OPTIMIZATION OF RESIN TRANSFER MOLDING PROCESSES USING SIMULATIONS COUPLED WITH EVOLUTIONARY ALGORITHMS

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Abstract

Today's RTM processes suffer from high scrap rates and difficulties during the process design phase. Simulation based process optimization can accelerate this development process. Coupling simulations with numerical optimization in highly automated programs can deliver optimum process parameters. Essential for automation is the precise and appropriate definition of the desired objectives. Beside complete mold filling and minimal filling time, a criterion concerning the matrix quality can be integrated. Since flow front confluences have a major influence on the matrix porosity an approach to include it into the optimization has been developed and is presented here.

1 Introduction

Today's development of structural parts manufactured by Liquid Composite Molding (LCM) is still based on time consuming try and error procedures. Numerical flow simulation software can contribute to design parts more efficiently and additionally reduce tooling costs. Usually, optimization is performed heuristically by modifying the processing parameters like gate and vent locations as well as the injection pressures, injection fluxes and their timing. The more complex a part geometry becomes the more parameter combinations become possible and less clear the process becomes on an intuitive level. So, using automated optimization many time consuming simulations can be run without human interaction. Several researches have coupled evolutionary optimization strategies in order to automate this process [1,2,6] (figure 1).

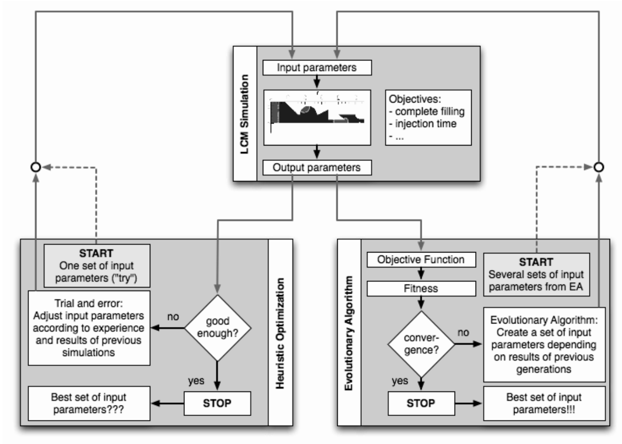

Fig. 1. Comparison of process optimization using an heuristic approach or evolutionary algorithms

An advanced integrated simulation and optimization approach is presented in this contribution that can improve process development significantly. Particularly, it takes flow front confluences into account that influence the matrix porosity [8]. Therefore a flow simulation software developed at the Center of Structure Technologies [7] has been coupled with an evolutionary optimization library [4].

2 Heuristic optimization

For geometrically simple parts an intuitive process optimization can result in significant improvements. The example of a hockey stick manufactured in an RTM process illustrates this. In the original process (figure 2) a single gate is used and a constant volume flow is applied. After 360 s the component is filled and a high maximum pressure of 18 bars is reached.

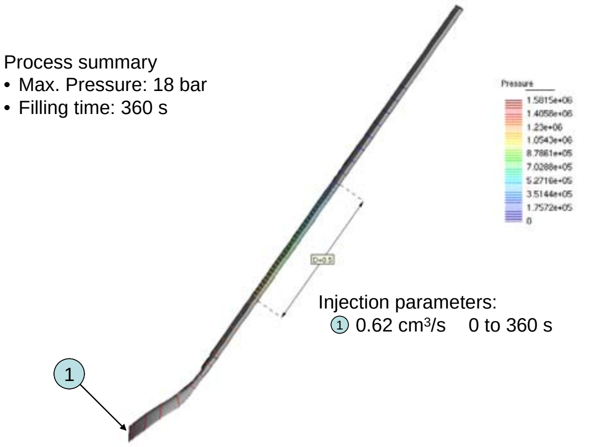

Fig. 2. Original impregnation process

For this part an empirical process optimization has been performed aiming at lower injection times and lower injection pressures, simultaneously. Therefore a sequential injection strategy has been chosen, shortening the effective flow path of the resin. After 40 s gate 1 is closed and the gates 2 and 3 are opened. Thus an injection with a maximum pressure of 8 bars and a filling time of 120 s are achieved (figure 3).

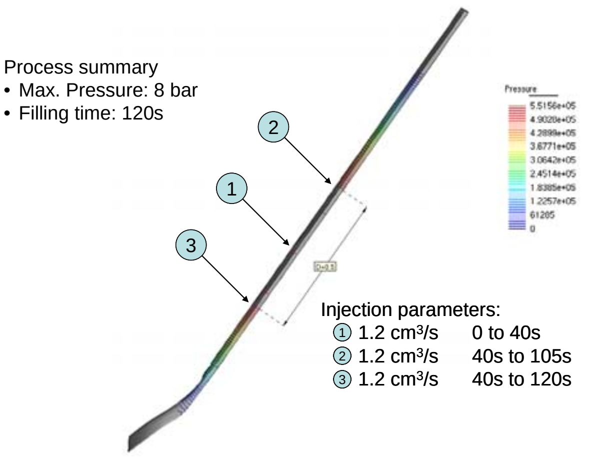

Fig. 3. Optimised impregnation process

3 Automatic Quality Assessment

For all optimizations a target definition is essential. In the case of evolutionary optimization algorithms a fitness function is used. It is generally composed of weighted fitness portions for each design objective and each constraint. Various process parameters can be considered:

- process related, e.g. fill time and fill degree
- quality related e.g. flow front confluences or flow front velocity
- or cost related e.g. maximum pressures and thus tooling expenses

Each of these values is assessed by comparing it with a desired value or range and an appropriate fitness portion is given. All simulations run by the evolutionary algorithm are evaluated, forming a single fitness value rating the quality of the process parameter set on which the simulation is based [3].

The appropriate definition of this fitness function is the Achilles tendon of process optimization. For instance the final fill degree must always be very high. Emphasizing low the fill time will on the one hand lead to fast filling processes. On the other hand low filling times can be achieved by high flow front velocities or configurations with large confluence zones. Both will result in rather poor matrix quality. Reducing the filling time is an important target, yet to enhance the quality of parts manufactured in LCM processes, it is important to balance process relevant aspects and quality aspects in the early process development stages.

4 Optimization of process parameters

Several process parameters can be modified by the Optimization. The most important ones are the gate and the vent locations. Beside these the injection pressures and the injection fluxes, and their timing are of high relevance. Additional paramteres like local temperatures may be taken into account, too.

Modelling of inlets can be critical if only few nodes are taken for each gate. In this case the effective gate size depends on the size of the connected elements [5]. It influences the filling time and the local pressures significantly. To avoid mesh dependant results the effective gate size must be kept constant at all locations. This can be achieved by local remeshing around the chosen gate location or by picking several nodes for each gate.

5 Reduce matrix quality in confluence zones

As a quality related criterion confluence area of the flow front are considered. Each time a node at the flow front gets filled the confluence angle is calculated. Therefore the flow velocities of all elements connected to the node are used (figure 4).

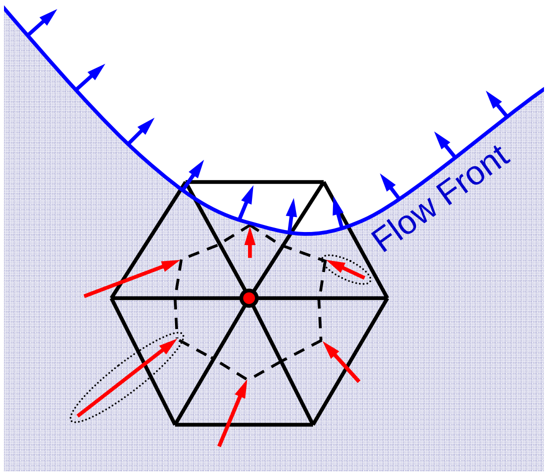

Fig. 4. flow velocities in elements connected to completely filled flow front node

First, the angel between each pair of velocity vectors is determined. Then, the confluence angle is scaled with respect to the norm of the flow velocities.

For illustration the two velocity vectors in figure 4 that are encircled by the dashed lines show a confluence angle of 115° which can be calculated by basic vector geometry operations. Obviously the confluence of case 1 in figure 5 with a velocity ratio of 3:1 is weaker than case 2 where both velocities are of the same magnitude. So the calculated confluence angle is scaled by a degradation function depending on the ratio of both velocities.

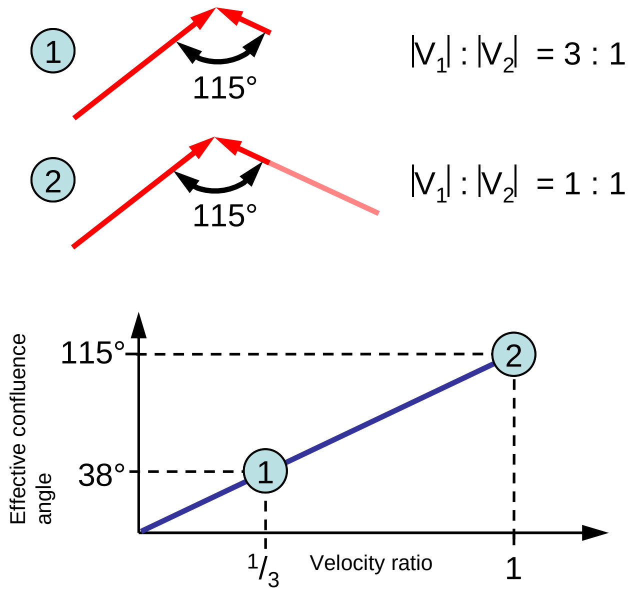

Fig. 5 effective confluence angle by linear scaling depending on the flow velocity ratio

For evaluation of the fitness portion an overall confluence area is calculated. Therefore nodes in a confluence zone are indicated by effective confluence angles above α_{krit}. α_{krit} must be chosen appropriately, and an angle of 40 ° was found to be reasonable. All confluence nodes contribute to the total confluence area, scaled by the estimated cross sections.

$$A_{Conf} = \sum_{n} (V_{node})^{2/3}$$

n: number of nodes
V_i: control volume of node i

6 Process Optimization Results

A complex shell component shown in figure 6 has been considered. An initial process with one fixed vent and two fixed flux gates was simulated as reference case. Then, a process optimization has been performed that could reposition the gates and the vent anywhere on the component and vary the gate’s flux rates.

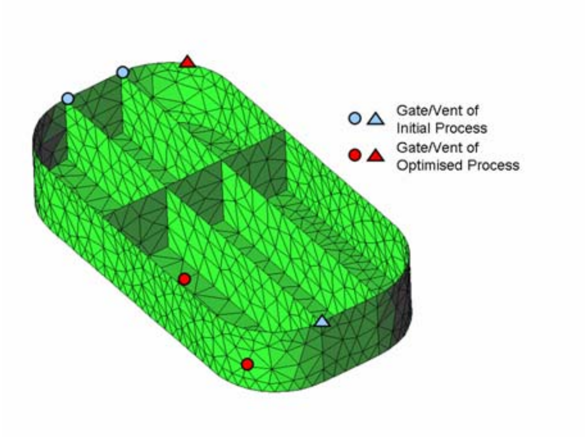

Fig. 6. Initial and optimized locations of gates and vents

Figure 7 shows the isobars of the final pressure distribution of the optimized process.

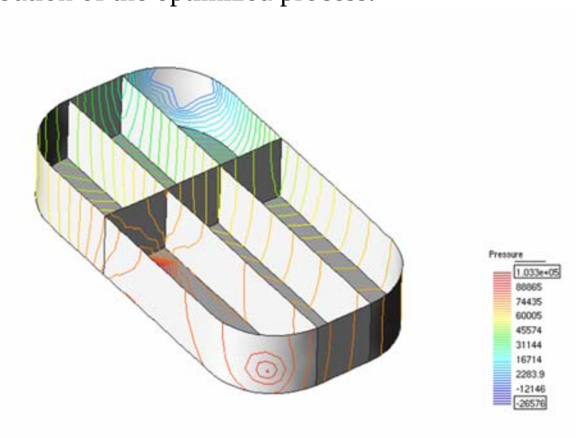

Fig. 7. Final pressure distribution of optimized process

For both, the initial and the optimized process, the final fill degree is above 99 % and the pressure is limited to an allowed maximum of 1 bar. However, the filling time of the optimized process could be reduced to approx. ¼ compared to the initial filling time.

7 Discussion & Outlook

Automatic process optimization can reduce required manpower for process optimizations significantly. However tuning of the target function is very sensitive. A clear benefit is the integration of quality related parameters.

The future focus will be on the investigation of the robustness of the optimized process against runners and other disturbances.

References

[1] B. Y. Kim, G. J. Nam, J. W. Lee, "*Optimization of Filling Process in RTM using a Genetic Algorithm and Experimental Design Method*", Polymer Composites 23 No. 1, 72–86, 2002

[2] R. Mathur, B. K. Fink and S. G. Advani, "*Use of Genetic Algorithms to Optimize Gate and Vent Locations for the Resin Transfer Molding Process*", Polymer Composites, Vol. 20, no. 2, pp. 167, 1999

[3] Jiang, S., Zhang, C., Wang, B., "*A Process Performance Index and Its Application to Optimization of the RTM Process*", Polymer Composites, Vol. 22, pp. 690-701, 2001

[4] O. König, Evolutionary "*Design Optimization: Tools and Applications*", PhD Thesis, ETH Zurich, Centre of Structure Technologies, 2004

[5] Modi, D., Simacek, P., Advani, S. "*Influence of injection gate definition on the flow-front approximation in numerical simulations of mold-filling processes*", International Journal for Numerical Methods in Fluids, Vol. 42, pp. 1237-1248, 2003

[6] Lin, M., Murphy, M., Hahna, H. "*Resin transfer molding process optimization*", Composites Part A: applied science and manufacturing, Vol. 31, pp. 361–371, 2000

[7] www.structures.ethz.ch/research/materials/SLIP

[8] Barandun, G., Ermanni, P. "*Liquid Composite Moulding: influence of flow front confluence angle on laminate porosity*", Flow Processes in Composite Materials (FPCM8) Douai, France, 11 - 13 July 2006