CASE 43

Optimization of Molding Conditions of Thick-Walled Products

Abstract: In an injection molding process, products of a thickness over 5 mm are called thick-walled products. Many of these products have problems such as sink, void, or abnormal shrinkage. To avoid such defects, molding time and cooling time have to be extended, resulting in a long overall molding cycle time. To improve the process, the generic function was considered where material must be filled uniformly to any spot inside the mold. After optimization, the molding cycle time was reduced and the quality loss was cut to one-third.

1. Introduction

Traditionally, the generic function of injection molding has been considered transformability to a mold or the capability of molding a product proportional to the mold shape. However, the resin caster discussed in this study is required to have sufficient strength because it is used as a cart carrying baggage. In addition, since internal voids occur quite often because the caster has a considerably thick wall, instead of the concept of transformability we selected as a generic function even filling of the inside of a mold with resin, that is, uniformity of density (specific gravity).

As a measuring method for analyzing density uniformity, we used a specific gravity measurement based on an underwater weighing method. A molded product was cut in five pieces (Figure 1). We chose in-the-air weight as a signal factor, *M*, and underwater weight as the output, *y*.

More specifically, splitting up a molded product and measuring both in-the-air weight (*M*) and underwater weight (*y*), we set the data to an ideal relationship equation (Figure 2).

The mixing ratio of recycled material was used as a noise factor. It affects the fluidity of resin material. At level 1 the mixing ratio is 1, and at level 2 it is 50. The control factors are listed in Table 1.

2. SN Ratio

The measured data are listed in Table 2. The data analysis procedure was as follows.

Total variation:

$$S_T = 19.1^2 + 22.3^2 + \cdots + 82.8^2 + 176.6^2$$

$$= 82{,}758.13 \qquad (f = 10) \tag{1}$$

Effective divider:

$$r_1 = 22.2^2 + 25.1^2 + \cdots + 202.8^2 = 54{,}151.02$$

$$r_2 = 23.3^2 + 26.0^2 + \cdots + 200.9^2 = 52{,}852.51 \tag{2}$$

Linear equations:

$$L_1 = (22.2)(19.1) + \cdots + (202.8)(178.5)$$

$$= 47{,}668.88$$

$$L_2 = (23.3)(20.2) + \cdots + (200.9)(176.6)$$

$$= 46{,}434.04 \tag{3}$$

Taguchi's Quality Engineering Handbook. Genichi Taguchi, Subir Chowdhury and Yuin Wu

Variation of proportional term:

$$S_\beta = \frac{(L_1 + L_2)^2}{r_1 + r_2} = 82{,}757.64 \qquad (f = 1) \tag{4}$$

Variation of proportional terms due to noise:

$$S_{N\beta} = \frac{L_1^2}{r_1} + \frac{L_2^2}{r_2} - S_\beta = \frac{47{,}668.88^2}{5451.02} + \frac{46{,}434.04^2}{52{,}852.51} - 82{,}757.64 = 0.08 \qquad (f = 1) \tag{5}$$

Error variation:

$$S_e = S_T - S_\beta - S_{\beta N} = 82{,}758.13 - 82{,}757.64 - 0.08 = 0.41 \qquad (f = 8) \tag{6}$$

Error variance:

$$V_e = \frac{S_e}{8} = \frac{0.41}{8} = 0.05 \tag{7}$$

Total error variance after pooling:

$$V_N = \frac{S_e + S_{\beta N}}{n - 1} = \frac{0.41 + 0.08}{9} = 0.05 \tag{8}$$

SN ratio:

$$\eta = 10 \log \frac{[1/(r_1 + r_2)](S_\beta - V_e)}{V_N} = 11.89 \text{ dB} \tag{9}$$

Sensitivity:

$$S = 10 \log \frac{1}{r_1 + r_2} (S_\beta - V_e) = -1.11 \text{ dB} \tag{10}$$

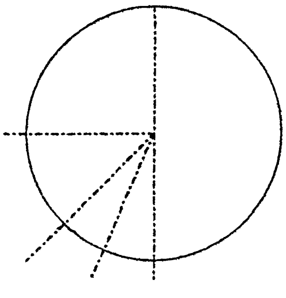

Figure 1
Division of thick-walled molded product

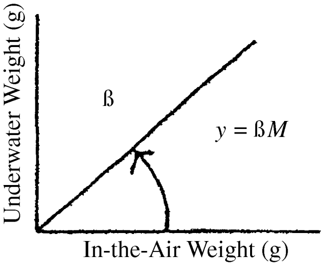

Figure 2
Ideal relationship

3. Optimal Condition and Confirmatory Experiment

The injection molding conditions were listed as control factors (Table 3). Figure 3 shows the shape of molded product. Nylon plastic was used as the resin material. Control factors were assigned to an L_{18} orthogonal array and the noise factor to the outer array. Eighteen experiments were conducted twice.

Due to poor setup conditions in experiments 1, 4, 11, and 17, the resin was not fully charged in the mold, so no products were obtained from the mold. Because of no data available, these conditions were treated as incomplete data. Analyses were made using the following two methods:

1. Find the worst SN ratio from experiment 1 to experiment 18; experiment 8 is the worst (−6.5). Double the value (−13). Put this value into experiments 1, 4, 11, and 17 to calculate the averages.
2. Ignore the missing values to calculate level averages. For example, the average of A_1 is calculated as A_1 = (total of experiments 1 to 9 except experiments 1 and 4) ÷ 7.

Based on these analyses, we created the response graphs in Figure 4.

The optimal configuration is estimated as follows:

1. Select levels with less missing data for each factor.
2. If the numbers of missing data are the same, select the level with a high SN ratio for the

Table 1
Control factors and levels

	Level		
Control Factor	**1**	**2**	**3**
A: injection pressure (%)	Low	High	—
B: resin temperature (°C)	Low	Mid	High
C: mold temperature (°C)	$B - 200$	$B - 190$	$B - 180$
D: injection speed V_1 (%)	Low	Mid	High
E: injection speed V_2 (%)	$<D$	D	$<D$
F: injection speed V_3 (%)	E	$<F_1$	$<F_2$
G: condition holding pressure (%) × time (s)	Low × long	Mid × mid	High × short
H: cooling time (s)	Short	Mid	High

Table 2
Example of measured data

Noise Factor [Mixing Ratio of Recycled Material (wt %)]	Signal Factor (M) and Output (y) (g)					
0	M	22.2	25.1	50.3	96.8	202.8
	y	19.1	22.3	44.3	85.3	178.5
50	M	23.3	26.0	48.4	94.5	200.9
	y	20.2	23.0	42.6	82.8	176.6

Table 3
Estimation and confirmation (dB)

	SN Ratio		Sensitivity	
	Estimation	**Confirmation**	**Estimation**	**Confirmation**
Optimal configuration 1	20.1662	14.2205	−1.0344	−1.1160
Optimal configuration 2	—	14.5307	—	−1.1170
Comparison	6.4157	9.8173	−1.1193	−1.0925
Gain 1	13.7505	4.4032	0.0850	−0.0235
Gain 2	—	4.7134	—	−0.0245

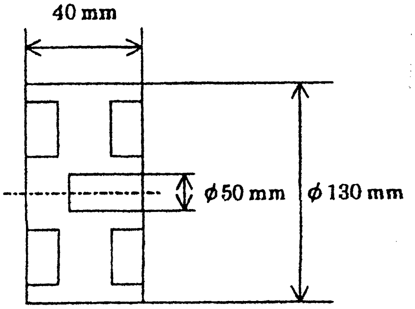

Figure 3
Shape of molded product

case when factor effects are estimated ignoring missing data.

Based on this procedure, we chose the following optimal configuration: $A_2B_2C_3D_2E_3F_3G_2H_2$. Under this configuration, the SN ratio is estimated as

$$\eta = 20.1662 \text{ dB}$$

Next, for the current configuration, $A_1B_2C_2D_1E_2F_3G_2H_2$, we calculated the SN ratio as

$$\eta = 6.4157 \text{ dB}$$

Then the improvements in gain under the optimal configuration were computed as:

$$\text{gain in SN ratio for the current configuration} = 20.1662 - 6.4157 = 13.7505 \text{ dB}$$

Although we conducted a confirmatory experiment under the optimal configuration estimated above, assuming that a significant reduction of molding time cannot be expected and the level range of cooling time, *H*, is set up too wide, for factors *A* to *G*, we defined the experimental results themselves as optimal levels. For factor *H*, we regarded an intermediate value between levels 1 and 2 (10 minutes less than the current cooling time) for another optimal calculation. This table reveals that we obtained fairly good reproducibility. Additionally, since optimal configuration 2, which was added to shorten molding time (or to reduce molding cost), has a higher SN ratio by 0.3 dB than the estimated optimal configuration 1 does, we concluded that it is possible to shorten the molding time under optimal configuration 2.

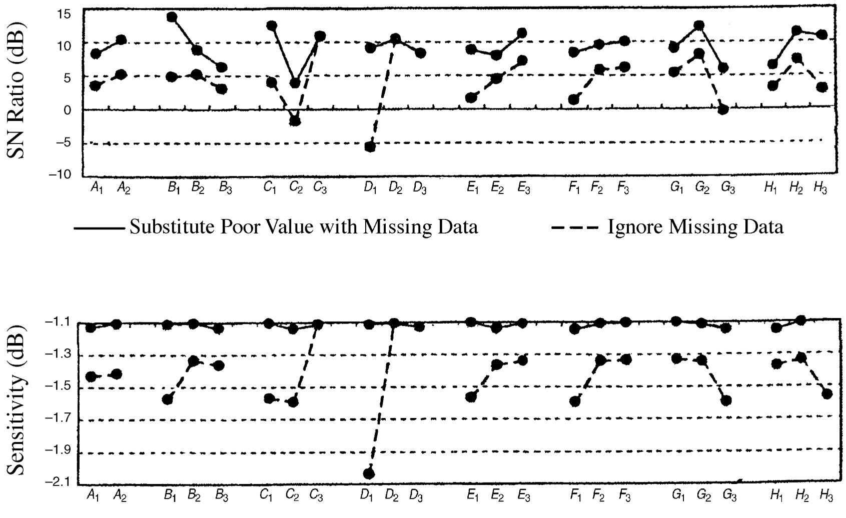

Figure 4
Response graphs

4. Economic Effect of Improvement

Now we computed a loss according to the effects obtained from this experiment.

$$\text{loss function, } L = \frac{A}{\Delta^2\sigma^2}$$

where A (loss when a defective product is produced) is assumed to be 400 yen/unit, Δ (tolerance in the process) is assumed to be 0.1, and σ (variance) is computed by the result of the confirmatory experiment. That is, converting $\eta = \beta^2/\sigma^2$, we obtain $\sigma^2 = \beta^2/\eta$.

The loss function for the case of the reference configuration is

$$L_1 = \frac{400}{1^2}\,(0.081) = 3244 \text{ yen/unit}$$

In contrast, the loss function for the optimal configuration is

$$L_2 = \frac{400}{1^2}\,(0.0272) = 1088 \text{ yen/unit}$$

Therefore, we can reduce the loss by two-thirds.

On the other hand, considering that the molding time is reduced by 10 s/unit, by multiplying this by the unit cost, we can estimate the monetary benefit as

$$\text{benefit by shortened time} = 10 \text{ yen/unit}$$

where 10/3600 is the shortened time (hours) and 3600 is the hourly molding cost (yen/hour). As a result, a 10-yen cost reduction in molding for each product is expected.

Converting this monetary benefit into a yearly amount, we obtain the following benefit due to the loss reduction in reference to our monthly production volume of 1000 units or annual production volume of 12,000 units:

$$(3244 - 1088)(12{,}000) = 25{,}872{,}000 \text{ yen/year}$$

At the same time, the monetary benefit due to the shortened molding time is

$$(10)(12{,}000) = 120{,}000 \text{ yen/year}$$

In the end, we can anticipate 25,992,000 yen/year.

Reference

Shinji Hanada, Takayoshi Matsunaga, Hirokazu Sakou, and Yoshihisa Takano, 1999. Optimization of molding condition for thick walled mold. *Quality Engineering*, Vol. 7, No. 6, pp. 56–62.

This case study is contributed by Shinji Hanada, Takayoshi Matsunaga, Hirokazu Sakou, and Yoshihisa Takano.