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Improving Optical Lens Processing Parameter Design by Integrating AHP and TOPSIS

Abstract. *Optical lenses are an integral component of optical information and optical-electric systems. Using PMMA (polymethyl methacrylate) as the material for making plastic optical lenses, this study integrated AHP (analytic hierarchy process), TOPSIS (technique for order preference by similarity to ideal solution) and the Taguchi quality engineering parameter design to find the optimization processing parameters that could provide effective control of the entire process. The results suggested that the proposed method could indeed achieve the optimized optical lens processing parameters.*

Abstract. D*o produkcji tworzyw sztucznych soczewek korzysta się z PMMA (polimetakrylan metylu) jako materiału. W artykule opisano proces optymalizacji projektowania i produkcji soczewek wykorzystujący model AHP (proces analityczny hierarchii) oraz TOPSIS (technika preferencji). Wyniki sugerują, że proponowana metoda rzeczywiście może osiągnąć optymalne parametry optyczne przetwarzanie obiektywu. (****Poprawa procesu projektowania soczewek optycznych przez Integrację metod AHP i TOPSIS****)*

Keywords: *PMMA; AHP; TOPSIS; Optimization processing parameters*
Słowa kluczowe: soczewki optyczne, projektowanie, AHP, TOPSIS

Introduction

Due to the rapid progress in optical information and communications technology, new optoelectronic products and components have been constantly developed, and have been in great demand. Optoelectronic components play a key role in the development of this industry, particularly, optical lenses can be regarded as an integral component of optical information and optoelectronic systems. Using Polymethyl methacrylate (PMMA) as the material for making plastic optical lenses, this study integrated AHP (analytic hierarchy process), TOPSIS (technique for order preference by similarity to ideal solution) and the Taguchi quality engineering parameter design. The orthogonal diagram was used in an experimental design to discuss and change the injection molding parameters. The S/N ratio data analysis method was used to find ways of improving the plasticizing and filling quality and to identify the major parameters, as well as the optimization processing parameters, to effectively control the entire process. The results suggested that the proposed method could indeed achieve the optimized optical lens processing parameters. The findings can serve as a reference for optoelectronic-related industries in promoting competitiveness and operational quality [1-5].

Table 1. Properties of the PMMA Material Used in this Study

Chemical Family Name	Acrylics	
Abbreviation	PMMA	
Material Structure	Amorphous	
Parameter	Value	Unit
Dissolution Density	1.0461	g/cm^3
Solidification Density	1.1621	g/cm^3

Optimization Design of Optimized Optical Lens Processes Integrating AHP and TOPSIS

Problem Definition

This study integrated AHP, TOPSIS and the Taguchi quality engineering parameter design. Experiments were conducted to find the optical lens process control factor level combinations that would minimize system sensitivity to noise factors and improve system robustness. According to the literature review, the warpage was used as the response value, namely, the objective characteristics. The minimized warpage was expected, and thus, it had the STB (smaller-the-better) characteristic. The optical lens manufacturing process is shown in Figure 1. The experimental material was optical-grade PMMA, as shown in Table 1.

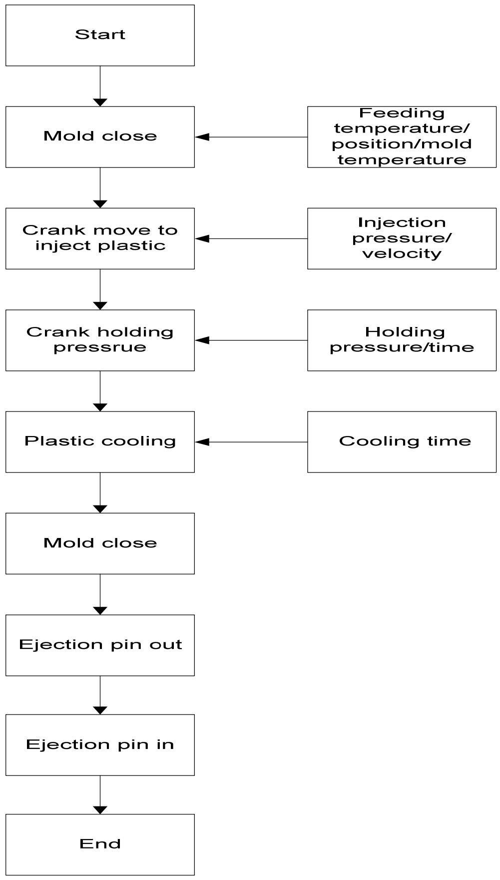

Fig. 1 Optical lens injection molding process flowchart

Status Measurement

The contour measuring instruments used in this study were examined by the following regulations and were found to be stable in quality. The processing capability analysis indicated that the current lens process capability was 0.76 ($C_{pk} \geq 1.33$ up to the standard). Hence, the current process capability had room for improvement [6-8].

Data Analysis on Integrating AHP and TOPSIS

Using expert experience and relevant literature review, this study selected four major properties as the evaluation criteria, including quality, price, time and reliability. According to the performance of different factors in evaluation criteria, appropriate scores in the permissible range were given, and then AHP was used to assess the relative weights of inter-property importance. Finally, TOPSIS was used to rank the order and establish all of the factors that could affect optical lens process and demand specifications. The selected relevant parameters and factors are shown in Table 2 [5].

AHP is a system analysis method used to process complex problems [9]. The method decomposes hierarchies by different levels to comprehensively assess the found network by quantitative judgment, so that the decision-maker can select information with better options to reduce the risk of incorrect decision-making. Meanwhile, the method can integrate expert opinions to carry out pairwise comparisons of the relative weights of various evaluation indicators and establish a comparison matrix for the calculation of eigenvalues and eigenvectors. The eigenvector refers to the preference order of various elements of certain hierarchies/levels. Finally, through the consistency verification of the maximum eigenvector, the relative weights of various evaluation criteria can be obtained as a reference indicator for decision-making. The decision-maker's judgment regarding the importance of various decision-making factors may be inconsistent. To determine the consistency in the decision-maker's judgment, consistency test of the pairwise matrix should be conducted. If the consistency index $C.R. \geq 0.1$, the matrix consistency is out of the permissible error range and the decision maker must reconsider the preference relationship between various decision-making factors. $C.R. = \frac{C.I.}{R.I.}$, $C.I. = \frac{\lambda_{\max} - m}{m-1}$, $\lambda_{\max}$ is the maximum eigenvalue, where *m* is the number of decision-making elements and *R.I.* is a random index. According to the abovementioned, after calculating the weights of the various hierarchical elements, a calculation of the entire hierarchical weight can be conducted. Finally, according to the ranking of the weights of various alternative plans, the preference order can be worked out to assist the decision-maker in making decisions.

The basic concept of TOPSIS is to define both the positive ideal solution and the negative ideal solution in order to find the solution closest to the positive ideal solution and farthest from the negative ideal solution. The positive ideal solution refers to the criterion value of the maximum benefit and minimum cost in all of the alternative solutions. On the contrary, the criterion value of the minimum benefit and maximum cost refers to the negative ideal solution. The TOPSIS method can be applied in the evaluation of a decision-making matrix of *m* solutions with *n* attributes as illustrated below; the calculation steps are as follows [7]:

Step 1: Original value normalization

Step 2: Establish the weighted normalization decision-making matrix

Step 3: Search for the positive ideal solution (A^+) and negative ideal solution (A^-), as shown in Eq.(1) and (2).

$$A^+ = \{(\max_i v_{ij} \mid j \in J), (\min_i v_{ij} \mid j \in J') \mid i = 1,2,...,m\} = (v_1^+, v_2^+, ..., v_j^+, ..., v_n^+) \quad (1)$$

$$A^- = \{(\min_i v_{ij} \mid j \in J), (\max_i v_{ij} \mid j \in J') \mid i = 1,2,...,m\} = (v_1^-, v_2^-, ..., v_j^-, ..., v_n^-) \quad (2)$$

where, *j*={*j*=1,2,…,*n*|*j* benefit criteria}, and *j´*={*j*=1,2,…,*n*| *j* cost criteria}. The benefit criteria refer to those indicators that have higher performance values if the values are bigger. The cost criteria refer to those indicators that have higher performance values if the values are smaller.

Step 4: Calculate the distances from the positive ideal solution (S_i^+) and the negative ideal solution (S_i^-) of various solutions. The distances from the positive ideal solution (S_i^+) and the negative ideal solution (S_i^-) are as shown in Eq.(3) and (4).

$$S_i^+ = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^+)^2}, i = 1,2,...,m \quad (3)$$

$$S_i^- = \sqrt{\sum_{j=1}^{n} (v_{ij} - v_j^-)^2}, i = 1,2,...,m \quad (4)$$

Step 5: Calculate the relative approximation of various solutions to the ideal solution, as shown in Eq.(5).

$$C_i^+ = \frac{S_i^-}{S_i^- + S_i^+} \quad (5)$$

where, $0 < C_i^+ < 1$, $i = 1,2,...,m$

Step 6: Rank the preference order. According to the results of Step 5, the relative performance of various solutions can be ranked, and a larger value indicates stronger preference. TOPSIS uses the relative approximate value of the positive ideal solution to rank the preference of solutions and avoid the difficulty of comparing a solution closest or farthest from the positive ideal solution and the negative ideal solution at the same time.

Table 2. Factor Analysis

Factor (KPIV)		Specification Requirements	Current Status	C_i^+
Fixed Factor	(1) Outlet Size	0.295-0.393mm^2	0.297mm^2	0.893
	(2) Injection Mode	Direct Pressure, Crank	Direct Pressure	0.732
	(3) Injection Material	Thermoplastic Material	PMMA	0.716
Control Factor	(1) Feeding Temperature	230-220 °C	235°C	0.683
	(2) Feeding Position	17-19 mm	18 mm	0.532
	(3) Injection Velocity	10-50 mm/s	35 mm/s	0.461
	(4) Injection Pressure	850-1150 bar	1050 bar	0.863
	(5) Holding Pressure	1000-1300 bar	1100 bar	0.812
	(6) Holding Time	6-12 sec	10 sec	0.551
	(7) Mold Temperature	80-100°C	95°C	0.792
	(8) Cooling Time	10-20 sec	10 sec	0.771
	(9) Mold Clamping Force	25-250 KN	255 KN	0.436
	(10) Screw Speed	5-45 m/min	20 m/min	0.429

To improve efficiency, it was assumed that the interactions between various experimental factors were insignificant and could be neglected in practice, as judged by engineers. In addition, the interactive effects between various experimental factors were regarded as part of the experimental errors, and thus the Taguchi method was applied in this experiment. There were eight factors in the experiment, and one of the factors had two levels, therefore, the L_{18} $(2^1 3^7)$ orthogonal diagram was selected and the factors were configured in it.

Experimental Improvement

The optical lens injection molding process in this experiment included the following steps:

(1) Prepare the materials.

(2) Set the feeding temperature, feeding position and mold temperature, and then carry out plasticizing and dissolving for injection molding preparation.

(3) After confirming the injection pressure and the injection velocity, fill the mold with molten plastic through the inlet.

(4) Set the holding pressure and holding time to minimize the molten plastic condensation.

(5) Set the experimental parameters using different cooling time settings.

(6) Remove the mold and open the mold cavity to inject the finished product, gate system and waste material by the ejector pin.

(7) After finishing the experiment, remove the optical lens for observation under a contour measuring instrument and record the results.

(8) Finish the experiment and record the results according the above order.

The experiment was repeated three times according to the orthogonal diagram configuration, and the original data are shown in Table 3.

Table 3. Experimental response value (μm)

Warpage (μm)		
0.832	0.752	0.812
0.798	0.896	0.856
⋮	⋮	⋮
0.793	0.839	0.862
0.846	0.798	0.784

This study applied the STB characteristics to work out a group of optimal experimental parameters and minimize the target value of the warpage. If the SN ratio unit is dB, then the STB characteristic SN ratio can be defined as the SN ratio of negativity, which can realize the general principle of a smaller MSD (quality loss) and a bigger SN ratio. The factor combination of a bigger SN ratio was $A_2B_1C_2D_3E_2F_2G_3H_1$.

Variance analysis was used to understand the impact of the parameters (control factors) on the quality attributes. It was found that the A, D, E, G and H factors, namely, the feeding temperature, injection pressure, holding pressure, mold temperature and cooling time had a significant impact. A total of 50 individual values were found after 50 repeated tests. The calculated C_{pk} of 1.68 was better than 0.76, indicating the success of the experiment.

Control

The original parameter combination of this study was $A_2B_3C_3D_2E_2F_2G_1H_3$. After analysis and verification of the two-stage program of the Taguchi parameter design method, this study found that the factor combination should be $A_2B_1C_2D_3E_2F_2G_3H_1$, as shown in Table 4.

Table 4. Improved Parameter Settings

Factor	Set Value
Feeding Temperature (°C)	225
Feeding Position (mm)	17
Injection Velocity (mm/s)	25
Injection Pressure (bar)	1100
Holding Pressure (bar)	1250
Holding Time (sec)	10
Mold Temperature (°C)	95
Cooling Time (sec)	15

Conclusions

This study integrated AHP, TOPSIS and Taguchi quality engineering improvement methods into optical lens processing, discussing the key factors and optimal levels to confirm process capability improvements and realize the minimized variance. Process capability indicators were also used to assess the process accuracy and precision in advance from the managerial and technological perspectives, in order to improve the overall process quality by optimizing the process using currently available resources. The calculated C_{pk} value of 1.68 was better than the original value of 0.76 [1, 4, 7, 8, 10].

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