Water-assisted Injection Moulding Technology. Simulation programs aid users with part design, mould layout and mould design. Simulation software, in comparison to optimisation trials, helps to cut development times and make significant savings. This report shows how the simulation of thermal stages contributes to improving the design of a water-assist injector.

Improved Injector Design by Water-assisted Simulation

Computer simulations offer an aid for implementing reliable and reproducible process control in the still-young water-assisted injection moulding technology. However, the use of modern CAE technology with water-assist is still not established, since, until now, no specialised water-assist modules have been available in the corresponding injection moulding simulation programs. Consequently, e. g. thermal simulations involve a major outlay for mould and injector design.

The injector, which forms the link between the water-assist system and injection mould, plays a key role in the entire water-assist process. A major aspect of this is the seal between the injector and polymer melt that is necessary for manufacturing parts that are dry on the outside [1–5]. The injector is subject to continually changing local temperatures from one cycle to the next. Heating during melt injection takes place in the changeover with cooling during water injection. Leaks at the injector, which often only occur after a certain number of manufacturing cycles, can also be traced back to unfavourable thermal conditions in this area. Against this background, the Institute of Plastics Processing (IKV) at the RWTH Aachen University analysed and studied the thermal conditions and relevant heat-transfer processes in the injection area with the aim of implementing an optimised injector design that promises greater process stability.

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Physical-mathematical Modelling of the Water-assist Injector

For the computer simulations, 2D, $2^1/_2$D or 3D programs are used, depending on the particular case. These programs differ considerably in the geometrical possibilities and limitations they offer, the modelling and simulation sequences, and the associated computer times and computer powers that are necessary. Since the thermal conditions in the water-assist injector and the injector area cannot be reduced to a 2D problem without thorough (and possibly unjustifiable) simplifications, the Sigmasoft program, a simulation tool based on 3D volume elements from Sigma Engineering GmbH, Aachen/Germany, is used.

Fig. 1 shows a cross-section through the generated 3D model of the hydraulic water-assist injector with the neighbouring mould region and the feed region to the part. This is an extremely precise reproduction of the real situation, made up of approximately 2 million volume elements in the relevant regions [6]. The region labelled "cavity/water" in the model shown in Fig. 1 has the following properties depending on the individual phases of a water-assist cycle:

- melt (during melt injection),
- water (during water injection, water holding time and water return), and
- air (during the rest of the cycle).

The movement of the injection needle for opening and closing the injector orifice in the closure cap is also taken into account by filling the upper region in the ▶

Cross-section of the 3D models

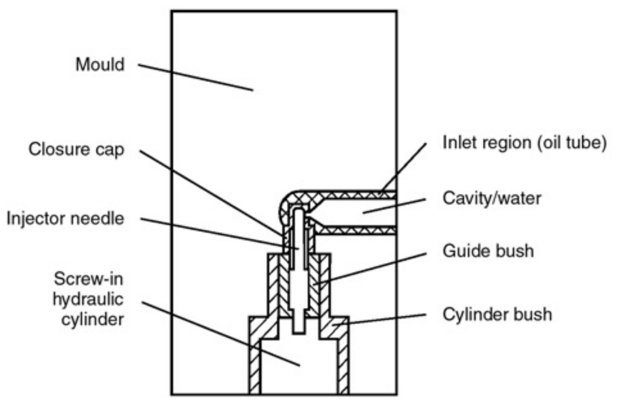

Fig. 1. The section through the 3D model shows the different regions of the injection, to which different initial data are assigned depending on the process phase

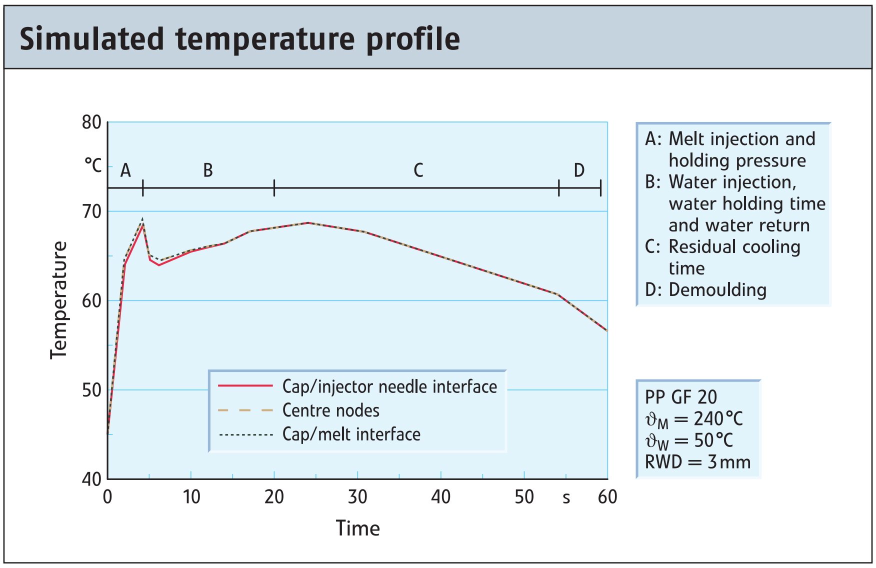

Fig. 2. The temperature at different points of the injector cap shows a characteristic profile for each cycle

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cap, corresponding to the actual water-assist process, either by the injector needle (with the outlet bore sealed), by water (during the water injection, water holding time and water return), or by air (after water return is complete and before the start of the next cycle). This reveals the reason for the model complexity and the effort that is necessary for a realistic simulation of the thermal conditions.

FEA Simulations

Fig. 2 shows the simulated temperature profile in the closure cap of the injector. During melt injection, the injector cap is rapidly heated by the surrounding polymer melt to 69 °C (mould temperature ϑ_W = 50 °C). The subsequent water injection suddenly reduces the temperature to 65 °C. Within the water holding pressure time, the temperature drops briefly for about 2 s. During this time, the water heats up and increasingly loses its cooling potential. The temperature in the injector cap therefore rises back to 68.7 °C. From this time, the temperature in the injector cap steadily falls to 60.7 °C in the course of the residual cooling time. While the part is demoulded, the temperature finally falls more markedly to about 56 to 57 °C.

Further computer simulations are carried out for a range of subsequent individual cycles. This is because it is not the isolated water-assist cycle that is of interest, but the states that occur during production, i. e. the sum of the continually repeating injection moulding cycles. Fig. 3 shows the profile of the simulated and measured temperatures of the closure cap for five successive water-assist cycles after part demoulding.

To refine these considerations, the resulting temperatures at the injection closure cap were considered more individually (end face and side face). As is to be expected, the closure cap temperature increases from the first to the second cycle. Only a small temperature rise can be ascertained between the next two cycles. From the third cycle, the simulation results no longer change significantly, so that a thermal equilibrium in the cap can be assumed.

Experimental Validation

The temperature measurements in the practical injection moulding tests with a thermal sensor confirm the temperature profiles simulated up to this point. After three cycles, the injector or closure cap has heated up to about 20 to 25 °C. However, both measurement curves continue to show a slightly rising trend that is no longer reproduced by the simulation. Such deviations of the simulation's results from the physical data can be explained by the fact that a simulation is always based on simplifications and assumptions, and a certain divergence from reality is unavoidable. A complicating factor is that the recording of the measurement data by means of thermocouples and contact thermometers is subject to errors.

In comprehensive water-assisted injection moulding tests at the IKV, water ruptures and leaks in the injector vicinity frequently occurred – despite the fact that the process is stable at the start. In view of the measurements from Fig. 3, such process disturbances can be attributed to just this continuous temperature increase. The sealing effect in the region of the injector apparently gets worse as the temperature increases, since the polymeric material can then no longer anchor to the same extent in the grooves, recesses etc. in the injector cap. An obvious way to

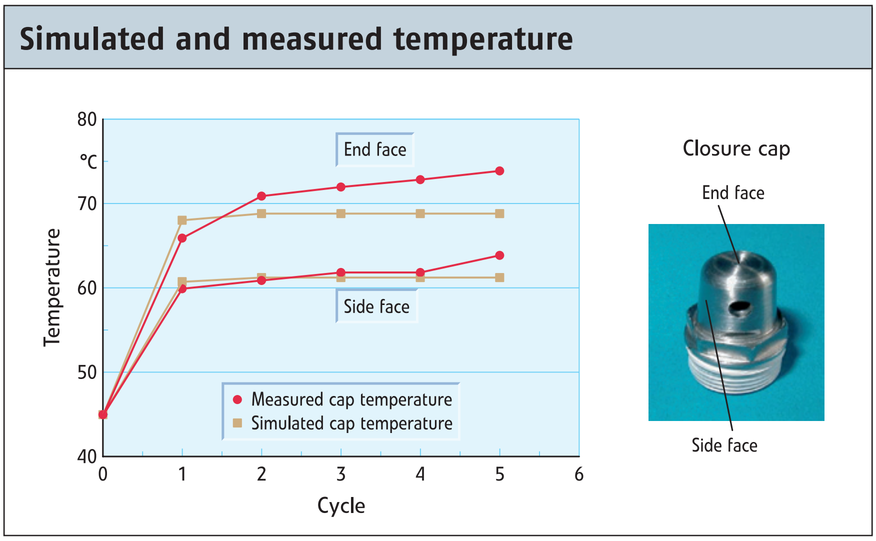

Fig. 3. The simulation can readily reproduce the temperature rise over multiple cycles, particularly at the side face

keep production temperatures at an adequately low and constant level in practice is to modify the injector.

Optimised Injector Concept

The above-described temperature problem can be solved by additional cooling.

Water-assist injector with internal cooling

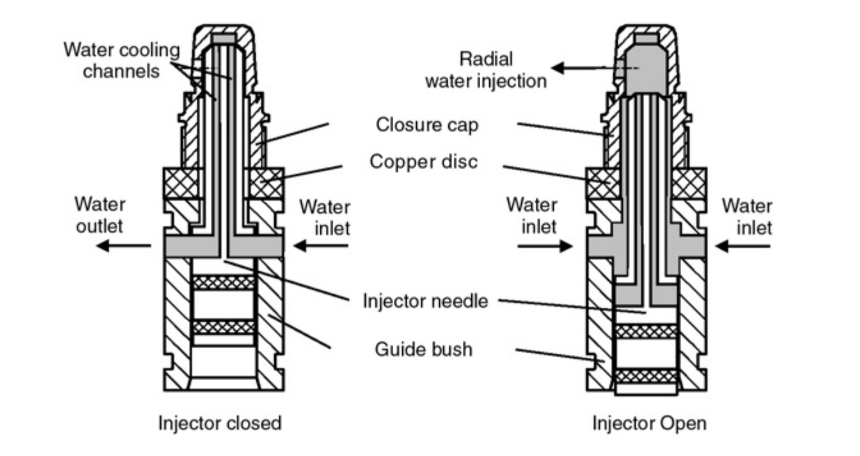

Fig. 4. The improved injector design permits effective cooling as far as the front tip of the closure cap

Fig. 4 shows a schematic view of a modified water-assist injector. In this case, the cooling is provided by the injector needle and guide bush, into which the cooling channels are integrated. The cooling can be active during the entire time in which the injector is closed. A recess should also be provided in the closure cap to permit water throughflow.

This modified injector will be implemented in a publicly funded research project in the near future and its sealing efficiency and process stability compared with other injector concepts.

Summary

The above-described studies have shown that heat-transfer processes in water-assisted injection moulding technology can be realistically simulated and therefore provide useful support to users with mould and injector design. The experimental validation in practical injection moulding tests shows good agreement with the results of computer simulations. However, it is (still) very laborious to obtain such results using current simulation tools for practical applications, since until now no specialised simulation modules have been available for water assist, as is the case for gas assist. In practice, additional injector cooling will be able to make a significant contribution to the greater stability of the water-assisted injection moulding process. ■

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