SRC TR 87-199

Initial Molding Condition Selection Based on Feasible Molding Space

by

I. Pandelidis and Q. Zou

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Based on Feasible Molding Space**

There are many factors that affect the quality of an injected molded part. These include mold cavity design, cooling system design and molding conditions selection. For an injection molded part, it is desirable to obtain the optimum part quality for a given cycle time. Part quality is most readily controlled by changing the molding conditions which include fill time, mold temperature, and melt temperature.

he melt temperature affects the weight of the part and the amount of residual stresses incurred to the part. When the melt temperature is increased, the pressure losses and melt viscosity decrease, subsequently the pressure drop in the runner will be reduced. Increasing the mold temperature allows slower fill times because the melted plastic will not cool below its flow temperature by the end-of-fill. Slower fill times will result in a lower shear rate as well, however more heat will be lost due to the increase in viscosity. Short fill times give higher pressure simply because the flow rate is very high. Long fill times will also increase the pressure because the plastic temperature decreases the viscosity increases.

Therefore, in order to obtain the best possible injection molded part, it is necessary to optimize the molding conditions in the cavity. This means finding the best combination of mold temperature, melt temperature, and fill time. By optimizing the molding conditions, defects such as warpage, shrinkage, sink marks, short shot and other problems found in injection molding can be eliminated.

For a given polymer being used in a given mold configuration there will be a large set of possible molding conditions. These possible molding conditions can be referred to as a "feasible molding space" which is a function of the mold temperature, melt temperature, fill time, pressure, shear stress, and temperature at the end-of-fill. Optimization of the molding conditions is then initiated from initial conditions obtained from the Feasible Molding Space.

Defining a Feasible Molding Space is the first vital step towards optimizing molding conditions in the cavity. Before optimizing molding condition, it must be decided whether or not the part is moldable.

First of all, we developed a methodology to automatically calculate the approximate maximum flow length. The maximum flow length is defined as longest disstance passed by flow during the filling. Therefore, in order to determine the maximum flow length, the flow pattern in the cavity must be known. A very simple method was used to characterized the flow in the cavity by creating a mimic flow in the mold.

For a chosen injection node, all its adjacent nodes were found. All these these nodes would be assigned a approximate fill time. Then these nodes were considered as the first flow front. Then, all of the adjacent nodes of this flow front were found and assigned another approximate fill time. this was the next flow front. This would keep going until all of nodes had its fill time.

The maximum flow length could be got by maximum flow front multiplying the disstance between fronts. The disstance between two fronts could be estimated as the average distant between the nodes. If we assume the average nodal disstance is the average disstance among injection node and its adjacent nodes, The average nodal disstance D can be define as following:

$$D=\sum_{a=1}^{m} \sqrt{X_a^2 + Y_a^2}\frac{}{m}$$

where, m is the number of nodes which are adjacent to injection node.X_a and Y_a is coordinate of the node.

Therefore, the maximum flow length can be defined maximu flow front mutilying the average nodal disstance:

$$L_f = N_f * D$$

where, N_f is the maximum number of flow front. D is the average nodal disstance.

For the multi-gated part, different flow had different flow rate. Therefor, the time interval δT_i for flow front i should be satisfied following equation:

$$\delta T_1 : \delta T_2 ..... : \delta T_n = P_1 : P_2 ..... : P_n$$

where, $\delta T_1, \delta T_2, ..., \delta T_n$ is time interval for $flow_1, flow_2, ..., flow_n$. $P_1, P_2, ..., P_n$ are the flow proportion for $flow_1, flow_2, ..., flow_n$.

In this case, according to flow balance, the fill time on the different flow fronts by the end of filling should be approximate same. In other words, the flow with different flow proportion the flow length should be different.

The quickest way is to estimate the maximal flow length and thickness of the part, and create the center gated disk model which radius equals maximal flow length with same thickness. It is well known that for a center gated disk mold with constant flow rate process, the flow, Q, can be defined as a function of the molded part thickness, the flow length, the fill time, and diameter of the runner [1].

$$\frac{Q=2*\pi*H}{\frac{t(R^2-D_r^2}{4)}}$$

where,	thickness	$2H$
	flow length	R
	fill time	t
	runner diameter	D_r

The corresponding fill presure equation is given as,

$$P_0 = \frac{3Q\mu}{8\pi H^3} \ln(1 + \frac{2Q}{\pi H D_r^2} t)$$

viscosity: μ

Because the melt plastic flow is ' non-isothermal', the fill pressure calculations required the true melt viscosity. This viscosity is a function of the melt temperature and shear rate. For example, viscosity can often be adequately characterized by a second order equations:

$$\log \mu = A_1 + A_2 \log S_r + A_3 T + A_4 \log S_r \log S_r + A_5 T \log S_r + A_6 T^2$$

μ:	viscosity
S_r:	shear rate
T:	temperature

Now the shear stress at the gate can be calculated. The dependence of the shear stress on the shear rate and viscosity is given by the equation as:

$$S_s = \mu_0 S_{r0} (S_r / S_{r0})_n$$

?

where

S_s	shear stress
S_r	shear rate

The models presented above, ignore two of the major phenomena occurring in mold filling: the maximum possible effect of viscous heat generation and heat transfer to the (usually) cold cavity surface. Those equations are not discussed here.

According to the above equations, the 'feasible molding space 'generation process is automated by several computer programs.A material data file must be created for the process, which contains the material data such as the material code, and its corresponding mold temperature, the melt temperature range,the maximum melt temperature (plastic burn temperature), and maximum allowable shear stress. The program utilizes such information as minimum mold and melt temperature, maximum mold and melt temperature to scan fill time(usually 0.20 second to 20.00 seconds). 8 boundary molding conditions can be determined by applying constraints of maximum shear stress, maximum pressure, and temperature distribution. These boundary molding conditions define the feasible molding space.

The following is the example of the program run. The material used in this sample is PA6 made by ALLIED and material code is A016. The mold temperature range is $60^0 C$ to $90^0 C$, The melt temperature range is $230^0 C$ to $280^0 C$. The maximum shear stress is $500,000$. the maximum melt temperature is $320^0 C$. The maximum flow length of the part is 200.00 mm and the thickness of the part is 6 mm.

First, $60^0 Cischosenformoldtemperature, 240^0 Cformelt.Botharemimimumtemperatures*$ $*? * *.Thefollowingresultsareobtained.$

FILL TIME	PRESSURE	SHEAR STRESS	TEMPERATURE
sec	Mpa	start	C
0.20	38.60	1239074	256
0.30	32.50	1019053	253
0.50	26.20	797505	249
0.70	22.70	679123	247
1.00	19.60	573508	244
1.50	16.80	473980	241
2.00	15.30	414622	238
2.50	14.50	374148	236
3.00	14.70	344319	234

First, let's look at the pressure to fill. At short fill time, the pressure is very high because the the plastic is flowing fast. As it slow down, the pressure drops. However, if the fill time is too long, the plastic will get too cold at the end of flow. The pressure will rise again. It is recommended not to mold a part slower than this fill time.The limitation of the maximum pressure is depended on injection machine. A maximum pressure on a injection machine is approximately about 138Mpa(20,000psi).Therefore, 100Mpa is usually used as design limit.

Then note the temperature at the end of flow. If this temperature gets too cold there will be problems at the end of flow such as bad finish, weld lines etc. For PA6 the temperature less $235^0 Cisoncoldside.Ontheotherhand, inordertoachievearesonablyuniformtemperaturedis$

A last consideration is the maximum shear stress level which may not exceed a specified level for that particular material.

2 boundary molding conditions are shown here:

mold temp.=$60^0 C$ mold temp.=60C
melt temp.=240C melt temp.=240C

Other combinations of minimum and maximum mold temperature with minimum and maximum melt temperature were chosen as following:

mold temp.=90C melt temp.=240C

FILL TIME sec	PRESSURE Mpa	SHEAR STRESS star	TEMPERATURE C
0.20	37.20	1171746	255
0.30	31.20	963713	252
0.50	25.10	754163	249
0.70	21.70	642217	247
1.00	18.70	542127	244
1.50	15.90	447799	241
2.00	14.20	391474	239
2.50	13.30	353018	237
3.00	12.70	324639	235

mold temp.=60C melt temp.=280C

FILL TIME sec	PRESSURE Mpa	SHEAR STRESS star	TEMPERATURE C
0.20	21.90	618732	288
0.30	18.20	509230	286
0.50	14.40	398832	284
0.70	12.30	339790	282
1.00	10.50	286938	279
1.50	8.80	237041	276
2.00	7.80	207181	273
2.50	7.10	186748	270
3.00	6.60	171637	268
5.00	5.40	135858	258

7.00	4.90	116785	249
10.00	4.80	99794	236

mold temp.=90C melt temp.=280C

FILL TIME sec	PRESSURE Mpa	SHEAR STRESS start	TEMPERATURE C
0.20	21.60	609834	288
0.30	17.90	501922	286
0.50	14.20	393117	284
0.70	12.20	334920	282
1.00	10.30	282817	280
1.50	8.60	233617	277
2.00	7.60	204166	274
2.50	6.90	184009	272
3.00	6.40	169097	270
5.00	5.30	133771	261
7.00	4.70	114919	253
10.00	4.30	98103	242

By the end of process, 8 boundary molding conditions are obtained.

MOLD TEMP.(C)	MELT TEMP.(C)	FILL TIME(SEC)
60.00(min)	240.00(min)	1.50(min)
60.00(min)	240.00(min)	2.50(max)
90.00(max)	240.00(min)	1.50(min)
90.00(max)	240.00(min)	3.00(max)
60.00(min)	280.00(max)	0.50(min)
60.00(min)	280.00(max)	3.00(max)
90.00(max)	280.00(max)	0.50(min)
90.00(max)	280.00(max)	5.00(max)

These 8 boundary molding conditions define 6 half spaces which determine a feasible molding space. The equation of fill time with mold temperature and melt temperature is approximately considered linear. One is about the maximum fill time and another is about the minimum fill time. The mold temperature is independent on melt temperature and fill time has no relation with mold temperature and melt temperature range. Therefore, the feasible molding space is like this:

$$T^{Min}_{mold} <= T_{mold} <= T^{Min}_{mold}$$
$$T^{Max}_{melt} <= T_{melt} <= T^{Max}_{melt}$$
$$f_1(T_{mold}, T_{melt}) <= Time^{min}_{fill}$$
$$f_2(T_{mold}, T_{melt}) >= Time^{max}_{fill}$$

The initial molding condition is the center of feasible molding space.

$$\frac{T^i_{mold} = T^{min}_{mold} + T^{max}_{mold}}{2}$$
$$\frac{T^i_{melt} = T^{min}_{melt} + T^{max}_{melt}}{2}$$
$$\frac{time^i_{fill} = f_1(T^i_{mold}, T^i_{melt}) + f_2(T^i_{mold}, T^i_{melt}}{2}$$

Conclusion

Using center gated disk model whose radius equals the maximum flow length of the part, the program can quickly define a feasible molding space for a part. This feasible molding space can not only be used to determine an initial molding condition , but also for post processing use. For example, this feasible molding space is the main constraints in the optimization process of molding condition. A well defined feasible can save a lot of computing time for the optimization process.

References:

[1] Fundamentals of Polymer Processing, *Stanley Midddleman*,1977 MaGraw Hill,Inc

[2] Injection Molding Handbook,

[3] Moldflow,*Colin Austin*

[4] Analysis of Melt Flow in Polymer Processing using Finite Elements, *Kalipada Palit*