Setting up an MPI Analysis

to Match an Actual Molding Process

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moldflow®

Contents

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Introduction

Why match an actual molding process in MPI

An actual molding process is matched so you can compare results between the simulation and the moldings. By making the comparison, you gain confidence and experience with:

- Modeling geometry.
- Material data.
- Simulation capability.

With future work, design decisions are made confidently knowing that you can use MPI to solve problems encountered in the design of new parts and tools.

What is usually compared

Comparing simulations to actual moldings is done in many ways: from comparing short shots to measuring warpage. Common methods of comparison include:

- Filling pattern.
- Location of weld lines.
- Location of hesitation.
- Injection pressure.
- Packing pressure decay.
- Warpage.
    - Deflections out of plane.
- Shrinkage.
    - In plane change in size.

Basic matching procedure

Matching an MPI analysis to an actual molding process requires ensuring many details are considered. This document will step through the procedure of ensuring that the model and process settings in MPI are as close as possible to the processing conditions used in production. In a perfect world, an analysis of the part including; flow, cooling and warp is done in the design stage before the tool is built. Practically, this does not always happen, and even if it does, the tool and process settings used in production are not the same as what was analyzed. You need to validate all the parameters, as much as possible, are the same between the analysis model and production part.

Steps

The basic steps include:

1. Verify the model in MPI is the same as the molded part.
2. Verify the runner system is modeled and the same as used in production.
3. Verify the cooling system is properly modeled.
4. Verify the cooling parameters used in production and MPI are the same.
5. Verify the correct material data is used.
6. Verify the filling and packing parameters are the same.
7. Verify the warpage process settings are correct.
8. Verify the there are no problems with the injection molding machine and the process was stable when the parts are molded.

Model verification

One thing you can count on, the model you analyzed is not exactly the same as what is being molded. There are many reasons for this including:

- Engineering changes between the time you analyzed the part originally and the time the mold was made.
- Tools are never cut exactly to the same dimensions as the CAD model.
- Core deflection.
- Maintenance on the tool such as insert replacement may not be to the same tolerances as the original components.

The most critical attribute to look at is the wall thickness. This can be done in two stages.

1. Verify the MPI model and the CAD model are the same.
2. Verify that the MPI model and molded parts have the same thickness.

Thickness verification

MPI to CAD

Midplane meshes

For midplane models, the thickness assignment is normally verified by the user in the initial construction, so there is less chance of an error with midplane models. However, the thickness diagnostic should be used to verify that thicknesses are correct. All features should be checked. In addition to the nominal wall being correct, look for areas that you know are thick or thin. If the midplane model is not correct in these areas, the analysis will not pick up race-tracking or hesitation. Also ensure that the mesh density is appropriate. There should be at least 3 elements across a significant thickness change. A thickness change will start to become significant if the wall thickness change is about 25% or more. The smaller the nominal wall becomes, the more significant wall thickness changes become.

Dual Domain meshes

For Dual Domain meshes, it is more important that the thickness be checked carefully, since Dual Domain automatically determines the thickness of the part. The user can manually set the thickness, but the change between the automatic calculation and the manual adjustment should only be done to correct for mistakes in the automatic calculation.

If the thickness assignments are not correct in Dual Domain in all locations, also look at the mesh match ratio. This should also be very high, (above 90%) to be considered a good model for the Cool + Flow + Warp analysis sequence.

3D

Since 3D does not have a thickness property, the thickness of the 3D model will be the same as the CAD model unless there is a meshing error when the initial surface mesh was created. Verify the mesh matches the imported CAD geometry to ensure a correct representation.

MPI to molded part

Assuming that the model is good between MPI and CAD, any problems found are likely due to tooling or engineering changes issues. Look for variations in wall thickness on the molded part. If possible, cut the part into pieces to be able to measure the wall thickness in many places. In Figure 1, the rim of the part was changed after the flow analysis was done, significantly changing the fill pattern. In this case, the thickness change is fairly obvious, but on most parts, changes in thickness are not so easy to detect. When the filling pattern between the simulation and the molded part are not correct, carefully compare the actual part thickness to the model.

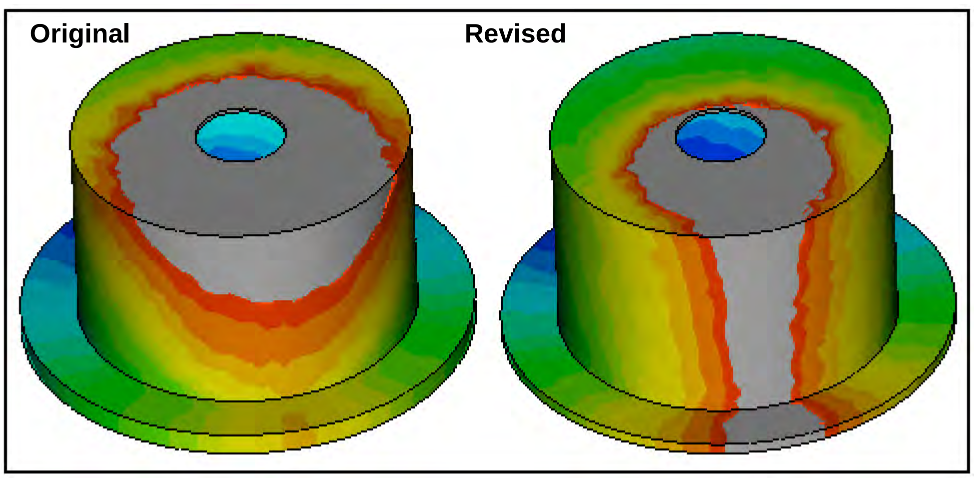


Figure 1: Change in thickness

Core deflection may be a problem. Check the wall thickness at several locations around cores to determine if the core has shifted. If you see a problem, it would be a good idea to check several parts to see if the thickness changes are consistent. If you see the core deflection, consider running a core deflection analysis. The predicted thicknesses of the part due to the deflecting core will be used in the warpage analysis.

Other geometry validation

It is a good idea to make sure not only thickness but other dimensions of the part are properly modeled between the MPI model and molded part such as over all dimensions, location of critical features, etc.

Runner system validation

The entire feed system must be created in the MPI model. The runner influences:

- Pressure drop required to fill the tool.
- Shear heat of the polymer.
- Flow rate in the cavity.

Many factors determine the importance of modeling the runner including:

- Pressure required to fill the runner compared to the part.
- Volume of the runner compared to the part.
- Processing conditions used, in particular flow rate.
- Polymer being molded.

Model the entire runner system

Figure 2 shows an example were the hot runner has a runner volume many times that of the part. The part's volume is 1 cm^3, and the volume of the runner is about 155 cm^3. The tool has 16 cavities and was modeled using occurrence numbers. The shot volume was 16cm^3, which is about 10% of the volume of the feed system. If the analysis was done using an injection time input based on the actual filling time of the part, the predicted filling time with the feed system would be much longer due to the compression of melt in the hot runner system as injection pressure increases. When the flow rate is increased so the predicted filling time for the part is equal to the actual injection time of the part, the injection pressure may increase significantly. Moldflow's support team has seen cases where the pressure to fill is double when the flow rate is adjusted. When comparing a simulation to actual moldings in such cases, it is critical that the same ram speed profile is used in the simulation and on the molding machine, ensuring the same volumetric flow rate is used in both cases.

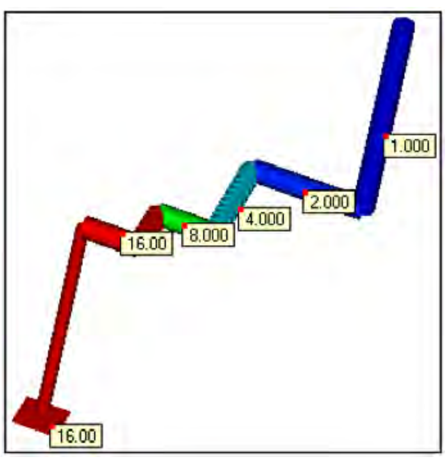


Figure 2: Occurrence numbers of a runner system

In Figure 3, the hot runner system is symmetric on the part. Valve gates were used on this tool and three of the valve gates were kept closed during the whole molding cycle. In the initial analysis, only the one open flow path through the runners was modeled as shown by the cyan runners in Figure 3. When the time for the flow front to reach two nodes representing pressure transducer locations was compared to a model with all the runners represented, the time to reach the nodes is different and shown in Figure 4. The reason for the difference is the flow rate is reduced in the full model due to the material being compressed in the entire hot runner system, even though only one valve gate is open. This example is similar to a test molding run by Baker AG and presented by Roland Thomas at Imug 2002.

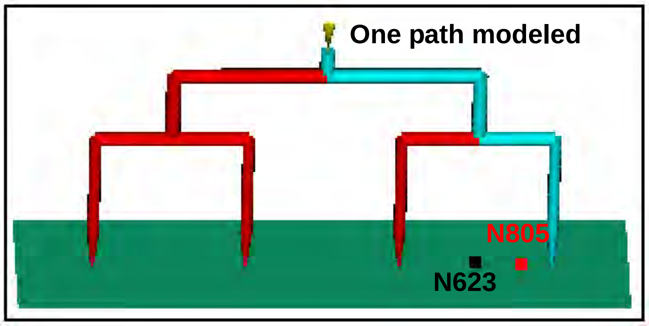


Figure 3: Modeling all runners

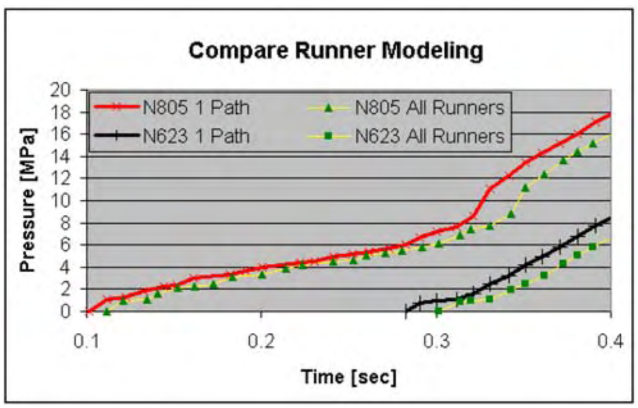


Figure 4: Time for material to reach a transducer

Runner and gate sizes

Ensure that the runners in the tool are correctly cut. The runners in the simulation model must be the same as the tool. If the runners are different, modify the simulation model and run an analysis with the actual sizes used in the tool. In many cases, the tolerances held on runner systems are not very good.

To see the influence of changes in runner and gate size, a two cavity model with geometrically balanced runners was created. The model with changed runners is shown in Figure 5. The nominal secondary runner is 5 mm in diameter, and the nominal tertiary runner is 4 mm in diameter. About 60% of the total pressure drop with these nominal runner sizes is in the feed system, the remaining 40% is in the part. The Velocity/Pressure switchover is at 99%. The runner size changes were 0.05 mm (0.002") and 0.25 mm (0.010"). The summary of there imbalance is shown in Table 1. The imbalance with only a 0.05mm runner variation in this case is probably acceptable in most cases, but the imbalance with a 0.25 mm runner variation is probably not acceptable.

The gate size nominally is 1mm thick by 3 mm wide. The shear rate at the nominal size is about 52,000 1/sec. Changes in runner size influence the gate shear rate because once one cavity fills, the entire flow rate is directed to the other cavity. The gate sizes were changed in the same increments as the runner, 0.05 mm and 0.25 mm. Table 1 also summarizes the change in shear rate.

The variation in balance will change widely depending on the specific mold design. It is best to ensure the size of the feed system in the simulation matches the sizes actually cut in the tool.

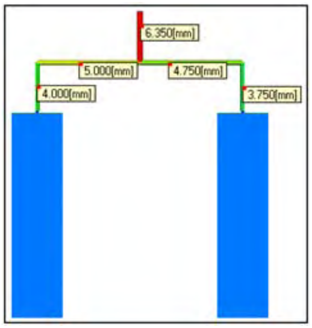


Figure 5: Runner sizes inconsistent

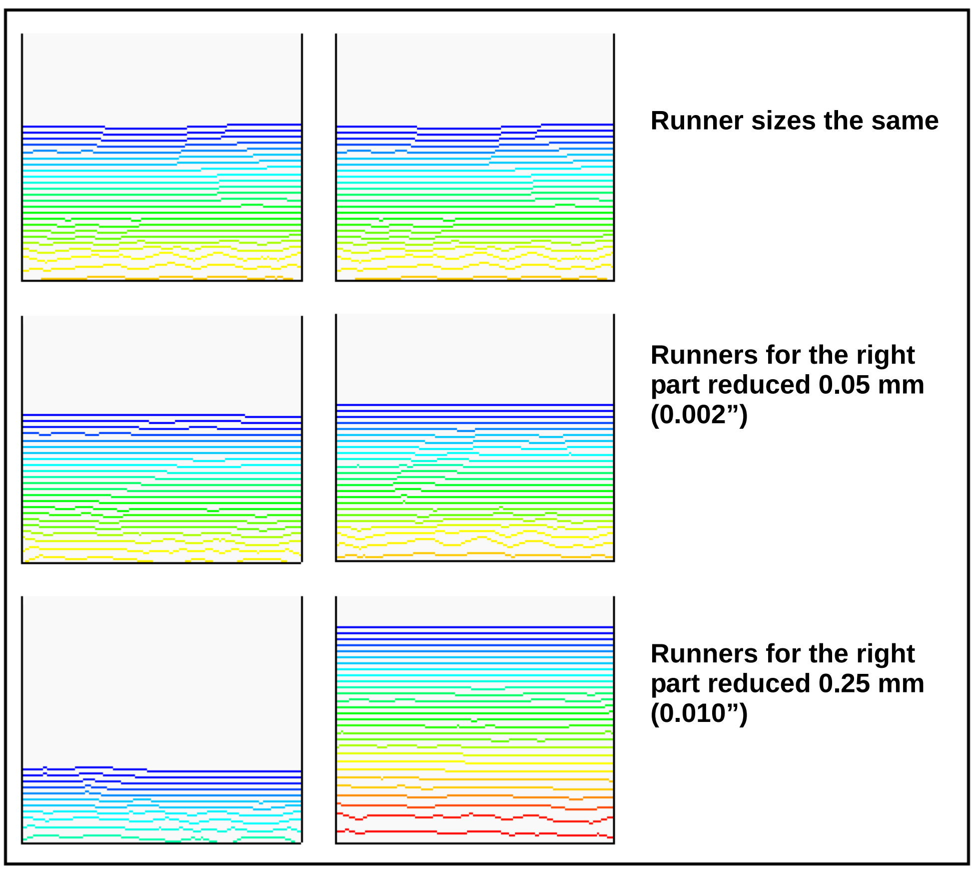


Figure 6: Fill time imbalance due to runner sizes incorrect

Table 1: Summary of imbalance with inconsistent runner and gate sizes

	Nominal sizes	Size off 0.05 mm (0.002")	Size off 0.25 mm (0.010")
Runner fill time imbalance	0%	0.36%	8.2%
Gate fill time imbalance	0%	0.18%	3.43%
Maximum shear rate	52,785 1/sec.	56,954 1/sec.	92,855 1/sec.
Gate shear rate imbalance	0%	7.32%	43.15%

For full round runners, make sure that the runner mismatch does not exist or is very low. Figure 7 shows an example of mismatched runners. Small amounts of mismatch can contribute to significant differences in pressure drop. If the runners are mismatched, the runners should be re-cut to eliminate the mismatch. If you need to model a mismatched runner, you should consider adjusting the runner diameter in the model to account for the increased pressure drop. This will be difficult to estimate.

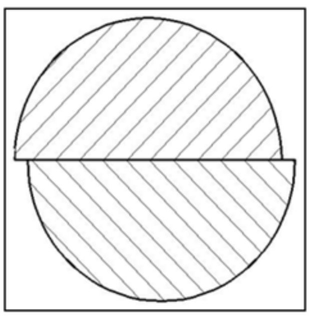


Figure 7: Runner mismatch

For trapezoidal runners, make sure you have correct dimensions in all directions. The same would be true for all non-round runner cross sections.

If possible, model the machine nozzle all the way back to the barrel of the machine. This will predict the pressure the best. If this is not possible, the pressure drop through the nozzle will need to be estimated. This will be discussed later.

Cooling system validation

Circuits

All the cooling lines must be modeled in the tool. Be sure to verify the actual placement of the waterlines in the tool. All the diameters should be verified.

Ensure that all the circuits in the tool are modeled with hoses as necessary to replicate how the tool is plumbed in production. This may be an issue as many tools are not plumbed the same way each time the tool is set.

If you think the coolant source is pressure limited and not flow rate limited, consider modeling the quick disconnects used on the tool. In general they are highly restrictive and will have a higher pressure drop for the quick disconnect as there is in the tool itself.

Mold material

The mold material should be considered. Most tools have several different tool materials in them. P20 is very common for the mold base. Other materials such as H-13, S-7, Stainless steels and others are used for various tooling components. The thermal conductivity of all these materials is close enough so the mold temperature distribution is statistically insignificant; however there is a statistical significance in the mold temperature. P20 is the default mold material. If the mold base is stainless steel or if most of the material, between the water lines and part, is a material other than P20, consider changing the mold material.

Inserts

If the tool has a copper alloy or some other high thermal conductivity alloy, make sure this area is modeled with an insert for the cooling analysis.

Mold boundary

When running a cooling analysis, the mold boundary should be created. The mold boundary does not have to be the exact size of the tool. It defines the boundary of space for the explicit heat transfer analysis. It is best to create it so it encompasses all other geometry, including:

- Part.
- Feed system.
- Water lines.
- Inserts.

The water lines & hoses do not need to penetrate the mold boundary. It is best if they don't.

To create the mold boundary

1. Determine the size to make the boundary.
   - It is best to make it a cube.
   - The boundary should be about 50 mm to 100 mm (2 in to 4 in) larger that the longest dimension in the mold.
2. Click **Modeling** ➡ **Mold Surface Wizard**.
3. Enter the dimensions in the X, Y, and Z fields.
4. Modify the layer assignments and attributes if desired.

   4.1. Move the nodes on the mold boundary to the mold boundary regions layer.

   4.2. Set the mold boundary elements layer to transparent.

Cooling parameter validation

Analysis sequence

The analysis sequence should be **Cool + Flow + Warp**. Preliminary analysis work can be done with different sequences, but the final sequence must be, Cool + Flow + Warp.

Coolant temperature

Both coolant flow rate and temperature are important to verify for the analysis. The coolant temperature is normally not difficult to verify, as the coolant source usually has some sort of temperature readout. If the coolant source is not a heater or chiller at the press, some sort of temperature validation should be done. If there is day to day or season to season variation in the water temperature, this will be a source for error in the results between MPI and the molding process.

Coolant flow rate

The flow rate of the coolant is normally much more difficult to verify. Depending on the cooling line layout, this can be a significant factor. Preferably, every circuit into the tool should have a controlled flow rate. This rarely happens. In this case, the total flow rate to the tool should be verified, even if this is as simple as timing the filling of a 5 gallon bucket with water. A better idea is a portable flow rate gauge that can be connected to a circuit using the quick disconnects.

If only the flow rate to the entire tool can be determined, the analysis should be set up using total flow rate rather than the flow rate per circuit.

To set the coolant properties

1. Select the Inlet Boundary Condition at the end of a coolant circuit.
2. Right-click and select **Properties** from the context menu.
3. Ensure the Coolant type is correct.
   - If it is not water, select the correct coolant from the database.

   3.1. Edit the coolant properties as necessary.
4. Set the correct **Coolant Control**.
   - The default is 10,000 Reynolds number.
   - **Total flow-rate (All Circuits)** allows you to specify the total flow rate going to the tool.
     - If total flow-rate is used, all coolant inlets must be set to this value.
   - Flow rate or pressure for each circuit can also be set.
5. Set the correct **Coolant inlet temperature**.

Coolant line fouling

With steel tools, minerals can build up the on the inside diameter of the coolant lines. The thermal conductivity of this mineral deposit is only about 2% of the steel. The thermal resistance of 1 mm of a mineral deposit is equal to about 50 mm of steel. MPI can't account for this buildup. If the tool has this buildup, the mold surface temperature will be hotter than is predicted in MPI. This may have an influence on the warpage, packing and possibly filling of the tool.

Material data

Material data is one of the most important inputs for the analysis. The simulation should use the exact material that is being molded and the testing should be verified. Moldflow has implemented a material data quality assurance program. This has improved the data quality in the material database. However, when working on critical problems, in particular warpage, it is critical that the best possible material data is used. In addition to using the exact grade of material, the material should have a known testing source. Figure 8 shows several examples of material data sources. The source has three components, rheological, pvT and mechanical properties. For the rheological data, the source is listed as:

- Moldflow.
- Manufacturer.
- Other.

The other source is one of many different third party testing facilities. It is important that all data in particular rheological data is tested with methods suitable for injection molding simulation. In most cases, the testing methods are not known for data sources of Other and Manufacturer. Although the testing methods used for materials that are listed as unknown may be appropriate for injection molding, the material data should be considered a potential source of error in the simulation when the testing methods are not known. The data needed is also dependant on the type of analysis work being done, what is being compared between the actual molding and the simulation and the mesh type used in the simulation.

Data source
Moldflow Corporation : pvT-Measured : mech-Supplemental
Manufacturer : pvT-Measured : mech-Supplemental
Moldflow Plastics Labs : pvT-Measured : mech-Measured
Moldflow Corporation : pvT-Supplemental : mech-Supplemental
Other : pvT-Measured : mech-Supplemental

Figure 8: Material data sources

Viscosity data

When the exact grade of material that is being molded is not in the material database and a substitute is being used, care should be taken when choosing a substitute. Try to find one with a similar viscosity. When choosing a substitute material, pick one with the same polymer family, similar amount of fillers, and the same manufacturer when possible. Expect about a 10% difference in pressure prediction for about a 10% change in filler by weight. When you select a grade from a different manufacturer, a 40% difference in pressure is common.

With some materials, their viscosity is highly dependent on the pressure at which they are molded. In the example of Figure 9, the pressure to fill increased 55 MPa (43%) when pressure dependence was considered, making the simulation much closer to the experimental value. However, most materials in the database do not have pressure dependence in the viscosity model. Consult Moldflow Plastics labs to obtain this data if it is needed.

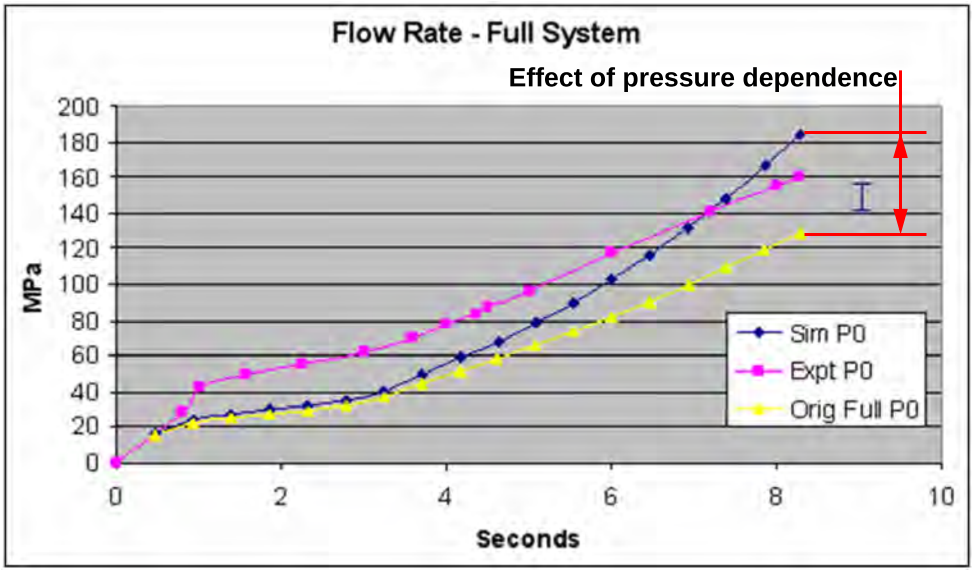


Figure 9: Pressure dependence effect on viscosity

Juncture loss coefficients

When the polymer passes through a change in diameter in a beam element such as the machine nozzle, runners or gates, there is a hydraulic pressure loss. This can be calculated using Bagley correction constants, C1 and C2. Some materials have these constants. For those materials that do not have the coefficients, they can be estimated. To find these values, click on the field specific help in the thermoplastics material dialog, Rheological Properties tab, Juncture loss method coefficients. Figure 10 shows an example of how the juncture loss better predicts the pressure loss through a machine nozzle.

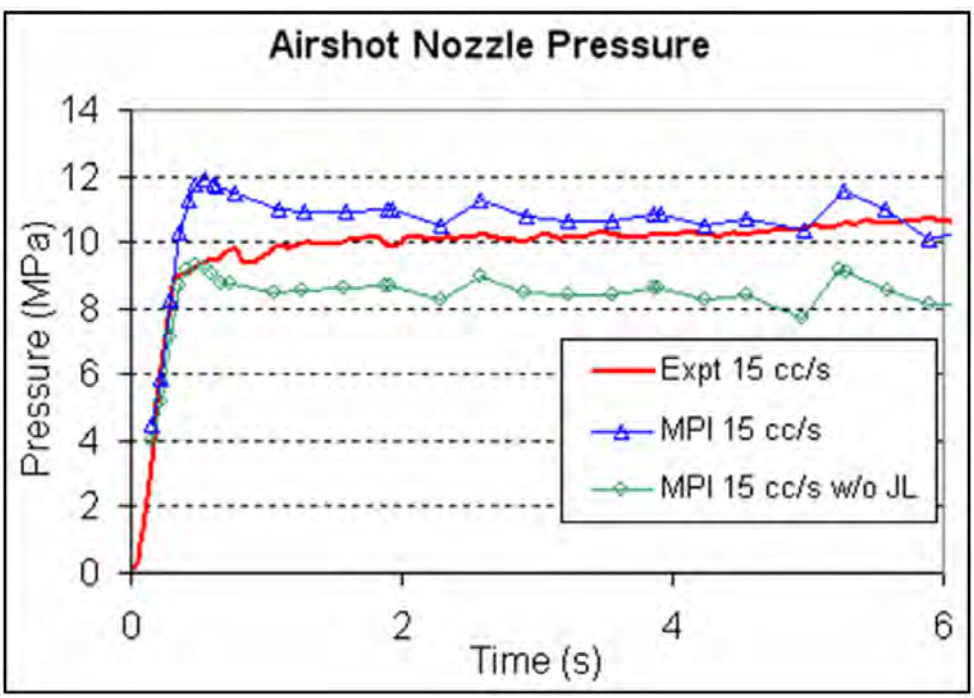


Figure 10: Juncture loss through a nozzle

PvT data

Figure 8 on page 10 shows an example of pvT data, as both Measured, and Supplemental. Measured data means the specific grade of polymer has pvT data; while Supplemental means the pvT data is from a material of the same chemical type and filler level. Supplemental data is adequate for filling issues, but should not be used when comparing attributes that rely on packing such as, linear dimensions, warpage, and pressure traces during packing. Measured pvT data should be used when doing a warpage analysis.

Mechanical data

Mechanical data should be measured when doing a warpage analysis. However, most materials do not have measured mechanical properties. For midplane and Dual Domain meshes using CRIMS or residual strain shrinkage models, the measured mechanical data is not as critical as it is for 3D warpage.

For 3D warpage analysis, the warpage solution is sensitive to the coefficient of thermal expansion (CTE). For most materials this information is supplemental. Preferably, this information should be specific to the grade. The 3D meshed part shown in Figure 11 was analyzed with different CTE values. The deflections are graphed in Figure 12. The CTE values were changed by +/- 25% and 50%.

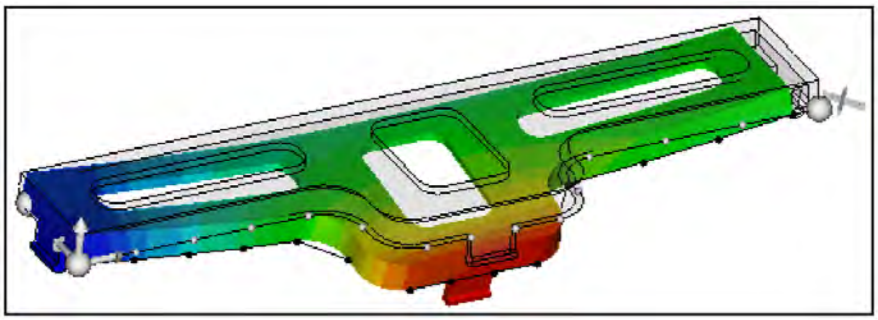


Figure 11: Path plot used to compare CTE values

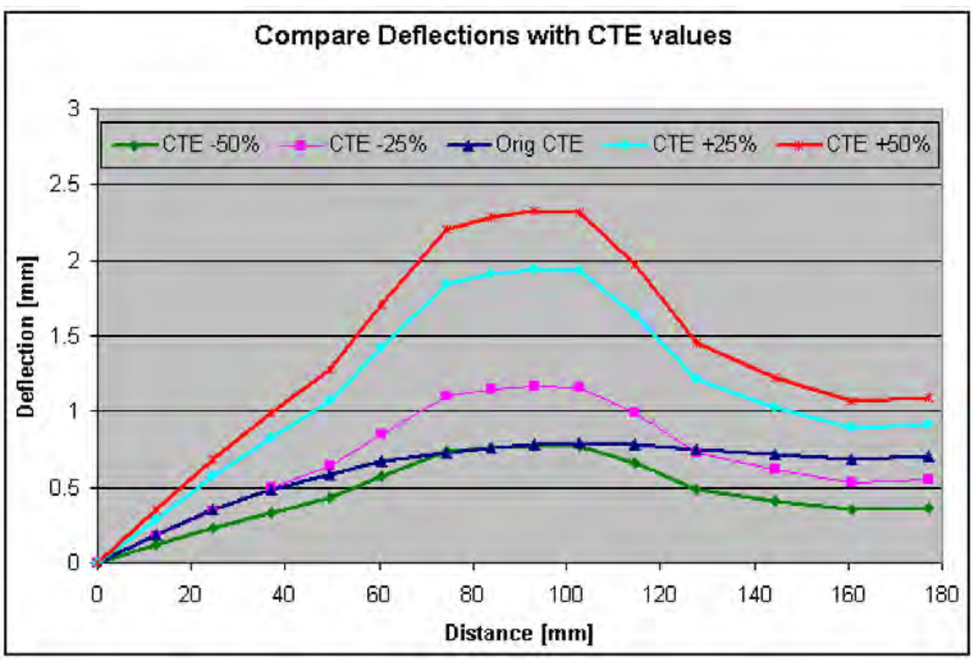


Figure 12: Comparison of CTE's on a 3D warpage analysis

Shrinkage data

When using midplane and Dual Domain meshes, shrinkage data should be used when comparing warpage results. Figure 13 shows an example of the warpage correlation for the part shown in Figure 14. When shrinkage data is not used, the shrinkage model is called the **Uncorrected residual stress** model. The magnitude of the warpage is good in trend, but the magnitude is improved when shrinkage data is used by using the CRIMS shrinkage model. When comparing linear dimensions, or warpage on the part, the CRIMS or residual strain shrinkage models must be used to get a good correlation. Both of these shrinkage models require shrinkage testing.

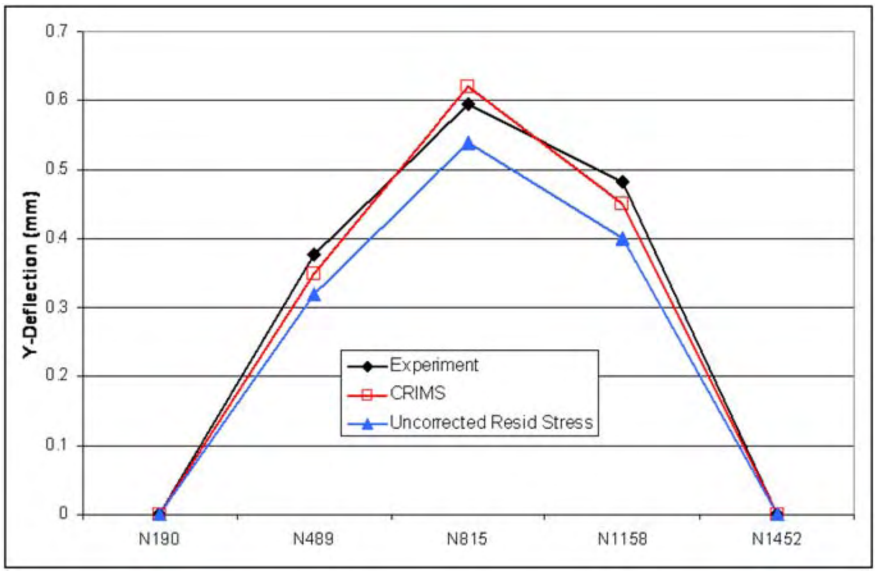


Figure 13: CRIMS vs. uncorrected residual stress (Courtesy of Rhodia Engineering Plastics)

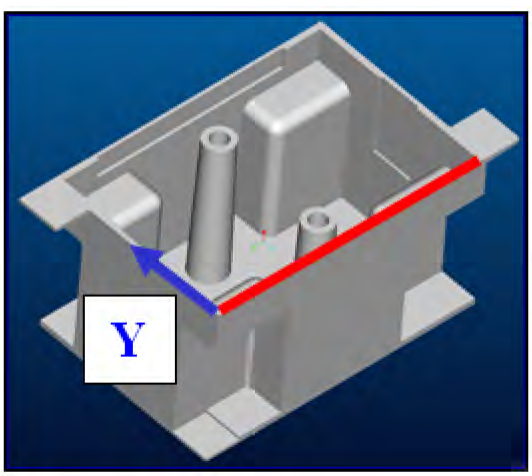


Figure 14: Part used to measure warpage (Courtesy of Rhodia Engineering Plastics)

Filling and packing validation

Molding machine definitions

Most flow analysis work can be done with the Default molding machine. However, if you need to duplicate the production process, you will need to either select the exact machine used from the machine database or create/modify an existing one.

To select a molding machine in a specific study

1. Double click on the **Process Settings** in the Study Tasks List.
2. Navigate to the **Flow Setting** page.
3. Click on **Advanced Options**.
4. Click **Select** in the Injection molding machine frame.
5. Pick the specific molding machine you are using.
    - Use the **Search** tool to help narrow down the search.
    - Click the **Select** button when the machine is found.

Edit machine definitions

If the machine being used in production is not found, the parameters of the machine can be edited.

To edit a machine

1. Double click on the **Process Settings** in the Study Tasks List.
2. Navigate to the **Flow Setting** page.
3. Click on **Advanced Options**.
4. Click **Edit** in the Injection molding machine frame.
    - This will allow you to edit the currently selected machine, probably the default machine.
5. Click the **Injection Unit** Tab
6. Ensure you set the following:
    - Maximum machine injection stroke.
    - Maximum machine injection rate.
    - Machine screw diameter.
    - Filling control.
    - Make sure you select the method your molding machine sets the filling or velocity control.
    - Ram Speed control steps.
    - Pressure control steps.

7. **Click on the Hydraulic Unit tab.**
    - Ensure the following is correct:
        - Maximum machine injection pressure.
        - Maximum machine hydraulic pressure.
        - Intensification ratio.
    - Make sure that the hydraulic pressure * intensification ratio = injection pressure.
8. Click on the **Hydraulic Unit** tab.
    - Ensure the following is correct:
        - Maximum machine clamp force.
        - Check, Do not exceed maximum clamp force.

If the machine information is not present or correct, you will not be able to properly set up the velocity profile that is used on the molding machine.

Setting the machine information as described above can only be used for study you have open when editing the data and any study you create by saving as or duplicating from this study.

If you plan on using these machine's settings again, create a molding machine property manually and save it to a personal database using **Tools ➡ New Personal Database**.

You may want review the online-help topic "**To create a new personal database**" for complete details. If you want to change the machine for this specific project look up the section "**Create/Edit Machine Manually**" at the end of this document for complete details.

Pressure limited simulation

Figure 15 shows an example of a simulation that is pressure limited. The Pressure at the Injection Location shows a flat line at the pressure limit. The simulation shows a short shot. In this case, the machine definition limited the pressure to 100 MPa. If the actual molding machine has a pressure limit that is much higher, the part may fill on the molding machine, but not in the simulation due to the pressure limit. Ensure the simulation uses the same pressure limit as the molding machine.

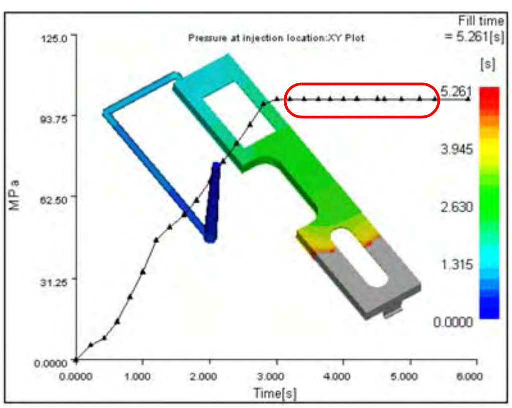


Figure 15: Pressure limited analysis

Production processing conditions

Collect all the information necessary about the processing conditions used for production. When possible, get printouts from the machine controller to see the actual settings and machine response rather than a machine setup sheet which may not reflect the currently running process. Previously, the coolant temperature and flow rate were discussed. Concentrate on the velocity and packing control and melt temperature information.

Velocity control

The most difficult aspect to match between MPI and the molding floor is the filling control information. There are many different methods machine controllers use to input this information. MPI gives you many methods to input filling control information. Ensure the information you have for the machine is in one of the formats available for input into MPI. Determine the following:

- The method of velocity input. The following inputs could be required:
  - Ram speed vs. ram position.
  - Flow rate vs. ram position.
  - %Maximum ram speed vs. ram position.
  - Ram speed vs. time.
  - Flow rate vs. time.
  - %Maximum ram speed vs. time.

Make sure you understand the units involved.

Also important is the starting ram position, and cushion warning limit. This information is required for the Absolute ram speed profiles listed above. The method of V/P switchover is also important. If position is used, the location must be known. If the molding machine uses a pressure transducer in the tool to control the V/P switchover, this information must be known. The location of the transducer and the pressure to trigger the switchover must be determined.

Packing control

The packing control is generally much easier to get and understand than the filling control. The main thing to determine in addition to the pressure and times used in the profile is the shape of the profile. Some molding machines can only use a block profile; others can have a linear decay in the profile, shown in Figure 16. A block profile has the pressure change instantaneously from one pressure to another and the pressures are constant. A liner profile has programmable times for the change between one pressure and another.

With packing control, make sure you know the pressure definition. It most likely will be hydraulic pressure, but some controllers use plastic pressure. Make sure you know what the pressure is and what pressure control you have set up in MPI. It is critical that you have the correct intensification ratio for the machine, or at least know what it is. You can’t assume 10:1.

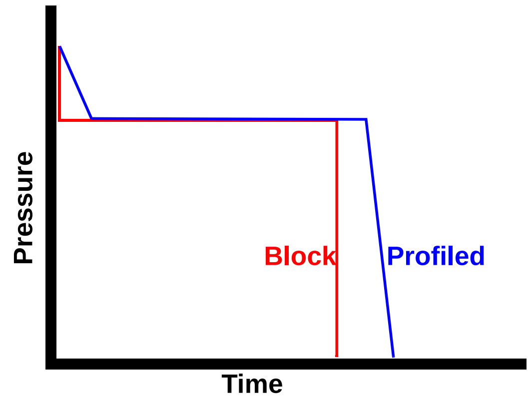


Figure 16: Example profiles

Machine hydraulic response time

The injection molding machine database includes a parameter for Machine hydraulic response time, as shown in Figure 17. The default machine has a very small value of 0.01 seconds. All of the specific machines in the database have a value of 0.2 seconds. This response time is used to interpret packing profiles with duration values less than the response time. When a packing profile has a 0 duration, the profile step uses the machine hydraulic response time value listed in the injection molding machine database. Figure 18 shows an example of how the profile is modified based on the response time in the machine database. One line represents the default response time, and the other represents a very long 1.0 second response time.

When entering a packing profile, the response can be handled in the following ways:

- Enter a 0 (zero) for a duration and let the default machine response time be used. The default molding machine have a very low value, faster than molding machines can respond, resulting in a unrealistic profile.
- Enter a 0 (zero) for a duration and modify the Machine hydraulic response time in the machine database to a more realistic value.
- Enter the duration with a realistic value to account for the machine response such as 0.2 seconds.

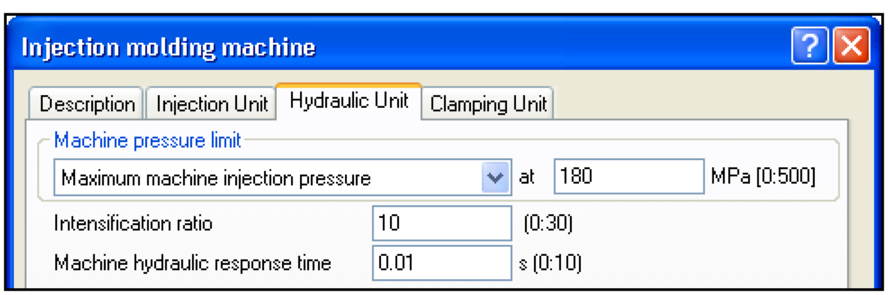


Figure 17: Machine hydraulic response time in machine database

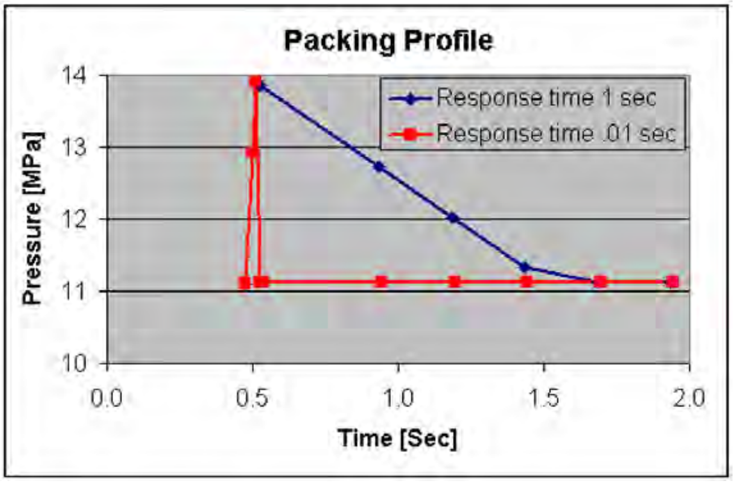


Figure 18: Graph showing influence of machine response time on packing profile

Melt temperature

On the molding machine, there is a wide variety of controls that influence the "melt temperature". For the purposes of a flow analysis, the melt temperature is uniform, and is equal to the temperature of an air shot.

Measuring the melt temperature on the molding machine

The best way to measure and verify the melt temperature is with an air shot.

To measure the melt temperature

1. During a stable production run, interrupt the process.
2. Purge a full shot at the flow rate of injection.
   - Depending on the size of the shot, the purging can be done:
   - Directly on the machine base.
   - On a piece of cardboard or some other type of insolated material.
   - In a Teflon cup.
3. Immediately measure the temperature with a hand held Pyrometer.
   - You want a pyrometer with a very quick response time as the melt is constantly cooling.

There is significant debate into the exact procedure used to measure the melt temperature when taking an air shot. Some parties say that stirring the molten plastic achieves the most accurate temperature. Others would say that the pyrometer should not be stirred. In either case, preheating the pyrometer to the expected melt temperature or above is generally considered a good idea.

The melt temperature should be measured several times to ensure a consistent answer, no matter what method of purge collection and stirring philosophy you adopt. Between each measurement, the molding press should be allowed to cycle to get the plastication stable again.

Setting the processing conditions in MPI

Once all the machine parameters are collected, the **Process Settings Wizard** can now be used to enter all the necessary inputs.

Cooling settings

Mold surface temperature

Since you are trying to duplicate an existing process, the cycle time is defined. The mold surface temperature is not used for this type of analysis except for an initial starting point.

However, this number should represent the **"Target"** mold temperature you would like to achieve. The cooling analysis will be driven by the cycle time and the coolant temperature entered.

> The difference between Mold surface temperature and coolant inlet temperature is at a minimum 5ºC (9ºF) to 70ºC (125ºF) at a maximum.
>
> Once the analysis is done, the actual mold surface temperature should be compared to the cooling analysis result. To do this, measure the cavity and core surface temperatures using an IR sensor or hand held pyrometer. Like the melt temperature, it should be done several times. The press should cycle 3 to 5 times between measurements. A minimum of 5 measurements should be done for each location.

Melt temperature

As discussed previously, the melt temperature entered should be based on an air shot purging.

Mold-open time

The mold-open time specifies the time taken from the completion of one molding cycle, to the beginning of the next. This information can be calculated from the process information for the press.

Specify injection + cool + pack time

The injection + packing + cooling time is equivalent to the total cycle time minus the mold-open time. The times for required here can be calculated from the machine setting printout.

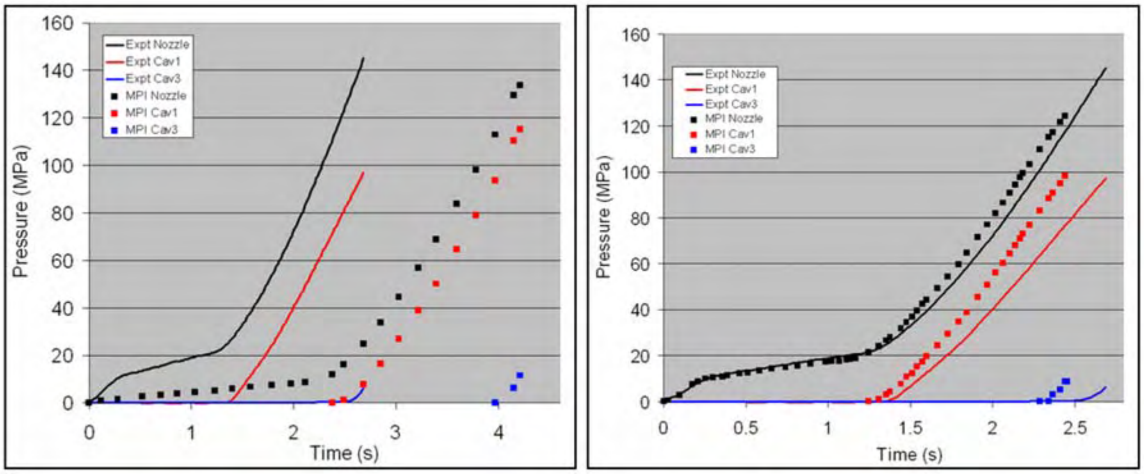
Cooling solver parameters

The preferred setting for the cooling solver parameters is to have the geometry influence **Ideal**, (This is the default), and the **Mesh aggregation** off. This pair of settings requires considerable ram and disk space and may not be practical. An alternative is **Ideal** with **Mesh aggregation** on. This is the default. It is a good compromise between computing recourses and accuracy.

Flow settings

Filling control

The only real choice that should be used when trying to duplicate a production process is **Absolute Ram Speed Profile**. Fill time, or flow rate can be used, but the vast majority of molding processes have some sort of velocity profile. By using fill time or flow rate, you are introducing errors into your analysis because you are trying to replicate an existing process. Fill time and flow rate are most common when optimizing the process, before production has started. Figure 19 shows an example of the errors caused by using an injection time versus using the actual injection profile. The graph on the left shows the pressure trace of the simulation using an injection time compared to the molding. The injection time was used based on the time to switchover. The graph on the right shows pressure traces when an actual ram speed profile was used. The simulation closely represents the time when the flow front reaches the pressure transducers and the pressure profile.



Using injection time **Using an injection profile**

Figure 19: Injection time vs. injection velocity

To define the absolute profile, the values of the profile must be entered with the values in the first column listed in ascending or descending order, depending on the profile. In Figure 20, the ram position must be entered in descending order. Also notice how the Starting ram position is larger than the first ram position of the profile. The ram speed between the starting ram position and the first ram position listed in the profile is the ram speed listed for the first ram position.

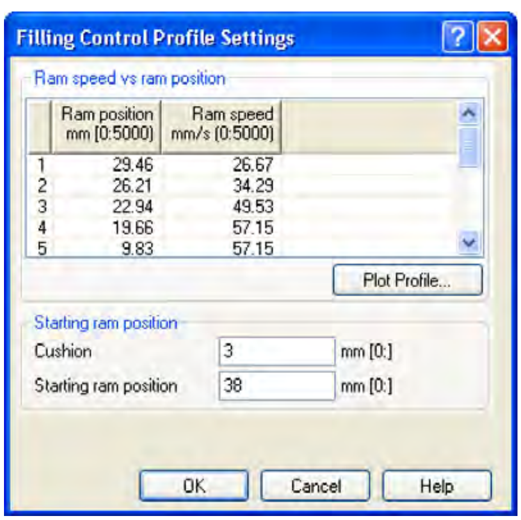


Figure 20: Absolute profile, ram speed vs. ram position

Velocity/pressure switchover

In most molding setups, switchover is done by ram position. Ram position defines the switchover by the location of the ram expressed in linear units of millimeters or inches. This switchover method can only be used with an absolute ram speed profile.

When comparing the pressures from the simulation to the actual molding, it is dangerous to consider just the maximum pressure. In Figure 21, the switchover was set at 90% and 99%. The difference in pressures are very significant due to the small thin geometry at the end of fill. When switching at 90%, the flow front is just entering the thin area and at 99%, the thin area is basically filled. If the simulation was compared to the actual part only by maximum pressure, the simulation may look like it is not predicting the pressure correctly, but the problem may be the switchover in the simulation vs. the molding.

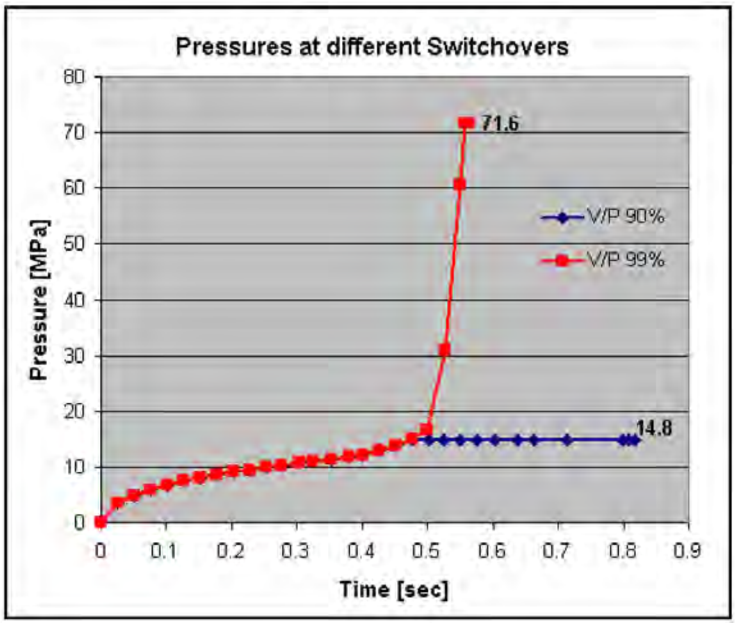


Figure 21: Pressure spike at end of fill

Pack/hold control

The pack/hold control must be defined. This specifies the method by which the pressure phase of the molding process is controlled. The following options can be set to enter your profile:

- %Fill Pressure vs. Time.
- Pack Pressure vs. Time.
- Hydraulic Pressure vs. Time.
- % Maximum machine pressure vs. Time.

The vast majority of the time Pack Pressure vs. Time is used. Many machine controllers output hydraulic pressure not plastic pressure. There are two ways to handle this:

- Use the Hydraulic Pressure vs. Time control.
- You must make sure the intensification ratio in the machine database is correct.
- Manually convert between Hydraulic pressure and pack pressure (plastic pressure) and use this pressure.

.

💡 If you need further assistance with how to setup a pack profile please see the help topic "To setup a packing profile."

Fiber orientation analysis check box

The "**Fiber Orientation**" check box is checked by default. If you are not running a fiber filled material the check box does nothing checked or unchecked.

The fiber analysis will run only if all the following conditions are met:

- Fiber license is available.
- The material is fiber filled with an aspect ratio is over 1.
- Most fiber aspect ratios on the database are 25.
- Fiber option is checked on.

Warp settings

The warp settings are different depending on the mesh type. They will be reviewed below. Warpage settings are not critical for duplicating a molding process, but many times you need to duplicate a molding process to solve warpage problems.

Midplane meshes

Warp analysis type

The default is automatic. However, by the time you are running this analysis to duplicate an existing process you should know if the part has buckled or not. This is the primary reason for the automatic. Therefore, the setting will probably need to be set to either:

- Small deflection.
- Large deflection.

If the part does not buckle, the small deflection should be fine. Many people choose large deflection anyway. The large deflection analysis would capture any slight non-linear trend in the deflection even if it did not buckle.

Isolate cause of warpage

Turn this option on if you want the analysis that you are setting up to output information about the dominant cause of warpage. You will receive four sets of deflection results representing the deflection of the part considering all factors of warpage including:

- Differential cooling.
- Differential shrinkage.
- Orientation effects.
- Corner effects.

For midplane meshes, this option is available for small deflection and buckling analyses. The buckling analysis results are in the Analysis Log of the analysis will include a sensitivity factor for each of the possible contributors. The small deflection analysis will be deflection plots.

Stress result(s) to output

The default is none, and generally is not changed. This setting will have no influence on the prediction of warpage. Stress results are used to view the residual stress on the part and as in input to MPI/Shrink.

Consider gate surface and cold runners

By default, gates and runners are NOT considered. If you were to change this, it would assume the gate and runners are not removed from the parts until the part has completely cooled and shrunk. The assumption with the shrinkage models is at least one week.

Consider mold thermal expansion

Select this check box if you want the warpage or stress analysis to consider the effect of mold thermal expansion on the warpage and/or molded-in stress levels in the part. During injection molding, the mold expands as the temperature increases, causing the cavity to become larger than its initial dimensions. This cavity expansion helps to compensate for part shrinkage during cooling, resulting in actual shrinkage that is smaller than that predicted without accounting for thermal expansion of the mold. This is generally off by default.

If you use this option, ensure that a suitable mold material has been selected. This is where the key material property used by this option - the coefficient of thermal expansion of the mold - is defined.

Consider corner effects

Select this option if you want the warpage analysis to calculate and account for deformations due to mold-restraint induced differential shrinkage. Use this option if your model has ribs or is box like geometry. Many times a warpage analysis is run with this on and off so the user can judge what setting is best.

Dual Domain meshes

Dual Domain can only run a small deflection analysis. It can't determine if the part buckles. Most parts will not buckle. The available warp options are discussed below.

Consider mold thermal expansion

This is the same as Midplane.

Isolate cause of warpage

Turn this option on if you want the analysis that you are setting up to output information about the dominant cause of warpage. You will receive four sets of deflection results representing the deflection of the part considering all factors of warpage including:

- Differential cooling.
- Differential shrinkage.
- Orientation effects.
- Corner effects.

Matrix solver

This option relates to the selection of the equation solver to be used in the warpage analysis. If this option is set to Automatic, the analysis will automatically use a matrix solver appropriate to the size of the model, and for Midplane models, compatible with the selected Warpage analysis type option. For small models, the Direct option is used. For large models, using an iterative matrix solver can improve the performance of the solver by reducing analysis time and memory requirement. The AMG option is preferred unless memory requirement becomes the limiting factor. You can override the automatic selection.

The Direct solver is a simple matrix solver which is efficient for small to medium sized models. For large models, the direct solver becomes less efficient and requires a large amount of memory (disk swap space).

The AMG (Algebraic Multi-Grid) iterative solver is very efficient for large models. Choosing this option can significantly reduce analysis time but requires a larger amount of memory than the SSORCG option. For Midplane models, the AMG solver does not support Warpage analysis type set to Automatic or Buckling.

The SSORCG (Symmetric Successive Over-Relaxation Conjugate Gradient) iterative solver (previously known as Iterative Solver) is less efficient than the AMG option for large models but requires less memory. For Midplane models, the SSORCG solver does not support Warpage analysis type set to Automatic or Buckling.

3D meshes

3D can only run a small deflection analysis. It can't determine if the part buckles. Most parts will not buckle. The available warp options are discussed below.

Consider mold thermal expansion

This is the same as Midplane.

Use mesh aggregation and 2nd-order tetrahedral elements

By default, this is checked. By unchecking this option, Advanced options are available including to isolate the causes of warpage. Using mesh aggregation is one method used to speed up the warpage calculations for the 3D warp analysis by collapsing the number of layers in the thickness to two, thus reducing the number of elements. Deflection results are then mapped back to the original mesh.

Number of threads for parallelization

The default is maximum. This uses as many processors on the computer as possible to reduce analysis time.

Viewing warpage results

When viewing warpage results, it is critical the deflections from the simulation are viewed with the same reference as the molded parts. In Figure 22, the front edge was compared using the default method of looking at the deflections called **best fit**, that does not use anchors and using anchors. The anchors define a reference plane. In the case of the dustpan, the edge of the pan is defined as the X-axis, and the bow of the front edge is in the Z-direction. The same reference must be used for looking at the deflection plots and the actual molded parts. With the Best fit, the zero deflection location is not known so you can't directly compare deflections with best fit to the actual part.

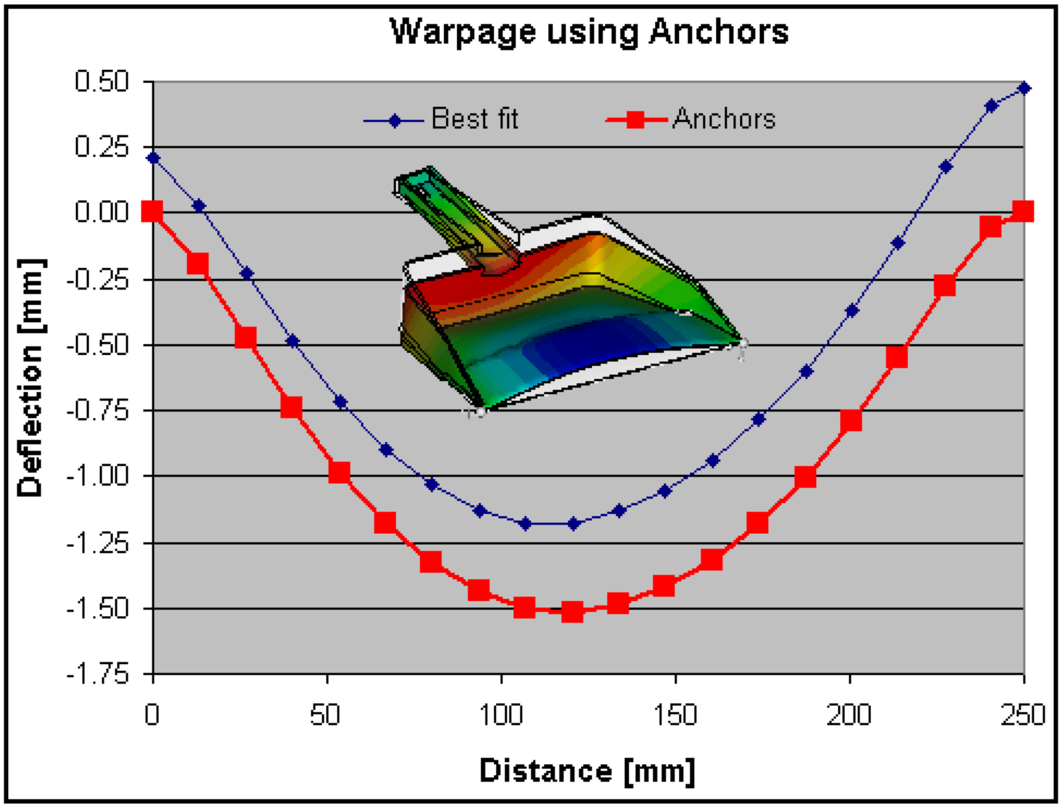


Figure 22: Use of anchors for viewing warpage

Molding verification

In addition to ensuring the analysis is correctly set up, the molding process must also be carefully checked to ensure it is consistent with how the simulation is run. Areas to check include:

- Machine capabilities.
- Ram speed profiles.
- Ram pressure profiles.
- Material preparation.
- Pressure measurement locations.
- Shot to shot variation.
- Venting.

Machine capabilities

Ram speed profiles

When setting the ram speed profile on the molding press, the profile must be achievable and stable. The achievable and stable profile can then be used in the simulation. In Figure 23, the machine controller was set with a flow rate of 93 cm^3/sec. However, the machine could not deliver that flow rate. The maximum flow rate achieved was only 68 cm^3/sec. and the average flow rate was only 52 cm^3/sec. The differences in flow rate will make a significant difference in how the part fills and packs out. The machine showed no indications of any problems when the 93 cm^3/sec. flow rate was not being achieved. It was only after viewing the ram position trace that an issue detected. The simulation must be run with the velocity profile the machine actual achieved, not the one that was set.

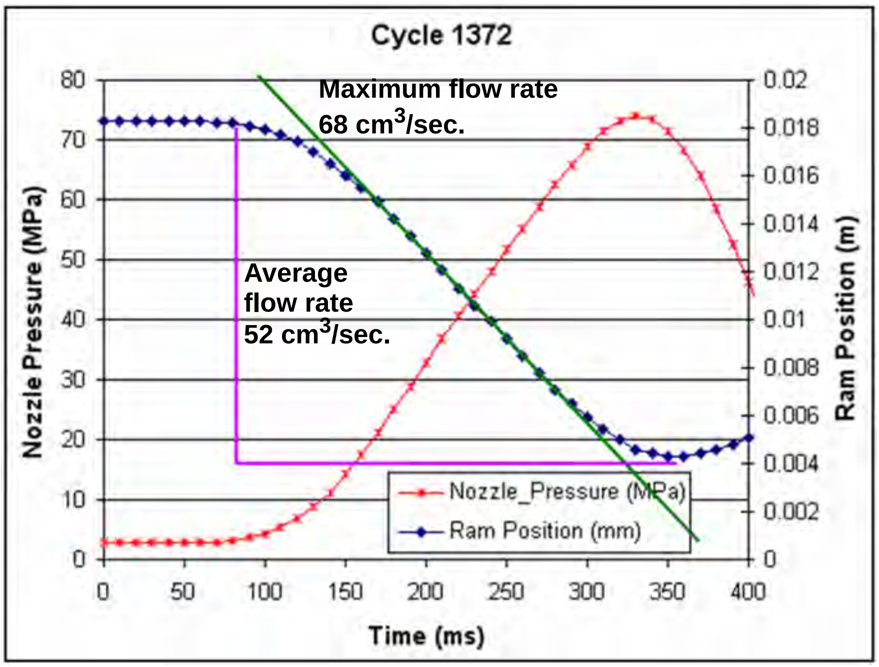
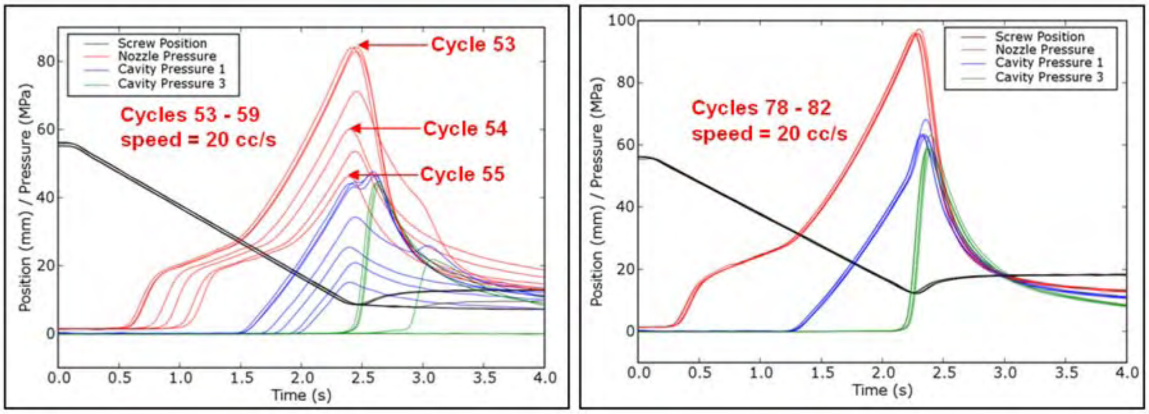


Figure 23: Injection speed capacity

Figure 24 shows an example of nozzle and cavity pressure traces both from unstable and stable cycles. On the left, the five cycles are not stable. The ram is moving about the same, but the pressures in the cavity are not stable. On the right, the press has stabilized. There is better shot to shot repeatability. It is only when the set velocity profile is achieved and is stable should the parameters be used in the simulation and the parts from these cycles be used to compare to the simulation.



Not stable **Stable**

Figure 24: Cycle stabilization

Ram pressure profiles

Like the ram speed profiles, the pressure profiles must be achievable and stable. Only a achievable and stable packing profile should be used as input to the simulation, and compare to the simulation.

Material preparation

Material tested by Moldflow is dried according to the specification of the material manufacturer. Therefore, the simulation assumes the material is properly dried. When molding parts to be compared to the simulation, the material must also be properly dried. Figure 25 shows when nylon was dried for 17 hours at different temperatures how the viscosity changes. Lower drying temperatures can cause a 2-5 times decrease in viscosity. This can change the pressure to fill by about 50%.

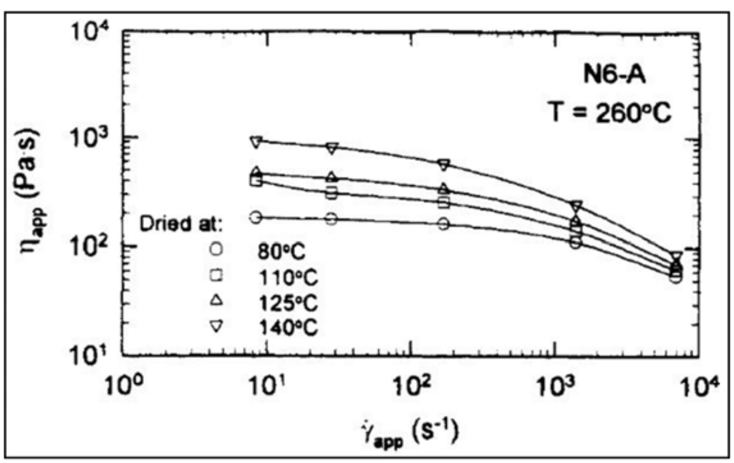


Figure 25: Viscosity changes due to drying (Y.P. Khanna, P.K. Han & E.D. Day, Allied Signal Inc., New Jersey. Polymer Engineering and Science 1996 Vol 36/13 pages 1745-1754.)

Pressure measurement locations

When comparing pressures between the simulation and the molding machine, it is important to know how the pressure was determined on the molding machine. If comparing nozzle injection pressure readings, then the analysis model should start in the nozzle at the location of the pressure transducer and the entire pressure trace between the simulation and shot are compared.

Figure 26 shows a difference between the injection pressure calculated from the hydraulic pressure and measured nozzle pressure. For the injection pressure calculated from the hydraulic pressure the hydraulic pressure was multiplied by the intensification ratio of 9.3. During the filling phase, the "hydraulic" injection pressure is always higher than the nozzle pressure by about 10 MPa. The differences are due pressure losses in the hydraulic system due to compressibility and resistance.

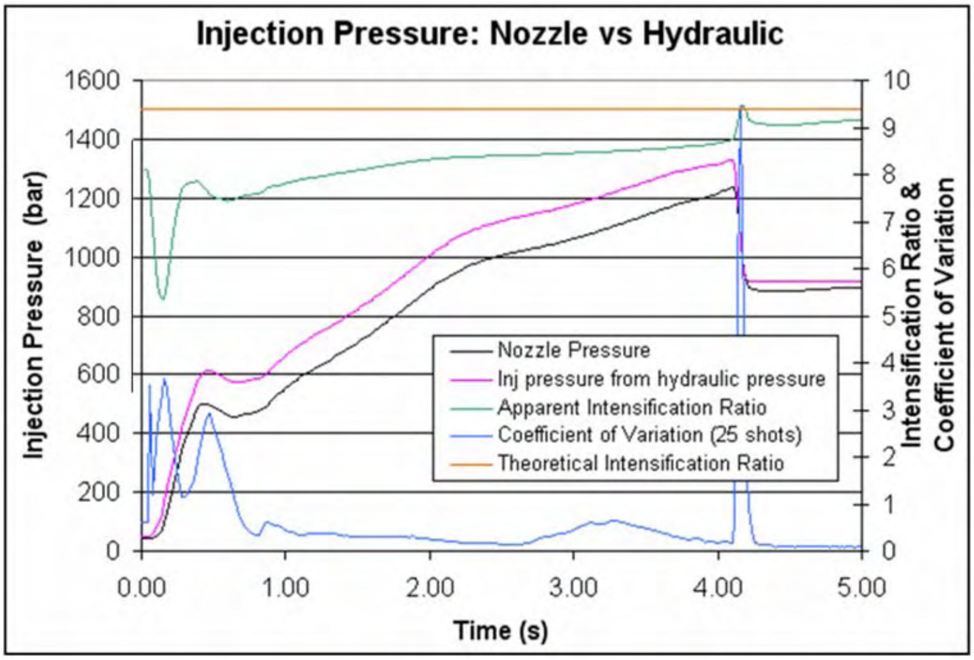


Figure 26: Nozzle pressure versus hydraulic pressure (R. G. Speight, P. D. Coates, J. B. Hull and C. Peters (1996) In-line Process Monitoring for Injection Moulding. IMechE, Part E, Volume 211, Journal of Process Mechanical Engineering.)

Sensors

When using pressure transducers, care must be used to ensure their proper performance. When a transducer is mounted under a pin, fit between the pin and the hole is critical. To much friction between the pin and the hole will delay in the signal and possibly lower the magnitude of the pressure. Mercury filled sensors can be inaccurate at the very top and bottom of their range. They also exhibit a hystereses effect.

Worn check ring

Figure 27 shows an example where the velocity profile in the simulation was set to the same profile as the molding machine. For cavity pressure transducer 2, there was a large error in the flow rate because the simulation indicates a different time to reach the location compared to the transducer. The problem was determined to be a worn check ring. Figure 28 shows the displacement of the ram and cavity pressure transducers in the cavity. The packing time was extended for a very long time. The ram continues to move even after the parts are frozen as indicated by a zero pressure at the transducer.

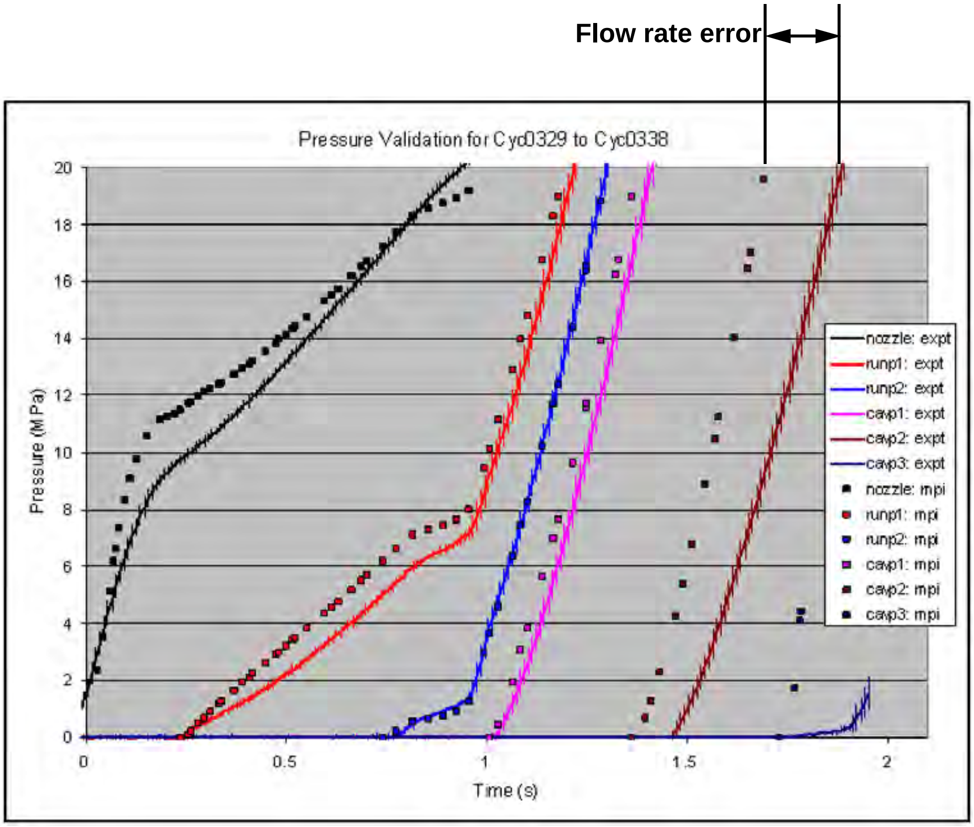


Figure 27: Error in cavity pressure due to worn check-ring

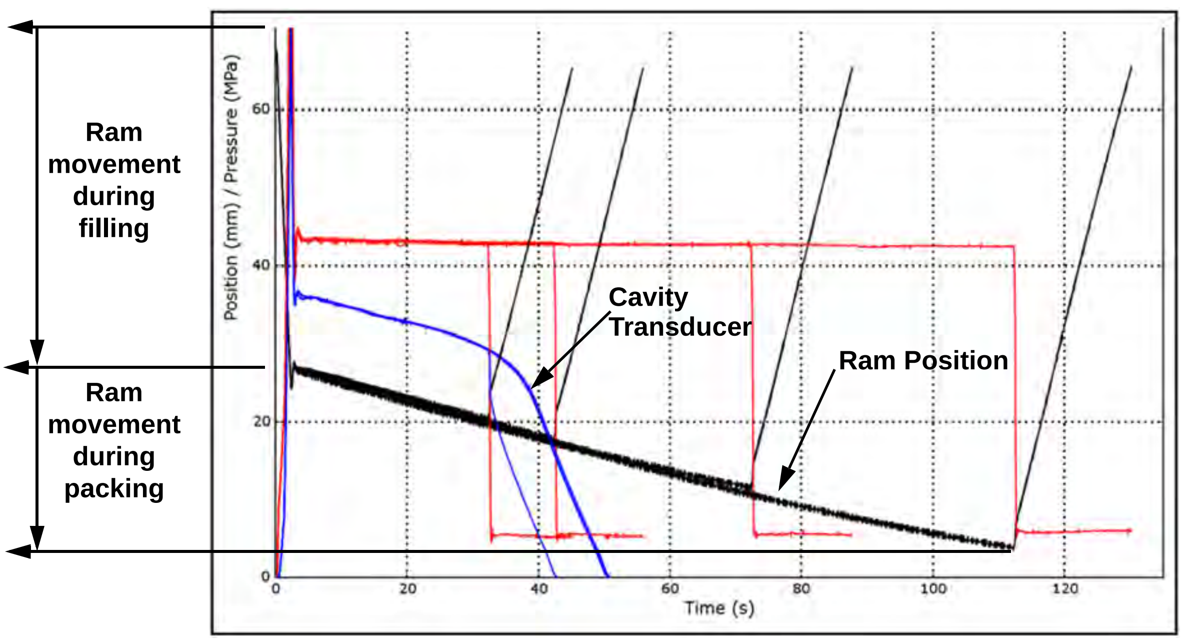


Figure 28: Validate worn check ring

Accounting for nozzle pressure drop

The pressure drop in the nozzle of the machine can be a significant amount of the total pressure required to fill the part. Preferably, the nozzle of the machine should be modeled from the pressure transducer location to the end. This will make it easy to correlate the pressure between the simulation and the molding. If modeling the nozzle is not possible, estimate the pressure drop. To determine the pressure drop through the nozzle back off the nozzle so it is not touching the mold surface, give yourself enough room like if you were purging the material. Make sure you are using the same process setup. Run through the process so it injects into the air. Take the pressure measurement and add this amount to the pressure given in MPI and this will be your total pressure drop.

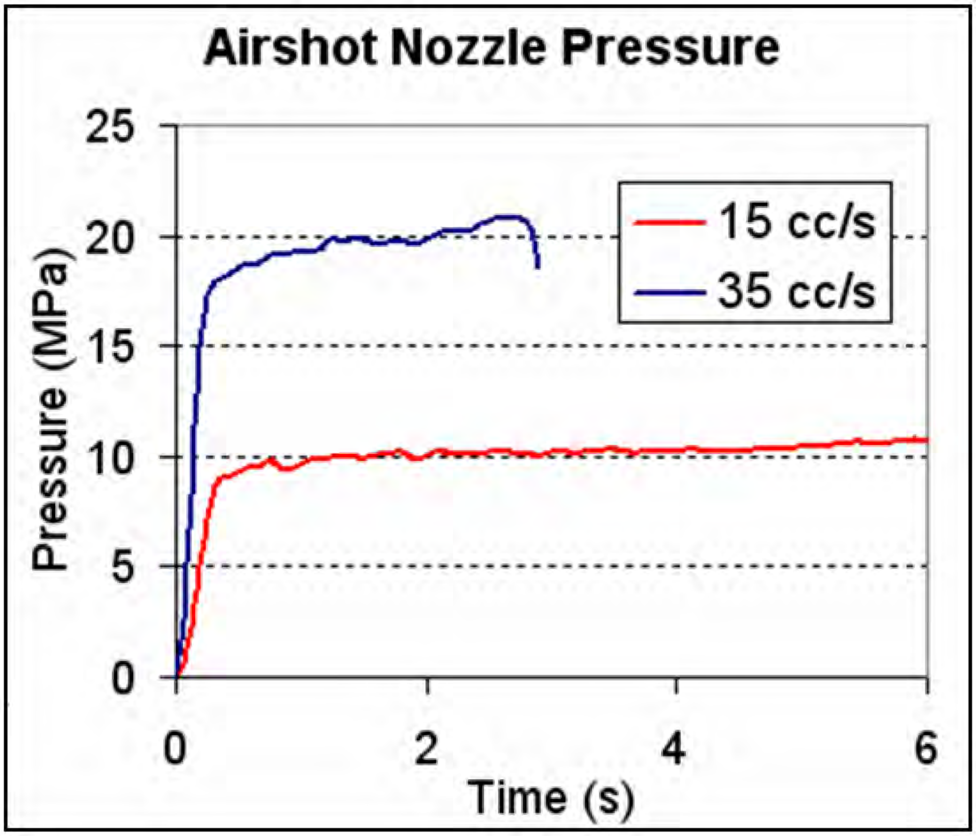


Figure 29: Nozzle air shot pressure

Shot to shot variation

When molding parts to be used to compare to the simulation, ensure that the process is stable before measuring the parts. Also, measure multiple parts. Ensure that you have repeatable measurements on the same part. Determine the average and 95% confidence intervals for the part. When comparing the simulation to the moldings, the simulation can be considered accurate when the simulation results are within the confidence limits of the experimental data. Figure 30 shows the deflection statistics for three molded samples of the same part, molded with nominally the same molding setup. There was a large variation in deflection between the three parts, so the confidence interval is very wide. Without knowing the shot to shot variation on the parts, if the simulation was compared to just one molded part, it may seem to be in error.

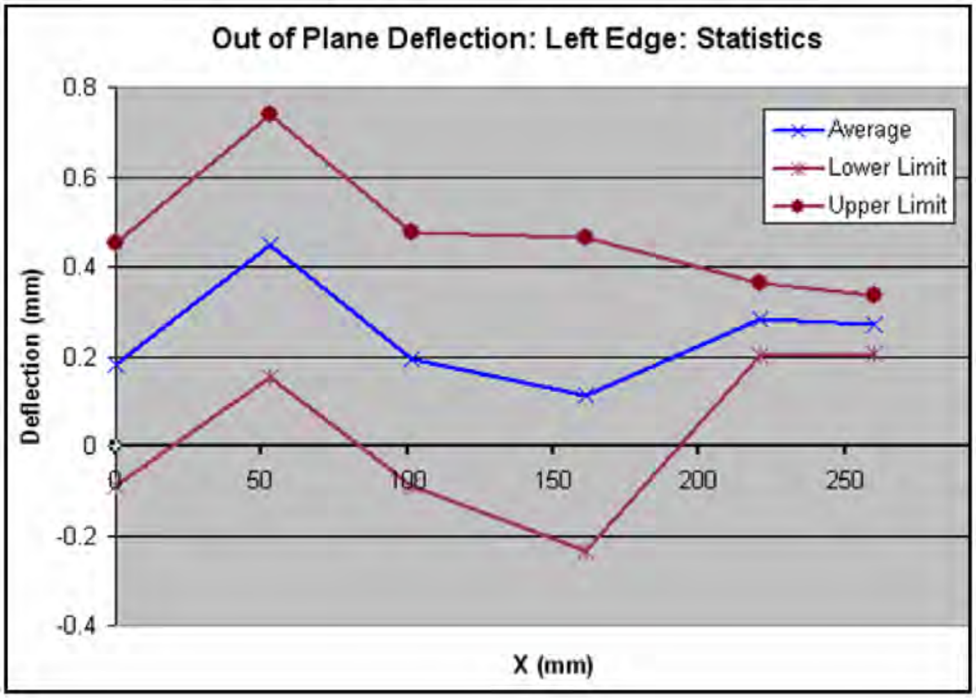


Figure 30: Shot to shot warpage variation

Venting

The simulation assumes perfect venting in the tool. if tools are not properly vented, the filling pattern may not be predicted correctly. Figure 31 shows a small sample part with 3 pressure transducers spaced evenly along the flow length. The third one is near the end of fill. With a constant flow rate, the flow front should get from one transducer to another at the same time, approximately one second. However, the third transducer shows an early reading.

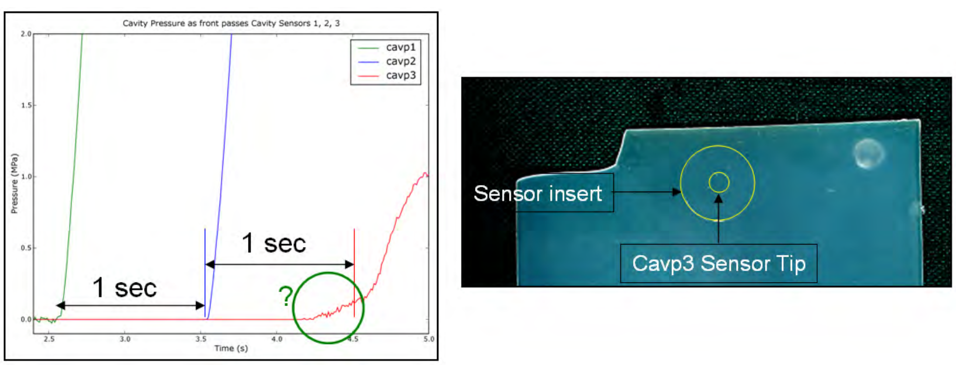


Figure 31: Short shot on part past pressure transducer

Figure 32 shows another short shot on the part, this time the flow front does not reach the transducer. However, this transducer still shows pressure. This is due to air pressure ahead of the flow front due to insufficient venting. In the graph of Figure 32, the solid red line is the original shot shown in Figure 31, and the dots represent the pressure with the short shot shown in Figure 32. The magnitude of the air pressure is less than 1 MPa.

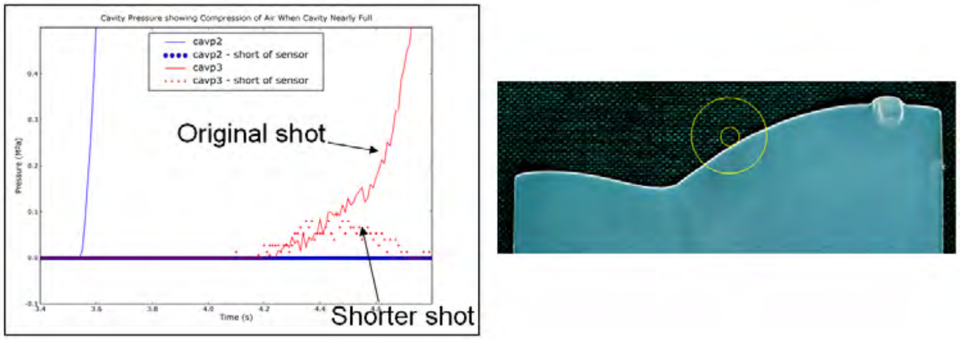


Figure 32: Second short shot before pressure transducer

Conclusions

A systematic approach for problem elimination is required when comparing simulation results to molded parts. Before the comparison is to begin, you must understand what is going to be used for the comparison, and ensure that both the moldings and the simulations are set up to provide the correct data necessary for the comparison. When problems occur with the comparison, a careful investigation of the factors that may cause the error must be done. These factors may be:

- Machine capability.
- Machine response time.
- Material preparation.
- Material characterization.
- Material stability.
- Part measurement methods and repeatability of measurements.
- Part geometry representation in the model.
- Matching of processing conditions in the simulation with those of the molding process.

Warp Troubleshooting Checklist

Use the following list to help ensure you have done everything possible to make sure the simulation is the same as the molded parts.

Acquire basic information

1. Obtain a copy of the study and screen shots that show a correlation problem between the simulation and molded parts.
2. Obtain a copy of the processing conditions used to create the molded part being compared.

Preliminary checks

1. Ensure there are no mesh defects.
    - High aspect ratios.
    - Intersecting elements.
    - Unoriented elements.
    - Etc.
2. Ensure the element orientation is correct.
3. Ensure the study has a runner system modeled.
4. Ensure the study has Cooling lines modeled.
5. Ensure there fill parameters and cooling time are **NOT** set to automatic.
6. Check for warning or error messages in the **Analysis Log**.

Verify the part thicknesses

Verify the feed system

1. There must be at least three beam elements or three rows of triangular elements across the gate.
2. Ensure tetrahedral or triangular elements are used when the width to height ratio of the gate is greater than 4:1.
3. Ensure the gate and runner sizes in the study are the same as the molded part/tool.

Verify the cooling system

1. Ensure the cooling channel placement and sizes in the study are the same as the tool.
2. Ensure the coolant media used in the study is the same as used when molding the parts.
    - Water, glycol, etc.
3. Ensure the coolant flow rates used in the study are the same as used to mold the parts.
4. Ensure the coolant temperatures used in the study are the same as used to mold the parts.
5. Ensure the mold material used in the study is the same material as the mold base.
6. Ensure any inserts used have the correct mold material defined.

    6.1. Ensure cooling lines and runners within the inserts have the same mold material as the insert.

7. Ensure a mold boundary is created in the study.
    7.1. Ensure the mold boundary mesh orientation is correct.

Verify molded material

1. Ensure the material being used in the analysis is the same material used to mold the parts.
    - Added colorant may affect the results, however most rheological and shrinkage testing is done without colorants added.
2. Ensure for fiber filled materials a fiber flow analysis was used. Verify there are fiber results.
3. Ensure for Fusion and midplane meshes the CRIMS or residual strain shrinkage models were used.

Verify filling and packing

1. Ensure the proper injection molding machine is selected if an absolute ram speed profile is being used.
2. Ensure the packing profile used in the analysis is the same as the one used to mold the parts being measured.
3. Ensure the melt temperature used in the analysis is the same as an air shot temperature and not heater band settings.
4. Ensure the mold surface temperature set in the analysis is the measured temperature of the mold surface (plastic/metal interface) and not just the thermometer temperature setting or coolant temperature.
    - This is only important if a cooling analysis is not run. If a cooling analysis is not run, this could be a bigger source of error than the wrong mold surface temperature.
5. Ensure the V/P switch-over position is correct.
6. Ensure the cooling time is specified and not set to automatic.
    - This is only important if a cooling analysis is not run. If a cooling analysis is not run, this could be a bigger source of error than the wrong cooling time.
7. Ensure the cool solver parameters are set to Ideal.
    - This may not always be possible due to computer limitations.
8. Ensure the mesh aggregation is off for parts with tetrahedral meshes.
9. Assign the proper mold open time.

Verify warp

1. Ensure the **consider corner effects** box is checked on the warp process settings page, if the part is deemed suitable for corner effects.
2. Ensure the anchoring system used to measure the warpage in the simulation represents the same constraints used to measure warpage for the actual parts.

Still having problems

1. Contact Moldflow Support.

2. Provide to support:

- Studies
- All information used above to validate the study to the molded part.
- Molded part, full shot with runners.
- Short shots, created at the same processing conditions used to make the full shot, just with a reduced barrel shot size.