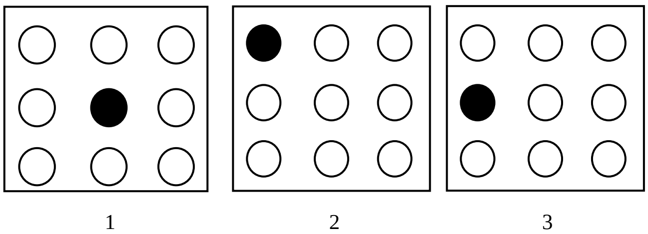

Fig. 9 Schematic of single tube with pores position in the preform

The results are listed in Table 2:

TABLE 2 MOLD FILLING TIME OF SINGLE TUBE

Position	No.5	No.1	No.4
filling time(s)	114	405.4	134.7

Different filling time can be learned from Table 2. The case of only the central tube in the preform takes the shortest time, case of corner tube takes the longest time, and case of edge tube takes less time.

2) Relationship between Mold Filling Time and Configurations of Three Tubes and Five Tubes with Pores in the Preform:

The schematics of tubes with pores location are presented in Fig. 10 and Fig. 11 and the results can be seen in Fig. 12 and Fig. 13.

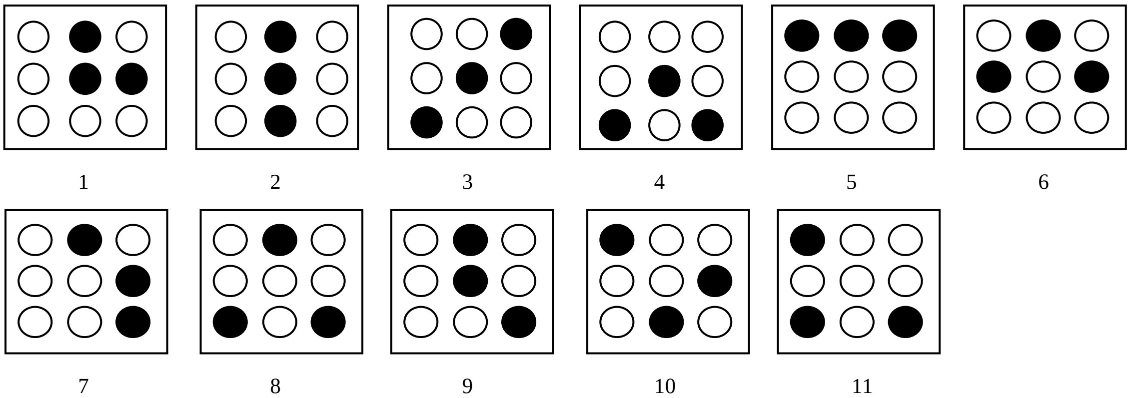

Fig. 10 Configurations of three tubes with pores in the preform

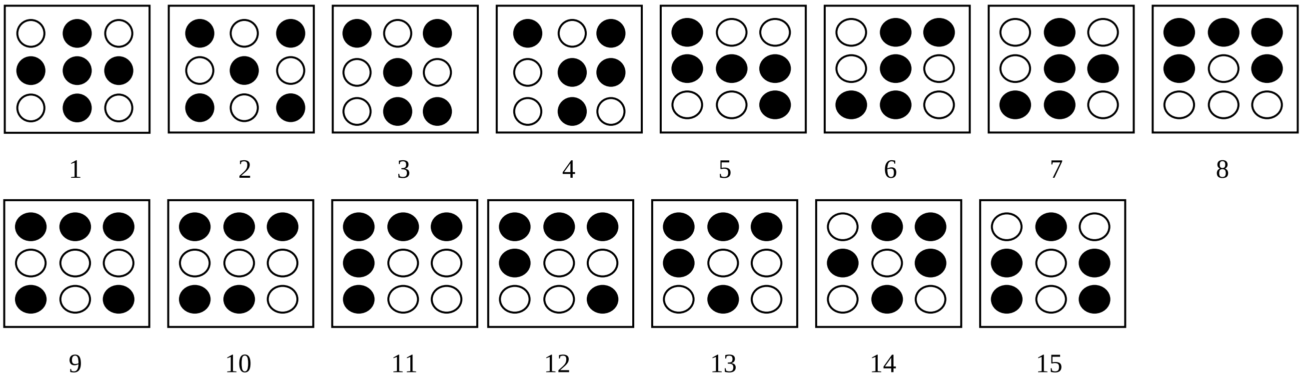

Fig. 11 Configurations of five tubes with pores in the preform

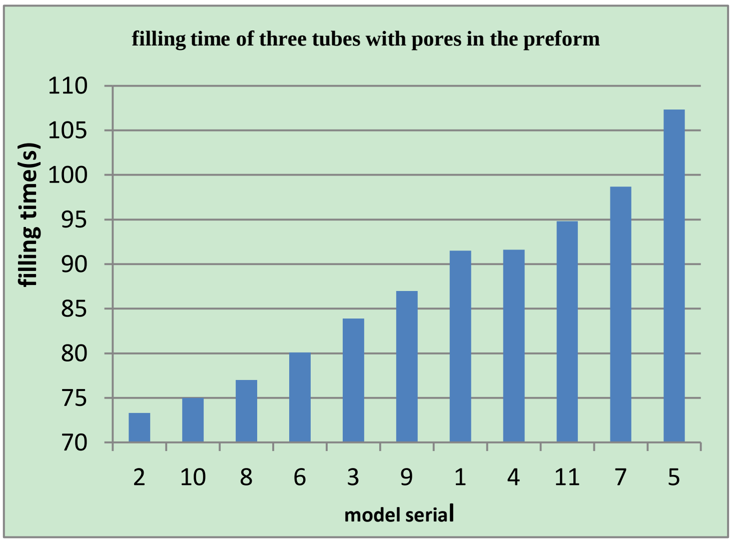

Fig. 12 Mold filling time of three tubes with pores configuration

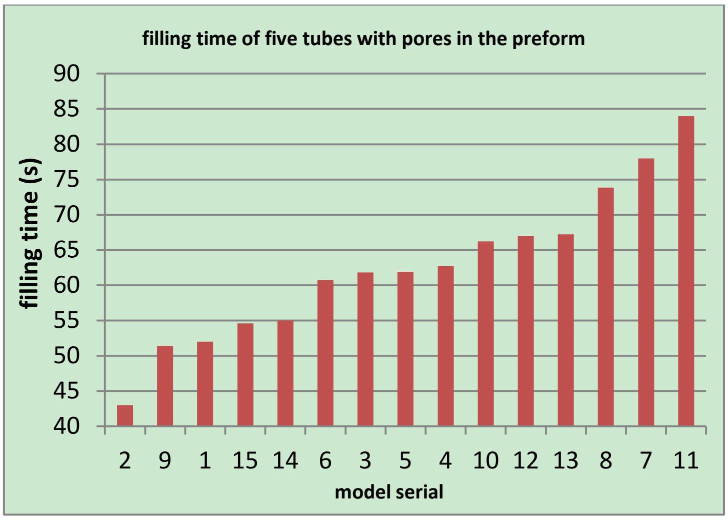

Fig. 13 Mold filling time of five tube with pores configuration

From Fig. 12, the configuration including tubes with pores of No. 2, No. 5 and No. 8 took shortest time among all the three tubes assembly; the longest was the configuration including tubes with pores of No. 1, No. 2 and No. 3.

From Fig. 13, the configuration including tubes with pores of No. 1, No. 3, No. 5, No. 7, and No. 9 took shortest time among all the five tubes assembly; the longest was the configuration including tubes with pores of No. 1, No. 2, No. 3, No. 4, No. 7.

IV. ANALYSIS

High permeability medium acted on resin flow distribution and made resin cover the upper surface on the preform. It is too fast to account for the total filling time especially for thick parts. The filling time mainly depends on through-thickness infusion. IIOS provides additional courses and paths for resin flowing and speeds up the whole part permeation as compared to conventional infusion. These courses and paths are pores and tubes with pores. The purpose of mold filling is to track different flow paths and cover the greatest possible porosity area in the preform architecture, in respect of the flow imbalance provoked by the gaps. Consequently, the pores parameters are valuable and have great effect for IIOS.

A. Analysis for Pores Depth Distribution and Filling Time

As mentioned previously, filling time decreased with the depth increasing. And high filling efficiency will be achieved when pores distribution is on the lower tube. It can be expressed as follows:

$$P = \rho g h \tag{3}$$

$$\mathrm{v} = \sqrt{2\mathrm{gh}} \tag{4}$$

Where, P is the pressure of h depth, ρ is fluid density, g is gravity acceleration, v is fluid velocity.

The above formulas came from fluid pressure theory and energy conversion theory. According to this generally acknowledged principle, the fluid pressure of one point in the tube is related to the depth of it. With the position down, the pressure will be strengthened. Pores placed deeper, the velocity of fluid flowing from it will be greater. It can be obtained by Equation (4).

Resin flows fast from the medium on the upper tube especially close to the medium. If pores are placed at the location, the infiltrated rate of resin from it is equivalent or lower than the former. Thus pores have a lower effect and cannot play active for the resin flowing and permeation in the preform. However, resin flowing slows down farther from the medium through thickness while resin flowing rate from pores will be greater. As the latter is greater than the former, pores began to serve as their speeding up permeation action. In particular, pores on the lower part of the tube, the velocity rate is higher than on the upper, so resin from the pores can quickly permeate the fiber near them and even farther deeper in the preform, which is difficult for traditional infusion. It will have great potential to reduce the mold filling time and enhance the impregnation efficiency of overall part.

If pores are located near the end of the tube, that is, they are close to the mould bottom, though the flowing rate speeds up, and infuses the near fiber, it cannot act for fibers beneath the pores.

B. Analysis for Tubes Arrangement with Pores in the Preform

From Table 2, Fig. 12 and Fig. 13, the arrangement and location of tube with pores in the preform play a more active role in the mold filling time.

Pores as pressure releasing vent for tube full with resin fluid changed the whole pressure gradient in the preform. As is known, when the pressure field is uniform, which is superior for resin flowing, the flowing domain will be uniform, too. Pressure variation or unbalance will control the flowing movement. The gradient will steer the resin flowing from high pressure domain toward the lower pressure domain. On the other hand, pores can be regarded as small resin resource. Resin progression profile on the level is a round with same permeability in every direction, impregnation time at which fibers farthest from the resource infused by the resin will depend on the whole mold filling. Namely, the mold cycle filling time relies on pressure gradient field and resin flowing distance in the preform.

When the tube with pores is in the center, corners on the bottom will be the farthest place, and lengths from the resource to them are same. As the tube with pores is in the corner, the corner towards this tube on the bottom will be the farthest place and it will be the latest reached position, which is the decide parameter to the filling time. As for pressure gradient, the center position makes equivalent pressure field and it makes the uniform velocity and finally resin will give out from the four vents on the bottom. On the other side, tube with pores in the corner position leads to unbalance pressure field and different velocity toward different direction and then the opposite vent is the only vent allowing resin flowing out.

Among the combinations of three tubes with pores, the second took the shortest time to fill the mold. Because three tubes with pores standing in the center and the symmetry axis, caused the same resin circuit in the two parts divided by them, moreover, the farthest distance resin flowing is the shortest among all the combinations. Pressure gradient distribution was same and so the flow rate driven by it was same, too.

When five tubes with pores were in presence in the preform, the position of one in center and others in four corners was superior. It will not only deteriorate the even pressure field but also provide resin resource for four corners on the bottom, which are difficult and latest places to reach according to the conventional infusion. Resin pours out from pores and gives a perfect flowing radiate to surrounding areas. It reduces the filling time and helps the impregnation quality. No. 11 combination cost the longest time among the combinations. It broke the pressure equilibrium and got unbalance flowing domain and slowed resin permeating rate. The corner without resin resource was the latest place to reach and the resin flowing circuit was the longest among five tubes with pores distribution.

V. CONCLUSIONS

Pores deeper location on the tube, bring larger pressure and then greater flowing rate, according to the liquid pressure principle and energy conversion theory. Accounting for economics, pores should be preset the lower part of the tube. But if they are close to the mould bottom, the efficiency would be lower.

Location of tubes with pores in the preform plays critical roles during process. Comparisons filling time of three tubes with pores assembly and five tubes with pores assembly, showed that the farthest distance resin flowing in the preform and pressure gradient field equivalent are key for filling process. While the farthest distance is shortest among the arrangements and the uniform pressure gradient distribution field is achieved, the filling time will be less.

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