Definitions of simulation outputs for Shell module Filling Analysis

The simulation outputs provided by Moldex 3D for Filling/ Packing/ Cooing and Warpage Analysis in Solid module are defined as follows.

Filling/ Packing Analysis

Melt Front
Melt front advancement is a position indicator as melt front boundary movement in different time duration in the filling process. With Melt Front Time, users can check the filling dynamics of the polymer with the animation function to understand how the polymer fills in the cavity. Especially, it is very important to realize whether the cavity fills completely or not.

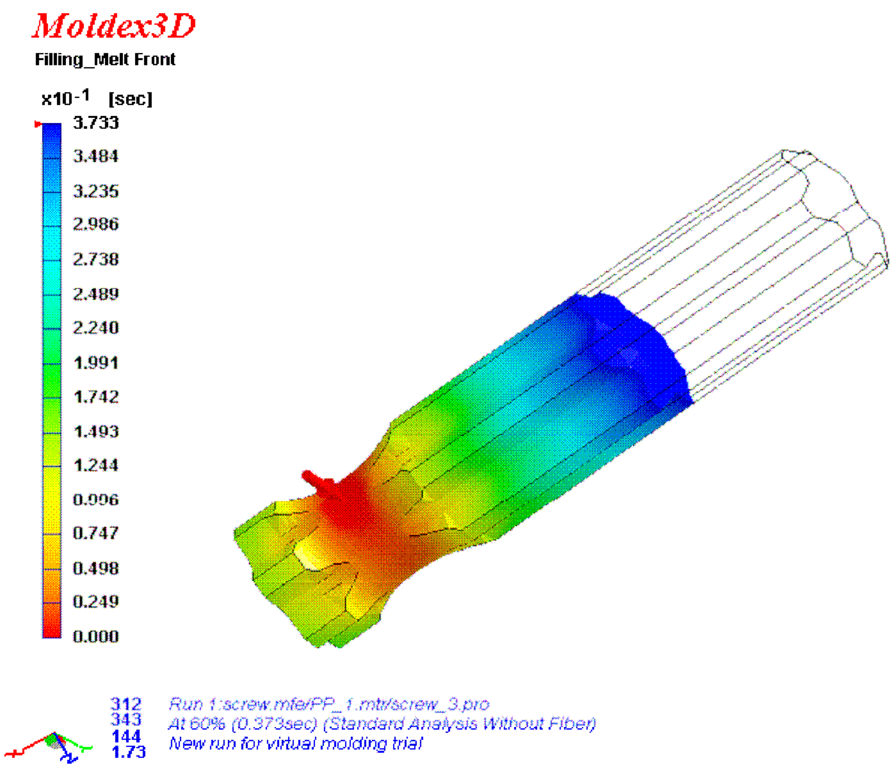

Fig 2-1. Melt Front Advancement at 60 % of Fill Time

Pressure
Pressure is defined as normal force per unit area. It shows the pressure distribution of the part cavity at the end of filling (EOF) stage. From the pressure distribution one can check the pressure transmission situation, check runner system pressure drop, and check flow balance of the design, and so on.

Temperature
It shows the temperature distribution at the end of filling. For 3D calculation, the temperature distribution expresses temperatures in all three dimensional for the full

cavity. To visualize interior parts, users can apply the Clipping function or Slicing function to examine as shown in Fig. 2-2.

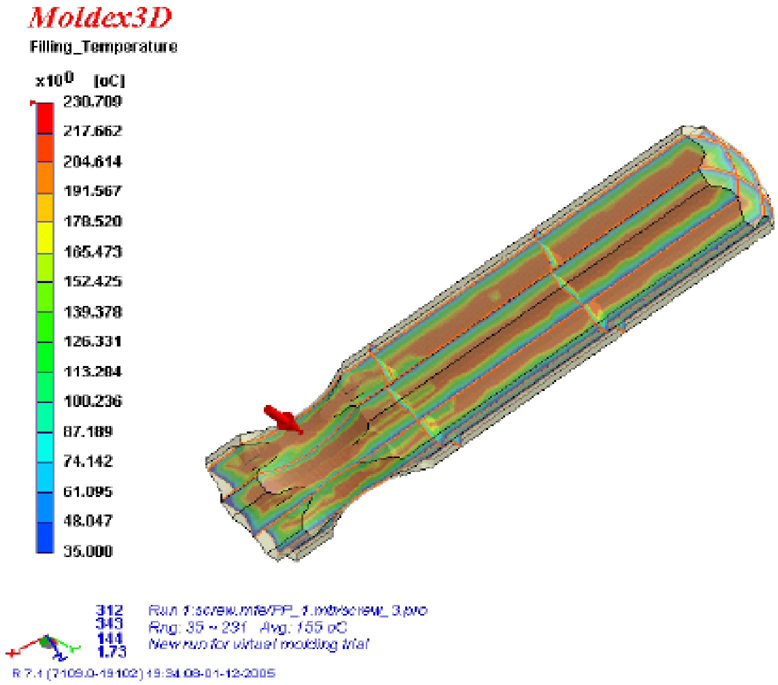

Fig 2-2. Temperature distribution at the end of filling.

Shear Stress

During the filling stage, viscous behavior of polymeric fluids will generate the shear stress. In general, the distribution can be used to predict the quality of product if it is not balanced. It will further result in warp and deformation of the finished products. In addition, when the shear stress is very high, it could force the molecular chains of polymers to be highly stretched or oriented, even broken. The recoil of highly stretched molecular chains has been proven to be the main issue in warpage. Shear stress is one source of the molded-in residual stress in molded parts. If the shear stress is not distributed evenly, it will cause some dimensional problems. If the shear stress is too high, it will result in stress-induced problems in the molded part. Normally, the shear stress should be controlled to be lower than 1 MPa.

Shear Rate

Shear rate is the rate of shear deformation of the material during polymer processing. A higher shear rate of polymer is equivalent to a higher rate of deformation, i.e. the molecular chains were drastically deformed. Therefore, shear rate distribution is related to the variation of velocity gradient and molecular orientation. Normally, high shear rate occurs at gates and thin cavities. If the shear rate is too high, (for example, > 10,000 1/sec), it could deform the molecular chains even to break and then weaken the strength of product.

X-Velocity, Y-Velocity, Z-Velocity
It shows the X-component, Y-component, or Z-component of the flow velocity of plastic melt in the cavity at EOF.

Volumetric shrinkage
Volumetric shrinkage shows the variation percentage of part volume due to the PVT characteristics of polymer materials. In general, positive value represents volume shrinkage while negative value represents volume expansion due to over-pack. Normally, the non-uniform volumetric shrinkage will lead to warpage and distortion of molded parts. Shrinkage of plastic parts is dependent upon their thermal expansion and compressible properties, i.e., the PVT relation. If the cavity volume at room temperature is Vc and the volume of plastic parts after mold ejection is V, then the volumetric shrinkage of plastic parts is defined as:

$$S_v = \frac{(V_c - V)}{V_c} = 1 - \frac{V}{V_C}$$

The specific volume of plastic parts after mold ejection follows the PVT relationship of the material. PVT relation is a strong function of temperature and pressure. The shrinkage rate is evaluated at room temperature (25 ^{o}C) and normal atmospheric pressure, based on the PVT characteristics of the material and the temperature/pressure distribution after the packing stage. The shrinkage is zero if the material has been assumed incompressible in analysis. If the density or specific volume of the polymer is the function of temperature and pressure, then volumetric shrinkage distribution can be predicted. The shrinkage rate would vary with the differential pressure and temperature at different locations inside the cavity where the polymer resides.

Cooling Time
It shows the estimated cooling time required under the given design and process conditions. This is the time estimated from cooling analysis for the computed mold cavity surface temperature and the estimated center temperature of the plastic part to be cooled enough to be ejected. This value can be used as an indicator of hot spot and cycle-time-restriction location.

Melting Core
It demonstrates the iso-surface of the ejection temperature of plastic melt at EOF. The enclosed region has the iso-surface with the temperature higher than the ejection temperature specified in the process condition.

Total Velocity
It shows the length of the velocity vector of plastic melt at EOF. It can allow users to realize how plastic melt flow near EOF.

Velocity Vector
It shows the vector plot of the velocity vector at EOF.

Cooling Analysis

Temperature
Temperature distribution of each mold cavity is shown in different colors at the instant of end of cooling stage depending on the loaded data set.

Cooling Time
This is the time estimated from EOP to the moment that molded part temperature has been cooled down to the ejection temperature. Please note that it's essential to have a reasonable Cool Time setting in process conditions to make this prediction more representative and meaningful. A few Filling-Packing-Cooling iterations help to improve the results as well.

Cycle-Avg. Heat Flux
This is the cycle-averaged heat flux of the part, i.e., the flux between the surface and cooling channel displayed in the screen during cooling phase. A higher Heat Flux indicates the better cooling efficiency.

Heat Load
This is the heat load of the part. Heat load is defined as the heat flux times the molding cycle and surface area. This value means the heat-released from the part via the part-mold interface.

Cooling Efficiency
This is the heating efficiency of the cooling channel. If Q1 is the total released heat through one cooling channel surface and Qp is the released heat of the part during molding cycle, the heating efficiency of the cooling channel is defined as Q1/Qp*100%. Positive value means cooling efficiency. Negative value represents heating efficiency.

Melting core
Melting core means that temperatures inside this region are not lower than ejected temperature. Region enclosed by the isosurface has higher temperature than ejection temperature specified in the process condition. This data can be used to check frozen layer thickness (region outside the melting core).

Warpage Analysis

Displacement
Displacement refers to the deformation of part caused by process-induced shrinkage and distortion. It is the difference between the dimensions of cavity and molded part. For the displacement in the x direction, it represents the displacement of parts along the x direction. Positive value denotes the quantity of distortion along the positive (+) x direction, while negative value is along the negative (-) x direction, which is as shown in Fig.2-3.

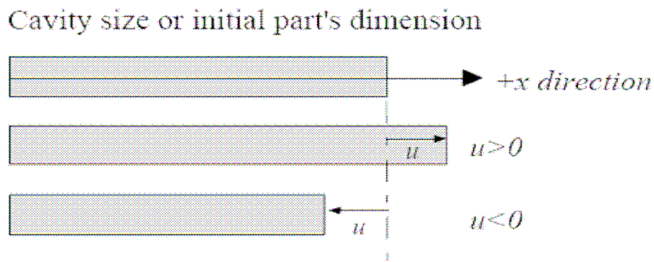

Fig 2-3 Definition for the Displacement

Displacement in y axis and displacement in z axis have the same definition as displacement in x direction. Besides, the linear shrinkage in one direction can be defined as the maximum displacement divided by the part's dimension in this direction; that is:
 Moldex3D provides several results to help users understand the causes of warpage, such as total displacement, thermal displacement and fiber orientation effect displacement.

$$\text{Max. Displacement in x direction} \approx u_{max} - u_{min}$$

$$\text{Linear shrinkage in x direction} \approx \frac{u_{max} - u_{min}}{L_x} \times 100\%$$

(X, Y, Z) Total Displacement
These displacements indicate total displacement occurring from the end of filling till the part cools down to the room temperature. It includes all factors affecting the behavior of warpage.

(X, Y, Z) Thermal Displacement
These displacements indicate the displacement that occurs from the ejection to the time the part has cooled to room temperature. Only the variation of temperature is considered.

(X, Y, Z) In-mold Constraint Effect Displacement
These displacements mean the displacement that occurs from the end of filling to the time the part is ejected. Here the mold constraint is considered.

(X, Y, Z) Fiber Orientation Effect Displacement
The fiber orientation effect deformation is defined as the difference between the following two deformations: (1) Final deformation due to all factors. (2) Deformation due to the random orientation of fiber. It presents the anisotropic effect of fiber orientation.

(X, Y, Z) Random Fiber Orientation Effect Displacement
These displacements indicate displacement that occurs from the end of filling to the time the melt has cooled to room temperature due to the fiber orientation effect.

Flatness
Flatness is the distance from selected node to reference plane. In Moldex3D, the reference plane can be defined by three ways: (1) Defined by one element; (2) Defined by three nodes; (3) Defined by plane equation.

Anisotropic Properties

The polymer without fillers mixed is assumed as isotropic material. It has isotropic material properties. On the other hand, the polymer with fillers mixed is assumed as anisotropic material. The fiber-filled polymer is one of anisotropic materials. Its anisotropic properties are depended on fiber orientation patterns. Furthermore, the anisotropic properties are obtained by integrating fiber orientation patterns and composite theory.

Moldex3D/Solid-Warp provides the distribution of stiffness modulus to help user understand the anisotropic characteristic of the part.

The major modulus means the maximum stiffness modulus.

The mean modulus means the mean stiffness modulus.

The minor modulus means the minimum stiffness modulus.

The x-axis modulus means the stiffness modulus along x-axis direction.

The y-axis modulus means the stiffness modulus along y-axis direction.

The z-axis modulus means the stiffness modulus along z-axis direction.