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Use of medial axis to find optimal channel designs to reduce mold filling time in resin transfer molding

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ABSTRACT

In Resin Transfer Molding (RTM) process, pre-designed channels branching out like runners from the injection port can be used for faster resin distribution and impregnation as compared to traditional single gate injection to reduce the mold filling time. To search for the optimal channel design for maximum fill time reduction, the Medial Axis (MA) of the part surface is defined. Next, a methodology is developed to search for the topology of the MA using Finite Element based mold filling simulation software. The MA location is corrected for a part with non-homogeneous fabric permeability. Finally, some case studies are presented to illustrate the effectiveness and accuracy of the channel design approach for RTM with the objective of minimizing fill time, when fabricating composite parts that contain complexities in both the geometric features such as compound curvatures and corners and in material properties such as non-homogeneous and highly anisotropic fiber preform permeability.

1. Introduction

1.1. Resin Transfer Molding (RTM) process

In Resin Transfer Molding (RTM), dry glass, carbon or aramid fiber preforms are placed inside the mold cavity of the net shaped part to be manufactured. The rigid mold is closed and clamped, compressing the fiber preform to the desired thickness. Thermoset resin from a pressurized reservoir is injected through the openings in the mold walls called as the injection ports as shown in Fig. 1. Resin injection continues until all the air between fibers of the fiber preform is displaced out of the mold through vents that are usually located on the boundary of the mold wall. The injection port is closed when the resin arrives at the vents. After the resin cures, the part is de-molded. RTM is widely used in manufacturing high fiber volume fraction composite parts that contains complex geometry features and requires high quality surface finish [1].

During the resin injection step, the most important objective is to fully saturate the fibrous reinforcement with resin, displacing all air and volatiles out through the vent to manufacture a void free part. To this end, proper venting schemes are needed so that no voids are trapped within the part. Usually this can be achieved by predicting the resin flow pattern within the mold cavity and placing vents where the resin arrives last [2–4].

Second important objective of this process is to reduce the time it takes to fill the mold with resin. This will increase the production rate and reduce manufacturing costs and also ensure that the empty spaces between the fibers are saturated before the resin gels and is unable to move due to the cross linking of the polymer chains. Two strategies, usually in combination, can be applied to reduce the fill time. First, high injection pressure can be used to increase the resin flow rate through the injection port or gate. This will obviously be limited by the stress or stiffness limits of the mold (or inserts like sandwich cores) and available injection hardware. Thus, this is a brute force method that can be employed up to certain limits after which it will become prohibitively expensive. Second, the injection location or locations may be optimized to evenly distribute the resin within the mold cavity. To improve on this approach, one can use multiple-gate injection systems, and arrange gate locations on the mold wall optimally to reduce fill time [5]. Also, one can create a resin distribution network to speed up the filling process. This can be achieved by either leaving gaps along one or more of the part edges to promote racetracking [6] or fabricating channels within the mold and connecting these channels with the injection port. The former is simpler but the distribution network is hardly optimal and would be difficult to reproduce from one part to the next. The latter allows one to achieve a controlled and a larger flow rate through the gate under

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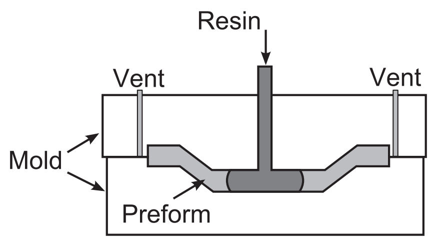

Fig. 1. Schematic of Resin Transfer Molding (RTM) process.

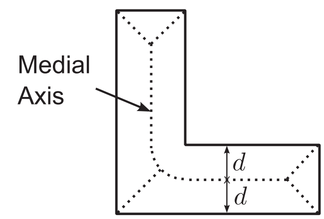

Fig. 3. Medial Axis definition based on distance for an "L" shape part.

constant pressure, and therefore reduce the filling time significantly, albeit at a cost of more involved flow patterns to be handled by the venting scheme [7]. For example in Fig. 2a, channels are machined within the insert on the surface of the core material when processing sandwich structures for faster flow. In Fig. 2b, the 3d printed mold is pre-designed with open channels for a faster filling time so the part is fully saturated with resin before it gels. To effectively benefit from these channels in reducing fill time and prevent void formation, the optimal topology of these channels needs to be determined.

For composite shell parts using isotropic or quasi-isotropic, homogenous fabrics of uniform thickness, it is straightforward to place the injection port at the center of the mold surface. If the part is symmetrical, the channel network can be machined along the lines of symmetry. Ideally, this strategy ensures resin arrival at the vent along the boundary in significantly shorter time than single injection gate. However, this task is not easy or intuitive if the geometry of the part is too complicated to find apparent symmetrical lines, or because the complexity in material property such as non-homogenous fabrics or fabrics with highly anisotropic permeability result in more complicated resin flow patterns.

Thus the objective of this paper is to develop methodologies to find the optimal topology of injection channels connected with injection gate for RTM process to reduce fill time. The method developed herein can deal with parts that include geometry and material complexities such as non-homogeneous material property and fabrics with highly anisotropic permeability. However, as RTM is usually used for shell-like composite parts manufacturing, through-thickness direction of mold flow is ignored and only in-plane mold filling pattern using effective in-plane permeability are addressed. The extension of this method to thick-walled parts with through-the-thickness non-homogeneities would be non-trivial [8], and more criteria have to be designed when through-thickness direction flow needs to be considered.

1.2. Previous work

Previously, few researchers have studied the channel topology and location optimization for faster resin infusion in LCM processes. Genetic algorithms have been used to optimize the topology of the injection channel [9,10], but the solution returned from this method does not always guarantee the air and volatiles are displaced towards the boundary, and therefore the resulting venting scheme can be complicated. Distance based Medial Axis concept, which is defined as the loci of points that have at least two distinct closest points to the boundary (Fig. 3), combined with level set theory and Fast Marching Method was used to generate the topology of injection channel [11]. However, certain drawbacks with this distance-based method limits its use for general injection line design and optimizations. First, generating the distance field to the boundary using level set theory and Fast Marching Method is extremely difficult when applied to curved or multifaceted 3D part surfaces without discretizing them. However, the discretization of the part surfaces brings the second drawback of the distance-based method: extracting medial axis topology by calculating the second derivative of the distance field is difficult and usually inaccurate. Third, the methodology only applies for isotropic material or quasi-isotropic material without thickness variations along the part surface, and the parts that use complicated and varying material properties cannot be addressed. Therefore, new method has to be designed to overcome these limitations.

In this paper, we modified the definition of the Medial Axis of the part surface based on the mold filling pattern to accommodate the RTM processing practices. Next, a method of separating the part surface into sub regions based on the flow pattern, which is defined as Voronoi Diagram is used to find the fill-time based Medial Axis of the part surface [12,13]. For parts containing preforms that have different permeability and/or thicknesses in different sections (non-homogeneous part), the location of the searched medial axis is further optimized based on the fill time field returned by the Finite Element based software. The last section illustrates examples to demonstrate the effectiveness and robustness of our methodology in finding optimal channel topology for parts that contains complexity in both geometry and in material property.

2. Medial axis definition based on the fill time

In computer graphics theory, medial axis is defined based on distance and is the loci of points that have at least two distinct

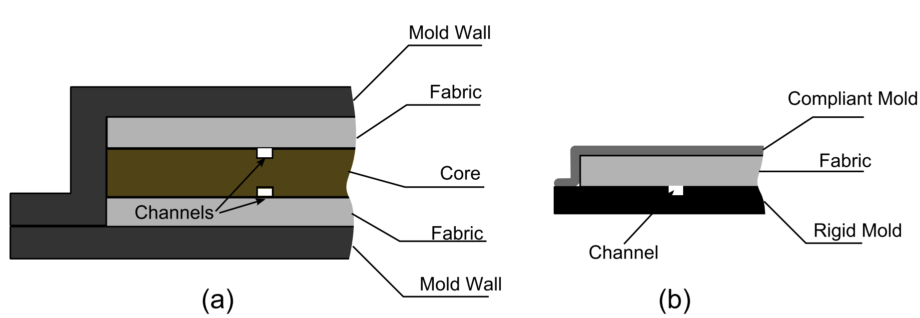

Fig. 2. Channels used in RTM processes to reduce mold filling times by creating a resin distribution network: (a) sandwich structures where channels are machined on the core material, and (b) channels are pre-printed on the inside surface of the mold wall.