DEVELOPMENT OF THERMOSET MOLD-FLOW ANALYSIS FOR THERMOSET FUEL CELL STACK PLATES

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Abstract

Highly filled, thermoset compression-molded fuel cell stack plates are key elements in the design of a high-performance, low-cost fuel cell stack. Much analysis, research and testing have been performed to meet performance and manufacturability criteria for these plates, which contain complex geometry and must meet exacting tolerances in some areas. A current deficiency in the development process is the inability to predict mold filling for the stack plates in a process with highly filled thermoset composites and compression molding. Mold-filling analysis can be used to optimize plate design, mold design and the manufacturing process, thereby saving time and improving quality.

This paper will discuss a strategy to develop mold-filling analysis with the goal of cultivating a predictive tool for use in the manufacture of fuel cell stack plates and highly filled thermoset composites. A series of molding trials was performed and the results were used to calibrate a model, resulting in a model that correlated well to the real-world case.

Introduction

Proton Exchange Membrane (PEM) fuel cell stacks are comprised of multiple plates sandwiched with gaskets and proton-exchange membranes. Figure 1 shows an example stack. These plates must meet several requirements for operation in the fuel cell environment. Plates must be:

- Electrically conductive;
- Thermally conductive;
- Chemically stable;
- Dimensionally accurate in terms of flow-field geometry;
- Flat and parallel on surfaces;
- Low in cost;
- And able to be mass-produced.

Many strides have been made in fuel cell plate design, material and manufacturing in order to create plates that meet these conditions. The material used in this case was a highly filled thermoset engineered by Bulk Molding Compounds, Inc. (BMCI) to meet the needs of the fuel cell industry. Compression molding is used for these parts because it offers several advantages for manufacturing. However, one shortcoming has been the lack of an analytical tool to predict molding performance.

Mold-flow tools have been used in industry to simulate and predict molding behavior of thermoplastic and thermoset materials, especially in injection-molding processes. These existing analytical models did not meet the needs of the highly filled thermosets and compression molding cycle used in making these fuel cell plates.

During a recent project, Plug Power desired to better understand the flow characteristics of the material during molding and how it affected finished parts. Figure 2 shows a simplified model of the plate used for this testing. With BMCI's assistance, a short-shot analysis was performed using a production tool to better understand how the tool filled. Figure 3 shows a graph of the percentage-fill steps used in the short-shot analysis. Photos were taken of each step to compare to any future analyses and to understand what effect design changes would have on the mold flow and moldability of the parts. In order to do this, The Madison Group was contacted to see if their compression molding thermoset analysis tool, Cadpress®, could be used to simulate the molded fuel cell plate.

BMCI provided the material data for simulation and Plug Power provided a simplified quarter-symmetry model of the part to The Madison Group to develop the mold-filling analysis. Figure 2 shows the model used for analysis. The Madison Group also used the short-shot data to help quantify the model to be used for the analysis. This information was used to build a model that would match the unique flow characteristics seen in this environment.

Simulation of Thermoset Compounds

Unlike thermoplastic materials that solidify at the cold mold surface during mold filling, thermoset materials create a viscous layer at the hot mold surface. This produces a slip boundary condition for the compound resulting in a "plug" flow phenomenon, illustrated in Figure 4. To capture this behavior during molding simulation, the Barone-Caulk flow model [1] with a hydrodynamic friction layer at the mold surface is used in the finite-element formulation.

Comparison of Simulation to Short Shots

Typically, the hydrodynamic friction is constant (isotropic) across the mold surface [2]. However, short shots of the flow plate showed that this was not the case. During compression molding, the compound was flowing preferentially in one direction due to the geometry of the flow fields.

To capture this effect, the finite-element program was modified to account for an anisotropic hydrodynamic friction. This modification allows for the use of a different friction factor in different directions to be specified at locations throughout the mold. Figures 5-12 show the predicted flow along with the short shot. Since the flow field is nearly symmetrical in the "y" and "x" directions, only one-quarter of the plate was modeled. This initial charge or "puck" is circular in geometry and placed at the center of the mold. Full charge volume was used for the short shot with shims used to stop the mold at specific mold heights.

Figure 4 quickly shows the preferential flow in the horizontal direction. Here, more material is flowing along the flow fields than across them. The simulation captures this effect quite accurately. After the compound hits the sidewall of the flow plate, a race tracking-type flow occurs. The compound accelerates up the wall causing two knit lines to occur at the top edge. This simulation predicts these two knit lines, although it over-predicts flow in the two thin manifold regions.

Knowing that the knit lines were predicted and realizing that there was an over-prediction of flow in the manifold region gave analysts confidence to move forward to improve flow. This entailed modifying plate geometry and charge location to produce a plate without knit lines.

Summary and Next Steps

The initial results from the mold-flow analysis showed good correlation to the real-world data. This shows that for a given molding condition with known data, the analysis model will give results that closely correlate the actual behavior. However, a series of steps should now be taken to both confirm and improve the analysis as a predictive tool that can be used for fuel-cell plate design.

1. Exercise the code for the current geometry with different preform locations and shapes. Perform short-shot studies to see if the analysis-predicted results match actual results.
2. Exercise the code for other geometries to see if similar results are generated.
3. Gather more short-shot study data for other thermoset compression-molded fuel-cell plates and materials. This would be used to develop a more generalized model that can accurately predict mold flow over a wide range of geometry and molding parameters.

In summary, it was shown that the analytical tool used in this study with the customizations done by The Madison Group was able to accurately predict the mold flow for a fuel cell plate molded with a conductive thermoset material. With the steps listed above, companies involved in design of molded fuel-cell plates will have another analytical tool available to help improve quality and reduce time-to-market for these parts.

References

[1] Baraone, M.R. and D.A.Caulk, J. Appl. Mech, 361-371 (1986).

[2] Davis, B.A., P.J. Gramann, T.A., Osswald, and A.C. Rios, Compression Molding, Hanser, Munich, 2003.

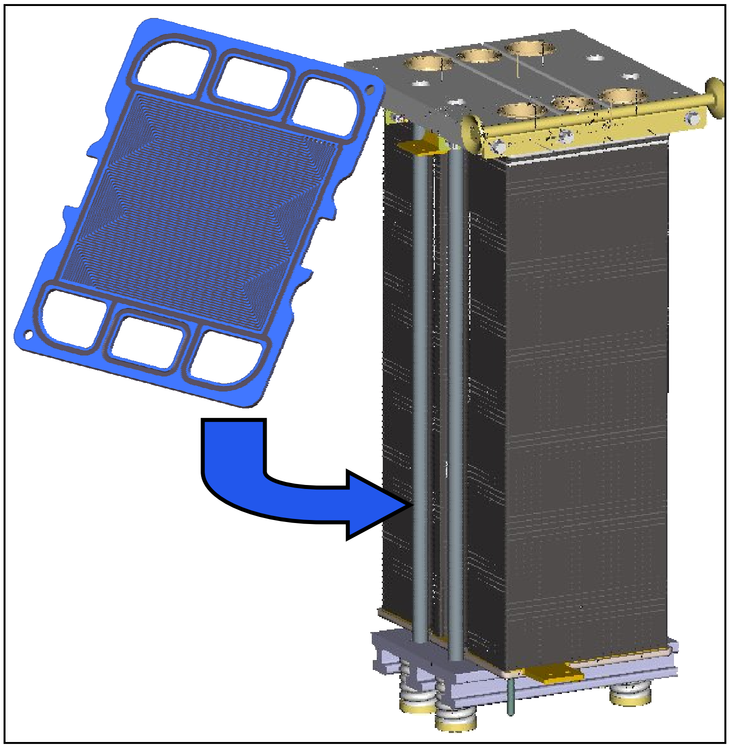


Figure 1: Fuel cell stack and fuel cell plate

Figure 2: Plate geometry used in analysis (simplified quarter plate model shown)

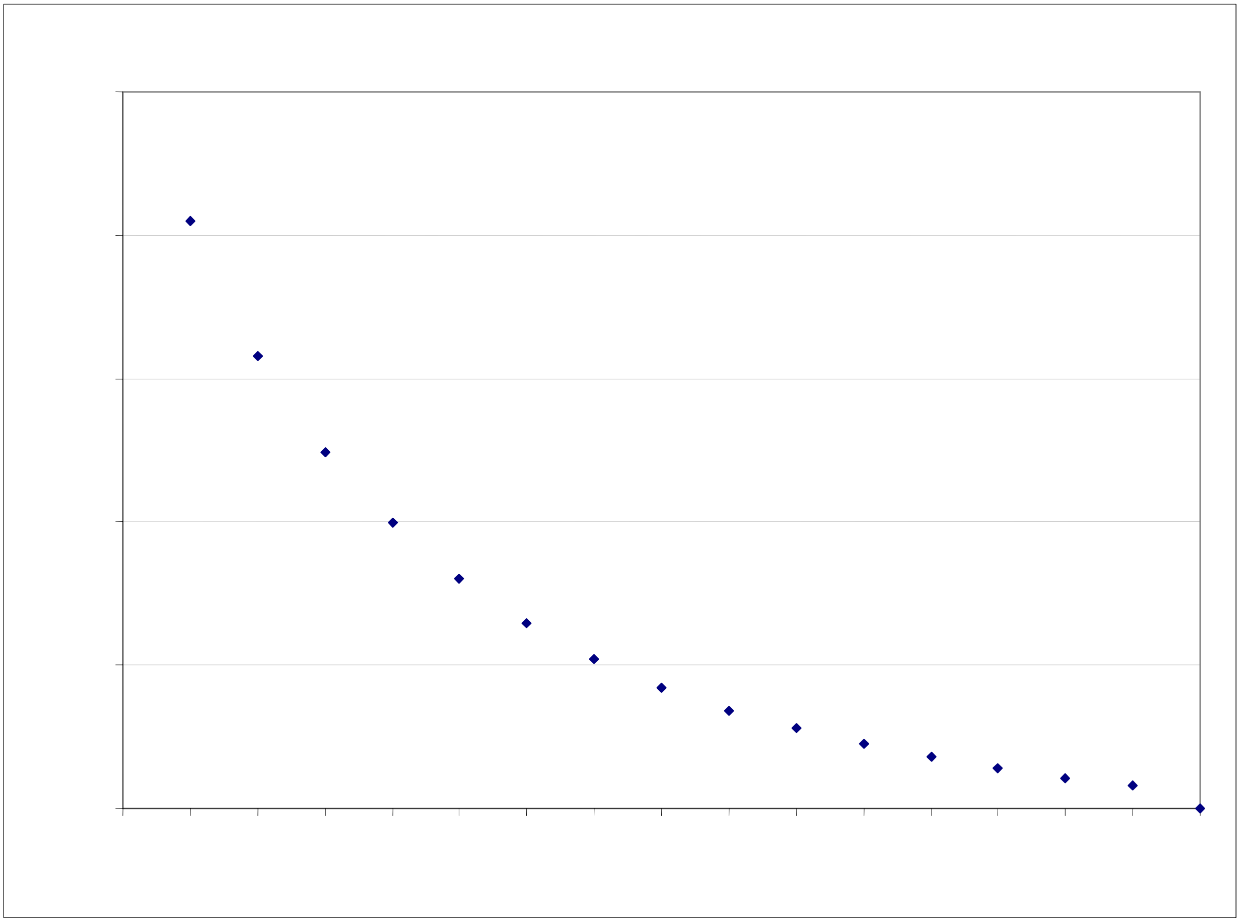


Figure 3: Short shot study data points

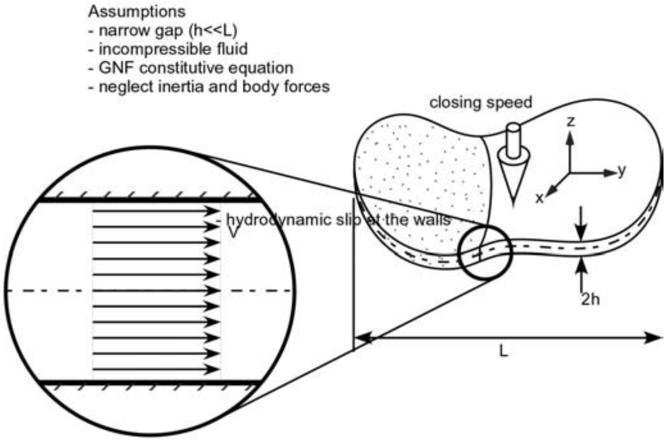


Figure 4: Barone-Caulk flow model.

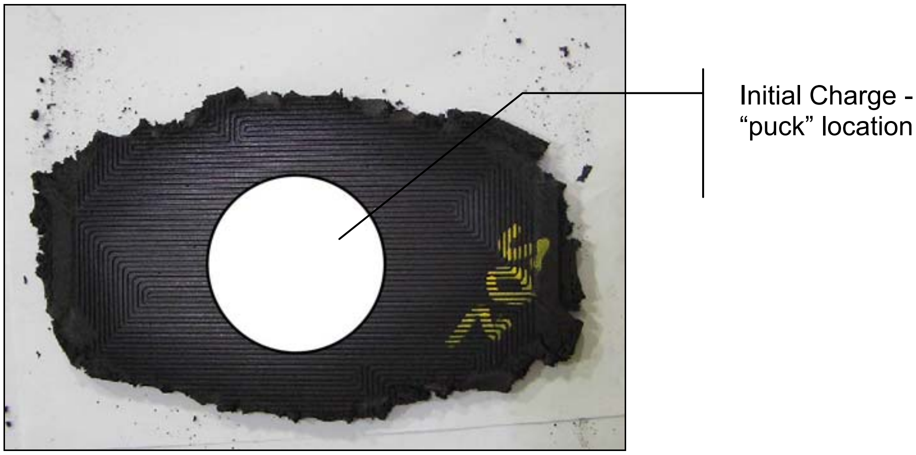


Figure 5: Charge placement on part.

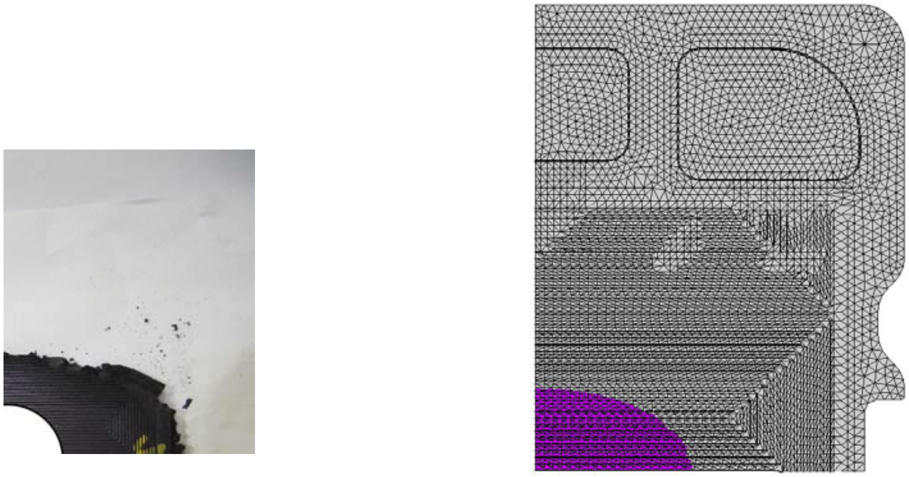


Figure 6: Initial mold filling with short shot and simulation. Note: due to symmetry one quarter of plate was modeled.

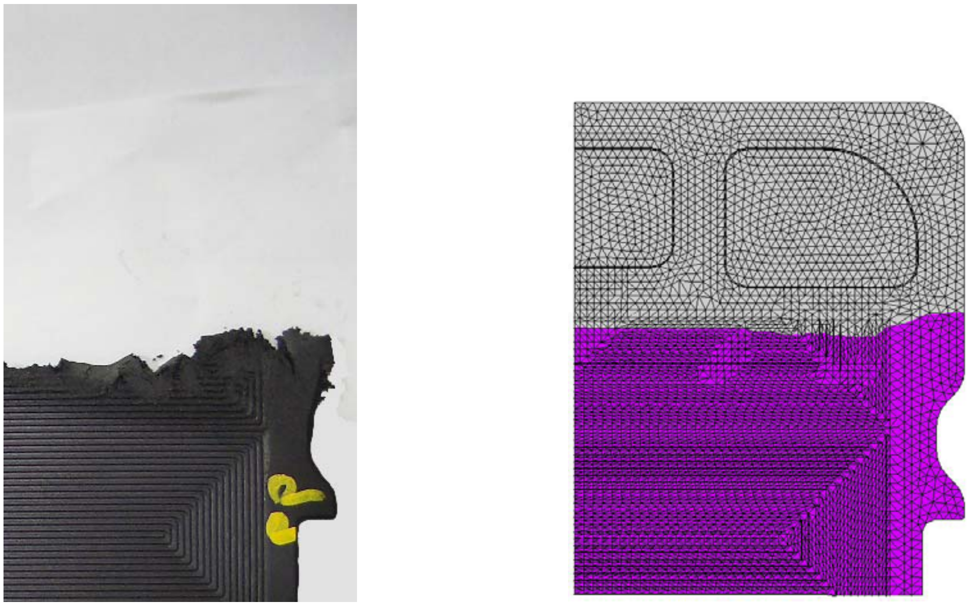


Figure 7: Mold filling during short shot and simulation.

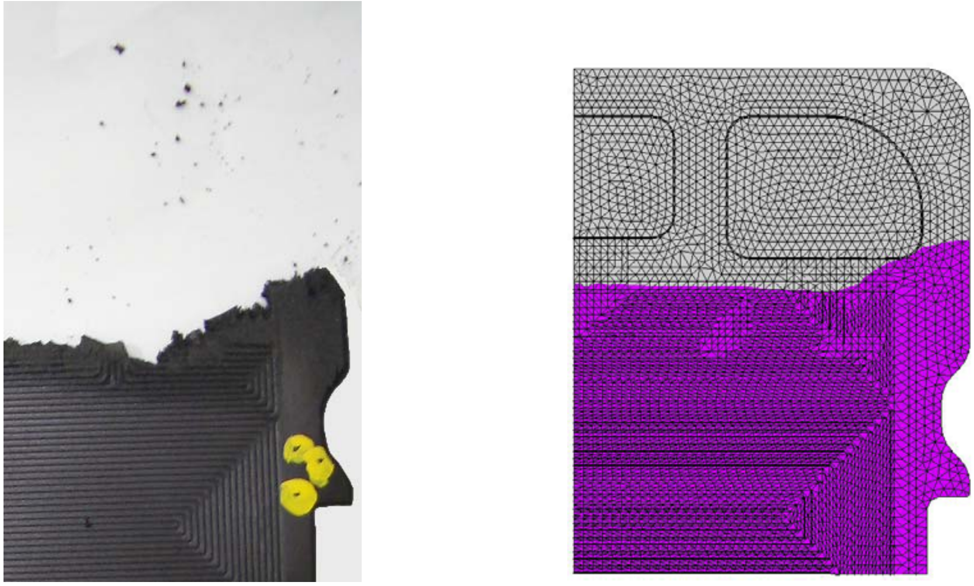


Figure 8: Mold filling during short shot and simulation.

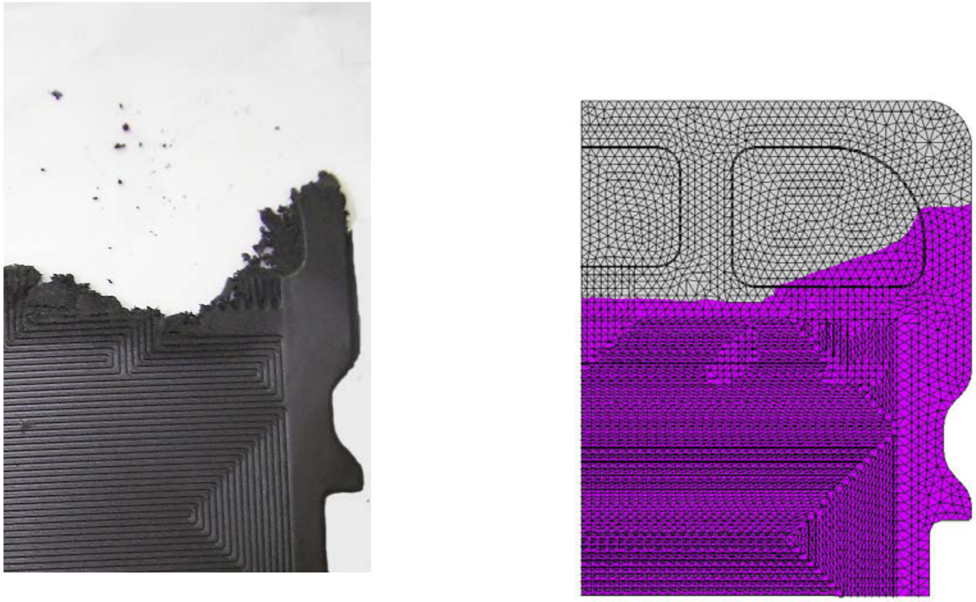


Figure 9: Mold filling during short shot and simulation.

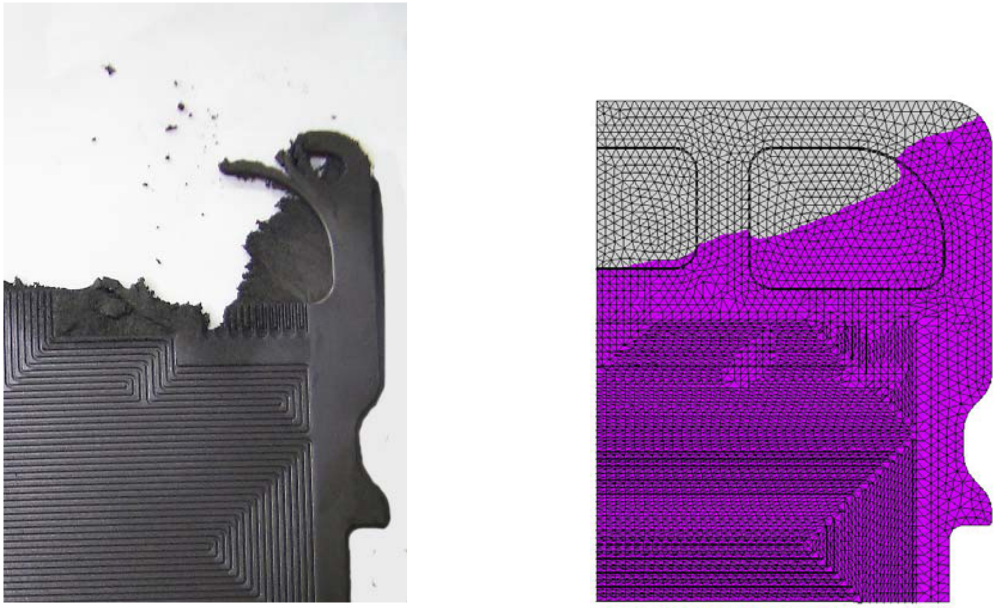
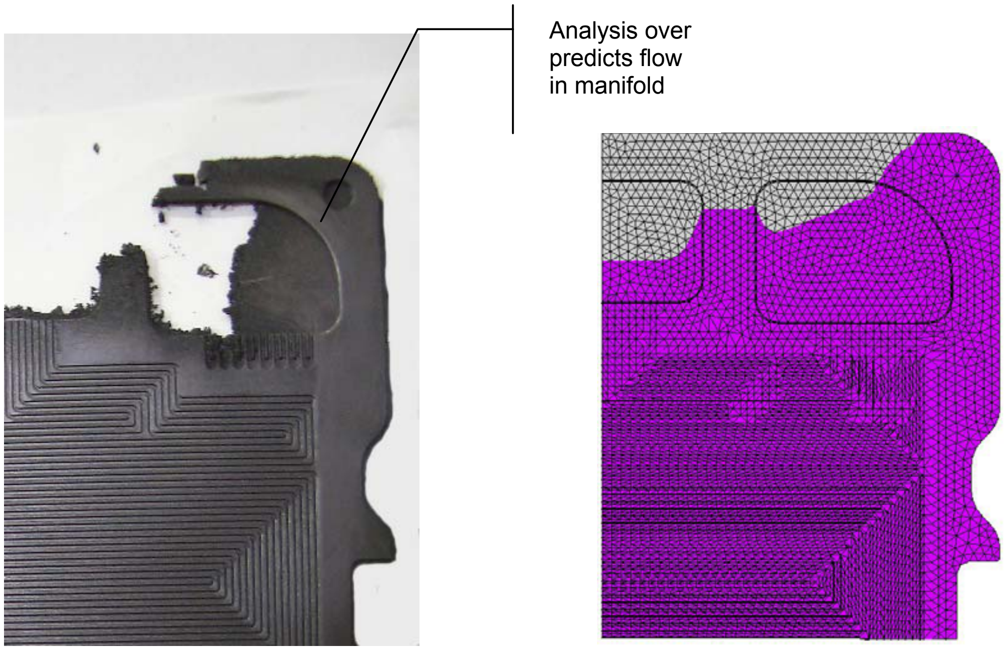


Figure 10: Mold filling during short shot and simulation.



Analysis over predicts flow in manifold

Figure 11: Mold filling during short shot and simulation.

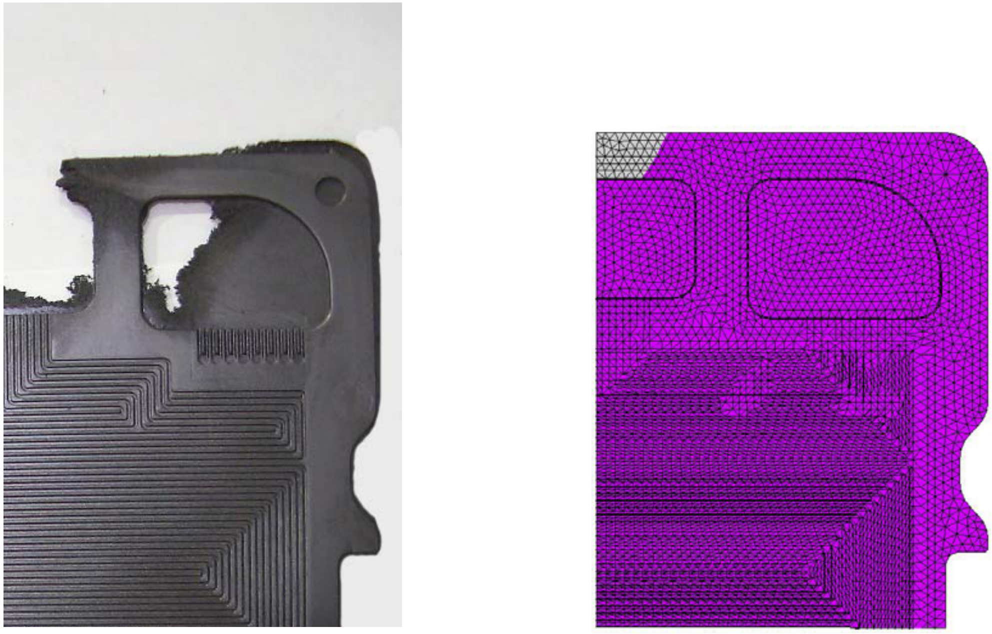


Figure 12: Mold filling during short shot and simulation. Note knit line location is accurately predicted.