



Moldflow Insight Sensitivity Study

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Class Summary

The Moldflow Sensitivity Study, a design of experiments (DOE), determined the impact of common Autodesk Simulation Moldflow Insight software processing inputs on common results. It also helped to determine the level of interaction among these settings and the impact of material- and geometry-specific interactions. We will highlight the methods used for performing the study, including tcodes, tcodesets, scripts, the Moldflow command shell, creation of studies, modification of studies, extraction of results, and more. Attendees will be able to repeat a similar study with their own commonly used geometries and materials. Study results will help Moldflow Insight users to increase efficiency by reducing design optimization time and determining the magnitude of impact of commonly used process settings. Note: This study included some functionality not currently available in the Moldflow Insight DOE module.

Learning Objectives

At the end of this class, you will be able to:

- Recreate a sensitivity study tailored to your product line and commonly used materials.
- Reduce design optimization time.
- Create modified studies and extract results from studies without using the Autodesk Moldflow Insight user interface.
- Take the right steps to enhance an experimental sensitivity study result.
- Observe a comparison of predicted parameter sensitivity against measured values.

About the Speakers

Laura Stuart

Laura has worked at TE Connectivity for almost 7 years as an Autodesk Moldflow Professional Certified analyst. She conducts some internal Moldflow R&D projects and provides internal Moldflow consulting, support, and training at TE. She is also TE's application owner for all Autodesk Moldflow products and the leader of TE's Global Plastic Analysis Working Group. Laura obtained her Master of Engineering degree in Engineering Science from Penn State Harrisburg and her Bachelor of Science degree in Plastics Engineering Technology from Penn State Erie. laura.stuart@te.com

Paul Brincat

Paul Brincat is a Senior Research Engineer at Autodesk Australia, based in the research and development offices in Melbourne, Australia. In 1999 he completed a Ph.D. in Engineering on a collaboration project between Moldflow and Swinburne University of Technology, working to predict entrance pressure losses experienced when molten polymers flow through narrow constrictions, such as injection molding gates. On completion of this project Paul has since worked for Moldflow in a number of roles, primarily in the field of injection molding machine research and control, from which a number of journal and conference papers have been published. paul.brincat@autodesk.com

Theoretical Sensitivity Study (Laura Stuart)

Problem Statement

A sensitivity study is, essentially, a large DOE that helps determine the magnitude of impact of specific inputs on specific outputs. In the example of a Moldflow sensitivity study, it helps determine the magnitude of impact of manufacturing process settings on simulation results. However, creating and executing studies for, and compiling results from, a large simulation DOE can be time consuming and prone to mistakes. Therefore, why manually create when you can automate?

This handout will help you to create a sensitivity study tailored to your product line and materials and thereby, reduce optimization time.

Solution

In order to create a sensitivity study, compile a list of variables, levels, materials and geometries. Then, the number of analyses to be performed will follow the equation below.

Resultant number of analyses = $M \cdot G \cdot L^V$, where:

M = number of materials

G = number of geometries

L = number of levels (e.g. high vs. low)

V = number of variables (e.g. melt temp, injection time, etc.)

Once this information is gathered, the scripting solution can be created and executed. The specific types of scripting used in this study are: Python, Moldflow command shell commands, and windows batch files. I chose Python since I was in need of advice from experienced programmers and Python was a language they knew and understood. However, most standard programming languages should suffice. The solution will be explained in pseudo code so it can be duplicated in any programming language of choice.

There are 5 basic steps to automating a Moldflow sensitivity study. Each one will be listed and explained in greater detail in the following pages.

1. [Create the CSV file defining DOE.](#)
2. [Create the Moldflow model.](#)
3. [Create the sensitivity study script.](#)
4. [Launch the batch file.](#)
5. [Extract the results.](#)

Solution Step 1: Create CSV file defining DOE

The first step requires the user to define a DOE equal to the number of levels raised to the number of variables (# of studies in a DOE = L^V). This DOE will contain all the process settings

and levels for each setting. Each CSV file will define a DOE. There will need to be one CSV file for each geometry and material combination (# of CSV files = M * G). Create the CSV file with the properties to be changed – e.g. mold temp, melt temp, fill control, etc. Make sure that the DOE table has one row per trial (i.e. one row per Moldflow study) as shown in Figure 1 that follows.

RUN	MoldTemp	MeltTemp	Fill	Pressure
1	60	250	2	Fine
2	100	250	2	Fine
3	60	275	2	Fine
4	100	275	2	Fine
5	60	250	3	Fine
6	100	250	3	Fine
7	60	275	3	Fine
8	100	275	3	Fine
9	60	250	2	Coarse
10	100	250	2	Coarse
11	60	275	2	Coarse
12	100	275	2	Coarse
13	60	250	3	Coarse
14	100	250	3	Coarse
15	60	275	3	Coarse
16	100	275	3	Coarse

Figure 1 - Example DOE

Solution Step 2: Create Moldflow model

Create one Moldflow study file for each geometry. In the Moldflow study file, define everything that will not be defined by the DOE variables (e.g. injection locations, mesh, material, etc.).

Example Moldflow model shown in Figure 2 that follows.

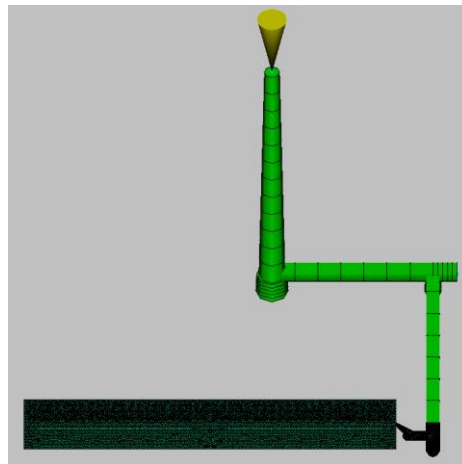


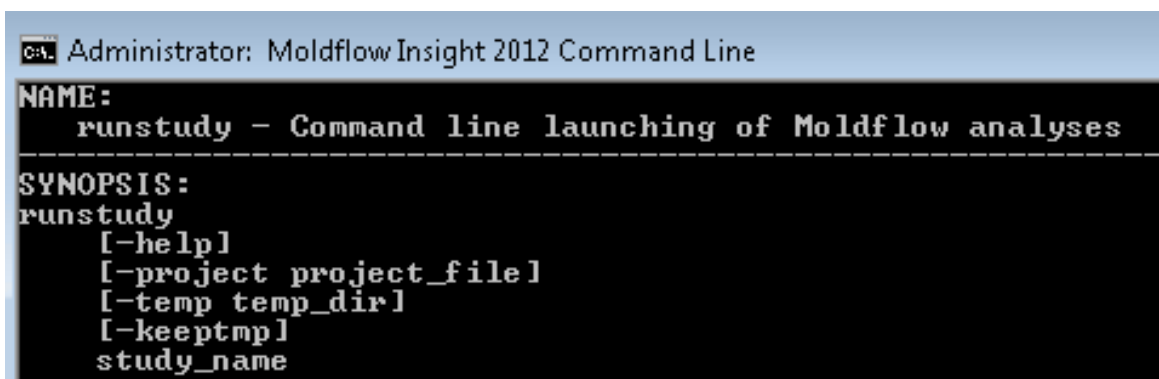
Figure 2 - Moldflow model

Solution Step 3: Create sensitivity study script

Creating the sensitivity study script is the next task in this process. The sensitivity study script will need to perform the following:

1. Define template XML file with variables for replaceable elements (e.g. properties, tcodesets, tcodes, etc.).
2. Open the corresponding CSV file.
3. For each trial/row/study:
 - a) Parse rows into values.
 - b) Replace values in XML template.
 - c) Write to XML file.
 - d) Call studymod.exe to generate new study with XML file replacements.
4. Create windows batch file with the following for each new study:
 - a) Runstudy.exe command.
 - b) Create a new directory named by <studyname>.
 - c) Copy into that directory the study file and all results.

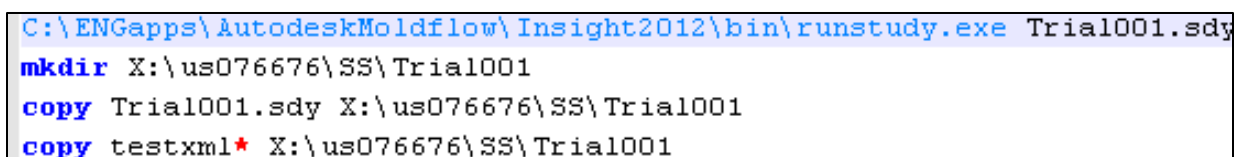
A snapshot of the runstudy command within the Moldflow Insight 2012 Command Line is shown in Figure 3 that follows. Figure 4 that follows shows an example of the text contained within the batch file.



```

Administrator: Moldflow Insight 2012 Command Line
NAME:
    runstudy - Command line launching of Moldflow analyses
-----
SYNOPSIS:
runstudy
    [-help]
    [-project project_file]
    [-temp temp_dir]
    [-keeptmp]
    study_name
  
```

Figure 3 - Runstudy.exe command



```

C:\ENGapps\AutodeskMoldflow\Insight2012\bin\runstudy.exe Trial001.sdy
mkdir X:\us076676\SS\Trial001
copy Trial001.sdy X:\us076676\SS\Trial001
copy testxml* X:\us076676\SS\Trial001
  
```

Figure 4 - Batch file example

Solution Step 4: Launch batch file

Next, simply launch the batch file.

Solution Step 5: Extract results

Finally, the results can be extracted. The first step in extracting the results is to create a new CSV file for results with column headers labeled by result name and rows labeled with row (i.e. study) name. In the result extraction script, for each subdirectory (i.e. study), do the following:

1. Open the out file corresponding with the Flow result. Then,
 - If the line starts with message id (tcode) 304007, record "Filled".
 - If the line starts with message id (tcode) 304008, record "Shorted" + value filled.
2. For each desired result value:
 - Build studyrft.exe command line with appropriate result tcode (as shown in Figure 5 which follows).
 - Run studyrft.exe.
 - Read result from the .val file and record value.
3. Write all results to a row of the CSV file

```

#Temperature, mold
row.append(studyrlt(file,'-result 5702 -max -unit Metric'))
row.append(studyrlt(file,'-result 5702 -min -unit Metric'))

#Deflection, all effects: Deflection
row.append(studyrlt(file,'-result 6250 -max -anchor N218516 N223934 N213104 -unit Metric'))
row.append(studyrlt(file,'-result 6250 -min -anchor N218516 N223934 N213104 -unit Metric'))

#Deflection, all effects: X Component
row.append(studyrlt(file,'-result 6250 -max -component 1 -anchor N218516 N223934 N213104 -unit Metric'))
row.append(studyrlt(file,'-result 6250 -min -component 1 -anchor N218516 N223934 N213104 -unit Metric'))

```

Figure 5 - Results extraction code example

Example of Frequently used Tcodesets and Tcodes

Tcodes within Tcodeset 30011 – Thermoplastic 3D Fill+Pack:

11002 Melt temp
 11108 Mold temp
 10109 Fill control (2=Injection time; 3=Flow rate)
 10100 Injection time
 10107 Flow rate
 10310 V/P Switchover by: (1=By % Filled; 8=Ram position)
 10308 % filled
 10313 Ram position
 10704 Packing Control (4=% Fill press vs. time; 2=Packing press vs. time)
 10702 % Fill pressure vs. time
 10707 Packing Pressure vs. time
 10102 Cooling time

Tcodes within Tcodeset 10080 – Thermoplastic 3D Flow & Warp Threading:

52040 Flow Threading
 4=no parallelization
 3=multi-threading
 2=maximum # of available threads
 52041 Specify # of threads to use for parallel processing in flow

Tcodes within Tcodeset 10080 – Thermoplastic 3D Flow & Warp Threading (continued):

641 Warpage Threading
 1=no parallelization
 3=multi-threading
 2=maximum # of available threads
 642 Specify # of threads to use for parallel processing in warp

Another helpful document was provided by Autodesk Moldflow with a title page “Tools within Autodesk Moldflow Insight to aid 3rd party optimization software” – contact Autodesk for a copy of the document.

Experimental Sensitivity Study (Paul Brincat)

Steps to Enhance an Experimental Sensitivity Study Result

To follow from the previous section's use of Insight to perform a simulation sensitivity study it can be beneficial to take a step back and look at a real molding sensitivity study, albeit a simple test case. But to ensure the relevancy of any comparisons between simulation results and experimental findings there are some considerations that should be made, which will be shown in this section.

Experimental Sensitivity Study

For this experimental sensitivity study a relatively simple corner geometry was used with an unfilled Polypropylene (Basell Moplen EP301K). To provide a focused investigation into the sensitivity of input parameters and output measurements a subset was used, as shown in the following Figure 6.

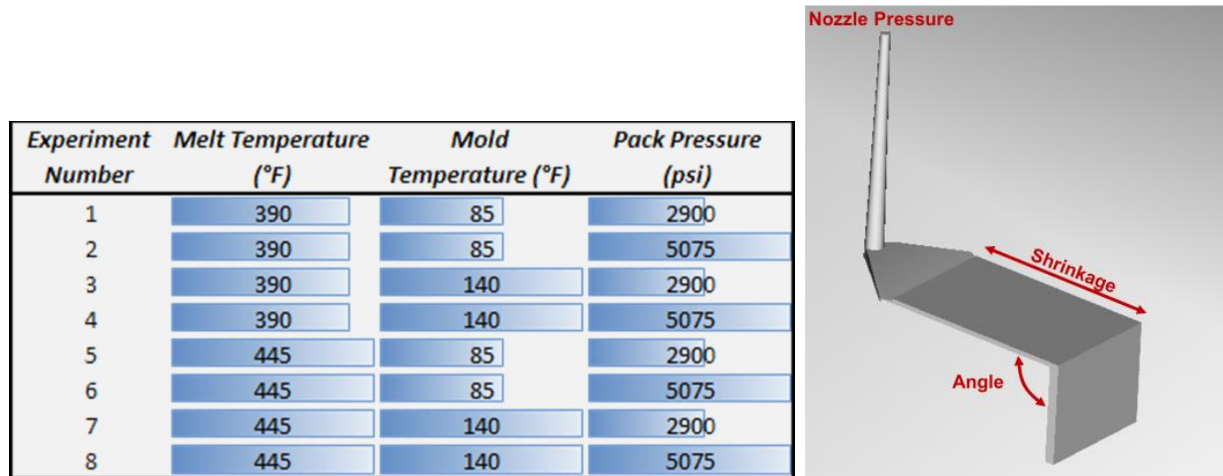


Figure 6 - (Left) Processing parameters varied; (Right) Corner test part with output characteristics of interest: End of Injection Nozzle Pressure, Shrinkage and Warpage Angle.

The part was molded on an Arburg Allrounder 520S with processing measurements recorded with a National Instruments data acquisition system (Figure 7 left). The dimensions of the parts produced were then measured using an optical measuring system (Figure 7 right).



Figure 7- Molding machine and measuring equipment.

To establish an accurate input parameter to output measurement relationship it is important to minimize any experimental error and uncertainty by following basic experiment procedure of:

- ensuring stable conditions prior to collection of the sample parts for measurement
- quantify the experimental uncertainty through the use of repeats

The fluctuation and its impact can be seen in the following Figure 8 for the measured Warpage Angle, where variation shows how taking a single part can lead to vastly different relationship.

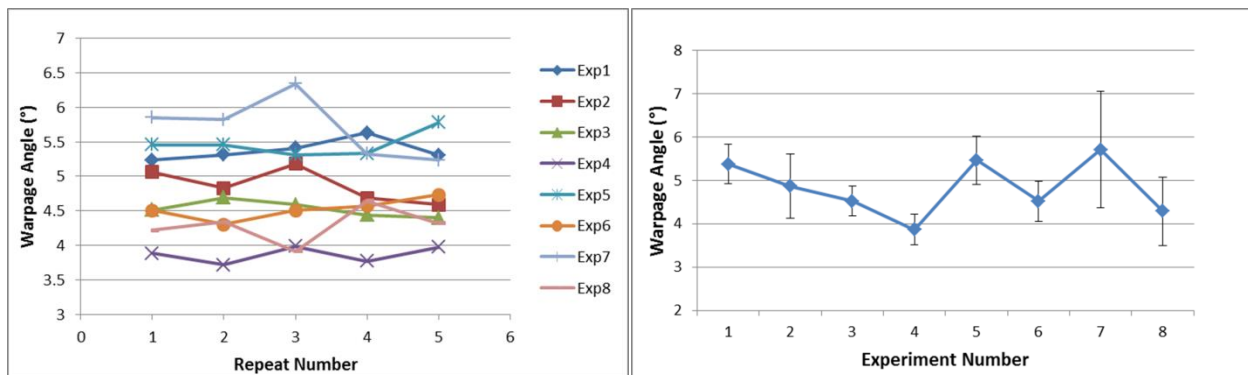


Figure 8 - (Left) Warpage Angle raw measurements for each repeat; (Right) Warpage average for each experiment condition, including variation.

Similarly, being aware of local measurement variations with parameters such as warpage can provide an additional level of confidence regarding the relationship. For example, a slight curvature of the part at the corner can affect the measured level and it is important that the relationship is maintained. See Figure 9 for a highlighted example.

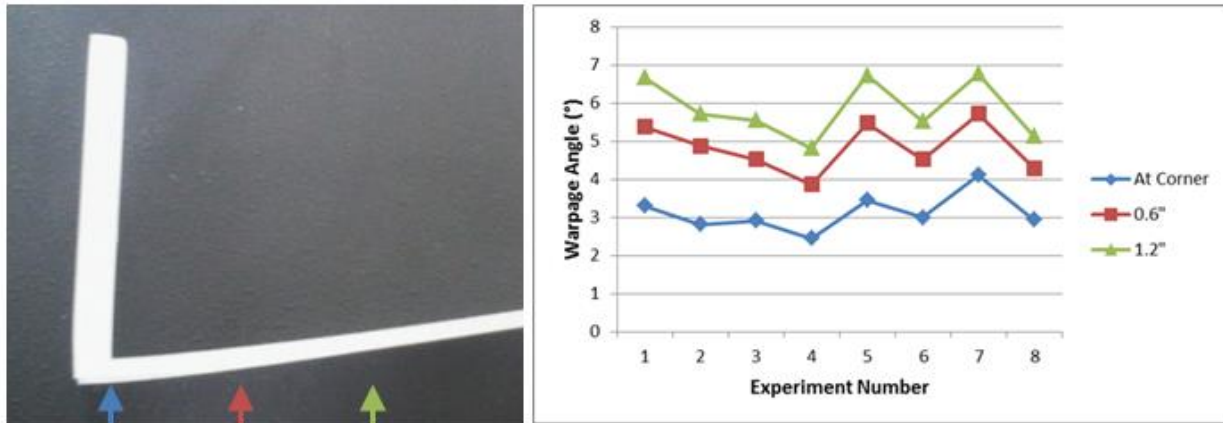


Figure 9 - (Left) Scan of actual part, with measurement position; (Right) Measurement position influence on the Warpage relationship, showing importance to compare at same location.

Simulation Uncertainty

Just as with experimental uncertainty, minimizing the simulation uncertainty is an important step. This can involve steps such as:

- selection of appropriate mesh sizing through a mesh sensitivity test (Figure 10 left)
- better representation of the material, such as use of CRIMS shrinkage model if available (Figure 10 right)

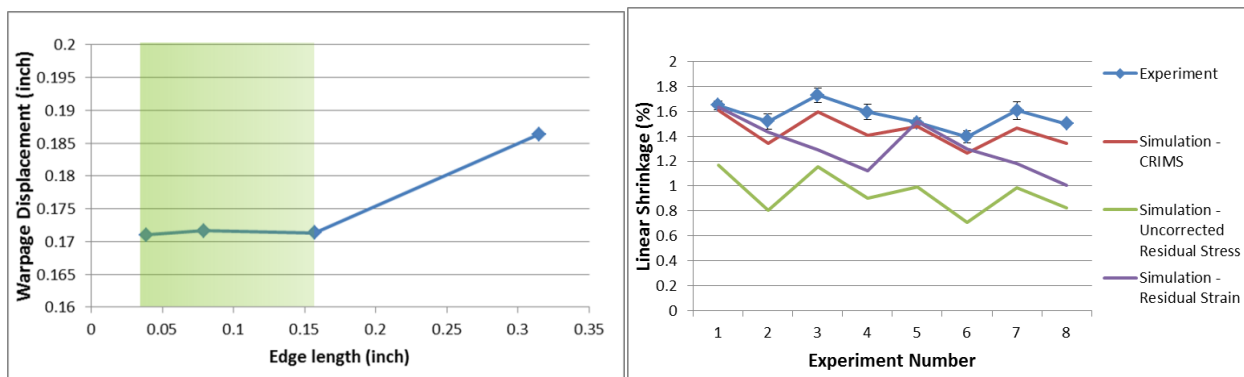


Figure 10 - (Left) Mesh sensitivity test based on warpage displacement; (Right) Impact of selected Shrinkage model on relationship fit.

Comparison of Predicted Parameter Sensitivity against Measured Values

Firstly the simulations were conducted with Autodesk Simulation Moldflow Insight 2013, Mid-plane mesh due to simple geometry using a Cool + Flow + Warp sequence, with geometry such as the nozzle, sprue and mold modeled. The predicted parameter sensitivity against the measured values can be seen in the following images in Figure 11.

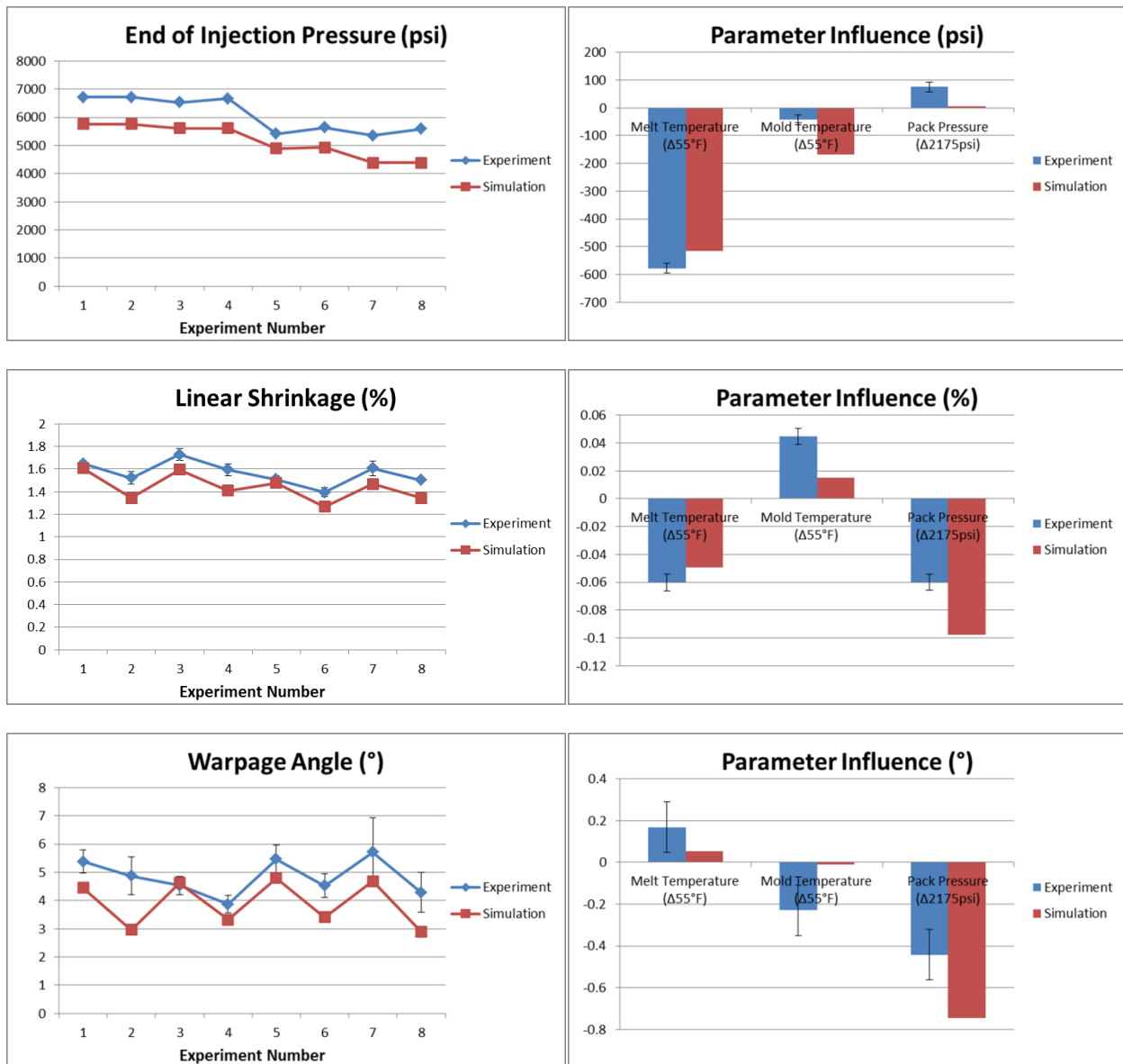


Figure 11 - (Left) Comparison of the predicted and experimental measurements for each condition.

Summary

Sensitivity studies provide much more than single simulation results. It would be ideal to get close to the measured values but the two key aspects of a sensitivity study are to observe the size of variation and the parameter trends. Also take note of expected influences such as machine dynamics that can have an impact on measured responses. It is important to consider uncertainties both in the experiment and simulation, as they can provide a clearer picture of the confidence in your results.