REAL WORLD LSR / SILICON CAE
MOLD THERMAL SIMULATION

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BIOGRAPHICAL NOTE

Torsten Kruse is a highly regarded industry expert in injection molding. Following a successful career with Arburg, Inc. (1988-1995), he formed his own company, Kruse Analysis, Inc. in 1995. He has develops customized in-house training courses for injection molders. He was a main platform speaker at NPE '94, and served as a consultant and part owner in the development of Paulson's Sim-Tech™ injection molding simulator as well as DVD based injection molding training courses.

While at Arburg, Kruse worked on customer's injection molding applications, designed and delivered customer training programs, and headed the internal injection molding applications department.

"For many years I have traveled throughout North America visiting hundreds of injection molding companies and seen thousands of injection molding applications and worked hands-on on hundreds of molds. That knowledge has given me a broad spectrum and expertise in injection molding that my simulation customers are enjoying now"

ABSTRACT

State of the art simulation considers every technical detail of an injection molding process. Mold filling and part curing can be evaluated with a high degree of accuracy. Mold temperatures throughout the entire molding cycle can be evaluated - considering an entire mold with all components and even the cooling of the parting plane in between two cycles. Several consecutive cycles can be performed to analyze a quasi stationary mold temperature. But until today, the full potential of simulation is often not generating the real world value necessary to substantiate working with a CAE engineering service.

This paper looks at a specific project and assesses filling patterns, part curing and especially thermal mold evaluations using various mold steels, heater cartridge placement as well as the use of insulation plates etc. Real world simulation results will be illustrated.

Real World LSR / Silicon CAE Mold Thermal Simulation

Polymer System Simulation

Polymer system simulation offers a variety of modeling methods. On one hand a simulation model can be very simple and can only contain part geometry and injection point. This reduced model is sufficient for showing the filling pattern and some general effects like weld lines and critical shear rates for development of part and gating geometries. On the other hand, the model can be as complex as the real world mold, containing all of the mold components and process parameters used in the real world. All of the mold components such as mold plates, slides, ejector pins, heater bands, air gaps, etc. are included in the simulation model. Each component is modeled with its specific thermo-physical properties. For example, it is possible to simulate the effect of using different mold materials with a very high or low thermal conductivity. Heater cartridges can be heated with the realistic wattage and can be controlled with a thermocouple point. Calculation of the simulation over several injection molding cycles can be used to evaluate the quasi stationary mold temperature. All types of heating and cooling media can be controlled (on/off) throughout the cycle for more realistic modeling of reality. Moreover, a tempering process after the ejection of the part can be analyzed. Each of these details plays a role in the final part quality and these impacts can now be evaluated and quantitatively understood with polymer system simulation.

Four Cavity Shot Glass Mold

To illustrate the mold temperature variations in a typical LSR mold we have chosen a four cavity shot glass mold (**M.R. Mold & Engineering Brea, CA**) to demonstrate how various mold steels will have an impact on the heat up, mold filling and part curing behavior. The four cavities have been modeled with different mold steels Cavity 1 = 420SS, Cavity 2 = BeCu / MoldMax, Cavity 3 = Aluminum, Cavity 4 = Titanium. Of course some of the mold steels will never be used to manufacture the actual cavities and for this paper we used them to only demonstrate the influence of heat transfer and mold temperatures.
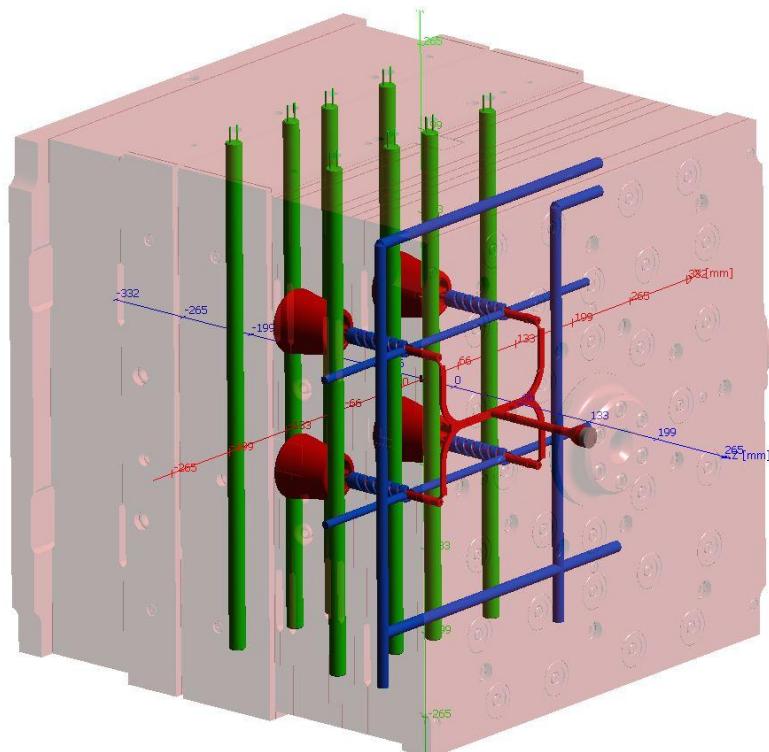
Knowing the heat history and temperature behavior during the molding cycle will help you troubleshoot the process and increase the part quality. However the real world application for this type of simulation should be known / used during the mold design phase. During the mold design phase changes can still be implemented, for example the heater cartridge and thermocouple placement etc.

Figure 1, Shows the mold model for the simulation, including the heater cartridge (green) the part and cold runner model (red) and the cooling water for plates and nozzle (blue).

Mold Design Evaluation

The mold evaluation contains three steps. The first step focuses on the gate location and the mold layout, number of cavities and runner system design. The conflict of goals between increasing the number of mold cavities and the fixed technical molding capabilities (max. injection pressure, runner and gating limitations, etc.) can be accurately evaluated in the virtual world.

The second step evaluates the mold tempering. Water, hot oil, thermal pins, and heater cartridges are placed into the simulation for evaluation of the quasi steady state thermal gradient of the mold after multiple consecutive cycles. This step provides information about heater efficiency, the best distance between heater and cavity as well as the best position for a thermocouple controlling the heater.

The last step considers the entire mold including all of the components such as plates, slides, air gaps, o-rings, heaters, cooling channels, etc. Simulations including the complete mold and process provide the foundation for a virtual design of experiments that is used to evaluate the mold performance and the process operating window. This final step provides valuable information prior to the real world mold trials. The slowest and fastest injection speeds, upper and lower mold/material temperatures can be determined during the simulation and tooling design phase of mold development, or in parallel with the mold construction. Critical cycle interruption times can be evaluated without real world shop floor testing.
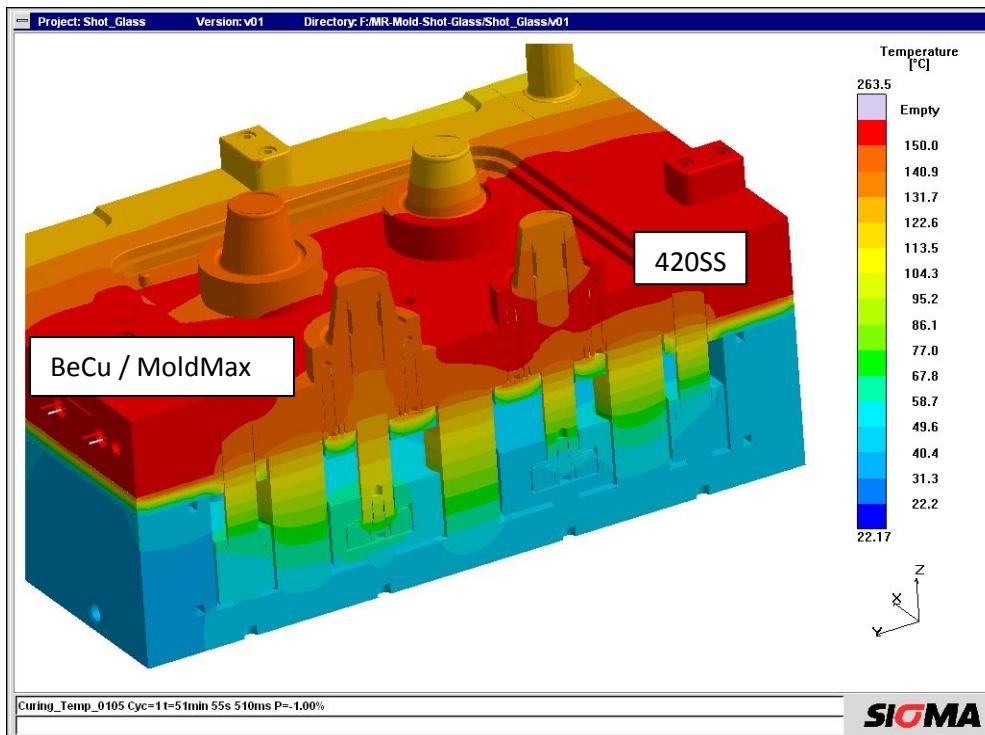
Figure 2, Shows the temperature distribution of the 3D mold system after the warm up phase of 1 hour and 55 minutes in a sliced view. Cavity 1 = 420SS and Cavity 2 = BeCu / MoldMax. The BeCu / MoldMax cavity shows a more uniform temperature distribution.
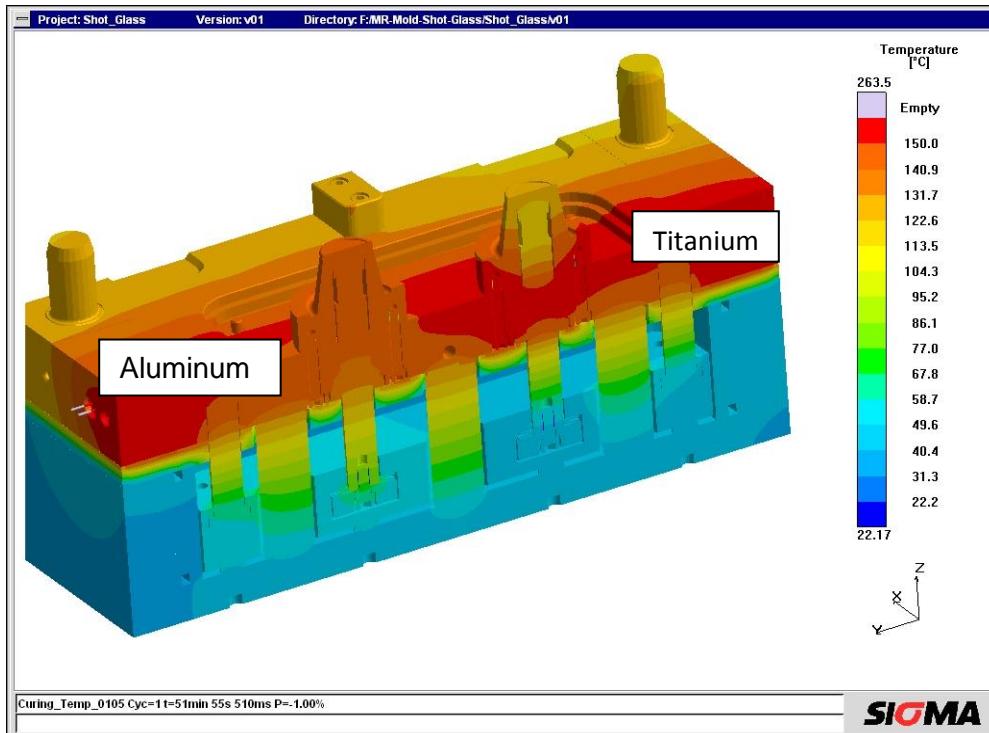
Figure 3, Shows the temperature distribution of the 3D mold system after the warm up phase of 1 hour and 55 minutes in a sliced view. Cavity 3 = Aluminum and Cavity 4 = Titanium. The BeCu / MoldMax cavity shows a more uniform temperature distribution.

The mold heat up was completed with a PI controlled calculation that, in general, is implemented in modern molding machine heater circuits or external controllers. The PI controlled heat up phase took 1 hour and 55 minutes to reach a stable heating behavior. The mold temperature distribution shows clearly the various mold steels can have a great influence on temperature distribution and uniformity.

Mold Steel	Density	Specific Heat	Thermal Conductivity
420 SS	7.73 g/ccm	462 J/kg-C	25 W/m-C
BeCu / MoldMax	8.35 g/ccm	360 to 420 J/kg-C	105 to 130 W/m-C
Aluminum A1	2.8 g/ccm	782.3 J/kg-C	138 W/m-C
Titanium Alloy	4.42 g/ccm	560 J/kg-C	7.2 to 11.7 W/m-C

Figure 4, Shows the steel thermal behavior is described by the density the specific heat and thermal conductivity.

Part Design Evaluation

Even if some molding issues can only be analyzed using a complete simulation model, a simple model considering only the part and a gating position can provide valuable information for part and tooling development. With a so-called part design model weld lines, venting positions, part geometry and a best case scenario for cycle time can be evaluated.

The flow and curing simulation we have completed for the four cavity shot glass mold show very interesting curing behavior. The curing behavior is definitely impacted by the steel thermal behavior.

For comparisons we have taken the percentage cured results at a cure time of 60 seconds. The simulation results show the BeCu and Aluminum mold material show a much faster curing and thus potentially a much faster cycle time can be achieved with the same part design and heating conditions.

Figure 5, Cavity 1 = 420SS Cavity 2 = BeCu / MoldMax Cavity 3 = Aluminum   Cavity 4 = Titanium
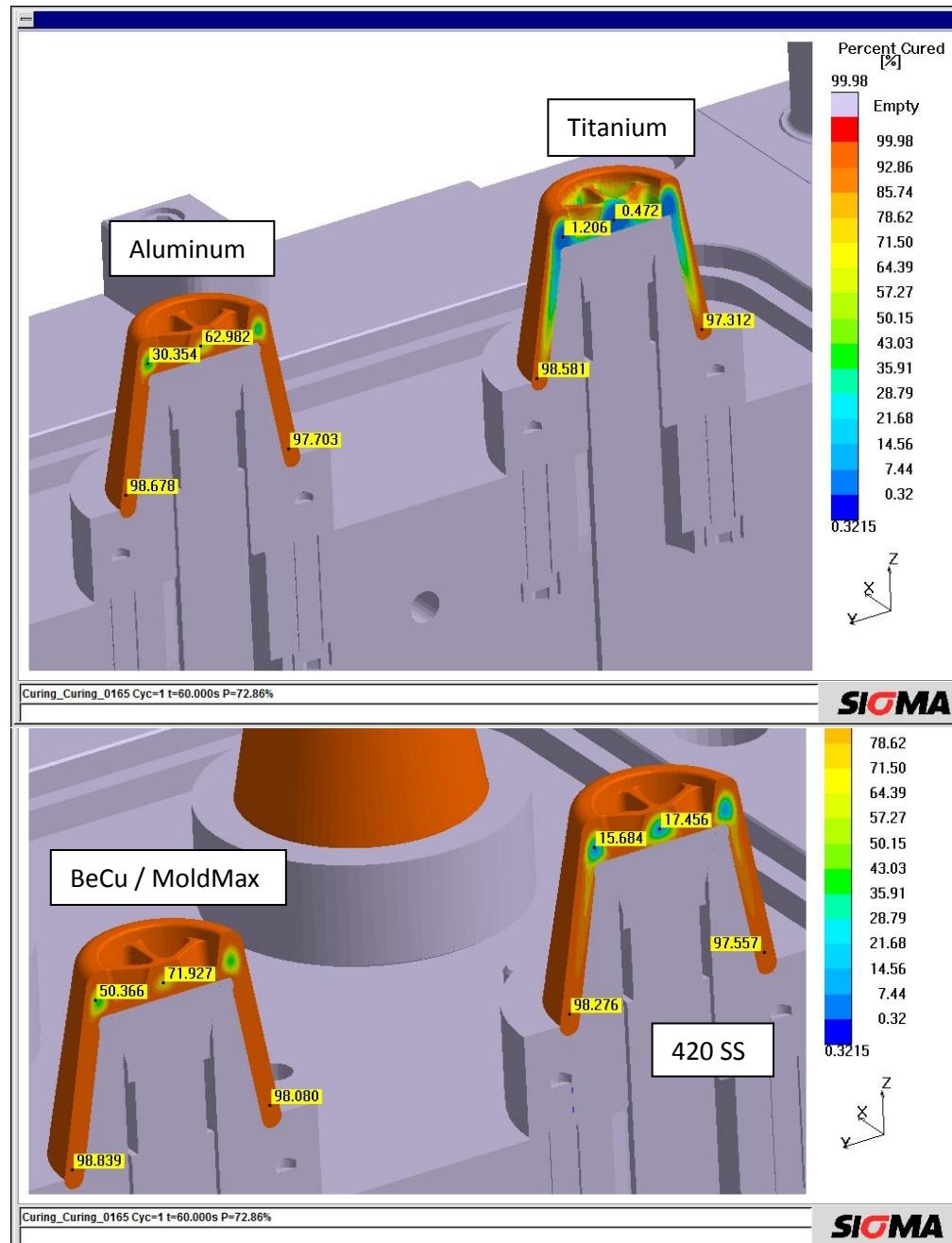
Process and Material Evaluation

The accuracy of the simulation model can be increased by adding only runner geometry. This improves the filling pattern and pressure calculations due to the inclusion of the effects of shear heating and more realistic process parameters. Analyzing the shear heating effect in the gate areas can be used to optimize the gate dimensions. Accurate simulations like these provide quantitative information to direct the gating design. The polymer passing through a correctly sized gate will generate enough shear heating to cure the part quickly but without scorching during filling.

Consideration of the critical details in the systematic simulation allows engineers to rely, with a high degree of confidence, on the simulation results. New methods of product development become possible with this high degree of accuracy. Based on a virtual curing reaction optimization, new materials can be designed to fit specific process needs. A specific process can be defined in the simulation (cycle times, initial material and mold temperature, etc.) and used as the base-line for a virtual material design.

Heater Cartridges

Designing a uniform mold heating system is very important to achieve uniform part quality. The proper placement of the heaters and the thermocouples is essential. Do you know how your heater cartridge really heats up? What is the effective heating length of your cartridge? A simple test can show you the actual heat up. Knowing the heat up effective length assist you in better placing heaters.
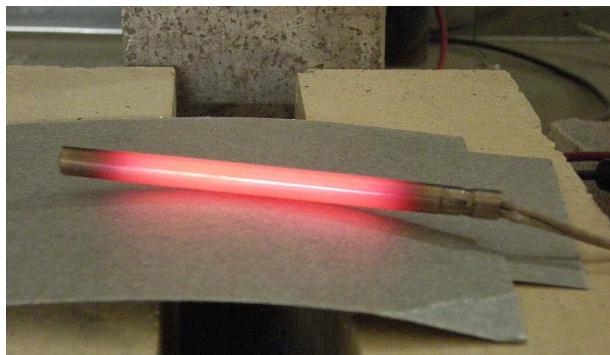

Figure 6, Shows a simple heater cartridge heating test

Conclusions

Polymer system simulation is an essential tool for a complete part, mold and process optimization. The use of best and worst case scenarios rules out costly real world development trials. Performing a complete heating evaluation of your mold design will lead to more uniform mold heat and uniform part quality. Polymer system simulation multiplies the engineering knowledge within a company and quantitatively supports their decision making process which maintains their position as leaders in the industry.

Common saving potential through a complete simulation approach provides cost avoidance as well as cost savings. Forward thinking companies will change common development routines using a virtual process evaluation, which leads to accomplishing smarter lean manufacturing goals.