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Step-by-step guide to Scientific Molding

By PlasticsToday Staff
Published: September 26th, 2011

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Manufacturers that design and produce critical-use devices containing precision-molded plastic parts must be certain those parts are defect-free and formed through a highly reliable and repeatable process that can be validated. The process must be repeatable across multiple production runs and consistently produce high-quality parts that achieve tight tolerances.

Scientific molding is a manufacturing discipline that is increasingly in demand by OEMs because it virtually guarantees top quality by removing all the guesswork from the injection-molding process. Compared to traditional "trial and error" molding that relies on guesswork to bring parts within specification, scientific molding uses sophisticated data collection and analysis techniques to document the specifications, settings, and steps required to ensure reproducibility over time and across equipment. Because all data associated with the process are recorded, the process can then be replicated as needed, even when production is transferred from one machine to another, with minimal setup time.

Developing a hypothesis, testing it, analyzing the results, drawing conclusions, building a process, and proving the results are reproducible are the key steps in scientific molding. The end result is a tightly controlled, repeatable manufacturing process that creates high-quality parts. At [Kaysun Corp.](#) (Manitowoc, WI), for example, scientific molding is applied across all phases of part manufacturing: design of the part, design and building of the tool, debugging the tool, material selection, and the injection-molding process. Different engineers with specialized expertise oversee each of these phases, as shown below

Stage	Objectives
Part Design	Designers assess customer's needs and requirements vs. their available resources. Specifics such as polymer selection, gating design, corner radii, draft and wall thickness are determined here.
Tool Design	Choose steel type, gate location; determine venting & cooling channel layout and ejector pins' location. (overall mechanical design of mold)
Tool Build & Debugging (the heart of the scientific molding process)	Develop robust process: program engineer conducts tests to define parameters and records data to form the template.
Production	Process technicians monitor production against template, identify and solve issues.
Assembly	Production techs perform dimensional checks.

How Scientific Molding Works

The key to scientific molding is capturing high-value process data and knowing what it means. Advanced processing and diagnostic tools are installed on equipment to create a customizable process monitoring and control system for plastic injection molding applications. Important scientific data-including temperature, pressure, material flow rate, material chemistry, cooling time and rate, material moisture rate, fill time, and mold conductivity-are all monitored in real time and compared to a "peak" template of values. Analysis of this data by trained scientific molding engineers can:

- Verify whether the right processes are running and running to template
- Receive immediate notification of any process deviation
- Detect and contain short shots and other defects
- Improve part quality to reduce or even eliminate manual sorting
- Have data for every part made for traceability
- View the status of all jobs from anywhere
- Be notified whenever exceptions occur

Digital in-cavity pressure readings reveal what is happening inside the mold during the injection process. These readings can be compared to previous job data and process templates to reduce time and improve continuity. Scientific molding data reduces the need for manual inspections and minimizes scrap. Mold deflection sensors can resolve issues regarding parting



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line flash, part dimensional changes related to mold deflection, clamp force, and mold robustness, as well as ensure correlations of part characteristics to key molding variables.

Using this data, Kaysun's scientific molding engineers determine exactly what is happening with the material inside the mold, specifically in terms of viscosity. They know (rather than guess) how the polymer flows into and behaves inside the tool. By recording data when the machine is producing at peak efficiency (top productivity with minimal scrap), engineers create a "peak" template of process parameters that can be replicated when:

- Specification issues arise during production
- An existing mold is set for a new production run
- Production is moved from machine to machine

Scientific molding is most beneficial during the molding stage, after the tool has been developed and debugged. It determines the best method of molding by analyzing the fill, pack, and hold stages separately; these data points are critical to creating the template with the highest degree of control. (In contrast, during the traditional molding, the mold is filled completely with first-stage pressure; the unrestrained kinetic energy produced by the fast fill makes the packing phase difficult to control, resulting in an increased rate of mold flash and other flaws, meaning fewer acceptable parts.)

Molds must be specially built or modified with cavity-pressure transducers that are electronically interfaced with both the injection-molding machine and a monitoring system. The fill and pack stages are separated in order to completely control the speed of the fill and prevent undesirable pressure levels. The material still fills the cavity quickly, up to 99% capacity, but since the pack stage is separate, the kinetic energy is spent before the material can flash the mold.

The remainder of the polymer is then injected with precise control in the pack stage, using second-stage pressure to pack out the mold and hold until gate seal. The pack rate goes at a low and precisely controlled speed until cavity pressure reaches the correct level, as recorded on the unique template for that production run. Sensors in the mold then take over process control, reading the material's behavior within the tool.

Using a scientific approach to molding results in much higher repeatability and 10 times or greater control compared to traditional molding methods-reducing costs to the OEM by conserving time and materials.

Molding Variables

Determining and duplicating all the parameters for a given material and molding situation are essential for process repeatability. The scientific molding engineer, well aware of the interdependence of all process variables, interprets the data and manipulates the parameters to achieve the ideal process. For example, melt temperature is affected by barrel temperature and screw speed and back pressure, to name a few factors. The main molding variables are:

- Temperature (of material and mold)
- Material flow rate
- Pressure (pack and hold)
- Cooling time and rate

Other factors include material moisture rate, fill time, and mold conductivity. Each of these factors is in turn affected by others in this highly complex process. Cooling time, for example, is influenced by the heat level in the material, the conductivity of the tool steel, and the geometry of the part. Since our engineers are trained to consider everything from the perspective of the plastic, they can manipulate the variables as needed to return the process to optimization.

Debugging the Mold

Debugging of the mold is the heart of the scientific molding process. In order to ensure consistent and repeatable production of flawless molded parts, the mold must be challenged completely before it's called into action. This is how its weaknesses are identified and corrected.

The process begins with the tool being put into the press so that the toolmaker and process engineer can thoroughly examine every aspect of its mechanical functionality. For a starting point, they use the recommendations specified by the supplier of the material to be molded; those settings are entered into the machine.

Next, the engineers conduct short-shot testing to assess the dynamic pressure loss and, in a multiple-cavity mold, to check for any imbalance among the cavities. This step is also the stage for a crucial objective: establishing the rheology curve (or viscosity curve) to indicate the best fill rate and pattern.

After this, gate seal studies are performed from both the pressure curve and the weight of the sample parts to see if the gates seal fully, and at what point, on the mold cavity (or multiple cavities). Engineers examine the test parts for any defects and record their findings along with recommendations for any adjustments in the process or the tool in order to correct the defects. They also record data on the melt temperature, fill time, mold temperature, coolant flow, cycle time, and pressure curves.

The parts then go to quality control for examination of their measurements, shot-to-shot consistencies, and overall quality. That information is used for any necessary adjustments to the tool, before new samples are made. The new samples then undergo the same quality testing, with necessary adjustments made again as needed.

All the process parameters are recorded, with their acceptable ranges shown, to form the template. This template will be followed throughout production to ensure top quality, efficiency, and repeatability.

Testing and Monitoring

After the process engineer has verified that the mold is functioning optimally, production begins. The production engineer monitors process parameters according to the template, with ongoing quality testing. If issues are identified, the specialist analyzes the data and forms a solution to return the process to conformation.

Testing and monitoring tools used during tool development and production include:

- Rheology curve (or viscosity curve)
- Velocity profiling
- Cavity pressure readings
- Gate seal (or gate freeze) studies
- Design of experiments

Design of experiments (or experimental design) refers to a related group of tests used in setting up the process parameters and troubleshooting process issues. This allows the molder to make simultaneous adjustments to the variables, saving significant time-sometimes days-over earlier troubleshooting methods based on intuition and guesswork.

Rheology testing helps determine the optimal viscosity and injection speed, making it a crucial part of scientific molding. Velocity profiling helps to determine the fastest fill rate that can be used without causing flash or other aesthetic flaws. Cavity pressure readings show the actual pressure inside the mold, making this the best tool for indicating the material's behavior where it cannot be observed.

During rheology studies, data measured during short-shot injections is used to create a viscosity curve that shows the ideal

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viscosity and first-stage injection speed. By analyzing injection speed, pressure, fill time, and gate-seal studies, the engineer determines the optimal mold parameters. Once these parameters are recorded as the template, it can be used to replicate the process across different machines.

How Scientific Molding Benefits the Manufacturer

Reproducible quality is the key to an efficient and cost-effective manufacturing operation. Because scientific molding is governed by science rather than art, these engineers can ensure consistency and repeatability in production-qualities that are in high demand by OEMs, who face more stringent regulations from the FDA, including process validation.

A predictably efficient process that delivers defect-free parts and critical-use products-medical devices, high-tech defense equipment, and automotive components, for example-with reduced loss of materials at minimal time and cost, can be achieved with scientific molding. It requires a combination of knowledge, experience, analytical skills, and the proper equipment and tools. At Kaysun, specially-trained scientific molding engineers are experts in each phase of product development, ensuring process conformation to the template. Aided by their analysis and interpretation of the collected process data, material science knowledge, and ability to solve issues, they use the scientific approach to design robust and repeatable processes that consistently deliver top-quality parts with high tolerances.

Editor's Note: This article is based on a white paper submitted by Dan Lindgren, Senior Project Engineer at Kaysun Corp. (Manitowoc, WI).

Great article, but imagine if

Submitted by Anonymous on September 28, 2011 - 6:29am.

Great article, but imagine if the Scientific Molding is preceded by proactive SCIENTIFIC HOMEWORK, i.e. the SIMULTANEOUS, EXPERT OPTIMIZATION of the apx. 400 mostly interactive variables of injection molding coming from a)material rheology/thermodynamics and shrinkage, b)part design, c)mold design, d)process design, e)machine parameters and f)planned, preferably sensor-based QC. Imagine that part designs that control apx. 70-80% of part cost, would be expert-optimized for processing; mold designs that control apx. 70-80% of part quality and productivity would be expert-optimized along with a designed process for the selected molding press and plant cooling conditions even before the mold design is started or the first steel chip falls. If the Scientific Homework is not completed, the often 54 HRC mold steel will hold the mistakes (coming from guesswork) very tightly – often even Scientific Molding cannot purge them out. After apx. 2000 optimized parts/molds I can say proactively expert-optimized, high performance, highly competitive mold/molding systems are the reality and able to bring back projects easily from offshore while improving company reputation through quality production and generating cost saving. Before the design freeze (part and mold) we provide our clients with a)precision shrinkage values, b)required cooling line size/locations (within 0.010 inch accuracy) for highest productivity and quality (the possible, minimum cycle time) and c)quick check of gating/filling robustness from the standpoint of both filling and precision packing(QUALITY) so they can rapidly start the mold design. After this step the finer analysis/optimization follows, including the design of the Robust Process. When the latter is completed we turn the project over to the management and the Scientific Molding folks who should have an easy time running the fast(time is money), optimized mold/molding systems.

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