The Study on the Optimization of Injection Molding Process Parameters with Gray Relational Analysis

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ABSTRACT: This paper studies the optimization of injection molding process parameters by using the gray relational analysis method. Nine experimental runs based on Taguchi method's orthogonal arrays are studied to pick the best factor level condition. The mechanical properties of yield stress and elongation are selected to be the target of quality. The factor levels are assessed according to the chosen two mechanical properties. The degree of influence that the controllable process factors exert on the mechanical properties is studied by investigating the correlation between them. From the analysis of gray relational grade matrix, the most influential process factor and the most easily influenced mechanical property can be picked. It is found that the melt temperature is the most influential factor to mechanical properties of both yield stress and elongation. The yield stress is more easily influenced by those factors than the elongation is. The sequence of the importance that the controllable factors affect the yield stress is slightly different from it for the elongation, but the melt temperature is still the most important factor.

KEY WORDS: PC/ABS blends, injection molding, optimization, gray relational analysis, tensile test.

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INTRODUCTION

IN RECENTLY YEARS, injection molding has become the most important manufacturing process in the plastics industry because it has advantages of short produce cycle, excellent surface and easily molded complicated shape. However, the characteristics of its product is affected by some variable factors such as process parameters, melt flow type, heat transfer effect, material properties and geometry of the mold. Polycarbonate (PC) and Acrylonitrile-Butadiene-Styrene (ABS) blend is one of the most frequently used engineering plastic blends mixing polymers together to produce a specified physical properties. Owing to PC has the properties of high thermal stability and good impact behavior and ABS is easily processed and economical, PC/ABS blends have been exploited by the industry especially in automotive appliances.

PC/ABS blends have been discussed in many papers but the investigation on the effect of injection molding process parameters on the mechanical properties are really sparse. Liu and Piggott [1] studied the tensile and impact properties of eight thermoplastic polymers. They found that there is a very good correction between tensile strength and punch shear strength. Bureau et al. [2] performed tensile tests on the compression molded and injection molded Polystyrene/High-Density polyethylene blends. The results showed that the mechanical behaviors of blends depend strongly upon the matrix orientation as well as the dispersed phase morphology and orientation. Greco et al. [3] studied the mechanical properties of different PC and ABS blends. They pointed out that tensile results were affected by ABS additions. Gauna et al. [4,5] added Ultrax or EPOLENE to the polycarbonate to improve the properties of injection molded blends.

The traditional method of multi-factorial experimentation is the "change-one-factor-at-a-time" method. It is that only one factor is varied, while keeping all the other factors fixed at a specific set of conditions. This method is popular due to its simplicity. However, its simplicity may lead to unreliable results and inadequate conclusions. Taguchi and Konishi [6] advocates the use of orthogonal arrays to measure the effect of a factor on the average result. It is found that the experiments are reproducible and those problems caused by the traditional "change-one-factor-at-a-time" method could be overcome. Later, Phadke [7], Wu and Willie [8] and others [9–13] applied the Taguchi method to design the products and process parameters.

In recent years, Deng [14] proposes the gray relational analysis. It is a method of measuring degree of approximation between sequences according to the evaluation of gray relational grade. So far the research of gray relational analysis has been focused the field of theoretical study [15,16], the application on the optimization of process parameters is not too much. Chang et al. [17–19] had used the gray relational analysis to obtain the optimization of several manufacturing processes. Lin et al. [20] applied further gray relational analysis with orthogonal arrays to design the machining parameter and got the same results in the gray relational analysis and the Taguchi method.

However, the optimization design of injection molding process parameters could be difficult as more than one mechanical properties are used to evaluate the quality of material. Especially some mechanical properties are conflicted each other. This paper studies the optimization of injection molding process parameters by using the gray relational analysis method. The mechanical properties of yield stress and elongation are selected to be the target of quality. Nine experimental runs based on Taguchi method's orthogonal arrays are studied to pick the best factor level condition. The factor levels are assessed according to the chosen two mechanical properties. The degree of influence that the controllable process factors exert on the mechanical properties is studied by investigating the correlation between them. From the analysis of gray relational grade matrix, the most influential factor and the most easily influenced mechanical property can be picked.

GRAY RELATIONAL ANALYSIS

Data Preprocessing

Let the original reference sequence and comparability sequences are represented as $x_0^{(O)}(k)$ and $x_i^{(O)}(k)$, $i = 1, 2, \ldots, m$; $k = 1, 2, \ldots, n$, respectively. A data preprocessing is normally required since the range and unit in one data sequence may differ from the others. In addition, it is necessary when the sequence scatter range is too large; or the directions of the target in the sequences are different.

The data preprocessing is a process of transferring the original sequence to a comparable sequence. Depending on the characteristics of data sequence, there are some methodologies of data preprocessing [21–23] available for the gray relational analysis.

If the target value of original sequence is infinite, then it has a characteristic of "the-larger-the-better". The original sequence can be normalized as follows:

$$x_i^*(k) = \frac{x_i^{(O)}(k) - \min x_i^{(O)}(k)}{\max x_i^{(O)}(k) - \min x_i^{(O)}(k)} \tag{1}$$

When the-smaller-the-better is a characteristic of the original sequence, then the original sequence should be normalized as follows:

$$x_i^*(k) = \frac{\max x_i^{(O)}(k) - x_i^{(O)}(k)}{\max x_i^{(O)}(k) - \min x_i^{(O)}(k)} \tag{2}$$

However, if there is a definite target value to be achieved, then the original sequence will be normalized in the form:

$$x_i^*(k) = 1 - \frac{\left|x_i^{(O)}(k) - OB\right|}{\max\{\max x_i^{(O)}(k) - OB, OB - \min x_i^{(O)}(k)\}} \tag{3}$$

Or, the original sequence can be just normalized by the most simple methodology, i.e., let the values of original sequence be divided by the first value of the sequence:

$$x_i^*(k) = \frac{x_i^{(O)}(k)}{x_i^{(O)}(1)} \tag{4}$$

where, $x_i^{(O)}(k)$ is the original sequence, $x_i^*(k)$ is the sequence after the data preprocessing, $\max x_i^{(O)}(k)$ is the largest value of $x_i^{(O)}(k)$, and $\min x_i^{(O)}(k)$ is the smallest value of $x_i^{(O)}(k)$.

Gray Relational Coefficient and Gray Relational Grade

After a data preprocessing is done, a gray relational coefficient can be calculated with the preprocessed sequences. The gray relational coefficient [14,21–22] is defined as following:

$$\gamma(x_0^*(k), x_i^*(k)) = \frac{\Delta_{\min} + \zeta\Delta_{\max}}{\Delta_{0i}(k) + \zeta\Delta_{\max}} \quad 0 < \gamma(x_0^*(k), x_i^*(k)) \leqq 1 \tag{5}$$

where, $\Delta_{0i}(k)$ is the deviation sequence of reference sequence $x_0^*(k)$ and comparability sequence $x_i^*(k)$, i.e.,

$$\begin{aligned} \Delta_{0i}(k) &= \left|x_0^*(k) - x_i^*(k)\right| \\ \Delta_{\max} &= \max_{\forall j \in i} \max_{\forall k} \left|x_0^*(k) - x_j^*(k)\right| \\ \Delta_{\min} &= \min_{\forall j \in i} \min_{\forall k} \left|x_0^*(k) - x_j^*(k)\right| \end{aligned}$$

ζ is the distinguishing coefficient, $\zeta \in [0, 1]$.

The gray relational grade [14,21–22] is a weighting-sum of gray relational coefficient. It is defined as follows:

$$\gamma(x_0^*, x_i^*) = \sum_{k=1}^{n} \beta_k \gamma(x_0^*(k), x_i^*(k))$$

$$\sum_{k=1}^{n} \beta_k = 1 \tag{6}$$

Here, the gray relational grade $\gamma(x_0^*, x_i^*)$ represents the level of correlation between the reference sequence and the comparability sequence. If the two sequences are identically coincidence, then the value of gray relational grade is equal to one. The gray relational grade also indicates the degree of influence that the comparability sequence could exert on the reference sequence. Therefore, if a particular comparability sequence is more important to the reference sequence than the other comparability sequences, then the gray relational grade for that comparability sequence and reference sequence will be higher than other gray relational grades. Gray relational analysis is actually a measurement of absolute value of data difference between sequences and could be used to measure approximation correlation between sequences.

EXPERIMENTAL PROCEDURES AND RESULTS

Material

Polycarbonate/Acrylonitrile-Butadiene-Styrene (PC/ABS) is used in this study. The material is a 60 vol% PC/40 vol% ABS commercial blend, named Cycoloy C1110 from General Electric Corporation. The average density, heat-distortion temperature, and mold shrinkage are 1.13 g/cm^3, 110°C, and 0.5–0.7%, respectively. Before the injection molding process, the PC/ABS material is heated to 110–120°C for 4–6 h to remove moisture for better molding quality.

Experimental Design

The product quality of injection molding are always affected by the process parameters such as cooling time, injection pressure, injection speed, injection time, filling time, melt temperature, ejecting pressure, mold temperature, mold geometry shape, material property of melt, melt speed and heat transfer action of flow field, etc. Some studies [24–30] had been made to understand the effects of molding variables on the physical and mechanical properties of fiber reinforced thermoplastics. In addition, however, Ho et al. [31] found that, for the PC/ABS materials, the filling time, melt temperature, and mold temperature are the most significant factors in the product quality control. In the general industrial application, the ram speed is also regarded as an important factor.

Therefore, here the experiment was conducted with four controllable 3-level factors and two response variables. The four factors of filling time, melt temperature, mold temperature, and ram speed with three levels are selected, as given in Table 1. The two response variables are yield strength and elongation of the tensile specimen. Normally, the full-factorial design would require $3^4 = 81$ experimental runs. However, the effort and experimental cost for such a design could be prohibitive and unrealistic. In the present study, the orthogonal array $L_9(3^4)$, as shown in Table 2, are used to study four parameters based on nine experimental runs.

The specimens are molded in a computerized reciprocating screw injection molding machine, with a maximum injection pressure of 170 MPa. The

Table 1. Experimental factors and factor levels for the injection mold conditions of PC/ABS blends.

	Experimental factors			
Levels of experimental factor	*A* Filling time (s)	*B* Melt temperature (°C)	*C* Mold temperature (°C)	*D* Ram speed (%)
1	2	220	50	20
2	6	240	65	60
3	10	260	80	100

Table 2. Orthogonal array $L_9(3^4)$ of the experimental runs and the experimental results of yield stress and elongation for PC/ABS blends.

Experimental run	*A* Filling time	*B* Melt temperature	*C* Mold temperature	*D* Ram speed	Yield strength (σ_y, MPa)	Elongation (%)
1	1	1	1	1	35.1	38
2	1	2	2	2	38.2	32
3	1	3	3	3	43.6	38
4	2	1	2	3	39.8	48
5	2	2	3	1	36.7	32
6	2	3	1	2	39.7	50
7	3	1	3	3	41.2	44
8	3	2	1	2	38.4	34
9	3	3	2	1	38.9	50

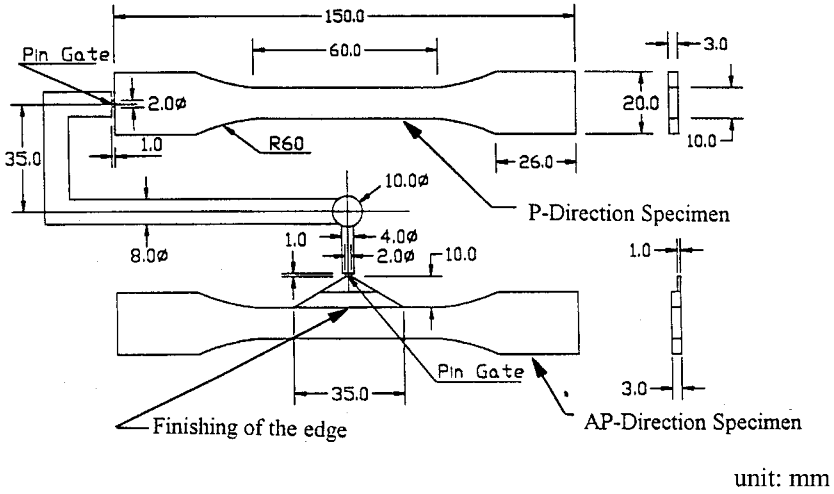

Figure 1. *The configuration of cavities and runners.*

dimension of mold cavities, the location and dimension of the pin gate is simulated by C-MOLD firstly for better filling process. The configuration of cavities and runners is shown in Figure 1.

Tensile Test

The procedure was followed the ASTM D638-91 specification [32]. The test was performed with a 10 tons computerized MTS (model 810) closed-loop servohydraulic system at a speed of 1 mm/min in room temperature. The specimens were loaded in tension monotonically until fracture. The software was employed to control the procedure and continuously recorded the load and the compliance displacement. Then, the engineering stress–strain curve was plotted. A typical plot of stress–strain curve is shown in Figure 2. The yield strength was obtained at 0.1% strain offset from the stress–strain curve. The elongation was also calculated from the stress–strain curve. The results are shown in Table 2.

ANALYSIS AND DISCUSSION

The Best Experimental Run

In this paper, the yield stress and elongation based on the tensile test results are listed in Table 2 for the material PC/ABS. Usually, the larger

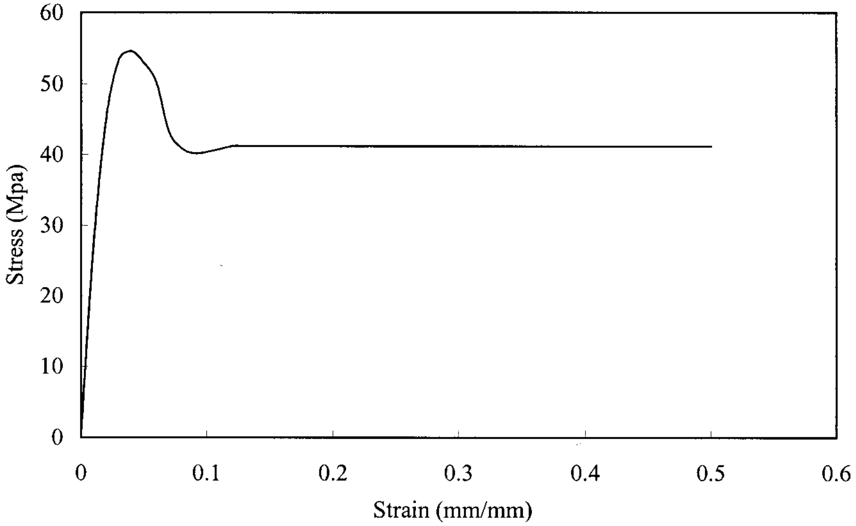

Figure 2. *A typical plot of stress–strain curve.*

the yield stress is, the better strength the material is. Also, the material toughness increases with increasing of elongation. That is the larger the values of these properties are, the better the material is. Although both yield stress and elongation should be compromised with each other to obtain the better material properties. Thus, the data sequences of yield stress and elongation both have the the-larger-the-better characteristics. The-larger-the-better methodology, i.e., Equation (1), is employed for data preprocessing. The maximum values of yield stress and elongation are set to be the reference sequence $x_0^{(O)}(k)$, $k = 1$–2. Let the results of nine experiments be the comparability sequences $x_i^{(O)}(k)$, $i = 1$–9, $k = 1$–2.

All the sequences after data preprocessing using Equation (1) are listed in Table 3 and denoted as $x_0^*(k)$ and $x_i^*(k)$ for reference sequence and comparability sequence, respectively.

The deviation sequences Δ_{01} can be calculated as follows:

$$\Delta_{01}(1) = \left|x_0^*(1) - x_1^*(1)\right| = |1.00 - 0.00| = 1.00;$$

$$\Delta_{01}(2) = \left|x_0^*(2) - x_1^*(2)\right| = |1.00 - 0.33| = 0.67, \text{ so}$$

$$\Delta_{01} = (1.00, 0.67)$$

the same calculating method for $i = 2$–9 are performed and the results of all Δ_{0i} for $i = 1$–9 are listed in Table 3.

Investigating the data presented in Table 3, we can find that $\Delta_{\max}(k)$ and $\Delta_{\min}(k)$ are as follows:

$$\Delta_{\max} = \Delta_{01}(1) = \Delta_{02}(2) = \Delta_{05}(2) = 1.00$$
$$\Delta_{\min} = \Delta_{03}(1) = \Delta_{06}(2) = \Delta_{09}(2) = 0.00$$

The distinguishing coefficient ζ can be substituted into Equation (5) for gray relational coefficient. If all the process parameters are equal weighting, the ζ should be chosen as 0.5 to calculate the values of gray relational grade. Table 4 shows the gray relational coefficient and grade for all nine comparability sequences.

Table 3. The sequences after data preprocessing.

Reference/comparability sequence	Yield strength (σ_y, MPa)	Elongation (%)
Reference Sequence	1.00	1.00
Comparability Sequences		
Experimental No. 1	0.00	0.33
Experimental No. 2	0.36	0.00
Experimental No. 3	1.00	0.33
Experimental No. 4	0.55	0.89
Experimental No. 5	0.19	0.00
Experimental No. 6	0.54	1.00
Experimental No. 7	0.72	0.67
Experimental No. 8	0.39	0.11
Experimental No. 9	0.45	1.00

Table 4. The calculated gray relational coefficient and gray relational grade for nine comparability sequences.

Experimental run (comparability sequences)	Orthogonal array $L_9(3^4)$				Gray relational coefficient		Gray relational grade
	A	B	C	D	Yield strength	Elongation	
1	1	1	1	1	0.3333	0.4286	0.3810
2	1	2	2	2	0.4404	0.3333	0.3869
3	1	3	3	3	1.0000	0.4286	0.7143
4	2	1	2	3	0.5280	0.8182	0.6731
5	2	2	3	1	0.3812	0.3333	0.3572
6	2	3	1	2	0.5215	1.0000	0.7607
7	3	1	3	3	0.6391	0.6000	0.6195
8	3	2	1	2	0.4497	0.3600	0.4049
9	3	3	2	1	0.4749	1.0000	0.7374

The idea of response table in Taguchi method is employed here to calculate the average gray relational grade for each factor level. The procedure is grouping the gray relational grades firstly by factor level for each column in the orthogonal array, and then averaging them. For example, in the first column in the orthogonal array, the run1, run2, and run3 are the experimental runs at which factor A was set at level 1. The associated values of gray relational grade for A_1 are those experimental runs' gray relational grades. Therefore, their average is the average gray relational grade for A_1:

$$\bar{A}_1 = \frac{0.3810 + 0.3869 + 0.7143}{3} = 0.4941$$

and

$$\bar{A}_2 = \frac{0.6731 + 0.3572 + 0.7607}{3} = 0.5970$$

$$\bar{A}_3 = \frac{0.6195 + 0.4049 + 0.7374}{3} = 0.5873$$

By the same method, the calculation is performed for each factor level and the response table is generated, shown in Table 5. Since the gray relational grade represents the level of correlation between the reference sequence and the comparability sequence, the larger value of gray relational grade means the comparability sequence has stronger correlation related to the reference sequence. The reference sequence we select here has the larger-the-better characteristic. Therefore, it means that the comparability sequence with larger value of gray relational grade will induce the desired material properties of larger yield stress and elongation. Based on this premise, we will select the level that results in the largest average response value. In Table 5, A_2, B_3, C_2, and D_3 has the largest value of gray relational grade for factor A, B, C, and D, respectively. As a result, $A_2B_3C_2D_3$ is recommended on the basis of the factor level combination.

Table 5. The response table for gray relational grade.

	Factors			
Levels	***A***	***B***	***C***	***D***
1	0.4941	0.5579	0.5155	0.4919
2	0.5970	0.3830	0.5991	0.5175
3	0.5873	0.7375	0.5637	0.6690

The Most Influential Factor

Using the gray relational analysis, the extent of injection molding process parameters affecting the mechanical properties can be investigated. Let the yield stresses and elongation of nine experimental runs be the original reference sequences $x_{\sigma}^{(O)}(k)$ and $x_{\varepsilon}^{(O)}(k)$, $k = 1$–2. The values factor level in the nine experimental runs are set to the comparability sequences $x_{A}^{(O)}(k)$, $x_{B}^{(O)}(k)$, $x_{C}^{(O)}(k)$ and $x_{D}^{(O)}(k)$, $k = 1$–2 for four controllable factors. All the sequences are listed in Table 6.

The data preprocessing are employed according to Equation (4), i.e., normalized by initial value, and the results are shown in Table 7.

Table 6. The reference sequences and comparability sequences for yield stress and elongation results and experimental factor levels.

	Comparability sequences				Reference sequences	
Experimental run	*A* Filling time (s)	*B* Melt temperature (°C)	*C* Mold temperature (°C)	*D* Ram speed (%)	Yield strength (σ_y, MPa)	Elongation (%)
1	2	220	50	20	35.1	38
2	2	240	65	60	38.2	32
3	2	260	80	100	43.6	38
4	6	220	65	100	39.8	48
5	6	240	80	20	36.7	32
6	6	260	50	60	39.7	50
7	10	220	80	100	41.2	44
8	10	240	50	60	38.4	34
9	10	260	65	20	38.9	50

Table 7. The sequences after data preprocessing for Table 6.

	Comparability sequences				Reference sequences	
Experimental run	*A*	*B*	*C*	*D*	σ	ε
1	1	1.0000	1.0	1	1.00	1.00
2	1	1.0909	1.3	3	1.09	0.84
3	1	1.1818	1.6	5	1.24	1.00
4	3	1.0000	1.3	5	1.13	1.26
5	3	1.0909	1.6	1	1.05	0.84
6	3	1.1818	1.0	3	1.13	1.32
7	5	1.0000	1.6	5	1.17	1.16
8	5	1.0909	1.0	3	1.09	0.89
9	5	1.1818	1.3	1	1.11	1.32

The deviation sequences are calculated by using the same method as mentioned in the previous section. Then, the deviation sequences and distinguishing coefficient are substituted into Equation (5) to obtain gray relational coefficient. Finally, the gray relational coefficients are averaged for equal weighting to get gray relational grade. Table 8 shows gray relational coefficient and grade for reference sequence $x_{\sigma}^{*}(k)$ and comparability sequences $x_{A}^{*}(k)$, $x_{B}^{*}(k)$, $x_{C}^{*}(k)$ and $x_{D}^{*}(k)$. The gray relational coefficient and grade for another reference sequence $x_{\varepsilon}^{*}(k)$ with the same comparability sequences are shown in Table 9.

Table 8. The calculated gray relational coefficient and gray relational grade for experimental factors to experimental result of yield stress.

	A **Filling time**	**B** **Melt temperature**	**C** **Mold temperature**	**D** **Ram speed**
Gray Relational Coefficient	1.00	1.00	1.00	1.00
	0.96	0.99	0.91	0.52
	0.89	0.97	0.85	0.35
	0.52	0.94	0.93	0.35
	0.51	0.98	0.79	0.98
	0.52	0.98	0.94	0.52
	0.35	0.92	0.83	0.35
	0.34	0.99	0.96	0.52
	0.34	0.97	0.91	0.95
Gray Relational Grade	0.6057	0.9721	0.9010	0.6125

Table 9. The calculated gray relational coefficient and gray relational grade for experimental factors to experimental result of elongation.

	A **Filling time**	**B** **Melt temperature**	**C** **Mold temperature**	**D** **Ram speed**
Gray Relational Coefficient	1.00	1.00	1.00	1.00
	0.93	0.89	0.82	0.49
	1.00	0.92	0.77	0.34
	0.54	0.89	0.98	0.35
	0.49	0.89	0.73	0.93
	0.55	0.93	0.86	0.55
	0.35	0.92	0.82	0.35
	0.33	0.91	0.95	0.49
	0.36	0.93	0.99	0.87
Gray Relational Grade	0.6163	0.9231	0.8819	0.5964

The gray relational grades in Tables 8 and 9 can be further arranged in the matrix form as following:

$$\gamma = \begin{bmatrix} \gamma(\sigma, A) & \gamma(\sigma, B) & \gamma(\sigma, C) & \gamma(\sigma, D) \\ \gamma(\varepsilon, A) & \gamma(\varepsilon, B) & \gamma(\varepsilon, C) & \gamma(\varepsilon, D) \end{bmatrix}$$
$$= \begin{bmatrix} 0.6057 & 0.9721 & 0.9010 & 0.6152 \\ 0.6163 & 0.9231 & 0.8819 & 0.5964 \end{bmatrix}$$

Here

$$\begin{aligned} Row1 &= (\gamma(\sigma, A), \gamma(\sigma, B), \gamma(\sigma, C), \gamma(\sigma, D)) = (0.6057, 0.9721, 0.9010, 0.6152) \\ Row2 &= (\gamma(\varepsilon, A), \gamma(\varepsilon, B), \gamma(\varepsilon, C), \gamma(\varepsilon, D)) = (0.6163, 0.9231, 0.8819, 0.5964) \\ Col1 &= (\gamma(\sigma, A), \gamma(\varepsilon, A)) = (0.6057, 0.6163) \\ Col2 &= (\gamma(\sigma, B), \gamma(\varepsilon, B)) = (0.9721, 0.9231) \\ Col3 &= (\gamma(\sigma, C), \gamma(\varepsilon, C)) = (0.9010, 0.8819) \\ Col4 &= (\gamma(\sigma, D), \gamma(\varepsilon, D)) = (0.6152, 0.5964) \end{aligned}$$

In the gray relational grade matrix, $Row1$ and $Row2$ show the values of the gray relational grade for the controllable factors to the material properties of yield stress and elongation, respectively. Therefore, the degree of influence that the response variables are exerted by the controllable factors can be found and the most easily influenced response variable is the maximum of $Row1$ and $Row2$. Here, $\max(Row1, Row2) = Row1 = (\gamma(\sigma, A), \gamma(\sigma, B), \gamma(\sigma, C), \gamma(\sigma, D)) = (0.6057, 0.9721, 0.9010, 0.6152)$. This represents the reference sequence of yield stress $x_\sigma^{(O)}(k)$ is the strongest reference sequence and means that the response variable of yield stress has a stronger correlation to those controllable factors in injection molding process than the elongation has. Therefore, the yield stress is more easily influenced by those controllable factors than the elongation is.

On the other hand, the values of the gray relational grade for the controllable factor A, B, C, and D to both the material properties of yield stress and elongation are shown in the $Col1$, $Col2$, $Col3$, and $Col4$, respectively. Therefore, the degree of influence that one particular controllable factor exerts on the response variables can be found and the most influential controllable factor is the maximum value of $Col1$, $Col2$, $Col3$, and $Col4$. Here, $\max(Col1, Col2, Col3, Col4) = Col2 = (\gamma(\sigma, B), \gamma(\varepsilon, B)) = (0.9721, 0.9231)$. It can be observed that the melt temperature $x_B^{(O)}(k)$ is the strongest comparability sequence among those injection molding process parameters. It means that the melt temperature has the strongest correlation to the mechanical properties of products. Therefore, the melt temperature is the most influential factor to mechanical properties of both yield stress and elongation.

From the comparison of *Row*1 and *Row*2, it is found that the yield stress is the most easily influenced response variable. However, if every item in the *Row*1 is checked, the degree of influence that every controllable factor exerts on the yield stress can be obtained according to the gray relational grade. In the *Row*1, $\gamma(\sigma, B) > \gamma(\sigma, C) > \gamma(\sigma, D) > \gamma(\sigma, A)$. It means that the importance of the controllable factors to yield stress, in sequence, is factor *B*, *C*, *D*, and *A*. On the other hand, in the *Row*2, it is $\gamma(\sigma, B) > \gamma(\sigma, C) > \gamma(\sigma, A) > \gamma(\sigma, D)$. The importance of the controllable factors to elongation, in sequence, is factor *B*, *C*, *A*, and *D*. Only the sequence of factor *A* and *D* is changed. The factor *B* is still the most important factor to the elongation. However, from the observation in the *Col*2 the degree of influence that factor *B* (the most important factor) exerts on the mechanical properties of yield stress and elongation can be seen. That is $\gamma(\sigma, B) > \gamma(\varepsilon, B)$. It means that the yield stress (response variable σ) is more easily affected by the melt temperature (factor *B*) than the elongation is.

CONCLUSIONS

A study is made on the optimization of injection molding process parameters by using the gray relational analysis method. Nine experimental runs based on Taguchi method's orthogonal arrays are studied to pick the best factor level condition. The results obtained are summarized as follows:

1. In this paper the gray relational analysis based on Taguchi method's orthogonal arrays is proposed to offer a way of studying the optimization of injection molding process factor level. Two mechanical properties of yield stress and elongation are selected to be the target of quality.
2. From the study on the response table of the average gray relational grade for each factor and level, it can be found that the largest value of gray relational grade for filling time, melt temperature, mold temperature, and ram speed is at 6 s, 260°C, 65°C, and 100%, respectively. Therefore, the factor level combination of filling time at 6 s, melt temperature at 260°C, mold temperature at 65°C, and ram speed at 100% is recommended.
3. The yield stress is the strongest reference sequence. It means that the response variable of yield stress has a stronger correlation to those controllable factors in injection molding process than the elongation has. Therefore, the yield stress is more easily influenced by those controllable factors than the elongation is.

4. The importance of the controllable factors to yield stress, in sequence, is melt temperature, mold temperature, ram speed, and filling time. On the other hand, the importance of the controllable factors to elongation, in sequence, is melt temperature, mold temperature, filling time, and ram speed.
5. The melt temperature is the strongest comparability sequence among those injection molding process parameters. It means that the melt temperature has the strongest correlation to the mechanical properties of products. Therefore, the melt temperature is the most influential factor to mechanical properties of both yield stress and elongation. If the degree of influence that melt temperature exerts on the yield stress and elongation is further studied, it can be found that the yield stress is more easily affected by the melt temperature than the elongation is.

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