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Optimization of Injection Molding Process Parameters to Improve Mechanical Strength of LFT Specimen

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Abstract

Despite their many advantages when compared to metal materials, automotive plastics are generally flawed in terms of mechanical strength and dimensional stability. Long fiber thermoplastics (LFT) can considerably improve these disadvantages. LFT can be manufactured using the injection molding method. However, short shot and lack of strength can occur based on process parameters. In this study, a mold is fabricated to produce specimens using LFT and the process range for complete molding is derived from basic tests of the injection molding process. Parameters affecting the strength are derived and analyzed to improve the mechanical strength of the injection specimens. Based on analytical results, the optimal process parameters for the highest strength within the given range are obtained.

Keywords: LFT(long fiber thermoplastics), Injection molding, process optimization, DOE(design of experiments), Taguchi method

INTRODUCTION

In general, plastics used in automobiles are advantageous over metals. They weigh less and can be mass produced because of their lower specific gravity and better moldability. Plastics can also be used for finishing because they can be easily formed into a composite, have excellent friction/abrasion resistance, and can be colored. [1]

However, despite these many positive characteristics, automotive plastics are largely disadvantageous in terms of mechanical strength and dimensional stability when compared to metal materials. Fiber-reinforced composites, which combine a polymer and reinforced fiber and are inorganic, are a recent development that can be used to overcome these disadvantages. Among the many types of fiber-reinforced composites, LFT is the most applicable to automotive parts. It can considerably improve mechanical strength and dimensional stability. LFT can be manufactured through injection molding processes of filling, holding pressure, cooling, and extraction after high-pressure injection into the cavity of the mold. However, short shot and lack of strength can occur based on process parameters.

Many studies have been conducted on the effects of injection molding conditions on products. Lim et al. used pressure and temperature sensors to measure and analyze the pressure and temperature in a cavity based on the changes in injection molding conditions.[2] Yoo et al. studied cavity pressure and tensile strength.[3] F. Manero studied temperature distribution during injection into the cavity[4], and W. L. Kruegar examined the cavity pressure change when filling in a square cavity.[5]

In this study, a mold is fabricated to produce specimens using LFT. In addition, the process range for complete molding is derived from basic tests conducted during the injection molding process. Parameters affecting the strength are derived and analyzed to improve the mechanical strength of the injection specimens. Based on analytical results, the optimal process parameters for the highest strength within the given range are obtained.

STUDY METHOD

Setting process parameters

The robustness of the structure based on the design method and the physical properties of the plastic material that constitute the injection product affect the mechanical strength in the injection process. The physical properties of the material affect the strength of the injection product based on the settings of the process parameters during injection molding. These include the resin melt temperature, injection pressure, holding pressure, holding pressure time, mold wall temperature, and cooling time.

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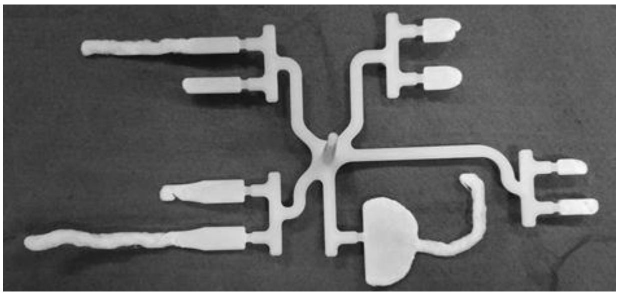
The characteristics of each process are as follows. Higher resin melt temperatures increase impact strength. However, different characteristics are observed depending on the material. When the temperature is set too high, the material thermally decomposes and a flash is easily generated. These present problems. In addition, injection pressure and speed affect the moldability of the product. High pressure is required to improve dimensional accuracy, but higher pressures generate reducing mold shrinkage and cracks, filling deformations.

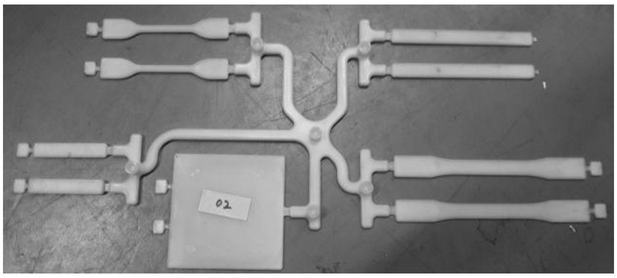
The characteristics of the injection molding process were considered in this study in order to examine the physical properties of the LFT material that constitutes the injection product. Therefore, the resin melt temperature, injection speed, injection pressure, and holding pressure were set as process parameters.

Fig. 1 shows both an incomplete specimen resulting from unsatisfactory process parameters and a complete specimen generated with process parameters in the normal range. Table 1 shows the process parameters and ranges. The injection compressor of Inhwa Glotech Co. Lt was used in this study.

Mass flow rate was calculated using mass flow rates with piston phase angles.



(a) Incomplete specimen



(b) Complete specimen

Figure 1. Results of injection mold

Table 1. Process parameters and range

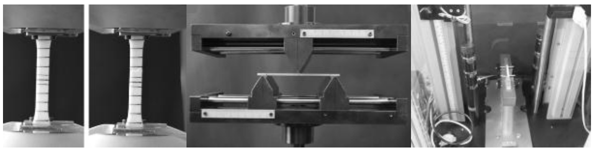
Group	Factors	Level		
		1	2	3
A	Melt temp. (℃)	220	225	230
B	Injection speed (%)	50	55	60
C	Injection pressure(bar)	30	33	36
D	Holding pressure(bar)	24	27	29

Tensile and flexural strength test

The specimens for the tensile and flexural strength test were fabricated according to ASTM D638-02 and D790-10. The test was conducted using UTM (MTS 858, 25kN) and the test speed was 5 mm/min at room temperature. [6,7]

Impact test

The impact test was performed using a drop impact tester (INSTRON dynatup 9250HV (Instron, Co. ltd.)), and the test data were stored in a PC using an AD converter.[8] Fig. 2 shows the testing environment for the tensile, flexural, and impact tests.



(a) (b) (c)

Figure 2. Testing environment

(a: tensile, b: flexural, c: impact)

Table 2. Results of tensile test

GF content	Tensile strength (㎫)			Average (㎫)
20 %	80	74	78	77.3
25 %	83	84	86	84.3
30 %	94	91	101	95.3
35 %	105	104	100	103
40 %	108	113	110	110

EXPERIMENTAL METHODS

Strength characteristics according to glass fiber content

Specimens were prepared by changing the glass fiber (GF) content in polypropylene to investigate their change in strength based on glass fiber content. The GF content was changed to 20, 25, 30, 35, and 40% for each of the five tests and a comparison analysis was conducted using the tensile strength test. Table 2 show the results according to the GF content. The test results confirmed that the tensile strength improved as the GF content increased.

Taguchi method

Among the various experimental designs, the Taguchi method provides a systematic and efficient method for optimizing process parameters and uses fewer experiments than most methods require for optimization.[9]

The Taguchi method can objectively and quantitatively evaluate both the effects of environmental conditions previously recognized as uncontrollable parameters as well as parameters such as mechanical errors and noise, which are difficult to control.

The signal-to-noise (S/N) ratio was used in the Taguchi method as a measure of improvement. The S/N ratio represents the ratio of the force of the signal input to the influence of noise. This S/N ratio is calculated using the test results. The better characteristics were applied for energy absorption in tensile, flexural, and impact strengths. The S/N ratio of the better characteristics can be expressed as (1).

$$S/N = 10\log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_1^2}\right) \quad (1)$$

Where n = number of experiments, y = results

Table 3 represents a table of orthogonal arrays prepared according to the four third-level factors. Fig. 4 shows the results of each test.

Table 3: L9(4^3) Orthogonal arrays of Taguchi method

Run.	Melt temp.	Injection speed	Injection pressure	Holding pressure
1	1	1	1	1
2	1	2	2	2
3	1	3	3	3
4	2	1	2	3
5	2	2	3	1
6	2	3	1	2
7	3	1	3	2
8	3	2	1	3
9	3	3	2	1

Table 4: Strength test results and S/N ratio

Run.	Tensile strength (㎫)				S/N ratio	Flexural strength (㎫)				S/N ratio	Absorbed energy(J)		S/N ratio
	1st		2nd			1st		2nd			1st	2nd	
1	113.9	124.1	115.8	114.3	41.35	183.7	193.7	173.1	164.4	44.99	2.9	4.5	10.75
2	87.3	-	114.7	110.3	13.61	167.2	165.9	171.1	167.3	44.49	2.9	6.1	11.37
3	103.0	103.3	107.8	116.2	40.60	163.3	183.6	169.1	178.1	44.76	2.6	3.8	9.64
4	112.7	109.9	112.4	112.9	40.98	163.6	154.2	169.1	159.9	44.15	6.5	4.8	14.74
5	115.8	114.5	104.7	112.3	40.95	184.4	147.1	164.7	168.4	44.32	6.9	4.4	14.40
6	110.4	109.2	113.2	108.7	40.85	152.2	186.4	172.7	163.5	44.47	6.1	-	18.71
7	109.3	110.5	113.3	107.2	40.82	168.9	168.1	172.0	169.0	44.58	3.7	4.0	11.69
8	122.9	115.7	113.7	118.1	41.39	172.3	172.4	171.5	172.9	44.72	3.7	5.1	12.53
9	109.6	113.4	112.8	113.8	41.01	170.8	173.9	170.3	159.3	44.52	5.7	3.6	12.67

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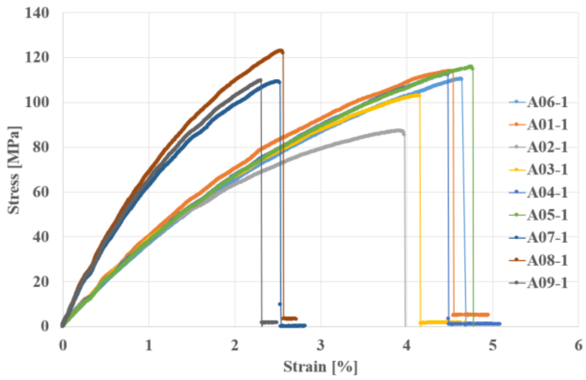
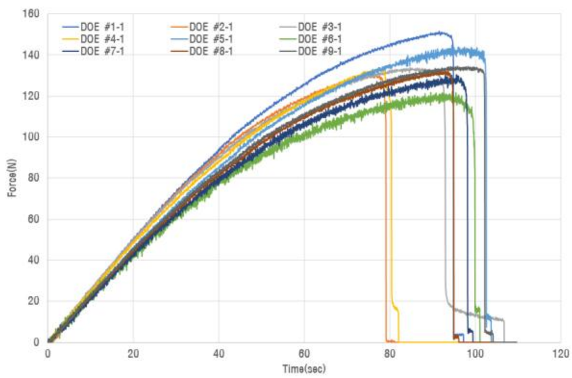
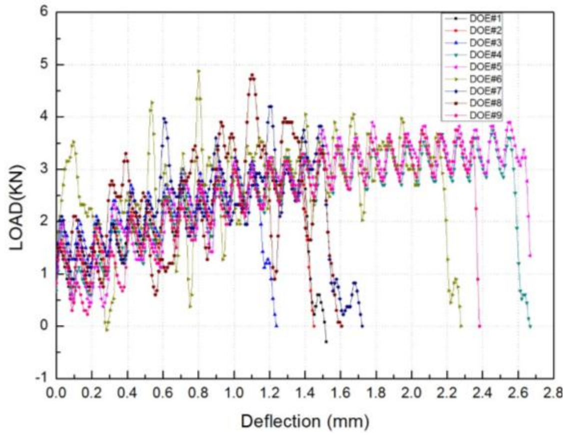


(a) Tensile strength



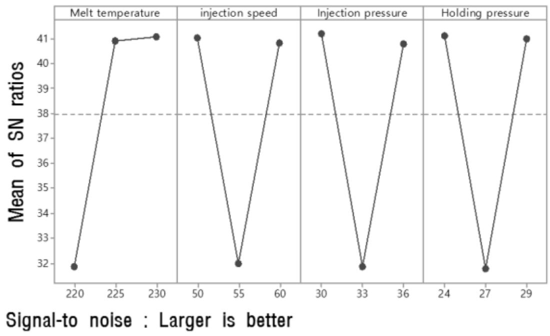
(b) Flexural strength



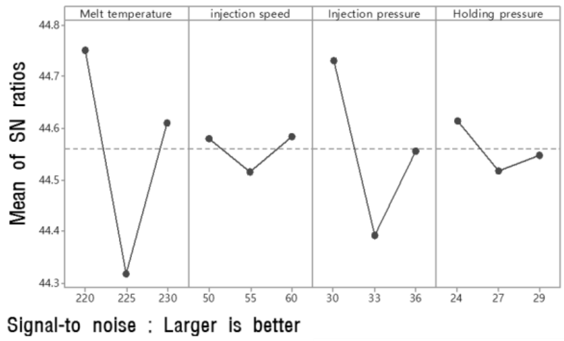
(c) Impact test

Figure 3: Test results

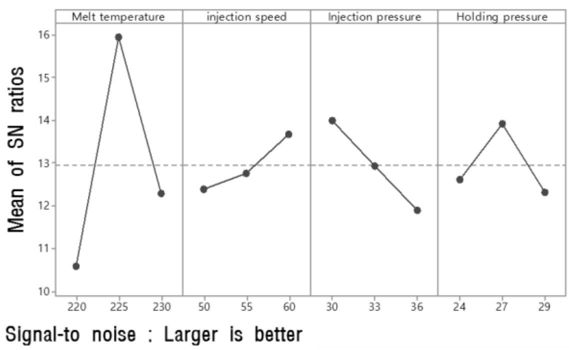
holding pressure, and injection speed. Absorbed energy according to impact test was affected (in the following order) by resin temperature, injection pressure, holding pressure and injection speed.



(a)



(b)



(c)

Figure 4: Main effects for S/N ratios

(a: tensile, b: flexural, c: impact)

RESULTS AND DISCUSSION

Table 4 shows the effect of the S/N ratio on the strength test results and mechanical properties. Test results showed that tensile strength was affected (in the following order) by holding pressure, injection pressure, resin temperature, and injection speed. Flexural strength was influenced (in the following order) by resin temperature, injection pressure,

Optimal process parameters

Table 5 shows the predicted process parameters that yield the maximum strength after we analyzed the strength test results of the LFT specimens. The results can be compared with the current injection molding process parameters of A1B1C1D1.

The S/N ratios and predicted results for each parameter can be calculated using Taguchi optimization tool in MINITAB.[10]

We confirmed that, among the optimal process parameters, injection speed and injection pressure could be applied under the same conditions for all three types of strength. The resin A3B3C1D1 could be applied to obtain the maximum tensile stress based on the third-level injection speed and the first-level injection pressure. The resulting tensile strength was expected to be 138.31㎫ and the S/N ratio 51.38. A1B3C1D1 could be applied for flexural strength and A2B3C1D2 for impact strength. The resulting flexural strength was expected to be 179.01㎫ and the S/N ratio 44.99. The absorbed impact energy was expected to be 6.1J and the S/N ration 18.71.

The application of the process parameters yielding maximum stress in each test improved tensile stress by 18% and absorbed energy by 65% compared to the results of A1B1C1D1, which were the basic process conditions.

Table 5: S/N ratio and average values according to the present and optimum condition

LEVEL				Tensile strength		Flexural strength		Absorbed energy	
A	B	C	D	S/N	Avg.	S/N	Avg.	S/N	Avg.
1	1	1	1	41.3	117.0	45.0	178.9	10.7	3.7
3	3	1	1	51.3	138.0	44.8	175.7	13.7	4.4
1	3	1	1	41.1	114.1	45.0	179.0	12.0	3.9
2	3	1	2	40.8	110.3	44.4	168.7	18.7	6.1

CONCLUSIONS

In this study, injection molding was performed to fabricate specimens using LFT. The process parameters affecting strength were investigated to improve the strength of the LFT specimens, and the minimum experimental design was established using the table of orthogonal arrays of the Taguchi method. We confirmed from the results of the strength test that the strength of the injection specimens increased as the GF content increased. The effects of process parameters on tensile, flexural, and impact strengths were analyzed. We confirmed that the injection speed and injection pressure were the same as the process parameters used to obtain the maximum strength of the specimens. As such, the optimal process parameters for the maximum strength in the specimens were obtained.

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