Acceptance Testing for Thermoplastic Injection Molds

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Abstract *— The injection molding process is the most important of all plastics processing processes due to its variety of uses and applications. The primary element of an injection molding process is the mold itself. Molds are expensive pieces of equipment that often cause their share of problems due to improper acceptance procedures.*
This research was limited to thermoplastic injection molds. The data was collected through interviews by phone. Practices with professionals during the acceptance process of a mold were discussed to gather an insight of the current situation. The results pointed out that many companies should implement and improve their acceptance procedures to avoid delays and money losses due to an improper methodology. A methodology was provided for molders based on scientific molding tests and it was evidenced that an acceptance procedure is needed for new molds.

Key Terms *—Acceptance testing, mold, plastic processing, scientific molding.*

PROBLEM STATEMENT

Injection molding is easily the most important manufacturing process for plastics parts. One of the most important components (if not the most) of any injection molding system is the mold tool itself. An injection mold is a metal tool which contains the cavity that holds the shape of the part. A lot of money, time and effort is put into building an injection mold. Several aspects influence how costly and how much time it will take; such as part complexity, runner design, part finish, part function, material selection, number of cavities and the list goes on. This makes the mold construction process an extremely important part of any project involving a new mold. However, it is not strange to see how many projects get delayed or fail and how many more result in significant financial losses due to this part of the process going wrong.

One aspect of how this can go wrong is process related. It is not uncommon to see projects in which process development and validation fail due to the inability of the mold to make good parts, either they do not meet specification limits, or they are uncapable of meeting process capability requirement. The customer ends up having the supplier work in new inserts to get the parts into specification. In some cases, it ends up going as far as shipping the mold back to the mold maker premises.

A previous approach to avoid this issue is performing several studies to determine the mold conditions. An important one, for example, is the development of a process window to determine if the dimensions are centered around the specification and if not, steel should be adjusted to center the process [1]. Other studies focus more on qualifying design areas in construction process such as runner balancing, hot runner design, venting and so on [2]. These methods are part of a series of techniques and studies which are called scientific molding or scientific processing. Scientific processing is a good methodology for process development, but it is usually used during the validation process. Some of these tools help in diagnosing the fitness of the mold for a stable process but, isn't it better to know that before the mold ships out of the mold maker?

Another aspect in which little attention is put, is the quality aspect of the development process of a mold. Measurement takes a big role during the validation process. For example, when debugging the mold, a shot is usually sent out to the customer as some kind of proof that the mold can make good, this parts may or may not be remeasured in the plant to verify if the parts are actually within specification. This is a good practice, but it should be paid more attention as sometimes the measurement method of both, the mold maker and the customer, may not correlate. This is a critical step in the process that is overlooked, and it is not usually considered.

This research will focus on covering methods during the acceptance of the tool in the supplier to make sure a mold is capable of a good process and avoid costly reworks and time loss. Quality and process engineering should play a role in the mold construction, which will be covered in the research.

By investigating about these methods, companies can improve the process of successfully accepting a new tool and avoid delays in their projects.

Research Description

This research is about acceptance testing for injection molds from the process standpoint. It is important because in the end, a mold will only be good when it is capable of achieving a robust process and to make sure the mold can achieve this goal, testing should be done at the mold maker to avoid costly reworks and project delays.

Research Objectives

- Describe practices from different companies and experts in the subject.
- Gather knowledge about the current status quo of the process of accepting a new mold.

Research Contributions

- Provide an approach for acceptance testing of molds.
- Show the importance of testing process conditions at the mold maker.

Literature Review

Tooling is a key foundation block when developing a work program. A poorly designed or improperly functioning mold can become the root cause for systematic failures. In addition, as continuous improvement projects are outlined, the mold should be reviewed for potential improvements through modification [2].

Fierce competition within the plastics industry is driving productivity and the need to do more with less. These same forces demand a very fast part-to-production lead time to win OEM molding programs, and, going beyond these challenges, require mold builders and processors to qualify and test molds within very tight time parameters. This competitive environment demands both speed and accuracy. The mold builder and manufacturer need to go to production as quickly as possible with tools to ensure solid quality control from their molds long before the presses start producing parts by the millions. Additionally, lead times for new mold builds have decreased drastically over the past few years. Although molds frequently are manufactured within the quoted lead time, it is in the mold sampling process that costs can spiral upward, and time is lost. Both factors negatively impact time-to-market and manufacturing efficiencies. During initial mold commissioning, there is a great deal of additional lost time and money when sampling and debugging the mold and the molding process to produce an acceptable product.

Several authors describe steps to determine the condition of a mold. David A. Hoffman [3] from Beaumont Technologies describes the following approach:

- Mold Samples
- Weigh Parts
- Determine Steel Imbalance in Flow
- Determine Steel Imbalance in Other Flows
- Determine Shear-Induced Imbalance

Another approach describes a mold qualification with a 6-step validation process. During this study, the function of the mold and its components, the determination of some of the process parameters, and the size of the process windows, are evaluated. Also, dimensional analysis to measure process capability are typically performed. The actual dimensions are not of major importance because the next step is to adjust the mold steel dimensions to mold the parts within the required specifications. The mold function qualification step is to determine the aesthetic process window (APW). Naturally, a wide window is desirable. Once the mold function and process windows are acceptable, the next step will evaluate the part quality [1].

Maybe the most prominent of all tests is the one registered by RJG, Inc. A company dedicated to providing trainings on injection molding of thermoplastics. They are also in the business of selling in-mold cavity pressure transducers along with a monitoring system called eDART. They have a trademarked, a methodology called Decoupled Molding which consist of the following:

- Decoupled I: Fills the cavity using speed until a predetermined pressure is reached, then stops pushing plastic into the cavity. This is generally used for thin wall molding and will exhibit higher-than-average shrink values due to little or no holding time/pressure.
- Decoupled II: Fills the cavity utilizing speed to 95-98% full visually, then applies a predetermined hold pressure that will pack more material into the cavity to minimize the effects of shrinkage. Usually this will produce average shrink values and will meet most molding applications. Here is a representation showing the inverse relationship between viscosity and cavity pressure in a Decoupled II process if no process adjustment is made.
- Decoupled III: Fills the mold cavity with speed to roughly 85% visually, then packs the cavity with speed to a predetermined cavity pressure before the machine transfers into a fixed holding pressure. Typically, this yields the lowest shrink rate and best consistency over time because of the two stages of speed control and moving the control from the molding machine into the cavity [4].

METHODOLOGY

The injection molding area is characterized by having a community of professionals dedicated to the development of techniques and methodologies for process optimization. This is called *scientific processing* and it consists of a group of studies to develop robust injection molding processes. The problem with this scientific approach is that it is usually done when the mold is already at the facility to begin with validation activities and then the consequent production start-up. But often, the end users find themselves unable to make good parts.

In this research, a qualitative method will be used to gain a deep understanding of good and bad practices in the process of accepting a new mold. The type of sampling that will be used will be the maximum variation sampling. The focus group will be people with experience in injection molding from job titles such as Injection Molding Specialist, Process Engineer, Molding Manager, or any person with enough expertise in this aspect of the process. The data will be collected through interviews and questionnaires to all individuals. The types of interviews will be through electronic means such as telephones, e-mail, and instant messaging as it may not be possible to visit or meet with the interviewers in any of the cases.

RESULTS AND DISCUSSION

A qualitative method was used to understand common practices in the industry. The sampling method utilized was the maximum variation sampling. The data was collected through a series of interviews by means of phone calls and videocalls.

The first question, "*How is the acceptance process in your plan?".* According to the respondents, one of the predominant factors is to have parts that meet the specification requirements. Basically, the minimum requirement is to have samples they can measure in plant to document that the mold is accepted. Some other participant agreed to this point, but also mentioned that some other things need to be checked and more tests need to be done to accept it. Other participants added the need to verify the balance of fill of the mold and the need to go to the mold maker to verify conditions such as part sticking into the mold, mold temperature stabilization.

The second question was "*In your view, how important is to have a procedure in place for mold* *acceptance testing*? All four respondents agreed that it is imperative to have a procedure as this is a critical activity and molds are very costly. When asked if they have a procedure in place, two out of four participants said yes.

The third question asked was "How *would you make sure a tool will be capable of a stable process before coming to your facility*" In this question, participants gave mixed responses. One participant said that they only take the samples they get from the supplier to approve the part. The three others said that they go to the mold maker before accepting a mold. Of these four, two go to the mold maker to check for mold connections, mold release condition, take some samples back with them and one of these two said that he would additionally tweak settings to see how the process responds, but it is not a requirement. The two others that have a procedure in place have a checklist to verify certain design aspects of the mold and perform several tests of the Scientific Injection Molding methodology, such as balance of fill, pressure drop, gate seal and cooling study.

The fourth question was "Why would you reject a tool?". One of the participants mentioned that as they only look at samples and verify if they are within specification, that is their only reference whether to accept a tool or not. Another interviewee added that part sticking into the mold is a reason not to accept a tool as the mold would not be able to run consistently. Other respondents added that they need a successful Scientific Injection Molding (SIM) study. One of them added the need for a DOE and a process window with all settings in which the process should be centered. If not, corrections should be made.

The fifth question was "What's the biggest issue you have had with a mold in plant after accepting it".

The first respondent mentioned a six-cavity mold in which one of the cavities was smaller than expected. They tried to adjust some parameters such as hot runner temperatures and pressure to no avail. Said cavity was steel adjusted to compensate for the difference of dimension, but this resulted in the cavity being larger than all the others. Hot runner balance was thought to be the culprit, so the mold hot runner system alone was sent back to the mold maker to make improvement. This delayed the project by one month. When the mold arrived, the condition was still present. In the end, the issue with the mold was related to an incorrect injection speed selection which caused a considerable filling imbalance in which one cavity specifically was affected the most.

The second respondent had a 12-cavity mold that required a series of qualification stages at the mold maker before sending the mold to the plant. These stages were as per their procedures. The tests included in their procedures are the tests per the Scientific Injection Molding methodology (balance of fill, gate freeze, etc.), a DOE and a 4-hours qualification run, in which 30 samples are taken to assess process capability. After all these requirements were met, the mold is sent to the plant and process validation starts with the process developed in the mold maker. Another 4-hours run in which also 30 samples are taken to assess process capability is required to accept the mold. When the samples were measure, one dimension was not meeting capability requirements due to being out of specification in the higher bound. The process was changed to attack this condition to no avail. Around two weeks were lost before the issue was found. The issue consisted of measurement error in which parts were not placed correctly when being measured.

The third response mentioned a 4-cavity mold. The part was like a flat rectangle. The mold went through a series of tests at the mold maker as part of their procedure. The mold was transferred to the plant and the performance qualification was ran, samples were taken for measurement and the parts met process capability requirements. The performance qualification run constitutes the first production lot from a new validated process, so parts were stored in boxes, ready to be sent out. However, when parts were about to be used for production, they were found to be deformed and unusable. It was later found out that the packaging of the product was at fault, as parts were stack hot on top of each other, which caused the ones on the bottom to bend the most.

The fourth interviewee mentioned a 2-cavity mold. The mold was sent down to the plant without visiting the mold maker and it had a high number of critical dimensions. When running the DOE, the samples were taken to the lab and measured, but some dimensions would not fall within spec in any of the combinations. The DOE was repeated with no luck. In the end, the issue was found to be the measurement method. After these, the company decided not to accept any mold without a visit.

Many of the issues explained during the interviews could have been resolved with a robust acceptance procedure. The first issue could have been fixed with a Balance of Fill study, which usually does not take more than thirty minutes. The second issue was the result of not doing a measurement correlation with the mold maker. The third issue was due to not evaluating the packaging of the product. Finally, the last one was another instance of not doing a measurement correlation with the mold maker.

How to perform an acceptance test for a new mold from a process standpoint

After the construction building phase is finished, the next thing is to coordinate a visit to the mold maker and agree on performing a run. Table 1 shows which tests to include in a mold acceptance test.

CONCLUSION

The aim of this study was to explore the different practices of mold acceptance testing that can be found in the injection molding industry. A qualitative approach was adopted using interviews to collect data for the research.

The study has provided insight on how companies manage their new molds during the acceptance phase. For some reason, many companies assume that it is enough to have samples from the mold trials in the mold maker. Other companies visit the mold suppliers to see the mold running but limit themselves to just that. Although it is better than having only the samples sent to the company, it is an opportunity that could be used to better test the equipment. Some companies do take advantage of this visit by challenging the equipment, although they mainly focus on functional areas and not in the process performance of the part.

Table 1
Mold Acceptance Test Requirements

Step	Test	Purpose
1	Viscosity	Find ideal injection speed
2	Cavity Balance	Determine if then mold balance is acceptable or not. If it is not acceptable, the tool should be adjusted.
3	Pressure Drop Study	-To diagnose critical pressure losses that would potentially cause a limited process. If the pressure losses are significant, the tool should be adjusted.
4	Cosmetic Process Window	Determine if there is an aesthetically process window. If this window is too small, molding good parts will be become a difficult task as any variation could potentially cause a defect. If this is the case, the tool should be adjusted.
5	Gate Seal Test	Find the optimum time of the holding phase.
6	Cooling time	Find a range for the cooling time and detect possible part sticking condition
7	GR&R and Correlation of measurements	Validate and correlate measurement methods between mold maker and your plant
8	DOE Run	Develop dimensional process window for the mold. If any dimension is not centered, steel adjustment must be performed to center this dimension.
9	Simulate a production run	Evaluate the process capability by running the mold for a few hours and taking samples to determine consistency of the mold.

There is an undeniable truth and that is that mold acceptance testing is needed. When the interviewees were questioned about the biggest issues they have had, most of them could have been solved by doing simple testing on the mold condition at the supplier

The contributions made in this research were:

- Provided an approach for mold acceptance testing.
- Evidence of the need for a formal procedure for mold acceptance.

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