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Fast and reliable gate arrangement pre-design of resin infusion processes

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In Resin Infusion (RI) processes, the flow front shape progression is mainly conditioned by the initial arrangement of the injection and vent gate line locations and the permeability of the preform. The main goal of this research is to develop fast (not necessarily physically-based) tools at the pre-design stage that could help designers with a suitable arrangement of injection nozzles and vents. This pre-design should then be validated by full-physics simulation or lab test, but could be considered as a suitable starting point in the designing process. RI simulators could eventually be equipped with this kind of pre-design tools as a means to provide very fast (at the cost of a somewhat reduced accuracy) designs. In the approach here presented the pre-design tools are based entirely on geometrical assumptions. Under these hypotheses, and assuming that the vents will be placed on the boundary of the piece, the distance field from this boundary will provide useful information on the optimal position of injection nozzles. In this work, inspired by the concept of medial axis, we propose a numerical technique that computes numerically approximate distance fields by invoking computational geometry concepts that can be used for the estimation of the gate arrangement in infusion processes. Detailed descriptions of the developed algorithm, together with first proofs of its performance are given.

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1. Introduction

Resin Infusion (RI) processes are one of the common techniques used in the industry for large composite parts production. This technique uses negative pressure to drive the resin into a laminate. Preform is laid dry into the mold and the vacuum is applied before the resin is introduced. Once the difference between fluid pressure levels at the inlet and the outlet is achieved, resin is sucked into the laminate via placed tubing. Fig. 1 (left) shows a diagram of this process. Process designers introduce a resin inlet channel network in the areas where the cosmetic quality of the piece is not relevant; see Fig. 1 (left). Resin infusion processes are usually slow due to the low-pressure gradient and the size of the geometries to infuse. For this reason, the channels are necessary to reduce cycle times. Using it as in Fig. 1 (left) the filling of a boat hull with 11.8 m length can be completed in 195 min. Spiral blind (pipes), has been commonly used to build these channels, Fig. 1. These components are hollow tubes made with a plastic strip rolled in a spiral shape. The resin flows much faster inside the pipe than inside the preform. When the resin fills the channel, it begins to permeate the preform through the holes left by the spirals.

Nowadays, the problem comes to optimize the shape and allocation of these channels. In general, optimization algorithms proposed in the literature have been based on Finite Element (FEM) simulation coupled with genetic algorithms, mainly focused in RTM problems. These algorithms have a high computational cost (hours) to find an acceptable solution. Researchers have been working intensively to propose alternatives to the standard FEM simulation based genetic algorithms. In [3] the use of neural networks was proposed to replace the simulation, meanwhile in [4,11] the distance between the nodes of the mesh was used as a filling-time approximation. In [2,6] gradient-based methods were introduced to improve genetic algorithms. In [5] a proposal was made to replace the genetic algorithm for the "*branch and bound*" technique. Another possibility that was analyzed in the literature was based on a map-based exhaustive search [9], where the probabilities of all the possible node vents were computed. This algorithm was combined in [8] to the "*branch and bound*" technique. The objective function was based on the reduction of the filling times, prevention of dry areas, homogeneous curing, etc. These indexes are known as "Process Performance Index (PPI)". In the

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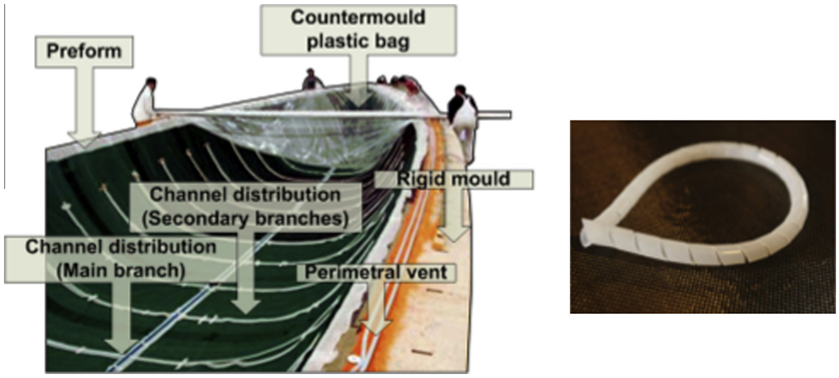

Fig. 1. Resin Infusion Process (left). Spiral blind, pipe, (right). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

optimization algorithms proposed in [1,4–6,8,9], the parameters used on them were the filling time and the prevention of dry areas. In [12] an index with the same objectives than the ones proposed [1,4] was introduced. However, dry areas were prevented by the correct orientation of the flow front with respect to the vent. This index was improved in [13] with the inclusion of the incubation time parameter.

Most of the optimization algorithms proposed in the literature focused in solving the inlet/outlet location in RTM [1–11]. A few exceptions [10,11] addressed the optimization of flexible countermould processes that involve complex shapes as shown in Fig. 1.

The aim of the optimization algorithms in LRI processes is the same than in RTM: the flow front must reach the vent (in LRI, the mold contour) at the same time and the filling time must be reduced as much as possible. To the author's knowledge, the literature does not offer tools to compute efficiently such a problem. The main reason is that in LRI processes, the inlet adopts complex configurations and accurate optimizations require too many direct solution of the filling process for each tentative inlet arrangement. However, the industry and, in particular, expert teams have the ability to design the resin channel distribution and getting amazing results. These expert teams use trial and error and their large experience, to obtain the optimal resin channel distribution, like the one depicted in Fig. 1.

The aim of our previous works was to obtain a tool to compute the resin channel distribution using the expert team criterion [14,15], in an automated way and with acceptable computational costs. In these works, the optimal channel distribution was divided in two parts: the "*main branch*" and "*secondary branches*", see Fig. 1. Main branch was obtained by applying the Delaunay triangulation to the vent (the mold contour). This algorithm provides the vertexes to be tangent with at least three contour points, see Fig. 2.

This *Main branch* was improved in [14,15] by means of the same concept: the use of secondary branches. Therefore, each secondary branch is equidistant to at least two contour nodes. Then, the bisector between these two nodes, passing through the tangency circle center, intersects in a main branch point. The secondary branch was defined from the intersection point of main branch to the circle center that ensures the tangency, see Fig. 3.

The main objective of this work is to develop fast numerical tools based on computational geometry concepts and use them as processing indicators to be used in pre-design stages. These numerical indicators are computed based on the naïve idea that as soon as the flow front is equidistant to the mold vent, it will reach simultaneously the vent and consequently the filling process will be optimal. Obviously, in general, such a solution does not exist if we proceed in one-shot with all the channels connected and simultaneously triggered. However, the optimal inlet gate arrangement can be searched for maximizing such criterion.

2. Objective and problem outline

LCM simulation is computationally expensive because it needs an accurate solution of flow equations during the mold filling process. Nowadays large computing times are not compatible with standard design and optimization techniques (many-query

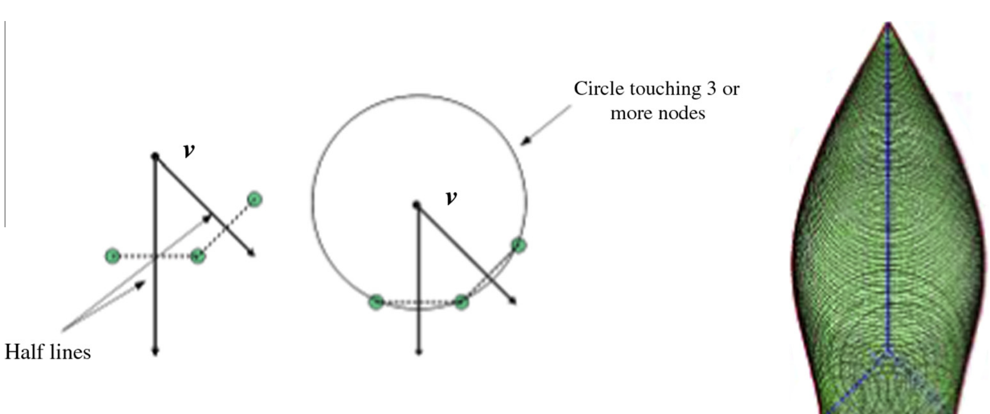

Fig. 2. Main branch computation (Left). Example of a Boat (Right). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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