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REAL WORLD LSR/SILICON CAE 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 mold. That knowledge has given me a broad spectrum and expertise in injection molding that my simulation customer 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 presents and discusses the financial impact of a complete simulation approach. Technical evaluation techniques will be discussed under the focus on cost optimization and lean manufacturing criteria.

PAPER

Real World LSR/Silicon CAE 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.

In polymer system simulation the mold temperature has an impact to the cross-linking reaction of polymers. The cross linking reaction influences the solidification of the material and, if the cross-linking reaction begins during the filling phase, it also impacts the viscosity. The influence of temperature and curing reaction on the viscosity is shown in figure 1. A high temperature will cause a low viscosity (continuous gray line) and an increasing curing degree will increase the viscosity (dotted grey line). The time dependent superposition of both effects is shown in the red line. This temperature and cross-linking dependent viscosity behavior can be considered in polymer system simulation.

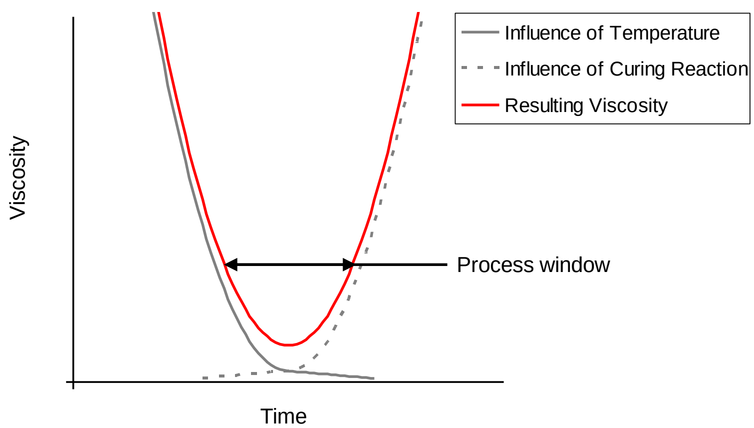

Figure 1, Measured curing degree curves.

The cross-linking reaction is mainly a function of time and temperature. The material input for simulating the cross-linking reaction is shown in figure 2.

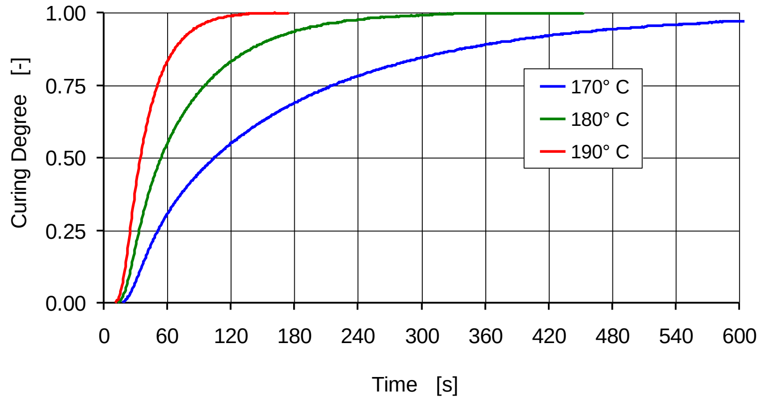

Figure 2, Measured curing degree curves.

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.

Figure 3 gives an example of a venting evaluation. The simulation indicates late areas of filling which trap more air than is desired and are indicated by the red areas. These areas require venting and this information is available when considering only the part and gating location. The labor for such a simple model is typically only 60 minutes or less, including meshing.

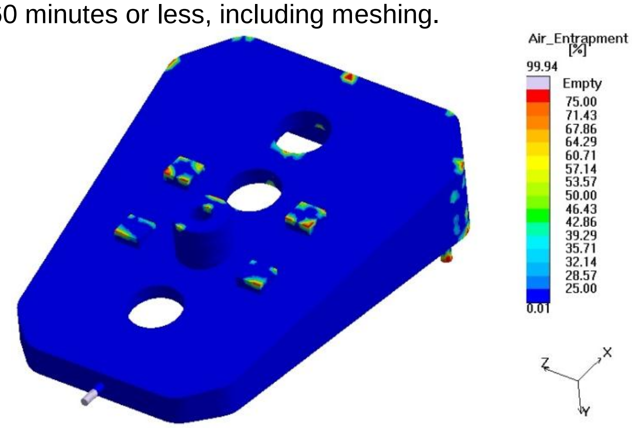

Figure 3, Locations of trapped air by %.

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. Simulating the effects of various rates of curing reaction provides information about the shape of the curing degree curves necessary to match a specific process to a specific material. The results of such a virtual material evaluation are shown in Figures 4 and 5. Figure 4 shows a curing reaction curve that is too steep and will cause scorch during filling. Figure 5 shows a curing reaction curve that is too flat and will cause a long cycle time or an external heating cycle to fully cure the parts. The material values are easily modified in the simulation interface. Optimized curing curves can be used as input for a material design.

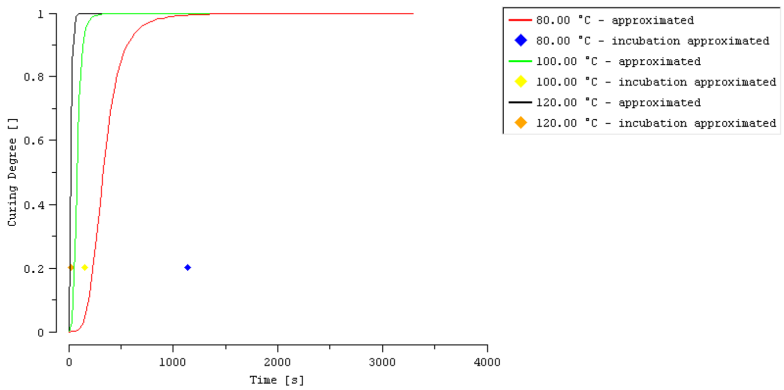

Figure 4, Fast curing reaction.

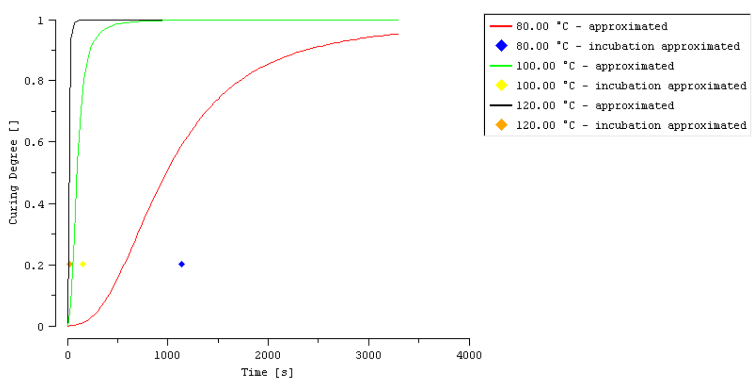

Figure 5, Slow curing reaction.

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.

An example of a simulation considering a complete LSR cold runner and mold is shown in Figure 6. The temperature distribution of the entire 3D mold system is shown in a sliced view. The thermal insulation between cold-runner and hot mold is clearly visible. The core has a lower temperature than the mold. Increasing the temperature of this core is advised to reduce the cycle time.

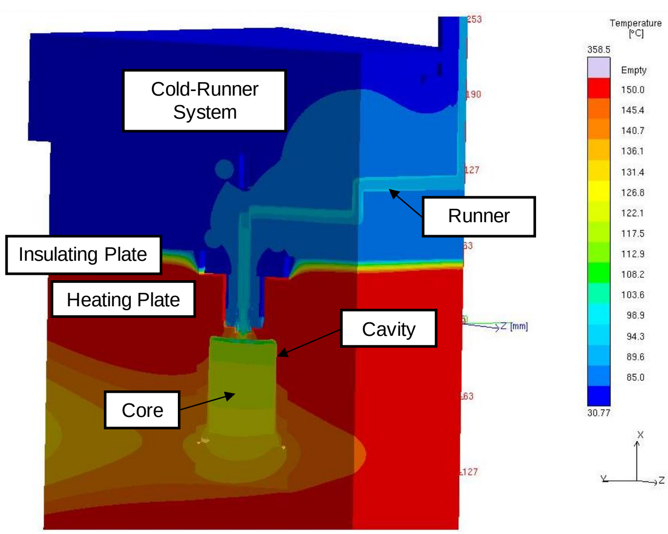

Figure 6, Quasi steady-state temperature distribution.

Cost Responsibility

The real cost for development and implementation of new parts is typically unknown throughout the industry. Even companies with a high awareness of these costs admit that only a fraction of the true costs are actually considered on an individual product line basis. The rest is overhead and is thought to be unavoidable, until now.

Which factors should be included in the true development cost; labor, material, building, energy, and even the cost of speed to market? What is the cost of a 30 day delay vs. the reward of 30 days early? It's obvious that except the material costs all of these factors are difficult to measure.

The following graph in figure 7 depicts the actual cost vs. the responsibility of the cost. In the beginning of the product and mold design the actual cost is very low while the decisions made at that level have a tremendous impact on the long-term actual cost.

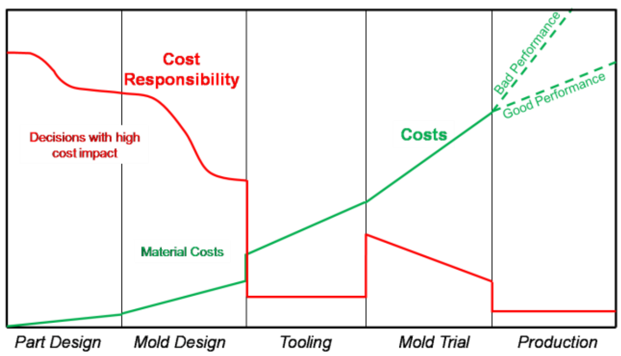

Figure 7, Actual cost vs. responsibility of cost.

Decisions about a part geometry during product development that create a more complex mold design; e.g. unnecessary holes, unfavorable wall thickness, bad geometry–material combination that causes long cycle times, etc. can create costs that will multiply throughout the entire development process. Even after the part design is finalized, the responsibility of cost is still high because the decisions made regarding the manufacture of the part can lead to higher production costs.

In the beginning of the mold design phase decisions about the number of cavities, mold layout, runner type and design, tempering and ejector/venting layout are made. These decisions will directly affect the productivity on the shop floor. The costs produced in this phase are slightly higher than in the part design phase due to increased labor.

After the mold design phase is complete, the costs steadily increase. Material is purchased (jump in the curve), additional skilled labor, machine and shop floor costs occur.

After the mold is built, failure or success of a development becomes visible: A part has to be injection molded and a stable production process has to be found. In this phase the costs are increasing. Labor can be in a best case scenario as low as one man, but an injection molding machine on the production floor has to be used and material will be “wasted”. The molder has a high responsibility to find an adequate process window in a timely fashion and not to damage the mold.

In the final production phase the costs can be high or low depending on the decisions made in the previous steps.

These five development steps (part design, mold design, tooling, mold trial and production) are theoretical. It's often necessary to complete some steps more than once producing additional costs. True development processes are much more complex, have several loops and the production phase is not evaluated with the molding of a good part; often handling and assembling processes have to be developed as well.

Saving Potential

Each molding trial typically costs $1,200 USD on a 100 ton machine and an average of 4 mold trials is necessary before a part is finally in production. The following cost example assumes a company builds only one new tool per month. The amounts shown include only the costs of injection machine, time, and labor during the shop floor trials. Costs do not include energy, material, or retooling costs.

Single mold trial		$1,200
4 mold trials required	4 * $1,200	$4,800
12 molds a year	12 * $4.800	$57,600

The complete simulation approach can provide cost avoidance as well as cost reduction. In this example, additional savings such as faster engineering, reduced time to market, lower tooling costs, more efficient and stable production, or improved quality are not included.

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.

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 will lead to accomplishing smarter lean manufacturing goals.