Scientific Molding:

A Manufacturer's Guide

KAYSUN
CORPORATION
INJECTION MOLDING & ENGINEERING SOLUTIONS

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Manufacturers of critical-use devices cannot afford to lose any time in getting their products to market. Advances in technology come rapidly, and other companies are vying for the majority of the market share. To ensure success, products must be designed and produced with ultimate precision and efficiency. That efficiency depends on eliminating production delays caused by flaws and inconsistencies in the manufacturing process.

Companies that design and produce critical-use devices containing precision-molded plastic parts must be certain that those parts will be formed with repeatable freedom from defect. The manufacturing process itself must also be repeatable across multiple production runs.

Since scientific molding is governed by science rather than art, thoroughly trained and properly certified molding engineers can ensure consistency, specifications conformance and repeatability in production because all data associated with the manufacturing process are recorded—and the OEM can count on getting the highest-quality components, parts and products time after time.

A predictably efficient process delivers defect-free parts with minimal loss of materials at minimal time and cost, even when production is transferred from one machine to another. Such an outcome is especially important in manufacturing critical-use parts and components.

This white paper:

- Explains how specialized molding engineers oversee the design, process and production of precision-molded plastic parts, so as to develop templates for repeatable production
- Examines the key benefits provided by today's scientific molding procedures, in general terms as well as with specific examples
- Explains the importance of molding engineers' proper training and certification in state-of-the-art scientific molding practices that optimize all aspects of part manufacture

What is Scientific Molding?

Scientific molding uses the key steps of the scientific method — developing a hypothesis, testing it, analyzing the results to draw a conclusion and proving the results are reproducible — to develop a tightly controlled and repeatable manufacturing process that results in parts consistently free of defects. 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 establish a robust process window and document the specifications, settings and steps required to ensure reproducibility over time and across equipment.

This practice is invaluable in developing and producing components for critical-use products—from medical devices and high-tech defense equipment to automotive components—where precision and reliability can mean life or death.

Engineers trained in scientific molding have developed a thorough understanding of what is happening with the material inside the mold, specifically **in terms of viscosity: they can visualize, rather than guess, how the polymer flows into and behaves inside the tool**. Their insight is invaluable in designing successful molds and molding processes, identifying process issues quickly and accurately, and determining and executing solutions to return the process to specification.

By recording data when the machine is producing at peak efficiency (top productivity with minimal scrap), the engineers create a template of process parameters to be replicated whenever:

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

Optimizing the process in this way minimizes production time, errors and costs for the OEM.

RJG, Inc. and DECOUPLED MOLDING℠

The Michigan company RJG, Inc., is an internationally known provider of injection molding education and technology.[1] In addition to supplying a comprehensive range of courses, RJG provides the equipment, testing and analysis tools, and software essential for scientific molding. Most notable is the RJG eDART™ system, a customizable assembly of measuring and monitoring tools for scientific molding.[2]

DECOUPLED MOLDING℠ is RJG, Inc.'s copyrighted **term for the scientific molding technique the company developed for the highest level of process control**.[3] The term applies to the molding phase of the process, after the tool has been developed and debugged. It is scientific molding that provides the most repeatable method of molding.

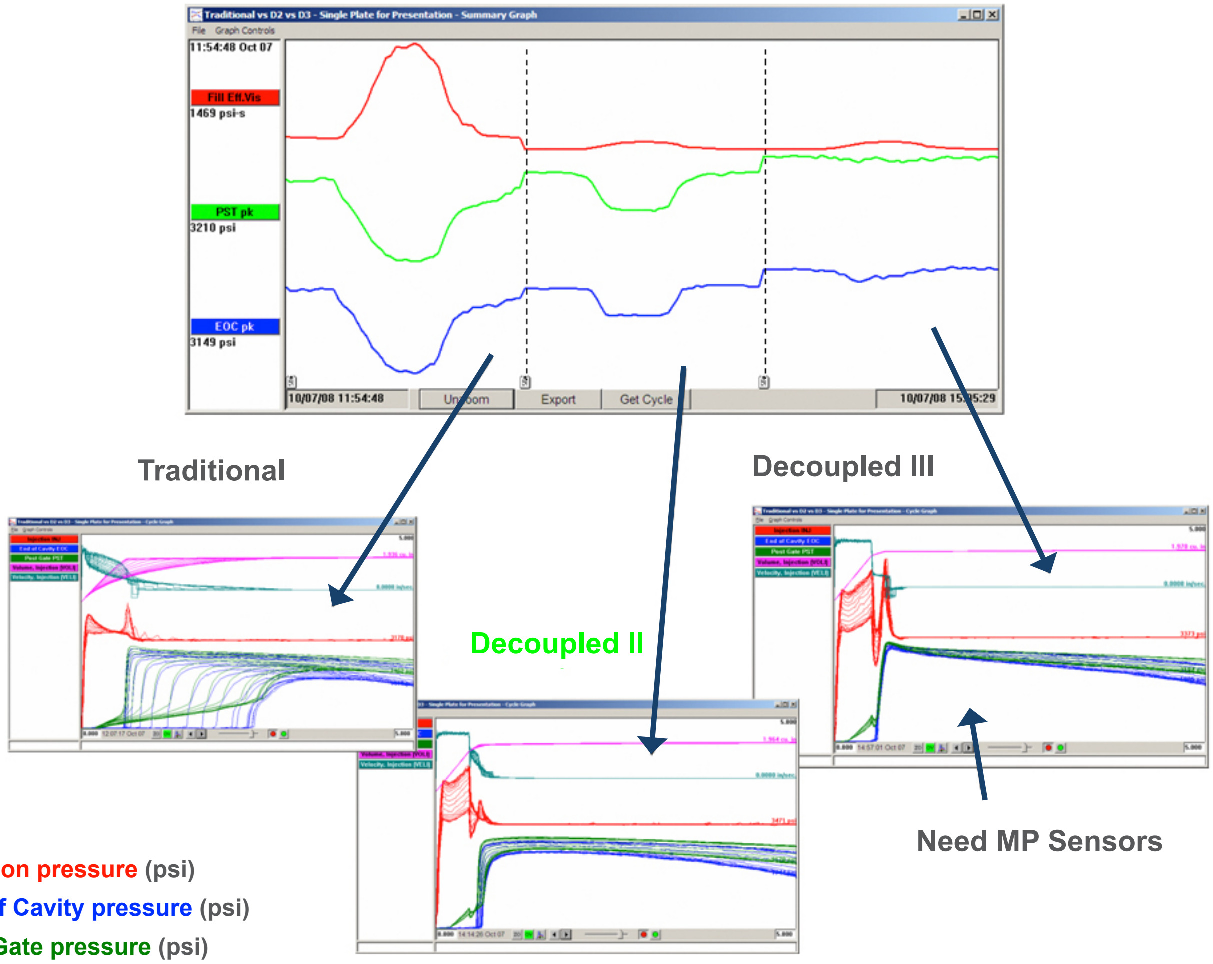
In DECOUPLED MOLDING, the **fill, pack, and hold stages are separated to give the molder the highest degree of control**. By contrast, in the outdated, traditional molding method (known as DECOUPLED I) the mold was filled completely with first-stage pressure; the unrestrained kinetic energy produced by the fast fill made the packing phase difficult to control. This lack of precision caused an increased rate of mold flash and other flaws, meaning fewer acceptable parts.

DECOUPLED II (fully decoupled) and DECOUPLED III (totally decoupled) are the methods in use today. In DECOUPLED II, the fill and pack stages are separated completely to control the speed of the fill and prevent an undesirable pressure level. The material still fills the cavity quickly, to 95-99% capacity, but since the pack stage is separate, the kinetic energy is spent before the material over-pressurizes the mold leading to tool damage, flash and other part defects. The remainder of the polymer is then injected with precise control in the pack stage, using second-stage pressure to pack out the mold until gate seal.

In DECOUPLED III, the process is further separated in that the pack-and-hold stage is also decoupled (the fill stage is the same as in DECOUPLED II). 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. Molds for DECOUPLED III must be specially built or modified with cavity-pressure transducers that are electronically interfaced with both the injection molding machine and a monitoring system. Since the kinetic energy is lowered more gradually than in DECOUPLED II, the pack rate in this more complex molding method is even more precise.

The graphs on page 5, figure 1, were taken from an RJG capability study on a specific polymer after the introduction of a 20% change in viscosity. Each graph contains an overlay of 10 consecutive shots in each of the three DECOUPLED MOLDING methods. The blue and green lines, representing End of Cavity (EOC) and Post Gate (PG) pressure, respectively, illustrate the increasing level of control from DECOUPLED I through DECOUPLED III when any viscosity change is introduced. For instance, **the viscosity of a given plastic can vary from lot to lot, requiring adjustments to the molding process parameters**.

Figure 1: RJG Graph Comparison of DECOUPLED MOLDING types.
Image Courtesy of RJG, Inc.



KEY:
Injection pressure (psi)
End of Cavity pressure (psi)
Post Gate pressure (psi)
Injection Volume (cubic inches)
Injection Velocity (inches per second)

Note the great variation in the blue and green lines in DECOUPLED I. There is clear improvement in DECOUPLED II, which gives the molder three times the control over EOC and PG pressure. The DECOUPLED III method, in which pressure sensors have been placed in the mold, affords vastly more repeatability, with 10 times as much control as the traditional method. This is indicated in the graphs by the decrease in variation in the blue (EOC) and green (PG) lines representing those pressures. Because the fill speed is controlled in DECOUPLED II and even more so in DECOUPLED III, the scientific molding process offers undeniable value to the OEM by conserving time and materials.

Molding Variables

Determining and duplicating all of the parameters for a given material and molding situation is the key to process repeatability. The 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, 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

Secondary 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 the molding engineer has been trained to consider everything from the perspective of the plastic, she or he is prepared to manipulate the variables as needed to return the process to conformation.

Debugging the Mold/Developing the Process

Debugging the mold is at the heart of scientific molding. In order to ensure manufacturing success through consistent and repeatable production of flawless molded parts, the mold must be challenged completely to identify and correct weaknesses before it's called into action.

The process begins with the tool being put into the press so that the toolmaker and molding engineer can thoroughly and systematically check every aspect of its mechanical functionality. For a starting point, they use the recommendations specified by the material supplier of the material, as shown in the example for polypropylene in the chart on page seven.

Specialty Compounds Polypropylene (PP)		
Typical Injection Molding Conditions	**English**	**SI Metric**
Temperatures		
Rear Zone	380 - 420ºF	193 - 216ºC
Center Zone	390 - 430ºF	199 - 221ºC
Front Zone	400 - 440ºF	204 - 227 ºC
Melt	375 - 450ºF	191 - 232ºC
Mold	90 - 150ºF	32 - 66ºC
Pressures		
Injection	10000 - 15000 psi	69 - 103 MPa
Hold	5000 - 10000 psi	34 - 69 MPa
Back	50 - 100 psi	0.34 - 0.69 MPa
Speeds		
Fill	1 - 2 in/sec	25 - 51 mm/sec
Screw	60 - 90 rpm	60 - 90 rpm
Drying		
Time & Temperature	2 Hrs @ 175ºF	2 Hrs @ 79ºC
Dew Point	n/a ºF	n/a ºC
Moisture Content	n/a %	n/a %

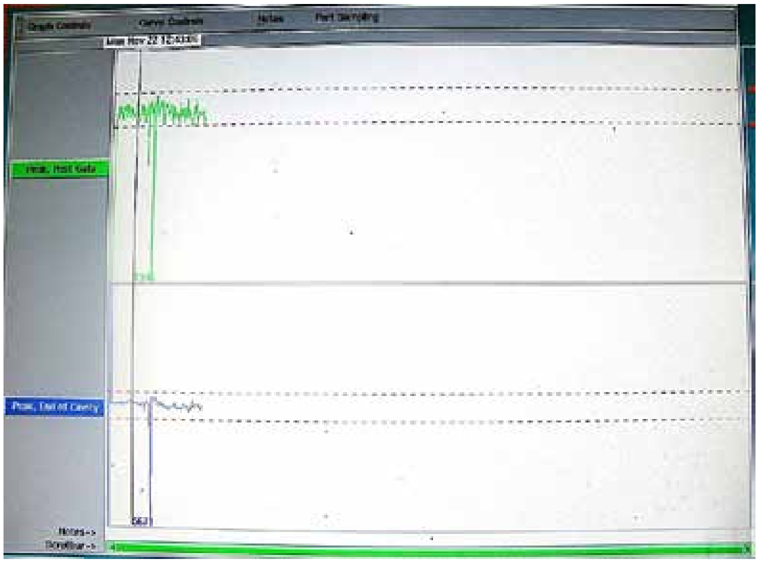
Next, the engineers conduct short-shot testing to assess the dynamic pressure loss and, in a multiple-cavity mold, to check for any imbalance among the cavities. This step also accomplishes a crucial objective: establishing the rheology curve (or viscosity curve) to indicate the best fill rate and pattern.

The decoupled process is then set up for further testing. Gate seal studies are performed using both the pressure curve and the weight of the sample parts to determine if the gates seal fully, and at what point on the mold cavity (or multiple cavities). Molding engineers examine the test parts for any defects and record their findings along with recommendations for process or tool adjustments. They also record data on the melt temperature, fill time, mold temperature, coolant flow, cycle time and pressure curves.

Then, the parts proceed to quality control for examination of their measurements, shot-to-shot consistencies and overall quality so any necessary tool adjustments are completed before new samples are made. The new samples then undergo the same quality testing, with necessary adjustments made again as needed.

All of the process parameters are recorded, with their acceptable ranges shown, to form the template that will be followed throughout production to ensure top quality, efficiency, and repeatability. The image below shows an actual production snapshot from the molding of a critical part for a GPS unit Kaysun was producing for a U.S. defense partner:

Figure 2: A production snapshot showing cavity pressure parameters.



The image shows the acceptable high and low for the cavity pressure. If the pressure rises or falls out of this ideal range, the press will shut down. In this example, the press had been deliberately shut down for maintenance, sending the pressure levels out of the lower control level.

The Importance of Scientific Molding Training and Certification

The required training for scientific molding engineers is rigorous and extensive. Depending on his or her specialty, the engineer completes successive certification levels in order to develop the comprehensive understanding necessary for reaching the objectives in any given precision-molding situation. Kaysun's scientific molding specialists receive most of their ongoing training in the discipline from industry leader RJG, Inc., whose notable certification levels include Systematic Molding, Master Molder I, and Master Molder II.

Successful scientific molding requires a combination of knowledge, experience, analytical skills, and the proper equipment and tools. The capable molding engineer applies these resources to each unique molding situation. Through their expert analysis and interpretation of the collected process data and their ability to resolve issues, they employ a scientific approach to design and document a robust and repeatable process that delivers consistently defect-free parts, ensuring process conformation to the template.

Tools for Testing and Monitoring

Once the mold has been verified as functioning optimally, production begins. Molding engineers monitor process parameters according to the template, with ongoing quality testing. If issues are identified, they analyze the data and form a solution to return the process to conformation.

Some of the 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
- RJG graph comparison
- 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. It allows the molder to make simultaneous adjustments to the variables, saving significant time—sometimes days—over earlier troubleshooting methods based on intuition and guesswork instead of informed analysis of scientific data. The **molding engineer conducts his or her analysis of the RJG graphs** showing the current process parameters (using solid lines) compared to the template parameters (shown in dotted lines).

Rheology testing helps to determine the optimal viscosity and injection speed, making it a crucial part of scientific molding. **Velocity profiling** helps 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 the eye can't actually see. This is really the core of scientific molding and where molding engineers' specialized training helps guide visualization of what's happening to the plastic inside the tool.

During rheology studies, data measured during short-shot injections is used to create a viscosity curve that shows the ideal viscosity and first-stage injection speed. **By analyzing injection speed, pressure and fill time along with gate-seal studies, the molding 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.

The eDART™ system may be used throughout the phases of scientific molding for testing as well as troubleshooting. The system is essentially a computer on wheels that can be rolled where needed to monitor molding variables, verify conformance to template, adjust process conditions, set timing and alarms, among other functions crucial to successful molding.[4] This collection of tools can be configured to the job at hand. It contains software that holds and organizes the process data for the molding job, forming the templates and yielding the RJG graphs that the technicians use to achieve the robust and repeatable process. While the eDART system is used only at particular points in the majority of molding situations, 30% of jobs are run with it constantly connected.

Case Study: Faucet Manufacturer

Here is an example of how scientific molding helped Kaysun solve a dimensional issue with a manufacturing partner, a producer of faucets.

Kaysun had designed a four-cavity mold to meet tight-tolerance requirements while also increasing efficiency by producing the four valve bodies at one time. During the molding process, the fourth cavity fell out of tolerance due to an issue with its diverter — there was a sink at the bore's end.

Our engineers reviewed the recorded data on the cavity pressure transducer graphs and found that the recorded pressure of the affected cavity differed from the other three. Based on this data and the type of defect, the molding engineers determined that there was an issue in the coolant line for the fourth cavity. A restriction was, indeed, detected and removed, allowing the fourth cavity to return to performing at specification.

Because the engineers were thoroughly trained in scientific molding principles and they had the pertinent data at hand, they were able to efficiently identify and correct the problem. The production run continued with minimal loss of time and material.

Kaysun Corporation: The Know-How to Ensure Success

Scientific molding is a complex process that runs through every phase in the production of precision-molded plastic parts. A mold with robust process capabilities gives the manufacturer the assurance of consistent quality and top efficiency. The OEM reaps the full benefits by enlisting a qualified molding partner early on, as the design phases—for both the part and the tool—begin.

Through their rigorous training and certification, the molding engineers at Kaysun Corporation design successful parts and tools, and the production engineers promptly detect and solve issues to save precious time and materials.

Give us a call or request a consultation with one of our specialized engineers to learn how we can apply scientific molding practices to improve your next critical-use project.

www.kaysun.com

800-852-9786

CITATIONS:

[1]*RJG, Inc., http://en.rjginc.com/, Company Overview*

[2]*RJG, Inc., http://en.rjginc.com/, eDART System™ Overview*

[3]*RJG, Inc., http://www.rjginc.com/company/history, Company History*

[4]*RJG, Inc., http://en.rjginc.com/, eDART System™ Overview*