



## Thermoplastic Injection Molding Analysis

### 1 Introduction

**Note:** Nothing in this standard supercedes applicable laws and regulations.

**Note:** In the event of conflict between the English and domestic language, the English language shall take precedence.

**1.1 Purpose.** The purpose of this test procedure is to enable optimization of injection mold tooling and processes to make "parts to print" per GM10067, Global Matching Part Submission deliverable.

**1.2 Applicability.** This specification applies to the computer aided engineering analysis of thermoplastic injection molding processes and tooling that will produce thermoplastic vehicle components globally. Concessions to this standard must be agreed upon by General Motors Engineering, which will be the Manufacturing Polymer Engineering (MPE), Manufacturing Engineer, or the GM Product Engineer, if MPE resources are not assigned to the part.

**1.3 Remarks.** This specification works in conjunction with the manufacturing requirements of Appendix E8 within the Statement of Requirements (SOR), and GMW15850, enabling an optimized tooling and process solution for thermoplastic injection molded parts.

### 2 References

**Note:** Only the latest approved standards are applicable unless otherwise specified.

#### 2.1 External Standards/Specifications.

None

#### 2.2 GM Standards/Specifications.

GMW15850                      GMW16365

#### 2.3 Additional References.

- Autodesk MOLDFLOW Expert Certification available at [www.autodesk.com](http://www.autodesk.com)
- Autodesk Moldflow Insight/Advisor available at [www.autodesk.com/products/moldflow/overview](http://www.autodesk.com/products/moldflow/overview)
- GM10067 Global Matching Part Submission available at <https://gmsupplypower.covisint.com>
- Statement of Requirements (SOR), Appendix E8

### 3 Resources

#### 3.1 Facilities.

**3.1.1 Calibration.** The test facilities and equipment shall be in good working order and shall have a valid calibration label.

**3.1.2 Alternatives.** Alternative test facilities and equipment may also be used. However, all measuring variables as specified in this standard shall be determined correctly with respect to their physical definition.

**3.2 Equipment.** Not applicable.

**3.3 Test Vehicle/Test Piece.** Not applicable.

**3.4 Test Time.** Not applicable, simulation process.

### 3.5 Test Required Information.

#### 3.5.1 General Information – Simulation.

**3.5.1.1** All Moldflow related files, related mesh, analyses, and reports generated by the Moldflow source are the property of General Motors Company and must be provided upon request (\*.sdy, \*.udm, \*.mfr, etc., see 7.1).

**3.5.2 Software.** Autodesk Simulation Moldflow Insight 2014 or higher will be used for all phases of the simulation.

**3.5.3 Material Characterization.** All materials used in simulation will be completely characterized using the appropriate Autodesk Moldflow Plastics Laboratory specifications for the type of analysis to be performed as identified in Table 1. Refer to 4.3.1 for definition of Phases. All required data for each material to be tested must be tested by an Autodesk Moldflow Testing Facility.

**Table 1: Material Testing Requirements**

| Phase   | Material Characterization              |
|---------|----------------------------------------|
| Fill    | Moldflow Plastic Laboratory (MPL): 125 |
| Pack    |                                        |
| Cool    |                                        |
| Warpage | Moldflow Plastic Laboratory (MPL): 150 |

**3.5.3.1** Material property testing will include, but is not limited to viscosity, transition temperature, thermal conductivity, specific heat, melt density, pressure volume temperature (PVT), juncture loss, extensional viscosity, coefficient of thermal expansion (CTE), corrected residual in-mold stress (CRIMS) and Mechanical properties (three-dimensional (3D) warp).

**3.5.3.2** Fiber filled materials will also have the following properties identified in the material file:

- Filler weight percentage
- Filler aspect ratio
- Filler mechanical properties data
- Filler CTE data

**3.5.3.3** If the material file (\*.udb, see 7.1) to be used is  $\geq 3$  years old, the material supplier must be contacted to verify the latest file is available.

**3.5.3.4** If the latest material file is  $\geq 3$  years old, General Motors Engineering must be notified so an evaluation can be made to determine if the material file still accurately represents the current material formulation. The material supplier may be required to develop a new material file if the formulation has changed.

**3.6 Personnel/Skills.** Personnel to have experience as Computer Aided Engineering (CAE) Analyst.

#### 3.6.1 Approval.

**3.6.1.1** The individual analyst completing Moldflow work must be approved by the General Motors Manufacturing Polymer Engineering Group.

**3.6.1.2** For Moldflow suppliers where multiple people have specific job assignments within the analysis workflow, there must be, at a minimum, one (1) approved individual reviewing all completed analyses before they are distributed.

#### 3.6.2 General Motors Approval.

**3.6.2.1** All individuals must receive Moldflow Plastics Insight Expert Certification from Autodesk before starting the General Motors approval process. All individuals must submit an application to start the approval process. Contact the appropriate GM Polymer Manufacturing Engineer to begin this process.

**3.6.2.2** To receive GM approval, Moldflow suppliers will be evaluated on their ability to analyze appearance and dimensional issues related to the following general guidelines:

- Identify issues with software
- Root cause analysis

- Correlate predicted to actual
- Solve issues with multi-discipline approach (tool/process/material)

## 4 Procedure

### 4.1 Preparation.

#### 4.1.1 Model Preparation.

**4.1.1.1** Mesh type will be agreed to by the certified Analyst, part supplier, and General Motors engineering at kick-off.

**4.1.1.2** Mesh type will be determined based on part geometry and mesh statistics.

**4.1.2** The mesh type selected must accurately represent the actual part thickness and volume. The final meshed volume must be within 0.5% of the solid volume.

**4.1.2.1** If Dual-Domain mesh is to be used for a cooling or warpage analysis, assigning thickness manually is not allowed. Manually assigned Dual-Domain thickness is allowable for fill and pack analysis only.

**4.1.2.2** If 3D mesh is to be used for any cold/hot runner element in the analysis, then the use of extensional viscosity within the material file must be used.

**4.1.3** The mesh type selected must meet the mesh statistic rule sets per Table 2 and Table 3.

**4.1.3.1 Element Aspect Ratio Rule Set.** See Table 2.

**Table 2: Acceptable Elements Aspect Ratios**

| Analysis                  | Software Release Version | Midplane/Dual-Domain           | 3D                             |
|---------------------------|--------------------------|--------------------------------|--------------------------------|
| Fill, Pack, Cool and Warp | Prior to 2016 Release:   | Average < 2:1<br>Maximum < 6:1 | < 30:1                         |
|                           | 2016 Release or Newer:   | Maximum < 20:1                 | Minimum: 5:1<br>Maximum: 100:1 |

**4.1.3.2 Dual-Domain Element Match Percentage Rule Set.** See Table 3.

**Table 3: Acceptable Element Match Percentage**

| Analysis                  | Match Percentage | Reciprocal Percentage |
|---------------------------|------------------|-----------------------|
| Fill, Pack, Cool and Warp | 90               | 90                    |

**4.1.3.3** Meshes of complex geometries may inherently not be capable of meeting the rule sets in 4.1.3.1 and 4.1.3.2. These meshes may be used with agreement between the certified analyst, part supplier and General Motors Engineering.

**4.1.4** A minimum of three (3) element rows are required in gate areas of changing thickness to predict hesitation and air traps in the flow front.

**4.1.4.1** When the gate width is < 1.0 in, the use of one-dimensional (1D) beams or 3D elements are acceptable. Gates that are > 1.0 in in the width dimension, the use of 1D beams is not allowed.

**4.1.5** When parts have openings in areas where knit lines are critical for appearance or strength, the mesh density must be increased around these features to properly predict knit line formation and location.

### 4.2 Conditions.

**4.2.1 Environmental Conditions.** Not applicable.

**4.2.2 Test Conditions.** Deviations from the requirements of this standard shall have been agreed upon. Such requirements shall be specified on component drawings, test certificates, reports, etc.

### 4.3 Instructions.

#### 4.3.1 Concurrent Engineering Phases.

**4.3.1.1** The part supplier is responsible to establish and coordinate a Moldflow strategy prior to starting any analysis. It is suggested that the strategy be outlined with input from the following participants:

- GM Product Design Engineer (DE)
- MPE Engineer
- Part supplier
- Tooling source
- Material supplier
- Hot runner manufacturer
- Moldflow source

**4.3.1.1.1** The minimum Moldflow strategy will be outlined in the SOR, Appendix E8. The milestone within the Global Vehicle Development Process (GVDP), and the Moldflow Iteration and type of analysis (Fill, Pack, Cool, Warp, Shrink) will also be outlined within SOR, Appendix E8. See Appendix A, Figure A1 for table listing the different Moldflow Iterations (MF0 thru MF2 and MF2') required for each Moldflow milestone within the GVDP.

#### Where:

**MF0** = Moldflow Iteration 0: Occurs around Concept Vehicle Engineering Release (CVER) or Design Sign Off (DSO) Pull Ahead Production Tooling (PAPT)

**MF1** = Moldflow Iteration 1: Occurs around Structure Vehicle Engineering Release (SVER) or CVER (PAPT)

**MF2** = Moldflow Iteration 2: Occurs around Integration Vehicle Engineering Release (IVER)/Production Data Release (P2) or SVER (PAPT)

**MF2'** = Moldflow Iteration 2': May be required after IVER for PAPT (see Appendix A, Figures A1 and A2)

See Appendix A, Figure A2 for timeline of how phases should be coordinated with the injection mold design, build, and tryout. The required minimum outputs for each phase are listed in Tables 4 thru 7.

**4.3.1.1.2 Phase 1.** Establish optimum number of gates and gate locations. Required for Fill, Pack, Cool, and Warp analysis, see Table 4.

**Table 4: Minimum Reported Outputs for Phase 1**

|                                                         |                                                             |
|---------------------------------------------------------|-------------------------------------------------------------|
| Describe Best Gate Location(s) Selection Criteria       | Weld/Meld Lines with Temperature                            |
| Fiber Orientation (if fiber filled material is used)    | Air Trap Location                                           |
| Grow From                                               | Pressure at Transfer                                        |
| Filling Pattern versus Time (Fill Time)                 | Pressure Distribution at End of Flow (EOF)                  |
| Required Clamp Tonnage                                  | Flow Front Temperature                                      |
| Warpage Results (Isothermal Cooling)                    | Clamp Force: XY Plot                                        |
| Pressure: XY Plot (at all post gates and end of fill)   | Pressure at Injection Location: XY Plot (Pressure vs. Time) |
| Dimensioned pictorial showing proposed gate location(s) |                                                             |

**4.3.1.1.3 Phase 2.** Establish material delivery system layout and design. The material delivery system must be modeled from the part gate(s) to the sprue bushing/machine nozzle interface. Required for Fill, Pack, Cool and Warp analysis, see Table 5.

**Table 5: Minimum Reported Outputs for Phase 2**

|                                                                                                            |                         |
|------------------------------------------------------------------------------------------------------------|-------------------------|
| All Phase 1 Outputs                                                                                        | Frozen Layer vs. Time   |
| Shear Stress in Part (95 <sup>th</sup> Percentile)                                                         | Bulk Shear Rate in Gate |
| Volumetric Shrinkage                                                                                       | Sink Mark Depth         |
| Dimensioned pictorial showing manifold bore and drop diameters, drop locations, runner and gate geometries |                         |

**4.3.1.1.4 Phase 3:** Establish cooling channel layout/design. Required for Cool and Warp analysis, see Table 6.

**Table 6: Minimum Reported Outputs for Phase 3**

|                                                                                           |                             |
|-------------------------------------------------------------------------------------------|-----------------------------|
| All Phase 2 Outputs                                                                       | Circuit Reynolds Numbers    |
| Cavity/Core Mold Temperature (Identify Hot Spots)                                         | Circuit Coolant Temperature |
| Average Part Temperature                                                                  | Thermal Insert Locations    |
| Required Flow Rates                                                                       | Required Inlet Pressures    |
| Dimensioned pictorial showing all waterline diameters, baffle sizes, and insert locations |                             |

**4.3.1.1.5 Phase 4:** Establish optimum process for dimensional stability and acceptable appearance. Required for Warp analysis, see Table 7.

**Table 7: Minimum Reported Outputs for Phase 4**

|                                                                                     |                                                                                 |
|-------------------------------------------------------------------------------------|---------------------------------------------------------------------------------|
| All Phase 3 Outputs                                                                 | Anchor Plane Map (as needed)                                                    |
| Warp All Effects                                                                    | Warp in X to Axis                                                               |
| Warp in Y to Axis                                                                   | Warp in Z to Axis                                                               |
| Total Part Weight (Gate Freeze)                                                     | Top two (2) variables from Design of Experiments (DOE) simulation.              |
| X-Direction shrink determined through a query of warp in X-direction mesh           |                                                                                 |
| Y-Direction shrink determined through a query of warp in Y-direction mesh           |                                                                                 |
| <b>Initial Processing Conditions</b>                                                |                                                                                 |
| Injection Rate Profile                                                              | Pack and Hold Profile (Pressure and Time)                                       |
| Core Temperature                                                                    | Cavity Temperature                                                              |
| Melt Temperature                                                                    | Cooling Time                                                                    |
| Valve Gate Opening (Percentage or Position)                                         | Fill Time (confirmed by simulation DOE)                                         |
| Valve Gate Closing (Time)                                                           | Clamp Tonnage                                                                   |
| Filling/Packing Phase– Re-opening/closing of Sequential Valve Gates (if applicable) |                                                                                 |
| Sequential Valve Gate opening/closing speed (if applicable)                         |                                                                                 |
| <b>Analyst Recommendations</b>                                                      |                                                                                 |
| Tool Shrink Values (all directions)                                                 | Tooling Strategies (Windage, Steel Safe, Mold Inserts, Conformal Cooling, etc.) |