A Systematic Approach to Diagnosing Mold Filling and Part Quality Variations

Sorry, champ. I'm afraid my mold is flawless. Maybe it's time you guys go back to "Processing 101."

Are you kidding me?!
Mold lead-times of ten to twelve weeks are becoming unheard of by today’s standards. Customer demands, and the thirst of Mr./Mrs. General Consumer for the next gizmo and widget, are requiring faster mold builds and quicker part approval times. But all too often a great deal of unexpected time and money are spent sampling and debugging the mold during the initial part approval process, with the end result being a part-to-production lead-time increase of several weeks to several months.

Rarely does a mold go in the machine for the first time and immediately start running production-ready parts. Typically the mold goes back and forth from the machine to the mold shop several times due to problems that are unexplainable or were not caught during the mold design or building stages. And unfortunately, various “solutions” are implemented to help get parts out the door, but these band-aid fixes usually do not solve the root cause of the variations. Of course everyone says they will fix the mold properly before production begins, and their comments are well intended. But we all know what usually happens…other priority projects come up, time is never found, and the molder is forced to live with a mold that has band-aids falling off revealing the scars of a poor design, build, and startup/debug procedure. This all creates long-term issues throughout the production life of the product.

But all is not lost. Some of these issues can be avoided. By implementing a systematic five-step approach to mapping the mold and tracking the variations accordingly (whether filling imbalances, mold maintenance, or part quality variations), the root causes of the problems can more easily be quantified, diagnosed, and solved. After all, plastic flow is a science and variations can be identified and solved by putting the pieces of the plastic puzzle together.

So let’s get started. Most molders today perform a short shot study during the initial mold sampling stage. This procedure can best be referred to as a “simplified mold balance analysis” and it usually consists of contrasting the heaviest cavity versus the lightest cavity and calculating a percent imbalance. This certainly gives the user a number…a perceived imbalance percentage…but now what? How can the user use the information gathered from this method to help diagnose and correct those variations? Consider the fact that your mold may have 4, 8, 16, or 32 cavities or more. Now you are trying to isolate the source of variations between those cavities with that one number. Sounds like a pretty difficult and impossible task for sure.

One the other hand, if we take a more scientific approach using a “systematic mold balance analysis”, it is possible to isolate the noises inside of a mold and separate the possible sources of the variations. And all this can be done in five easy steps. This five-step process takes fundamental plastic flow characteristics and applies them to the layout of the mold in order to identify “Flow Groups”. By doing such, it becomes much easier to see the variations in the mold, what is causing them, and how to eliminate the sources of the variations. Sounds cool, right? So let me explain further…

NOTE: When performing a systematic mold balance analysis it is important that none of the cavities are full. It is typically recommended that the best filling cavity is visually 80% full. Use the 80% rule with caution depending on your part geometry and mold design.

Consider that all filling and part quality variations from cavity-to-cavity within a mold are typically a result of a pressure drop difference to and/or within the cavities. By analyzing a simplified pressure drop equation for round channels:

$$\Delta P = \frac{8Q/\eta}{\Pi r^4}$$

Figure 1: Pressure drop equation for round channels
channels (see Figure 1), we can separate out the variables into two main groups: (1) mold steel imbalances \((l = \text{flow length}, r = \text{radius of the flow channel})\), and (2) shear-induced viscosity imbalances \((\eta = \text{viscosity})\).

As such, if the pressure drop was the same to all cavities then all the parts should fill & weigh the same, even when doing a short shot analysis. But most molders and mold makers would agree that this rarely ever happens.

So, digging into this further, we first need to separate the mold cavities into “Flow Groups”, or groups of cavities that have the same material shear history and therefore the same material viscosity conditions \((\eta)\) (see Figure 2). This allows us to eliminate viscosity imbalances as a possible source of variation within the Flow Groups. Therefore, any imbalance from cavity-to-cavity within a given Flow Group has to be caused by the other variables \((l, r)\), and as such those possible sources have been termed “Steel Imbalances”.

It has also been proven through numerous studies that cavities of different Flow Groups receive different material properties. Thus the major source of variation between Flow Groups must be a result of “Shear Imbalances”, or viscosity \((\eta)\) differences.

By now you are probably wondering what exactly is a Steel Imbalance or Shear Imbalance. So let’s continue to break it down further:

1. **Steel Imbalances Explained:** These variations are typically found within the mold steel dimensions. These variations may be caused by a non-geometric runner layout, differences in the machining of the part cavities, variations in gates sizes and/or gate land geometry, runner lengths, runner diameters, venting, or other sources. In addition, cold slugs can cause filling and part quality variations, and are considered a Steel Imbalance since they are easily solved through mold design modifications. Molding machine variations would also be considered a source Steel Imbalance. Machine variations may include: broken heater bands, worn screws, and worn valves. Basically any variation that is non-shear related would be categorized under Steel Imbalances. Sometimes the Steel Imbalances are easily identified while others take more time. But regardless, by following this systematic approach the user can eliminate the possible sources one by one and the overall time to diagnose the mold and part variations will be greatly reduced.

2. **Shear-Induced Viscosity Imbalances Explained:** Despite the geometric balance on what has traditionally
been referred to as a "naturally balanced" runner system, these runner systems introduce significant variations in melt conditions (i.e., temperature, pressure, and material properties) due to the non-Newtonian properties and laminar flow characteristics of plastics. As such, what must be recognized is that conventional geometrically balanced runners actually create multiple flows, or Flow Groups, much like the old “tree” or “fishbone” branching runners. These Flow Groups in turn produce multiple families of parts in the mold, which create variations from cavity to cavity such as dimensions, warp, flash, sink, short shots, etc...

3. What About Cooling and Hot Runner Molds? The largest impact of cooling differences between cavities (i.e., surface finish, shrink, warp, and sink) occurs during the packing and cooling phases of the molding cycle. Since we are evaluating short shots (fill only parts), variations in mold temperature can be eliminated as a major source of imbalance since it has a minimal impact on the weight of short shot samples.

Hot runner manifold systems add another level of complexity. One must understand that hot runners typically exhibit the same shear-induced viscosity imbalances seen in cold runner systems. However, hot runner manifolds also have many additional variables that are sometimes more difficult to isolate. These additional variations will be grouped under “Steel Imbalances” for the purpose of separating shear imbalances from other imbalances. Hot runner Steel Imbalances may include temperature fluctuation, gate size variations, mismatch of “plugs” in the melt channels, thermal expansion differences, and heater band and thermocouple placement and functionality.

Summary of Test Data: Figure 3 is a summary of the data collected from studies consisting of 25 multi-cavity injection molds. Though the test molds contained 8 cavities, it is important to realize these variations can also be seen in lower cavitation molds...including single cavity molds. The plot contrasts the average Steel Imbalances within Flow 1 and Flow 2. It can easily be seen that shear-induced imbalances are typically largest contributing factor to variations in multi-cavity molds.

NOTE: Though the test molds contained 8 cavities, it is important to realize that shear-induced variations can also be seen in lower cavitation molds...including single cavity molds.

The user has to realize that different solutions are required for each root cause. This systematic mold balance analysis allows the user to optimize the mold using a scientific approach.

REMINDER:
- Steel Imbalance: variation WITHIN a Flow Group
- Shear Imbalance: variation BETWEEN the Flow Groups

We will now look at a case study that takes you through the process of collecting, organizing and interpreting the data. The example mold and the parts it was producing were exhibiting problems with filling imbalances, flash, short shots, and dimensional variations (sound familiar to anyone?). The company sent in the mold balance data using the typical format of calculating a percent imbalance by comparing the heaviest cavity to the lightest cavity. Using traditional imbalance calculations, the maximum imbalance was determined to be whopping 50.8% between the cavities (Figure 4).
Ok, great…now what? What would you suggest to fix the imbalances? How do you know, by calculating only one number, what the root causes of the variation are? A pretty difficult task for sure. This simplified mold balance analysis certainly gives you a percent imbalance, but it gives you very little information to determine the root causes of the variations and how to solve them.

Now let’s take this mold and look at it through a different set of eyes. We are going to tear the data apart, re-organize it, and calculate a great deal of more useful information.

First we need to assign a quadrant letter designation (A, B, C and D) and then determine the Flow Groups and which cavities belong to each Flow Group. This 16-cavity runner layout produces four sets of Flow Groups (Figure 5). The next step is to take the data collected by the short shot analysis and re-organize and graph it according to Flow Group designations. This allows us to calculate steel imbalances within each Flow Group and shear imbalances between the Flow Groups.

This systematic mold balance analysis gives more useful information to help determine the root causes of the mold filling and part quality variations. The shear imbalance was calculated to be 31.6% maximum, and the steel variations ranged from 19-37% within the Flow Groups.

And now that the two main sources are separated and quantified, you can determine the solutions for each root cause. Melt rotation technologies (MeltFlipper® technologies) could easily be utilized in this mold to solve the shear imbalances. However, this technology would not fix the steel imbalances in the mold. Therefore you would need to determine the source of steel imbalances and address them independently. You can begin to diagnose the steel conditions by comparing the heavy cavity to the light cavity within each Flow Group (not across the entire mold) and look for differences in gate size, gate land geometry, venting, wall thickness variations, runner sizes, etc…

HINT: One way to help determine the root cause of steel imbalances is to look for trends. If you see a trend in the data, this is telling you that there is a common root cause to most of the variation.

After studying the data from this mold, it was noticed that the cavities in quadrants A & D were always heavier than the cavities in quadrants B & C. By looking at the Flow Group schematic of the runner, you will see that the cavities in quadrants A & D are all on the left side of the sprue. This tells you that something is different from one side of the mold versus the other side.

Now you can begin to measure, verify, and eliminate each possible steel imbalance source that would cause one half of the mold to fill before the other half until the true root cause of the variation was found. Through a process of elimination, the main source of steel variation in this mold was ultimately found to be within the diameter of the primary runners. A variation of 0.006” (0.152 mm) was measured between the right primary runner versus the left primary runner. The larger primary runner was on the left side of the sprue. And according to our pressure drop equation (refer back to Figure 1), a larger radius means a lower pressure drop which means an easier flow path for the plastic.

This analysis correlates exactly with the data from the systematic mold balance analysis. The entire process described within this case study took less than 30 minutes to complete, including the identification of the primary runner variation. Using the simplified mold balance analysis, we simply would not have had enough information to provide the insight to easily identify the root cause of the steel imbalances within this mold.

QUIZ: Now it is time to see if you understand the concepts we have presented here. From Figure 6 on the next page, see if you can answer the following questions:

1. How many Flow Groups are in this mold?
2. Which cavity numbers belong to each Flow Group?
3. Which cavity appears to have a steel imbalance?
4. Which cavities would you compare when evaluating the shear imbalance in this mold?

BONUS QUESTION: What is wrong with this short shot sample?
industry become more competitive and profitable in world markets. The company's expertise lies within an in-depth understanding of polymer flow and processing technologies which enable molders and moldmakers to decrease lead-times while maintaining a high quality level of process and part control. Products include the patented MeltFlipper® melt rotation technology, 5 Step Process™ systematic mold balance analysis software, CAE by BTI™ flow simulation services and Pro-Series training seminars.

**Conclusion / Company Contact Information**

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