**AMM019**

# Taguchi Method: The Solution to Excessive Warpage and Shrinkage of Injection Molded Automotive Parts

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## *Abstract*

Polypropylene is widely used for producing automotive parts with the injection molding. Many studies showed that the excessive warpage and shrinkage, commonly found in these parts, are resulted mainly from the mold surface temperature differentiation and non-uniform melt pressure distribution during the injection molding leading to mismatch or difficulties when those parts are to be assembled with their counterparts. To cope with the excessive warpage and shrinkage of the molded parts, Taguchi method was applied to design the possible molding conditions in order to identify the most influencing factors responsible for these problems. In addition, the best combination of the process parameters was analyzed by means of the regression analysis. In this study, PP TBJHHMNR NH-1 grade was used for producing the automotive part. The parameters including the injection speed, packing pressure, mold temperature, and cooling time were varied systematically using Taguchi's orthogonal array table. It was found that the major process parameters responsible for the excessive shrinkage and hence warpage were the mold temperature and cooling time, respectively. Surprisingly, it was revealed that the injection molding parameters had little to no effect on the tensile and flexural strength of the tested parts. Validation of the best combination of the process parameters can be suggested by the regression analysis.

***Keywords****:* Injection molding process, Taguchi method, Warpage, Shrinkage

## 1. Introduction

Thailand is one of the biggest centers of automotive parts manufacturing industry in South East Asia. In recent years, instead of using metal, the manufactures have been focusing on replacing metal by polymeric materials due to the demand of better mechanical performance, thinner, lighter, smaller, high production rates and minimal waste. The plastic injection molding process plays an important role and is most widely used for producing parts from thermoplastic and thermosetting plastics.

Frequently, plastic injection molders face with the problems such as part warpage, sink mark weld line, flow mark, and low quality surface. These defects are normally found in the parts with complex geometries and not only affect the part surface appearance but also the internal structure or strength of the product. With these problems, the secondary operations such as painting or manual finishing are applied for blending the surface defects. All this will increase the production time and cost. [1-8]

In conventional injection molding (CIM), a continuous cooling method by circulating the constant-temperature medium in cooling channels is used to control the mold temperature. In this way, a high mold temperature will result in a long cooling time and low productivity. Therefore, the production efficiency is restricted by the mold temperature of CIM. A high mold temperature is usually not recommended for CIM from the economic viewpoint. In order to produce the thin part, increasing the injection pressure or selecting the low viscosity plastic material is usually used in the conventional injection molding. Although high injection pressure can increase the melt flow rate, it will cause high residual stress, warpage and low product properties. These defects must be covered up by secondary processes, such as sanding and painting operations which are not only dangerous to human's health and the environment, but also increase the whole production cycle time and costs of production. [9]

In the aspect of sink mark, Erzurumlu and Ozcelik [10] tried to minimize the sink mark for different plastics by combining Taguchi design of experiments (DOE) and numerical simulations. The results demonstrated that the rib design and processing parameters have significant influences on sink marks. Using the similar method, Shen et al. [11] investigated the effects of processing variables and cavity geometry on sink marks. The results showed that the most significant factor is the part thickness followed by the holding pressure, melt temperature and mold temperature, respectively. In the aspect of warpage, most of the researchers were focusing on minimizing it via optimizing the processing conditions. Taguchi DOE is a very simple and effective method to evaluate the effects of processing variables on warpage and find out the optimal processing condition.

This research work is aiming to increase the efficiency of injection molding and improve the quality of motorcycle parts by means of the Taguchi method. This method will not only help to find out the most influencing parameters controlling the part warpage and shrinkage but also to enhance the overall efficiency of injection molding process.

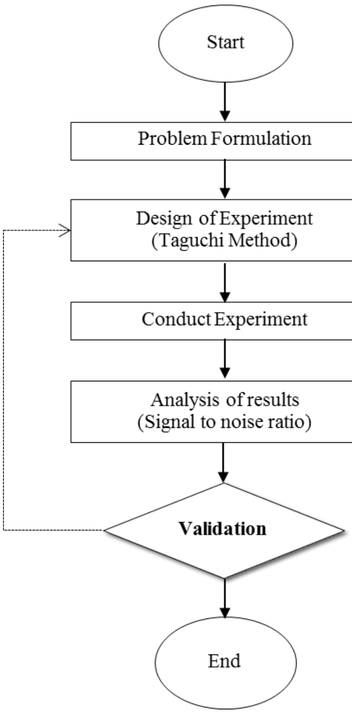


Fig. 1 Design of Experiment flow chart

## 2. Experimental

### *2.1 Material*

Polypropylene (PP TBJHHMNR NH-1) from Grand Siam Composites co., ltd. was used in this investigation. The properties of PP compounds are shown in Table. 1

Table. 1 The properties of PP TBJHHMNR NH-1

| Properties | Value | ASTM |
|---|---|---|
| Tensile strength (Mpa) | 27.39 ± 0.1 | D638 |
| Tensile Modulus (Mpa) | 1406.08 ± 7.12 | D638 |
| Izod Impact strength (J/m) | 10905.19 ± 159.09 | D256 |
| Flexural Strength | 30.78 ± 0.54 | D790 |
| Flexural Modulus | 831.20 ± 19.06 | D790 |
| Heat Distortion Temperature (°C) | 54.2 ± 0.73 | D648 |
| MFI (g/10 min) at 210 °C | 7.84 | D1238 |
| MVR ($cm^3$/10 min) at 210 °C | 9.11 | D1238 |
| Melt Density (g/$cm^3$) at 210 °C | 0.86 | D1238 |

### *2.2 Injection Molding Machine*

The motorcycle part, Base License Light K60F, was produced by using injection molding machine (TOSHIBA, EC100S-3A) and mold temperature controller (Com eMore Type: VTM-040 Series: 98085)

### *2.3 Design of Experiment*

Injection molding experiments according to 3-level L9 Taguchi method were designed using four process parameters; mold temperature, melt temperature, packing pressure and cooling time as shown in Table 2-3.

Table. 2 Taguchi's 3-level L9 orthogonal Array

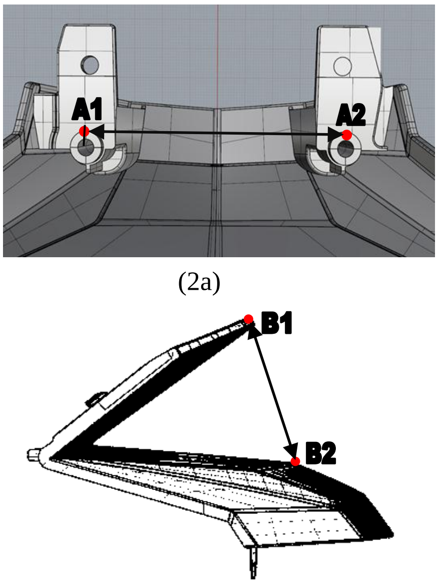
| Experiment No. | $T_{mold}$ (°C) | $T_{melt}$ (°C) | $P_{pack}$ (Mpa) | $Cooling_{time}$ (s) |
|---|---|---|---|---|
| 1 | 32 | 200 | 35 | 8 |
| 2 | 32 | 210 | 40 | 10 |
| 3 | 32 | 220 | 45 | 12 |
| 4 | 36 | 200 | 40 | 12 |
| 5 | 36 | 210 | 45 | 8 |
| 6 | 36 | 220 | 35 | 10 |
| 7 | 40 | 200 | 45 | 10 |
| 8 | 40 | 210 | 35 | 12 |
| 9 | 40 | 220 | 40 | 8 |

Table. 3 Four selected factors and three levels

| Factor | Level 1 (Low) | Level 2 (Medium) | Level 3 (High) |
|---|---|---|---|
| Mold temperature (°C) | 32 | 36 | 40 |
| Melt temperature (°C) | 200 | 210 | 220 |
| Packing Pressure (Mpa) | 35 | 40 | 45 |
| Cooling time (s) | 8 | 10 | 12 |

### *2.4 Measurement of Shrinkage and Displacement*

The post Shrinkage and displacement between the points A1-A2 and B1-B2 (Fig. 2) were measured after the part has been injection molded and stored in a cool and dry place for 48 hours using a digital venial caliper and Profile Projector (PH-3500) with ZDPak II software measurement, respectively.



(2a)

(2b)

Fig. 2 The measurement points between A1-A2 (2a) and the measurement points between B1-B2 (2b)

### *2.5 Mechanical Testing*

Base License Light parts were cut into tensile specimen (according to ASTM D638 Type V) by laser cut machine. The test was conducted using the Universal Testing Machine INSTRON 55R4502 with the load of 10 kN ± 0.1%, at the cross head speed of 10 mm/min and grip distant of 25.4 mm (Extensometer, Dynamic 2620-601 S/N 204208 at 24 °C, 50% humidity).

The parts were also laser cut into specimens as shown in Fig. 3b for three-point bending testing (according to ASTM D790). Specimens measure 5 mm x 30 mm x 2 mm. The test was performed using the Universal Testing Machine INSTRON 55R4502, with the cross head speed of 0.33 mm/min, support span of 20 mm at 24 °C and 49% humidity.


(3a) (3b)

Fig. 3 Tensile specimen Type V (3a) And Flexural specimen (3b)

## 3. Results and discussion

### *3.1 Shrinkage and Displacement analysis*

For the determination of S/N ratio, the smaller the better equation (1) were suitable for analyzing the degree of shrinkage and displacement.

$$\text{S/N ratio} = -10\,\text{Log10}\,(1/n\sum (Y_{ideal} - Y_{i})^{2}) \quad (1)$$

Table. 5 displays the calculated S/N ratios of shrinkage and displacement between A1-A2 and B1-B2.

Where,

S/N ratio = Signal to noise ratio,
n = The number of experiment
$Y_i$ = Response value in a given experiment
$Y_{ideal}$ = The desired standard value

Table. 5 The experimental results of shrinkage and displacement between A1-A2 and B1-B2

| Exp No. | Average Displacement A1-A2 (mm) | S/N ratio | Average Displacement B1-B2 (mm) | S/N ratio |
|---|---|---|---|---|
| 1 | 65.02 | 0.14 | 56.84 | -18.24 |
| 2 | 65.03 | 0.25 | 57.33 | -17.70 |
| 3 | 65.03 | 0.30 | 56.72 | -18.36 |
| 4 | 64.89 | -0.91 | 56.93 | -18.14 |
| 5 | 64.98 | -0.16 | 55.69 | -19.38 |
| 6 | 64.84 | -1.26 | 56.17 | -18.92 |
| 7 | 65.01 | 0.07 | 56.84 | -18.24 |
| 8 | 64.91 | -0.78 | 56.91 | -18.16 |
| 9 | 64.87 | -1.09 | 55.64 | -19.43 |

Table. 6 The regression coefficients of the displacement between point A1-A2

| Parameters<br>Regression output | | Mold temperature | Melt temperature | Packing Pressure | Cooling time |
|---|---|---|---|---|---|
| coefficient | Level 1 | 1.003 | -0.003 | -0.049 | -0.054 |
| | Level 2 | 0.000 | 0.000 | 0.000 | 0.000 |
| | Level 3 | 0.172 | -0.455 | 0.656 | -0.147 |
| | Difference | **1.003** | 0.455 | 0.705 | 0.147 |

Table. 7 The regression coefficients of the displacement between point B1-B2

| Parameters<br>Regression output | | Mold temperature | Melt temperature | Packing Pressure | Cooling time |
|---|---|---|---|---|---|
| coefficient | Level 1 | 0.711 | 0.209 | -0.020 | -0.729 |
| | Level 2 | 0.000 | 0.000 | 0.000 | 0.000 |
| | Level 3 | 0.202 | -0.490 | -0.236 | 0.065 |
| | Difference | 0.711 | 0.698 | 0.236 | **0.794** |

Table. 6-7 show the regression coefficient of the displacement between points A1-A2 and B1-B2, respectively. The regression coefficient is a constant value that represents the changing rate of one variable.

For each parameter, the difference between the maximum and minimum value of the coefficients (Fig. 4) indicates the importance or weighting of each parameter on the interested property. The higher the differences, the more important it is of that parameter on the interested property.

From Fig. 4 it can be concluded that the mold temperature is the most influencing parameter on the shrinkage and displacement between positions A1-A2 whereas the cooling time is the most affecting parameter to the shrinkage and displacement between positions B1-B2.

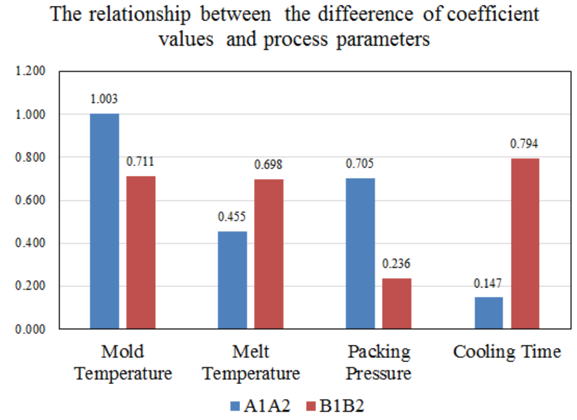


Fig. 4 The relationship between the difference of coefficient values and process parameters

In addition, the best parameter combination for acquiring the optimum process condition and hence part quality could be obtained from the regression analysis. From the regression analysis the best parameter combination for producing parts with the least shrinkage and displacement between the points

A1-A2 and B1-B2 can be summarized as listed in Table 8-9.

Table 8. The best parameter combination for producing parts the least shrinkage and displacement between A1-A2

| **Best Combination Parameter at A1-A2** | | | | |
|---|---|---|---|---|
| Condition Parameter | Optimum Parameter | | Parameter Value | Unit |
| Mold Temp. | Low | 1 | 32 | °C |
| Melt Temp. | Medium | 2 | 210 | °C |
| Packing Pressure | High | 3 | 45 | MPa |
| Cooling Time | Medium | 2 | 10 | sec |

Table 9. The best parameter combination for producing parts with the least shrinkage and displacement between B1-B2

| **Best Combination Parameter at B1-B2** | | | | |
|---|---|---|---|---|
| Condition Parameter | Optimum Parameter | | Parameter Value | Unit |
| Mold Temp. | Low | 1 | 32 | °C |
| Melt Temp. | Low | 1 | 200 | °C |
| Packing Pressure | Medium | 2 | 40 | MPa |
| Cooling Time | High | 3 | 12 | sec |

### *3.2 Mechanical Properties*

Tensile and flexural properties of the tested parts are exhibited in Fig. 5-6. It was observed that experiment number 4 showed the best tensile properties (Fig.5) whereas experiment number 5 and 6 (Fig.6) provided the highest flexural strength and flexural modulus, respectively.

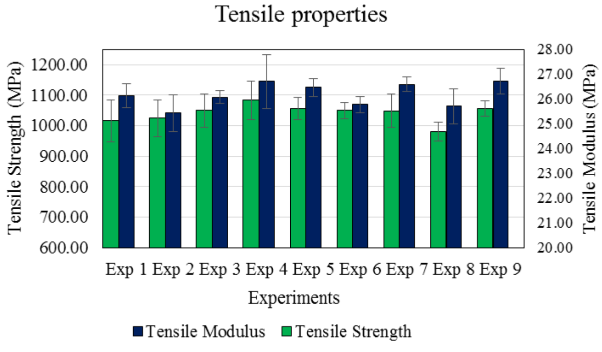


Fig. 5 Tensile properties results

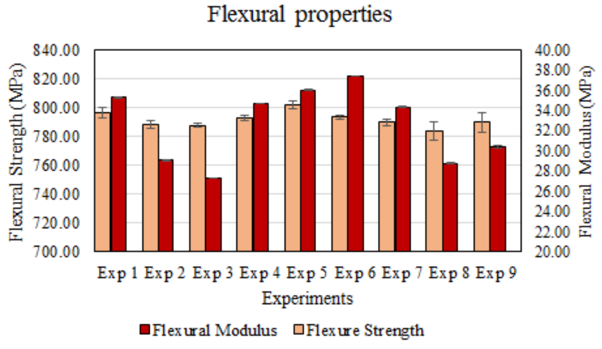


Fig. 6 Flexural properties results

Table. 10 The mechanical properties from experiment

| Exp. | Tensile Strength (MPa) | Tensile Modulus (MPa) | Flexure Strength (MPa) | Flexural Modulus (MPa) |
|---|---|---|---|---|
| 1 | 25.11 | 1098.40 | 33.75 | 806.78 |
| 2 | 25.22 | 1041.02 | 32.60 | 763.47 |
| 3 | 25.53 | 1093.13 | 32.48 | 750.63 |
| 4 | 25.95 | 1144.69 | 33.21 | 802.58 |
| 5 | 25.61 | 1124.75 | 34.54 | 812.01 |
| 6 | 25.53 | 1068.99 | 33.31 | 821.70 |
| 7 | 25.51 | 1135.66 | 32.78 | 800.17 |
| 8 | 24.68 | 1063.11 | 31.92 | 761.32 |
| 9 | 25.61 | 1145.68 | 32.77 | 772.52 |

Table. 11 The tensile and flexural strength and S/N ratio

| Exp. | Tensile Strength (MPa) | S/N ratio | Flexure Strength (MPa) | S/N ratio |
|---|---|---|---|---|
| 1 | 25.11 | 27.99 | 33.75 | 30.56 |
| 2 | 25.22 | 28.03 | 32.60 | 30.26 |
| 3 | 25.53 | 28.13 | 32.48 | 30.23 |
| 4 | 25.95 | 28.27 | 33.21 | 30.42 |
| 5 | 25.61 | 28.17 | 34.54 | 30.77 |
| 6 | 25.53 | 28.14 | 33.31 | 30.45 |
| 7 | 25.51 | 28.13 | 32.78 | 30.30 |
| 8 | 24.68 | 27.84 | 31.92 | 30.07 |
| 9 | 25.61 | 28.17 | 32.77 | 30.31 |

The regression analysis was performed based of the greater the better equation as shown in Equation (2).

The greater, the better equation;

$$S/N\ ratio = -10\ Log10\ (1/n\sum 1/Y_i^2) \qquad (2)$$

Where,

S/N ratio = Signal to noise ratio,
n = the number of experiment
$Y_i$ = Response value in a given experiment

The S/N ration from equation (2) was interpreted into the regression coefficient of tensile strength and flexural strength as shown in Table. 12-13

Table. 12 The regression coefficients of tensile strength

| Parameters<br>Regression output | | Mold temperature | Melt temperature | Packing Pressure | Cooling time |
|---|---|---|---|---|---|
| coefficient | Level 1 | -0.144 | 0.117 | -0.166 | 0.008 |
| | Level 2 | 0.000 | 0.000 | 0.000 | 0.000 |
| | Level 3 | -0.147 | 0.135 | -0.014 | -0.015 |
| | Difference | 0.147 | 0.135 | **0.166** | 0.022 |

Table. 13 The regression coefficients of flexural strength

| Parameters<br>Regression output | | Mold temperature | Melt temperature | Packing Pressure | Cooling time |
|---|---|---|---|---|---|
| coefficient | Level 1 | -0.194 | 0.063 | 0.030 | 0.208 |
| | Level 2 | 0.000 | 0.000 | 0.000 | 0.000 |
| | Level 3 | -0.318 | -0.037 | 0.101 | -0.096 |
| | Difference | **0.318** | 0.100 | 0.101 | 0.304 |

Table 14. The best parameter combination for tensile strength

| **Best Combination Parameters for tensile strength** | | | | |
|---|---|---|---|---|
| Condition Parameter | Optimum Parameter | | Parameter Value | Unit |
| Mold Temp. | Middle | 2 | 36 | °C |
| Melt Temp. | High | 3 | 220 | °C |
| Packing Pressure | Middle | 2 | 40 | MPa |
| Cooling Time | Low | 1 | 8 | sec |

Table 15. The best parameter combination for flexural strength

| **Best Combination Parameter for flexural strength** | | | | |
|---|---|---|---|---|
| Condition Parameter | Optimum Parameter | | Parameter Value | Unit |
| Mold Temp. | Middle | 2 | 36 | °C |
| Melt Temp. | Low | 1 | 200 | °C |
| Packing Pressure | High | 3 | 45 | MPa |
| Cooling Time | Low | 1 | 8 | sec |

Table 12-13 summarize the optimum process condition for tensile and flexural strength, respectively.

## 4. Conclusion

Taguchi method played an important role on minimizing the trial numbers in the actual injection molding process. Furthermore, it could be used to investigate the optimum parameters in injection molding that are responsible for the excessive shrinkage and warpage of the molded parts. It was found that in order to produce parts having reduced shrinkage and displacement between the points A1-A2 and B1-B2, the following parameters should be used: the mold temperature, melt temperature, packing pressure, and cooling time at (32°C, 210°C, 45 MPa, 10 s), (32°C, 200°C, 40 MPa, 12 s), respectively. Moreover, the packing pressure is the most influential factors to the shrinkage and displacement between positions A1-A2 whereas cooling time is significantly effects on the displacement between positions B1-B2.

## 5. Acknowledgement

The author would like to thank the NUI-RC Scholarship Program for the financial support, National Metal and Materials Technology Center (MTEC, a member of NSTDA, Thailand) for supporting the experimental laboratory equipment, and Century Plastic co., ltd for supplying PP TBJHHMNR NH-1 resins and providing injection molding machine throughout the study.

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