Evolutionary Algorithms Based Optimization of Filling Process in LCM

Boris Meier, Gion A. Barandun, and Paolo Ermanni

Center of Structure Technologies
ETH Zurich, Switzerland
boris.meier@imes.mavt.ethz.ch

SUMMARY: Simulation of LCM processes has been implemented in the in-house developed Finite Elements toolbox "FELyX" in 2-D, 2.5-D and 3-D. A Finite Element mesh with triangle, tetrahedral or brick elements is used. The program can be coupled to Evolutionary Algorithms, which are efficient methods for multi-parameter optimization. They have been successfully tested in structural optimization. Coupling to LCM simulation allows the determination of optimum process parameters including gate and vent locations as well as injection pressures and timing considering different objectives. Objective functions can be defined with respect to laminate's quality (no air entrapments) on the one hand and a short filling time on the other hand. The method was validated experimentally by optimizing the LCM process for complex 2-D and 2.5-D geometries. The obtained gate locations and injection pressures show remarkable improvements compared to heuristic optimization.

KEYWORDS: Liquid composite molding, simulation, evolutionary algorithms.

INTRODUCTION

Liquid composite molding (LCM) technologies are used for efficiently manufacturing structural composite parts of high quality. Further advantages are relatively low equipment and tooling costs as well as an excellent design flexibility.

Finding an optimal process configuration is usually the product of a long-term and expensive trial-and-error procedure. Reliable process simulation tools might contribute to significantly reduce production time, costs, and risks. There is commercial software available for LCM simulation.

Shojaei [1] presents a good review on the progress of modeling and simulation research in this field for the last two decades. In the field of optimization some research studies have been conducted coupling LCM simulation to Evolutionary Algorithms [2-6]. Special focus lies on definition of a process quality index that is needed as a measure of "optimization degree". There is still a need for further research, especially in 2.5-D and 3-D optimization. In our case we concentrate on efficient process cycles, i.e. short filling times and no dry spots.

BODY OF THE PAPER

Implementation of LCM simulation

FELyX (the Finite Element LibrarY eXperiment) [7] is an open-source finite element solver that has been developed at the Center of Structure Technologies, ETH Zurich. It is implemented in the generic programming language C++ and it includes a tool for structural analysis as well as for isothermal LCM simulation. Theory of LCM simulation has been discussed thoroughly in previous studies [1,8].

FELyX is able to store large amounts of data to hold the entire information of a finite element model. It stores all data in vectors templated with the appropriate data objects. The implementation in FELyX shows a high flexibility compared to commercial programs.

- Different element types can arbitrarily be mixed.
- Vents can be closed automatically as soon as the flow front reaches them.
- Gates can be opened and closed at any time, even time-dependency of pressure is applicable.
- Gates can be opened as soon as the flow front reaches them. This is useful for sequential injection.
- FELyX is independent from any pre- or post-processor since in- and output file formats can be adjusted.
- Additional element types may be added.
- Non-isothermal features could be implemented without reorganizing the whole code.
- New research results can be implemented immediately into the code.

Finally FELyX is at least as computationally efficient as commercial software.

Coupling to Evolutionary Algorithms

In order to develop optimal LCM manufacturing processes, the use of several simulation runs is unavoidable. There is a multi-objective optimization task with the two objectives of minimum injection time and complete fill.

According to the output parameters input parameters are varied. This could be done by any optimization procedure like heuristic optimization or by an optimization algorithm. Input parameters are gate and vent locations, gate pressures and timing of gates and vents.

Evolutionary algorithms are stochastic search methods that mimic the metaphor of natural biological evolution [9]. This method was implemented with the Evolving Object Library [10] and linked to FELyX (Fig. 1). It creates individuals of different process configurations. For each individual a simulation run is performed in parallel on an IBM cluster and the fitness is calculated with respect to the simulation's output parameters. The fitness determines which individuals will figure as parents for another generation of individuals (survival of the fittest).

Many LCM optimization studies in literature use node numbers as position variables of gates and vents. This does not seem to be appropriate since node numbers of similar value do not necessarily lie close to each other. Therefore a small change of node number could lead to a big change of the position of the node which leads to bad convergence behavior of the optimization algorithm. The present study uses Cartesian coordinates to describe locations.

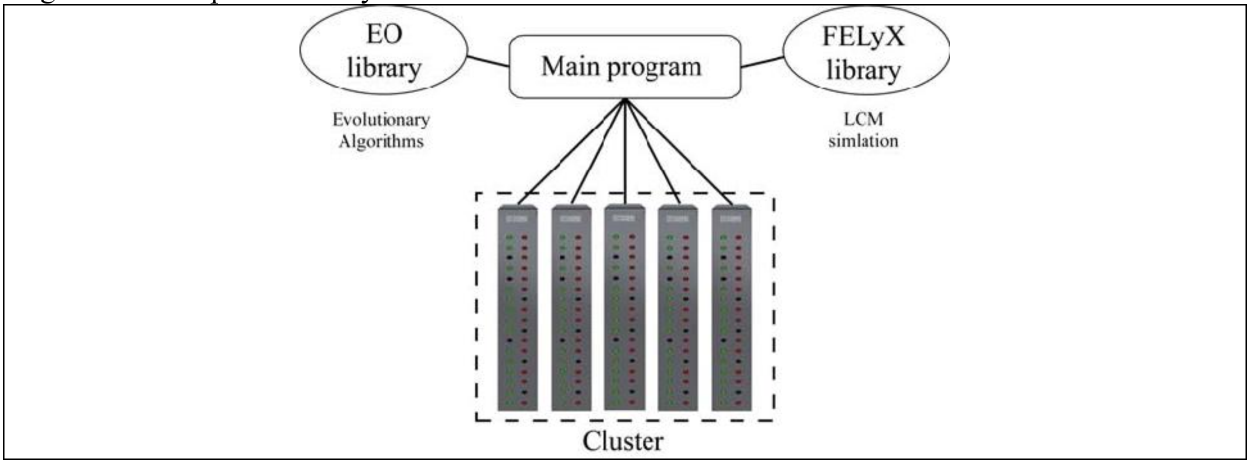

Fig. 1 Scheme of computational optimization procedure

Optimization in 2-D

A 2-D mold (550 mm x 125 mm) shown in Fig. 2 is considered. The numbers beside the gates denote the injection pressure in bar (10^5 Pa). Line injection at the bottom was left unchanged during the optimization.

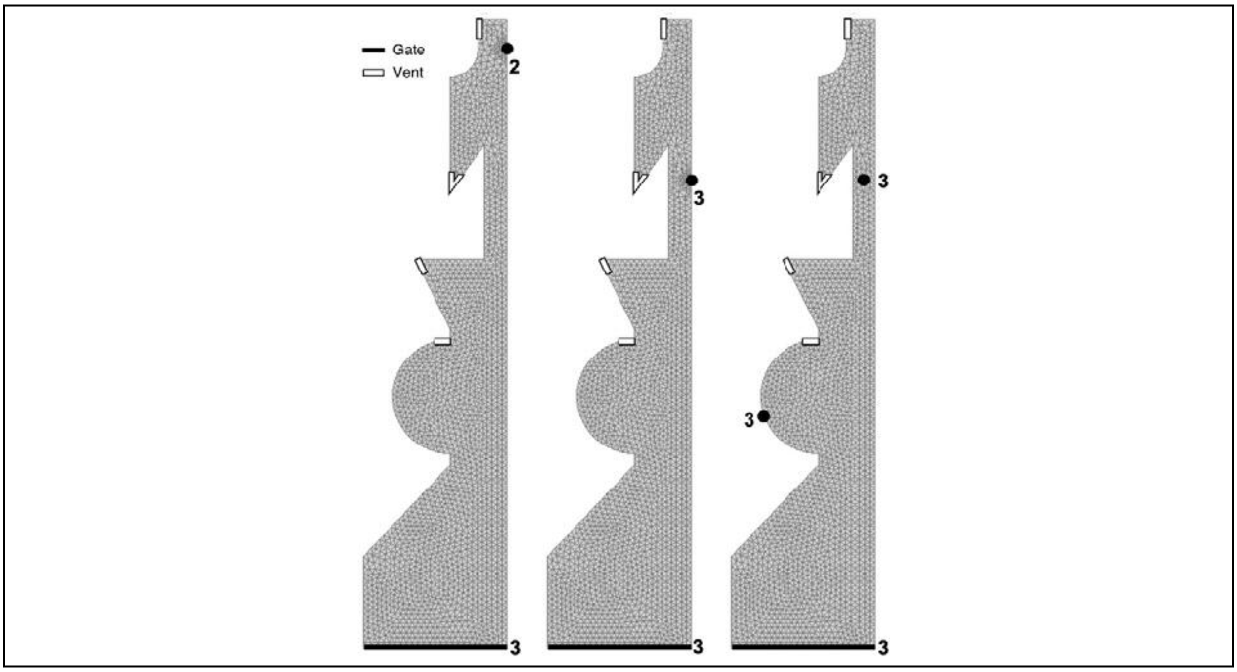

Fig. 2 Different process configurations
(left: original, center: 1 point gate optimized, right: 2 point gates optimized)

Original	1 point gate optimized	2 point gates optimized
319 s	225 s	106 s

Tab. 1 Filling time of different process configurations

The figure on the left-hand side shows the original process configuration developed during a diploma thesis, with a filling time of 319 s (Tab. 1). The figure in the center is the result of an optimization run with two variables: Gate position (right side) and pressure. As expected, the injection pressure was set to the maximum of 3 bar which leads to a much shorter filling time. In the figure on the right side an additional injection point is considered. The gate locations are considered to lie anywhere on the mold, i.e. there are 6 optimization variables now, four coordinates and two pressure values. The optimal configuration shows a remarkable improvement compared to the original process.
Injection pressure is usually applied to several nodes instead of one single node to avoid insufficient accuracy due to mathematical singularities [11].

Optimization in 2.5-D

A quarter of a wing-nose part (300 mm x 105 mm x 250 mm) shown in Fig. 3 is considered, having a preform permeability of 10^{-10} m^2 and the resins' viscosity is 0.1 Pa s. The part's thickness is 2 mm for z<=0 and 4 mm for z>0. Five vents are placed intuitively at the locations shown. The injection pressure is set to 3 bar.
The optimum spatial arrangement of three injection gates shall be obtained. Nine (3 x 3 coordinate components) variables optimization is performed using Evolutionary Algorithms. Population size is set to 30. After 50 generations the configuration shown in Fig. 3 turns out to be optimal. There are no dry spots and the filling time is at a minimum of 93 s.

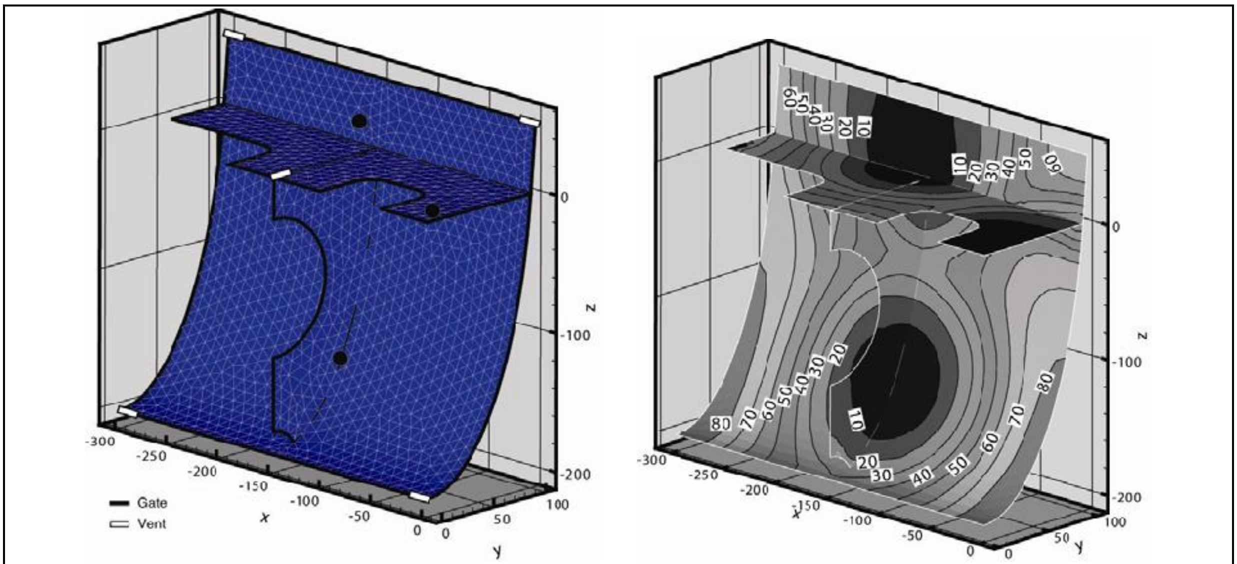

Fig. 3 Optimal process configuration and simulation result of a 2.5-D form
(left: mesh, gates and vents, right: isochrones)

Each injection gate is represented by three coordinates. Although the Evolutionary Algorithm identifies possible gate locations anywhere inside of the brick-like space spanned ($-300<x<0$, $0<y<105$, $-200<z<50$) as indicated in Fig. 3, an additional algorithm finds the closest nodal points on the mold which are used as gates. A set of neighboring nodes can then be used by the FEM model to simulate the flow through the gate.

CONCLUSIONS

LCM simulation has been implemented. The simulation program is coupled to an optimization algorithm. Gate or vent locations are represented in the Evolutionary Algorithm in a new promising way that works in 2-D as well as in 2.5-D and 3-D. Results of optimization runs show efficient process configurations, that would hardly have been achieved by trial-and-error methods.

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