Why Plastic Flows Better in Aluminum Injection Molds

An investigative study directly comparing melt flow characteristics of general purpose resins in QC-10 aluminum molds and P20 steel molds.

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Part 1 Introduction

There have been numerous articles published regarding the cycle time advantage aluminum molds have over steel when configured with the same gate, part geometry and cooling channels, but there is little specific information available to demonstrate why this happens and how it improves the injection mold process.

Alcoa Forge and Cast Products teamed up with Aluminum Injection Mold Co. (Rochester, NY) and sponsored a case study to uncover the differences known to exist when molding thermoplastics in aluminum versus steel molds. The key objectives were to quantify the differences by comparing how thermoplastics react in an aluminum mold versus a steel one, measure those differences, and share the results of the experiment. The results should help mold makers and molders better understand the potential savings and improvements for molding plastic components in aluminum tools, specifically addressing how:

1) Plastic material flows longer distances with less injection pressure, when compared to steel
2) Molds fill faster and more efficiently
3) Parts have minimal warp and better dimensional stability

Aluminum's thermal conductivity is nearly 5 times greater than that of steel (table 1). In a 2002 article published in Moldmaking Technology[1], Douglas Bryce discusses an IBM tooling study comparing identical aluminum and steel molds producing the same plastic components over a five year period. The article suggested that the aluminum molds cost up to 50% less to build and can be delivered in one half the time. It went on to say these tools produced higher quality products having cycle times that were 25 to 40% less than the steel molds.

Measurement	QC-10	P20
Thermal Conductivity BTU/ft/hr/ft^2/°F	92.2	20.2

Table 1

In 2005, an article written in the Moldflow publication, Flowfront[2], looked at computer simulation of cycle time and cooling versus actual molding. After carrying out simulations on 12 parts which had very different characteristics in terms of shape, size and plastic materials, it was concluded that significant savings in total cycle time could be realized by using aluminum instead of steel molds. Cycle time savings of 10-20% were seen in cases where there were no critical tolerances linked to the deformation of the part due to the effect of the heat. However, savings of 60-200% were seen in cases where heat deformation affected critical design tolerance levels.

Studies like these are relevant to the industry and this case study looks at the basis of why plastic flows better in aluminum.

Part 2 Tooling

Spiral test molds, built in accordance to ASTM D3123-98 were selected for the tool design. This shape would standardize the channel length, size of overall mold, cooling and gate location. In addition, each mold was fitted with a series of 4 thermocouples to monitor and document, in real time, what the metal does when injected with molten plastic. All the thermocouples were connected to a data logger and computer for data collection. For the aluminum molds, we used QC-10 mold plate and for the steel molds, P20. Six molds of identical geometry were built - three in QC-10 and three in P20. The spiral mold shape was sized at 6 mm wide and channel depths of 1 mm, 2mm and 3mm, respectively. The sizes of the tools were a standard 7" x 8" master unit die and all the mold plates were the same thicknesses. (Fig. 1)

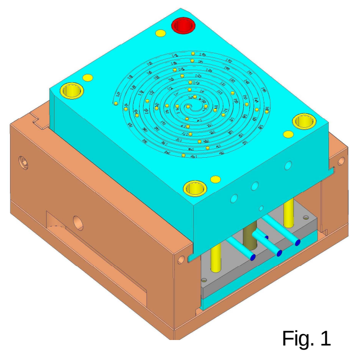


Fig. 1

The sprue diameter was identically sized for each of the six unit molds. Identical water lines were drilled to complete the cooling circuits. Four of the six molds, the 1 mm and 2 mm molds in both materials, were fitted with thermocouples that came in from the back and were approximately 0.5 mm from the cavity surface. On the 3 mm spiral unit molds, a 5th thermocouple was placed into secondary vent area to monitor the vent temperature during molding. All six molds were laser engraved on the "A" side in inch increments from 1" to 67". The surfaces were finished with a 600 grit stone. The test was set up in a 55 ton Toyo injection mold machine.

Seven unfilled, general purpose thermoplastic resins were selected for this trial: polyethylene, polypropylene, polystyrene, ABS, PC/ABS, nylon, and polycarbonate.

Part 3 Molding Trials

Trial 1: Same melt temperature, same mold temperature per manufacturer's recommended parameters; seven resins, six tools

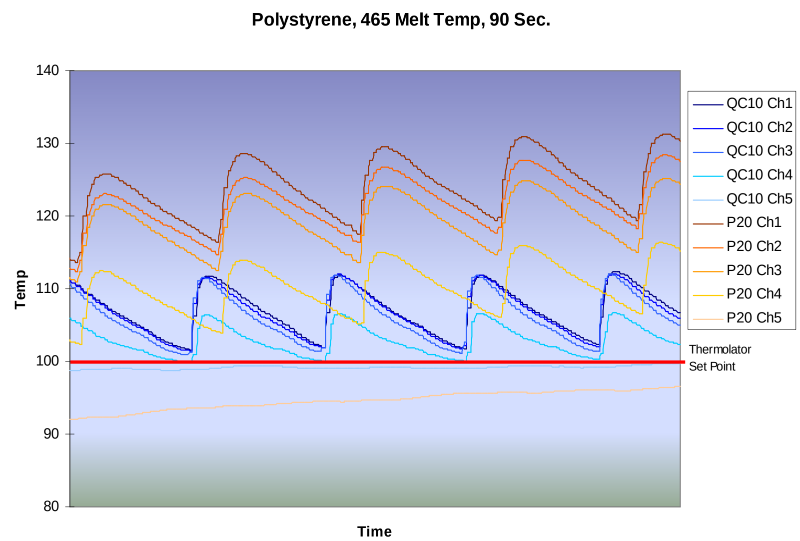
This trial fixed a predefined orifice, a predefined temperature and a predefined injection pressure (< 1000 psi). A 25-piece sample was run for each mold group. Our hypothesis suggests that the flow lengths would be dramatically different between the QC-10 and the P20 molds because of aluminum's higher thermal conductivity. The material was dried for the prerequisite period of time and prepped for molding. The melt temperatures were set to the resin manufacturers recommended settings and the molds were brought up to the manufacturer's recommended temperature as well. The P20 molds were run first in all the materials. The data found the average spiral flow length to be 10" to 15", consistent with the manufacturer's specifications. The QC-10 molds were run in all the materials as, expecting to see a dramatic difference in flow length. We did not.

The flow length results were in the same range of the P20 molds. We were puzzled by these findings. In the end, all the materials yielded basically the same results in all the molds used. Not the expected outcome.

With over 25 years experience in processing aluminum tools, we were sure that this trial would demonstrate what is known to be true. The group had to stop and rethink the situation. We were searching for something that we knew was there, but did not know how to quantify it, yet. After much discussion, it was decided we needed to run the same materials in a trial that included pack and hold.

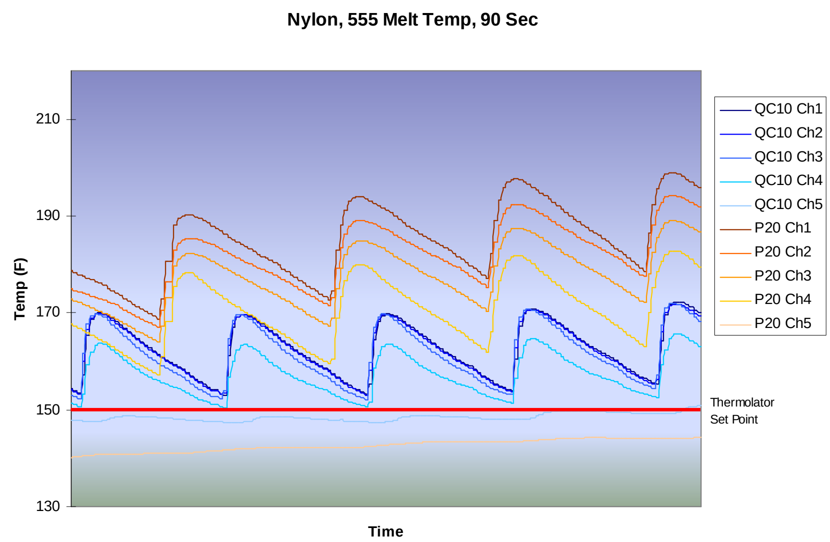
Trial Two: Seven resins; six molds with monitored temperatures, pack and hold

The second trial was initiated, again recording temperatures. The injection mold pressure remained at the baseline of the material used from trial one. This time the experiment was to process each unit mold as if molding a run of parts in production. Each mold trial began as a short shot (shorter length spiral, in this case) and proceeded to pack out the part to get the best achievable result. Cycle was established when the sucker pin pulled the sprue clean and the part was cool enough to eject. Cycle time and mold temperatures were documented for each tool running at least 25 parts at cycle.



In the QC-10 molds, the temperature graph during this process showed a near vertical increase in temperature from mold set point of about 10 to 12 degrees to an immediate drop back to set point before the mold opened. For a point of reference, the mold cycle for polystyrene was 12.2 seconds as we finished with the QC-10 group of molds. All three thicknesses, although yielding shorter flow lengths going from 3mm thick to 1mm thick, were in the same 12.0 to 12.5 second range for total shot to shot cycle.

The P20 steel molds were run at the same temperatures as QC-10. The first observation was the change in how the mold temperatures reacted as the molten plastic was injected. The temperature did not spike up and down with the same intensity as it did in the QC-10 molds. In addition, the cool down time was much more gradual. Also, P20 typically over ran the mold temperature set point by an average of about 20 degrees.



The increase in the mold temperature due to the injection melt was an additional 15-20 degrees. With all this excess temperature, i.e. mold overshooting and temperature increases with very slow recovery, we saw a difference of 20+ second cycle shot to shot in P20 versus the QC-10 cycle of about 12 seconds. At this point, we believed we had finally found the reason that plastic molds better in QC-10, and decided to continue another trial to verify our findings.

<u>Trial Three</u> - Two materials, 1 amorphous and 1 semi-crystalline, 3 mm unit molds of QC-10-and P20, pack and hold

We decided to use only polystyrene (amorphous) and nylon (semi-crystalline) with the 3 mm unit molds in QC-10 and P20 in this verification trial because we had found virtually no difference in flow length between any particular mold family and between any materials in the previous trials.

	QC-10	P20	QC-10	P20
Polystyrene				
Melt – F	465	465	430	430
Mold – F	100	100	100	100
Cycle – sec.	12.3	21.8	12.0	17.5
Flow Length	34"	34"	27"	27.5"
Nylon				
Melt - F	555	555	510	555
Mold - F	150	150	150	150
Cycle - sec.	21.0	24.0	20.3	22.0
Flow Length	52"	53"	39"	39.5"

Table 2

We then wanted to look at melt temperature versus flow length versus cycle time. We started with temperatures on the low side of the resin manufacturers recommended barrel temperature for the resin we were using. We also set the mold temperature to the lowest recommended set temperature. We ran the P20 mold in both materials, noted cycle times, mold temperatures and injection pressure. We then ran the QC-10 mold in both materials, again noting cycle times, mold temperatures and injection pressures. After compiling data, we moved all temperatures to the highest barrel temperature and ran each mold, both materials, again collecting same data. In both temperature tests in trial three for polystyrene, QC-10 cycle time stayed consistent with findings of trial two, 12-13 seconds. In the lowest temperature test, P20's cycle time was in the 20-21 second range, similar to trial two's findings, but in the higher temperature test, it jumped nearly 25%.

Part 4 Findings

The QC-10 molds heated five times faster than the P20 molds, as we set up to run each trial. Across all the trials, the QC-10 mold temperature stayed consistently within 1-3 degrees of the mold temperature set point. During the inject phase, a temperature spike of 10-20 degrees with an abrupt return to set point was observed.

The P20 mold temperature stayed consistently 10-25 degrees above mold temperature set point. During the inject phase, additional increases of 15-30 degrees were observed before slowly trending downward.

When using the QC-10 molds, we did not see an appreciable change in cycle time, part to part, even when we ran the materials at the high end of the manufacturers recommended melt/mold temperatures. However, the P20 molds continued to get hotter and the cycle time became even longer.

In view of these findings, it is not surprising that there are some plastic consultants extolling the virtues of running plastic resin as much as 100 degrees below the manufacturer's recommended settings when using P20 or other steel injection molds, even though doing so could void the manufacturer's guarantees.

Part 5 Conclusion

The results of this experiment were both a surprise and not a surprise.

We were not surprised to prove what we set out to prove, but the road that led us there was an unexpected one. We were pleased to show that plastic parts molded in aluminum would minimize warp and enhance dimensional stability, allow molds to fill faster and more efficiently and allow plastic material to flow greater distances with less injection pressure when compared to steel. We demonstrated that using aluminum gives the benefit of making molds less expensive to produce, shortening mold delivery time, producing higher quality molded plastic parts and enabling the realization of producing more plastic parts per day.

The surprise in the experiment was that the expected results were achieved in a different, unexpected way. We thought we would arrive at the desired results because aluminum molds would take on heat from the hot melt during the injection phase, enabling the plastic to fill the mold cavity more quickly with less pressure and less density change. Conversely, we felt that the steel molds would take on less heat, thereby creating more "skinning", and restricting the flow front resulting in the need for higher injection pressure and causing density changes from the gate to the longest flow length.

What we actually found was that the QC-10 did not take on or hold as much heat as we previously thought, thus allowing the molten plastic to move in quickly and quench quickly, therefore there was not a density change due to excess injection pressure. We discovered that the steel actually took on and held much more heat. During the inject phase, plastic filled the cavity and stayed molten much longer allowing for additional inject pressure which caused density changes before solidification.

We hope the information provided in this paper adds to the knowledge base used to consider aluminum as a choice for your next production injection mold.

References:

1. Douglas Bryce, Moldmaking Technology, *"Why Offer Aluminum Molds for Production",* April 2002

2. Claudia Zironi, Flowfront Magazine, "*Competitive Advantages of Aluminum Molds for Injection Molding Applications: Process Simulation Used to Evaluate Cycle Times",* April 2005

3. American Society for Testing and Materials (ASTM), West Conshohocken, PA. Is a nationally recognized independent test agency. The ASTM test number D3123-98 describes a spiral flow mold for use with thermosetting molding compound, and also states there appears to be no universal standard for thermoplastics.

Biographies

David Bank, President, Aluminum Injection Mold, Co. – Dave has over 25 years of experience manufacturing aluminum injection molds. He is the founder of Papago Industries, a maker of prototype and short-run injection molds, which he sold in 1998. Beginning in 2003, Dave re-entered the injection mold building business and opened what is now Aluminum Injection Mold, Co.

Aluminum Injection Mold is an industry leader in providing creative solutions in plastic to a wide range of customers including automotive, medical, computer/business machines, telecommunications, and consumer products. Additionally, Dave is the inventor of the AIM Frame. AIM Frames are Alcoa QC-10 molds with tool steel clamp rails and support pillars. The pillars have diameters scaled to the mold frame and are ground to the full thickness of the mold halves. Steel opens and closes on steel.

Dave has spoken at numerous technical events over his 25+ years and has chaired several committees involved in product and tooling design.

Dave Klafehn, Processing Consultant – Dave has more than 29 years experience in the injection molding industry. He worked at Eastman Kodak for over 10 years in component manufacturing, specializing in equipment maintenance, calibration, and process troubleshooting. During his time as director of manufacturing he gained interest and experience using aluminum molds to decrease tooling and manufacturing costs while improving part quality. He implemented the use of aluminum molds for production including the use of the MuCell Process. He also designed and processed hybrid aluminum and steel tooling with annual volumes of over 40 million parts.

Ron Smierciak, Market Development Manager, Alcoa Forged Products – Ron has been engaged with the development of Alcoa's mold alloy, QC-10, since 2005. He is responsible for the market development of Alcoa QC-10 mold product. Ron actively promotes the benefits of aluminum tooling to molders and original equipment manufacturers in North America, Europe, and Asia.

Prior to his involvement with Alcoa and QC-10, Ron developed and marketed metal products in diverse industries including thin film coatings for the semiconductor and flat panel display industries, and fabricated products for the chemical processing and petrochemical industries.