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# A Study on the Process Optimization of Microcellular Foaming Injection Molded Ceiling Air-Conditioner 4-Way Panel

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# 초미세발포 사출성형을 이용한 천정형 에어컨 4-way 판넬의 공정 최적화에 관한 연구

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## ABSTRACT

Deflected 4-way panels of ceiling air conditioners produced by injection molding process have caused dew condensation at the edge of products. In order to prevent this drawback with reducing weight and deformation, this study proposed renovated process adopting microcellular foaming. According to results from 2-sample t-test and analysis of variance(ANOVA), the critical factors affecting weight were melt temperature and injection speed. In addition, the vital effects on deformation were structure at the edge, mold temperature and cooling time. Optimal conditions of these parameters were derived by regressive analysis with CAE and response surface method(RSM), and then applied to an actual design and process stage to analyze performance. As a results, it clearly showed that new process improved process capability as well as reduced both weight and deformation by 18.8% and 71.9% respectively compared to the conventional method.

**Key Words :** Ceiling Air-conditioner(천정형 에어컨), Deformation(변형), Dew Condensation(결로현상), Microcellular Foaming(초미세발포), Process Optimization(공정 최적화)

## 1. Introduction

Plastic injection molding has been widely used in various industries since it is useful to produce complex shaped products based on advantages such as excellent productivity and mechanical properties, high-quality surface state, and light weigh[1,2]. More recently, as injection molding application fields have diversified and the technical levels required in industries have increased, various injection molding technologies have been developed. Among them, much attention has been paid to microcellular foaming molding technology.

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Microcellular foaming employs chemical foaming agents that generate N2 or CO2 gas during thermal decomposition to create fine cells inside the injection-molded parts. A large number of studies have been conducted on microcellular foaming, since it can reduce raw materials in proportion to the volume of foamed fine cells and improve sound proofing and insulation[3~5].

This study applied microcellular foaming to the 4-way panel production process used in ceiling-type air-conditioners, thereby finding the process conditions that simplified the complex processes and reduced the high investment cost, as well as achieving light-weight product and minimizing deformation. The current process capability regarding product weight and deformation produced with existing injection molding was analyzed, and the influencing factors were selected on that basis. To evaluate the degree of influence of the factors, analysis on the possible factors was conducted using two-sample t-tests and analysis of variance (ANOVA). In addition, regression analysis method and reaction surface method (RSM) were used to derive the optimized conditions.

# 2. Experiment method and conditions

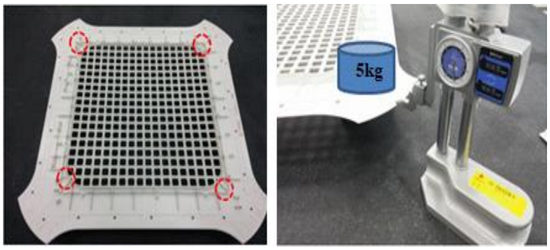
## 2.1 Experimental target

The experimental analysis target was the air suction unit in the ceiling-type air-conditioner shown in Fig. 1. In the injection molding process, which was the existing production method, high-impact polystyrene resin was used. However, this study employed polypropylene (PP), considering the economic feasibility, in the microcellular foaming molding process used in this study. The product dimensions were 800 x 800 mm. The cooling was discharged and distributed by the air guide installed along the edges in the air suction unit in four directions. An insulator was installed between the air guide and air suction unit.

## 2.2 Analysis and diagnosis of process state

When deflection occurs due to deformation in the air suction unit, condensation occurs due to clearance of the insulator installed between the air guide and air suction unit. Thus, this study aims to replace the existing insulator and minimize the weight and deformation of the air suction unit by using microcellular foaming, which has excellent insulation characteristics, to prevent the condensation phenomenon occurring due to the deflection by the product deformation and the weight.

To set up the upper limit of the dimensions and product weight, manufacturing date of the product, and lot number of the raw materials were classified to six groups, and five samples from each group were taken to measure the deformation and weight. To measure the deformation, the four supporting points used during product assembly were supported as shown in Fig. 1(a), and the edge area was measured as shown in Fig. 1(b) using a height gauge after placing a 5-kg weight considering the self-weight. The upper limit of the dimension applied in this study was set to 3 mm, which was a starting point of condensation. The process analysis results on deformation showed median value of 1.96 mm, which deviated from the upper limit of the dimension.



(a) (b)

**Fig. 1 (a) Support point and (b) measurement method for deformation of air inlet grill**

The goal weight of the product was set to 1,450 g considering installation and use convenience and cost. The process capability of the weight in the existing product was 1,751 g, which showed a large deviation from 1,450 g, which was the upper limit of this dimension.

## 2.3 Selection of trivial many factors and analysis of possible factors

The following possible factors that affected weight reduction were selected through various data, expert's advice, and theoretical verification: screw's shape, additive, raw material, foam agents, resin temperature, injection speed, molding temperature, and cooling time. In addition, the following factors related to deformation reduction were selected: screw shape, additive, raw material, injection speed, resin temperature, molding temperature, cooling time, structure of the edge, and heating time of mold-shaped part. To select a vital few factors out of the selected possible factors, two-sample t-tests and ANOVA were used.

The analysis of the product weight according to a screw shape was conducted as follows: the foam agent content was fixed to 2 wt%, and difference in weight between general and foam screws was analyzed using the two-sample t test. Microcellular foaming did not occur in the general screw, since it was a single-spiral shape, and little turbulent flow was generated inside the screw, so that mixing gas and resin did not occur sufficiently. In contrast, the foaming screw shape applied in this study was a two-line spiral shape, thereby increasing feed rate, resulting in a high mix rate. In addition, compressive ratio was designed from 2.1 to 3 to have the gas and resin become a single phase for a short stay time inside the barrel at the high-pressure state, and the length-to-diameter ratio (L/D) was changed from 15 to 25 to improve mulling. The analysis results showed that P value was 0.00, (below the significance level 0.05); thus, it was revealed as one of the vital few factors. However, no other variables except for the analyzed screw shapes could be selected, and replacement during the experiment was inconvenient; thus, the foam screw that showed the improvement effect was selected as the optimum level.

For the additives, 2% of cross-linking agent, which showed the closest value to 1,450 g, which was the reference weight, was selected as the fixed value. In the same manner, the foam agent was excluded from the few vital factors as 709v70, which displayed the minimum weight mean was selected as the fixed level.

For the weight difference according to the resin temperature, the product weight was compared when the resin temperature was 210℃, 230℃, and 250℃ using the ANOVA method. The analysis result showed that the P value was 0.00, which indicated that it is a vital factor, and the upper limit of weight specification was satisfied at a range of 230–250℃; thus, the minimum weight point of the product was deemed to exist in this range. Accordingly, a thermal stabilizer was added to the raw material, and a coating agent was added to the foam agent, thereby conducting the first-phase optimization in the 230–250℃ range.

The injection speed level was set to 30mm/s, 65mm/s, and 100mm/s, and analyzed using ANOVA. Its P value was 0.00, which verified that it was one of the few significant vital factors affecting product weight. The minimum value of product weight was found in a range of 65–100mm/s. Thus, the first-phase optimization was conducted based on this range.

In addition, P values of other selected possible factors such as raw material, molding temperature, and cooling time were all > 0.05. Thus, they were not selected as vital factors.

To select the vital factors in relation to the product deformation, an analysis was conducted similarly using the same method that selected the factors that influenced the weight. For the screw shape, a foam screw was selected as the optimal choice in terms of effect on the improvement of dispersion.

For the additive, analysis was conducted after setting the level to Talc 10%, Talc 15%, and cross-linking agent 2%, but no significant effect on changes in dispersion by the additive type used were found. Thus, the additive was classified as category-type data, and cross-linking agent 2% that displayed the minimum deformation was fixed to the optimum level. The raw material was also classified as category-type data, and out of Homo-PP and Co-PP, the former was selected due to the low deformation to conduct optimization.

Two-factor by two-level factorial design (22 FD) was conducted using the 2.5D module of Moldflow to evaluate the effect of the structure in the product edges on deformation. To analyze the microcellular foaming molding, CO2 was used as a gas in the input conditions, and for cell's density and size, the results verified by the specimen were reflected. Table 1 presents the selected evaluation levels, and the reinforcement location was the edge area in the air suction unit, as shown in Fig. 2(a). The analysis results showed that when the width and height were 3 mm and 0.5 mm, respectively, deformation was the largest as 3.5 mm, and the smallest deformation was changed when the width was 15 mm, regardless of the height. Based on the result from the experiment design, Pareto chart analysis was conducted according to the structure. The analysis result verified that the interaction of the width and height of the reinforced structure was not significant in terms of the deformation of the product, and that the width had more significant effect on the deformation than the height. Thus, the width was selected as a vital factor that influenced the deformation in the reinforced structure.

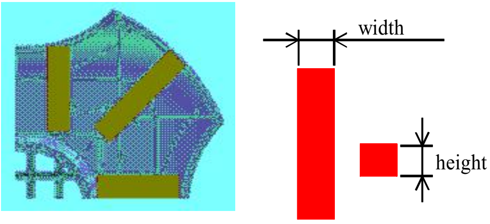
ANOVA analysis was conducted at mold temperatures of 30℃, 40℃, and 60℃ to analyze the correlation between mold temperature and product deformation. The analysis result verified that the P value was 0.00, which indicated it was an influencing factor. However, the upper limit of deformation was derived as higher than 3.0 mm. Thus, mold temperature was predicted by conducting a regression analysis. The mold temperature that satisfied the target upper limit was 70℃. Thus, it was set below 70℃ during the optimization process for conducting the experiment.

In the same method, a cooling time was set to 20s, 35s, and 50s, and the levels of product deformation were analyzed via ANOVA. Similar to the molding temperature, P value was lower than the significance level, so it was selected as one of the few vital factors. However, it did not satisfy the upper limit of deformation. To determine the cooling time that satisfied the upper limit, regression analysis was conducted, and the range of the optimization process was selected as below 68.8s.

The P values of other selected possible factors such as resin temperature, injection speed, and heating time were higher than the significance level, so they were not considered as vital factors.

**Table 1 Conditions of factorial experiments**

| Factor | Level | |
|---|---|---|
| | 1 | 2 |
| A. Width (mm) | 3 | 15 |
| B. Height (mm) | 0.5 | 1.2 |



(a) (b)

**Fig. 2 (a) Structure at the edge and (b) shape**

## 3. Optimization of the vital few factors

### 3.1 Optimization through regression analysis method

Range of width was selected as 3–15 mm for the optimization of the edge width, and regression analysis was conducted based on the deformation calculated through the computer-aided engineering (CAE) analysis. The analysis results verified that the deformation was reduced as the width increased when the range was 3–12 mm, but the deformation started to increase when the width range was 12–15 mm. Based on this result, regression analysis was conducted. The results determined that the change in deformation in a range of 9–15 mm of width followed the quadratic equation form, and after a certain width, it was ejected before solidification, thereby playing a role in inducing deformation.

Thus, degree of the product deformation was checked in a range of 9–15 mm that displayed a correlation of the quadratic equation form, and the second regression analysis was conducted to calculate the width that induced the minimum deformation. The width used in the second regression analysis and the product deformation according to the width are presented in Table 2. The correlation between product deformation D and width W can be defined by Eq. (1).

$$D = 13.21 - 1.909 \cdot W + 0.07619 \cdot W^2 \qquad (1)$$

**Table 2 Results of regressive analysis**

| 1st regressive analysis | | 2nd regressive analysis | |
|---|---|---|---|
| Rib width (mm) | Deformation (mm) | Rib width (mm) | Deformation (mm) |
| 3 | 3.5 | 9 | 2.2 |
| 6 | 3.0 | 10.5 | 1.6 |
| 9 | 2.2 | 12 | 1.2 |
| 12 | 1.2 | 13.5 | 1.4 |
| 15 | 1.7 | 15 | 1.7 |

Based on the above Eq. (1), the minimum deformation was revealed at 12.5 mm width.

### 3.2 Optimization through reaction surface analysis method

To calculate the optimization values of resin temperature ($T_{melt}$) and injection speed ($V_{inj}$), which were vital factors that affected the product weight (W), $2^2$ and RSM were employed. Each level was set based on the first optimization range in Section 2.3. Based on the RSM results, variance analysis was conducted including the second interaction considering the second reaction model. The analysis result showed that the P value of the second interaction was 0.987, which was larger than the significance level, resulting in insignificant results for weight change. Thus, reaction surface regression analysis was conducted after excluding the second interaction, thereby deriving the reaction surface equation as presented in Eq. (2).

$$\begin{aligned} W = 6318.2 - 37.923 \cdot T_{melt} - 8.0513 \cdot V_{inj} \\ + 0.07890 \cdot T_{melt}^2 + 0.048376 \cdot V_{inj}^2 \end{aligned} \qquad (2)$$

RSM was conducted to determine the fitness of the reaction model applied to the derived Eq. (2). The results showed that the P value was 0.987 in the lack-of-fitness test. This verified that the regression equation of injection speed and resin temperature with regard to the weight fit well.

The weight optimization of $2^2$ RSM was conducted with regard to the resin temperature and injection speed. The results showed that when the resin temperature was 240.4℃ and the injection speed was 83.2mm/s, 1,426.3g of the minimum product weight could be obtained. The total satisfaction assessment result was 0.987, which was close to 1.000, indicating that the derived value fit well.

Similar to the method applied to analyze the effect on the product weight, the $2^2$ RSM was used to analyze the effects of the mold temperature ($T_{mold}$) and cooling time ($t_{cool}$), which were vital factors that influenced the product deformation. The derived values in the possible factor analysis in Section 2.3 were used as the range of each level. Based on the $2^2$ RSM results, variance analysis was conducted, including the second interaction, considering the second reaction model. The analysis result showed that the P values with regard to the quadratic squared term of molding temperature and cooling time were 0.136 and 0.367, respectively, which were larger than the significance levels, and the second interaction was 0.009, which was closer to the 0.005 significance level. Thus, reaction surface regression analysis was conducted after excluding the quadratic squared term of molding temperature and cooling time, thereby deriving the following Eq. (3).

$$\begin{aligned} D = 20.31 - 0.2151 \cdot T_{mold} - 0.1388 \cdot t_{cool} \\ + 0.001500 \cdot T_{mold} \cdot t_{cool} \end{aligned} \tag{3}$$

The lack-of-fitness test on Eq. (3) showed that the P value was 0.416, which was larger than 0.05, indicating that the regression equation of molding temperature and cooling time was well fit with regard to the product deformation. However, a slope in the second interaction in both of the vital factors was 0.0015 in the reaction surface equation, which was very small, and theoretical analysis and empirical phenomenon showed an opposite trend. In addition, with the increase in cooling time, solidification ratio increased, resulting in lower deformation rate. Thus, Eq. (4) can be made by excluding the second interaction.

$$D = 20.31 - 0.2151 \cdot T_{mold} - 0.1388 \cdot t_{cool} \tag{4}$$

The optimal conditions of molding temperature and cooling time were set to 92℃ and 46s, respectively, considering the performance and reproducibility of the mold temperature control device of the product manufacturer. As a result, the product deformation was 0.48 mm, and the total satisfaction was 0.92.

### 3.3 Verification of improvement capability of optimal condition

Based on the regression analysis method and RSM, the optimal conditions for product weight and deformation were derived. Thirty samples were fabricated by renovating existing molding through 1,800-ton injection molding machine of LS Mtron and high temperature control system Rich5 of Yudo based on the calculated conditions to evaluate the process capability of improvement, product weight and deformation.

The mean of product deformation was reduced from 1.96 mm to 0.55 mm, and the standard deviation was also decreased from 0.46 mm to 0.19 mm, while the process capability was increased from 2.2 to 14.5. The mean and standard deviation of product weight were also reduced, from 1,751.4 g to 1,425 g, and from 1.49 g to 1.13 g, respectively, and the process capability was increased from -219.75 to 26.01, showing a large improvement compared to the existing process.

## 4. Conclusions

This study applied microcellular foaming technology to reduce the production weight and deformation as well as achieve functional improvement of a 4-way panel in the ceiling-type air-conditioner produced by existing injection molding processes. In addition, regression analysis and RSM were used to derive the process conditions that minimized the product weight and deformation, thereby obtaining the following conclusions.

1. The analysis of possible factors was conducted using two-sample t test and ANOVA, and the results showed that the few vital factors that influenced the product weight were resin temperature and injection speed, and the factors that affected the deformation were width of the edge, resin temperature, and cooling time.
2. Regression analysis results verified that the product deformation was minimized when the width of the edge was 12.5 mm.
3. The RSM was utilized to select the optimal conditions of resin temperature, injection speed, mold temperature, and cooling time that affected the process conditions. The optimal conditions of each factor were 240.4℃, 83.2mm/s, 92℃, and 46s, respectively.
4. The derived optimum conditions were applied to the production process, and the results exhibited that the means and standard deviations of production weight were reduced by 18.6% and 24.2%, respectively, and the process capability was increased from -219.75 to 26.01, indicating significant improvements. In addition, the means and standard deviations of product deformation were also reduced by 71.9% and 58.7%, respectively, and the process capability was improved from 2.2 to 14.5.

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