Simulation and Control of the LCM-Process with Future Matrix Systems

Weyrauch, F.; Stadtfeld, H. C.; Mitschang, P.

Institut fuer Verbundwerkstoffe GmbH
Erwin-Schroedinger-Strasse 58, 67663 Kaiserslautern, Germany

Corresponding Author's e-mail: florian.weyrauch@ivw.uni-kl.de

SUMMARY: To increase the efficiency of LCM (Liquid Composite Molding) it is important to increase the number of manufactured parts and to assure a constant quality. Therefore, a concept to design and develop a controlled LCM process will be presented in this paper. The concept is based on a decision tree. A modular program package was developed to implement such a decision tree or a process chart in LabView®. An experimental verification to react on a Race-Tracking-Effect will be presented. In a second study in-situ polymerizing PBT was used and was injected by a completely automated and controlled RTM-Process (Resin Transfer Molding).

KEYWORDS: RTM, Race-Tracking-Effect, Controlled Process, Decision Tree, CBT, PBT

INTRODUCTION

To produce complex and high stressed parts, resin injection processes like RTM are used more and more often. For economic efficiency it is recommended to reduce the rejection of a part and to speed up the process time without reducing the part quality. The use of fixed open loop control can result in different shapes of the flow front and this can result in an incomplete filled part. The use of a closed-loop control is recommended. Different authors use offline algorithms which are defined in the design phase. An example is the stepwise opening of a gate when flow front reaches the gate position [1, 2]. In this case a simple ON/OFF switch is needed which turn to 'ON' when a sensor detects the resin at the gate location. Another example of an offline designed control is the use of an algorithm based on a decision tree [34]. The advantage is that only point sensors are needed to react on different situations inside the mold and the decision tree can be designed during the mold design.

CONTROLLED RTM-PROCESS

The Institut fuer Verbundwerkstoffe GmbH uses such a decision tree to design a controlled RTM process. The first step to design the decision tree is the selection of different relevant disturbances. One example for a disturbance is the wrong positioning of fabric layers inside the mold. In this case there could be a gap between the fabric and the edge of the mold. In this gap the resin flows rapidly forward and changes the desired shape of the flow front. This is a very common effect and is called Race-Tracking-Effect [5, 6]. The result can be that a certain region is surrounded by resin and the entrapped air can not leave, causing a dry spot in the fabric.

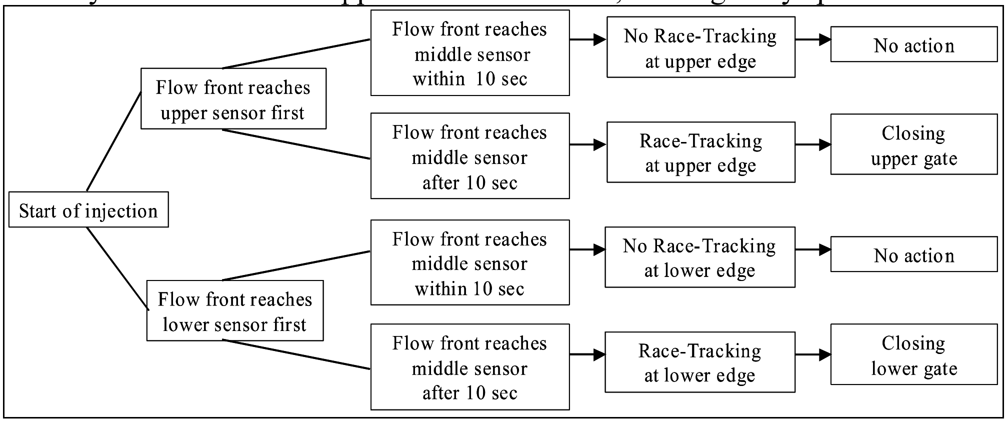


Fig. 7: Decision tree to react to the Race-Tracking-Effect

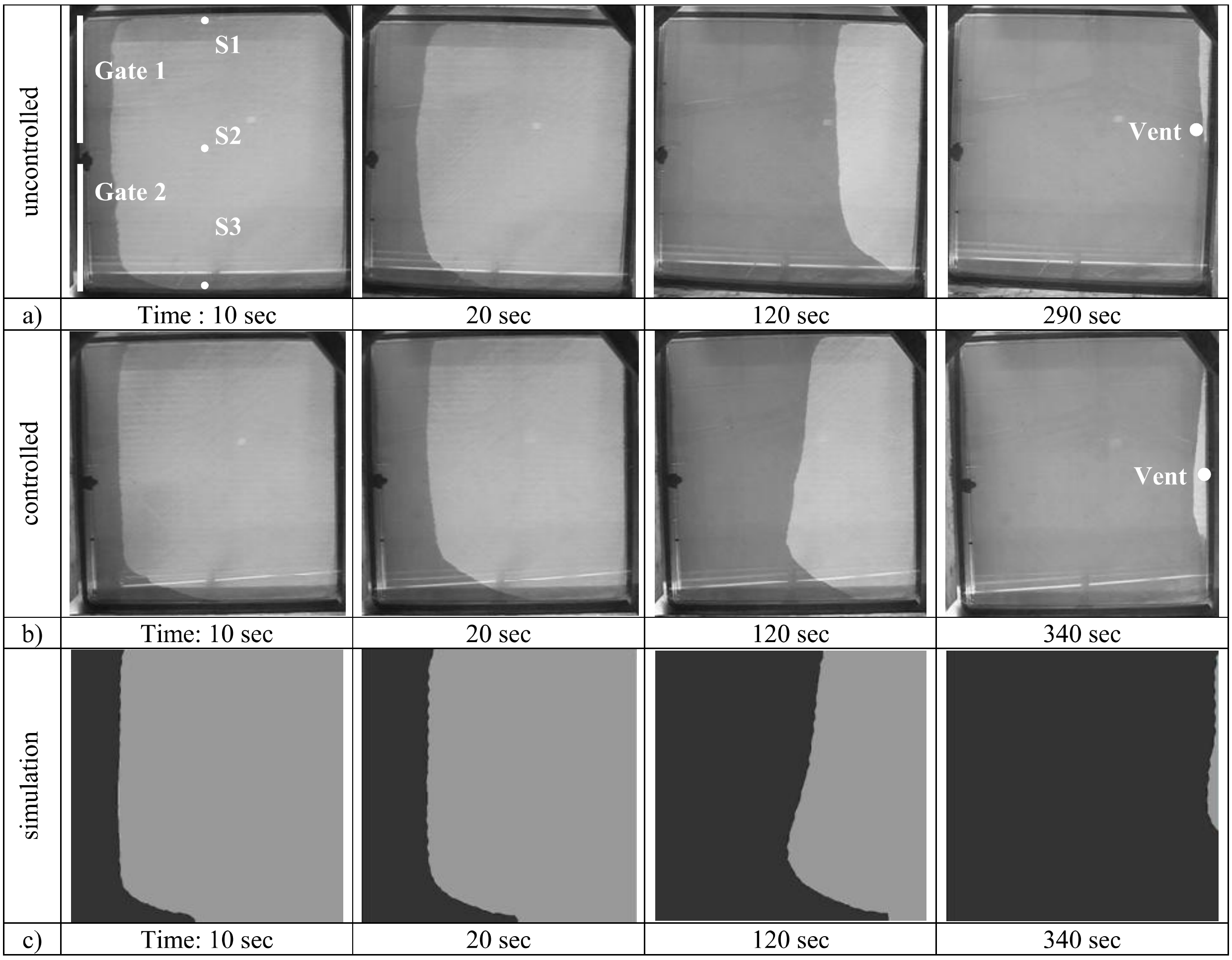


Fig. 8: Comparison between injection without control (a), with control (b), and with the simulation of controlled injection (c)

In Fig. 7 a decision tree to control an injection into a quadratic mold with either a Race-Tracking-Effect at the upper or lower edge is shown. On the left side of the mold two line gates were used to inject the resin. Three sensors in the middle axis perpendicular to the flow direction are needed to decide if there is a Race-Tracking-Effect and if so, at which edge it occurs. In Fig. 8 the flow front of an uncontrolled (a) experiment is compared with a controlled (b) experiment at several time steps. In the shown case the Race-Tracking-Channel is located at the lower edge. The movement of the flow front can be seen by the darker, already filled, areas. Within the controlled experiment the last filled area is around the vent and the part is filled completely. Within the uncontrolled test the upper right edge stays dry because the entrapped air can not disappear through the vent. The result is an incompletely filled component. The disadvantage of the controlled process is that it takes a little longer to fill the cavity but this will be compensated by receiving a completely filled component. In the third row (c) of Fig. 8 the filling simulation used to get the parameters to design the decision tree is shown. It can be seen that the simulation (c) and the experiment (b) are almost identical.
To implement the decision tree into the injection environment, which is controlled by a measurement computer, a system of modules was developed. Modules for all tasks of a controlled injection were programmed to be used with the Software LabView®. These are the modules to collect the data of the different sensors, the modules to handle the actuators (valves, pressure pots), and the modules to build up the decision tree. For example, to design the decision tree there are modules which wait for a certain event or branches dependent on the status of a switch, or they stop further decisions if an emergency button is pressed. The decision tree can easily be programmed by 'Dragging and Dropping' the modules inside the LabView® environment.

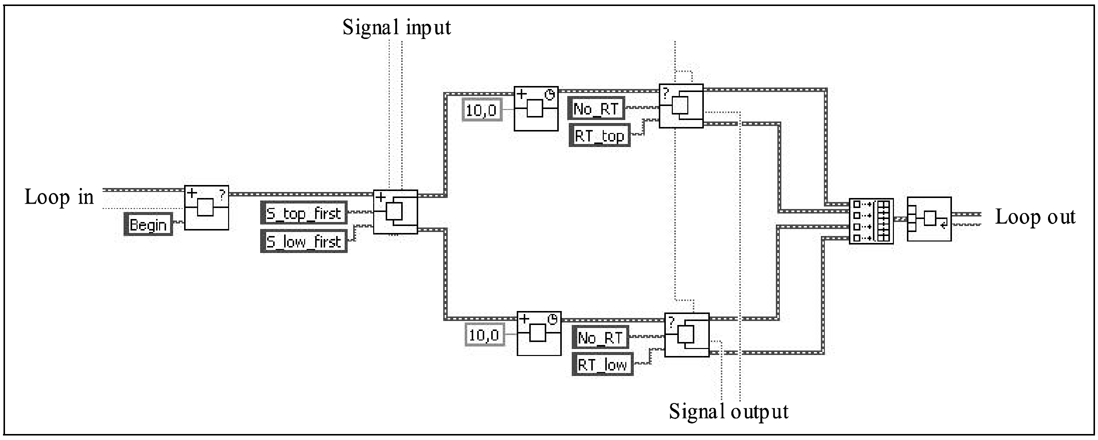


Fig. 9: Decision tree to influence the Race-Tracking-Effect designed within LabView®

As can be seen in Fig. 9, the programmed decision tree looks similar to the plotted one (Fig. 7). This results in an user friendly program because it is easy to read and easy to maintain. The decision tree modules can also be used to program a flow chart of an injection process. A further advantage of such a computer controlled process is that the documentation of every process step is easy to be handled.

Controlled injection with in-situ polymerizing PBT

The control concept was also used for producing plates with an in-situ polymerizing polybutylene terephtalate (PBT). The used system was CBT® Resin a product of Cyclics Corporation. The advantages of this system are that it has a very low viscosity at injection temperature and polymerizes into solid PBT within a short cycle time [7]. CBT® Resin is a low molecular weight oligomer material, which is available e.g. granule or powder form and melts above 150°C. During heating up the viscosity decreases to 20 mPas at 180°C. The polymerization takes place inside the heated mold using a catalyst. The polymerization is finished in less than 10 minutes (200°C mold). If the mold is cooler than 220°C the PBT is solid and can be removed from the mold without cooling down the mold. Therefore, reheating the mold prior to the next injection is redundant. This aspect and the short polymerization time results in a very short cycle time, making the process attractive for economic serial production.
A problem occurring in several injections with CBT® Resin is associated with this short cycle time and the low viscosity. Therefore, the flow velocity of the CBT® Resin is high and the fibers inside the mold are moved by the fluid. This can be solved, for example with a new positioning of gates and vents, but for an existing mold another solution is needed. Former injections were achieved in a vacuum process using a 2-component CBT® Resin system. After opening the gate, the CBT® Resin flows inside the mold driven by the pressure difference of 1 bar. This leads to a high flow rate in the beginning of the injection. To prevent this the injection process was changed and a pressure pot was used. A pressure pot offers the ability to start the injection with a slight increase of the injection pressure. Due to the fact that it is not trivial to calculate the forces moving the fibers inside the mold, the pressure ramp was defined as follows. Increasing the pressure from 0 bar to 2 bar in 30 seconds and keeping this pressure until the end of the injection. The end of the injection is detected by a temperature sensor which is placed inside the pipe from the gate into the resin trap (Fig. 10). At this position the sensor is outside of the heated mold and if the hot resin reaches the sensor, a clear increase of the temperature can be seen (Fig. 11 left). Thus, this method is a very easy way to check if the resin reaches a vent. This signal is used by the control to close the gate. The gate and the vent were opened and closed by automatic valves which clamp the flexible tubes.

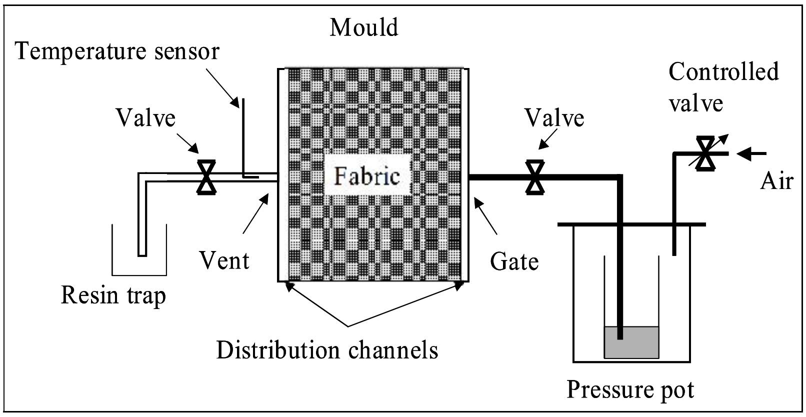
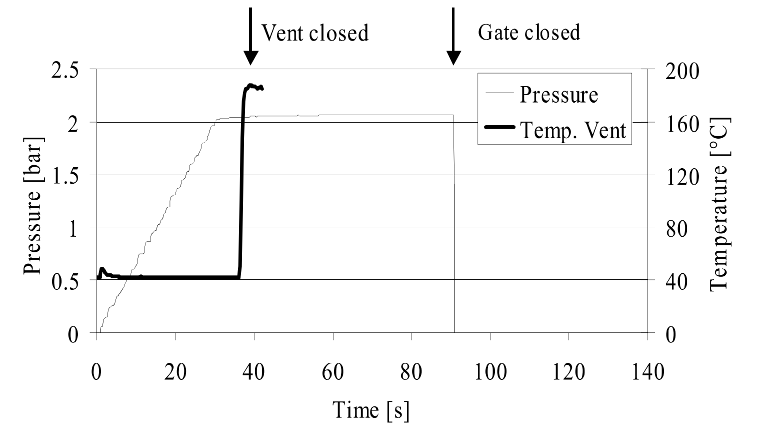


Fig. 10: Experimental set-up

In Fig. 11 (left) the time curves of the injection pressure inside the pot and the temperature at the vent are shown. In the first 30 seconds the pressure ramp can be seen. 9 seconds later the temperature at the gate increases rapidly from 42°C to 190°C and the valve at the vent closes. After further 60 seconds the gate valve closes and the pressure inside the pressure pot drops down. This time is needed to be sure that the micro-impregnation of the fibers is completed. With this controlled injection process the problem with the fiber movements was solved and good parts were injected. A second advantage of this controlled process is that less CBT® Resin is needed because of the short time the valve closes after the cavity is filled. This is not possible if the process is handled manually. The designed process is very robust and the used equipment like the sensor or the pressure pot are standard products. Thus, this is an easy and cost efficient way to inject the resin using a controlled process. A plate injected with this controlled process using a ±45° non crimped carbon fiber fabric is shown in Fig. 11 (right).



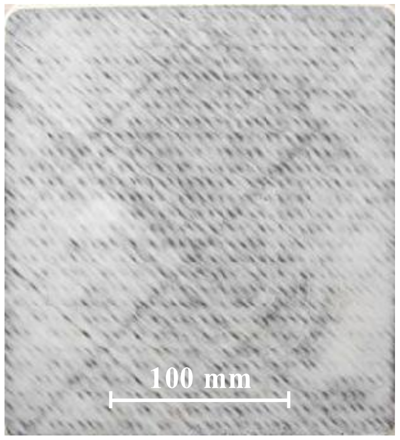


Fig. 11: Measured injection pressure and temperature at the vent position and injected plate

CONCLUSION

In this paper a controlled LCM-process was introduced. With the help of the developed modules it is very easy for engineers to create an efficient control for injection processes like RTM. The advantage of a controlled process is that the rate of rejected parts can be decreased, while a constant, well documented quality can be guaranteed.

ACKNOWLEDGEMENTS

The authors acknowledge the financial support provided by the "Deutsche Forschungsgemeinschaft" for funding the project in the frame of the DFG-Research-Group "FOR 360" and Cyclics® Europe GmbH for supporting the CBT® Resin research work.

REFERENCES

[1] Dirk Heider, C. Hofmann J.W. Gillespie, Jr.: "Automation and control of large-scale composite parts by VARTM processing", *'45th International SAMPE Symposium and Exhibition Science of Advanced Materials and Process Engineering Series*, Vol. 45', SAMPE(Ed.), Long Beach, CA, May 21-25 2000, pp. 1567-1575.

[2] Moon Koo Kang, Jae Joon Jung, Woo Il Lee: "Analysis of RTM process with controlled multiple gates resin injection", *Composites Part A,* Vol. 31 (2000), pp. 407-422.

[3] E. M. Sozer, S. Bickerton, S. G. Advani: "On-line strategic control of liquid composite mold filling process". *Composites Part A*, Vol.31 (2000), 9, 1383-1394.

[4] Bickerton S, Stadtfeld HC, Steiner KV, Advani SG: "Design and application of actively controlled injection schemes for resin-transfer molding", *Composites Science and Technology,* Vol. 61 (2001): pp. 1625-1637.

[5] Simon Bickerton ; Hubert Stadtfeld ; Karl Steiner ; S.G. Advani: "Active control of resin injection for the RTM Process", *Proceedings of the 13th Technical Conference on Composite Materials ASC Baltimore Maryland*, Sept. 1998, pp.232-245

[6] P. Mitschang, A.Ogale, J. Schlimbach, F. Weyrauch, C. Weimer: „Preform Technology: a Necessary Requirement for Quality Controlled LCM-Processes", *Polymers & Polymer Composites*, Vol. 11 No. 8, 2003, pp.605-622

[7] R. Eder: „Cyclic Thermoplastics – Properties and Processing", *Proceedings "IVW Status-Kolloquium*", Kaiserslautern, Germany, 8. + 9.11.2001, Vol. 25, pp. 33 – 43