The Study of Parameter Optimization for Screen Printing using Consistent Fuzzy Preference Relations and Taguchi Methods

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Abstract

Flexible pressure sensor pad is a remote medical care product. Its main function is to determine the body health information of the bed patient being cared. Through the device itself or the emergency distress call device in the health center, warning signals can be given to the caretaker. It is manufactured using the screen printing technology to print circuits on the sensor pad. Generally, when using the general screen printing technology, parameters are determined through trial and error or based on engineers' experiences. However, there are many parameters to be set when applying a screen printing technology. Thus, different engineers often have different opinions on parameter settings.

This study aimed to propose a mechanism to resolve the parameter setting issue for the manufacturing process using the screen printing technology. First, this study defined the research question based on the literature review and experiences from the industry. Then, this study determined the important parameters required during the manufacturing process by applying the Delphi method and the consistent fuzzy preference relations method, and the levels of the parameters based on on-site engineers' experiences. Then, this study adopted the Taguchi methods to design the experiments and obtain the better solution.

A real case was implemented and analyzed to demonstrate the proposed approach's effectiveness. The results show that our proposed method can improve the uniformity of print thickness.

1. Introduction

The phenomenon of population aging with more people needing to be cared is a global trend with impacts around the world. Every family will be influenced by issues such as changes in care resources and manpower shortage. More care receivers or the elderly will be looking for help from nursing homes and health care institutions. In other words, more care receivers or the elderly will be applying for foreign nurses or home care services (Chuan-Shih Wu, Tsair-Rong Chen, and Sheng-Yao Lin, 2015).

With the advancement of information technology, the traditional health care model has been changing with newly developed medical technology and instruments. According to a survey in the US, about 3/4 consumers were willing to use a remote health care system. Remote health care will become more and more popular. A veterans' hospital in the US set up an interactive video system in the homes of 46 elderly people. The responses of the elderly were very good. One caregiver could do 24 e-visits a day, efficiently reducing the labor cost. The remote health care industry has become a trend in aging societies.

The flexible pressure sensor pad is a remote health care product. The circuits on the sensor pad are produced using the screen printing technology. When there is a weight loaded on the sensor pad, a micro-current circuit is created. When the weight is removed, the circuit is broken. This is how the product determines the physical condition of a care receiver in bed. Lastly, the caregiver responsible for this care receiver is warned through the device itself or the emergency call device of the relevant medical station (Chuan-Shih Wu, Tsair-Rong Chen, and Sheng-Yao Lin, 2015).

The quality of screen printing is considered high if the print thickness is very uniform for the same screen and for the same batch. This study explored the printing parameters which would influence the uniformity of the print thickness in screen printing. The printing parameters for screen printing are usually set using the trial-and-error method while referring to engineers' experiences. However, there are many printing parameters to be set. And there are often too many opinions regarding these parameters. This study aimed to develop a systematic method to find the optimal combination of parameters to improve the stability of the printing process.

1.1 Limitations of the Study

1. This study used only one material printing material.
2. This study used only one printer for the experiments.
3. This study used only one type of ink for the experiments.

2. Literature Review

Screen printing has been broadly applied. It can be applied to printing materials which are flat, curved, too hard, or too soft, such as paper, leather, and ceramics. It features high efficiency and low cost. Therefore, screen printing is closely related to almost every industry. That is why this study aimed to develop a systematic method to find the optimal combination of parameters for screen printing for the purpose of improving the stability of the printing process.

this study adopted the Taguchi method after considering the cost, to reduce the number of experiments required. As for the input factors of the experiments, because there weren't enough data to apply methods such as PCA, this study interviewed the experts and applied the Delphi method and the CFPR method to determine which factors to use. The research methods will be illustrated in the following sections.

2.1 Delphi Method

The procedure was designed to obtain the most reliable consensus of opinion of a group of experts by a series of intensive questionnaires interspersed with controlled opinion feedback, with the results of each round being fed into the next round. It involves the selection of procedures for suitable experts, development of appropriate questions to be put to them, and analysis of their responses.

The intended outcome is that by the final round the experts will have reached a consensus of opinion on the issues put before them.

The process is continued until a consensus is reached on the various issues under consideration, or until it becomes evident that no further consensus can be developed. Generally, Delphi runs to two to seven rounds of questioning, at most. (Adnan and Morledge, 2003)

2.2 Consistent Fuzzy Preference Relations

The Consistent Fuzzy Preference Relations, also known as CFPR, aims to improve the deficiency of Analytic Hierarchy Process(AHP). (Herrera-Viedma et al., 2004) Following one of the characteristics of AHP, CFPR uses the addition of transitivity to establish a comparative preference matrix, thus avoiding the problem of consistency in the process of decision making. Thus, the preference relation that the evaluators want to express can be displayed.

The CFPR approach is used to construct the decision pair-wise matrices (PWM), in which the pair-wise comparisons based on additive transitivity (Herrera-Viedma et al., 2004).

The concept and steps of using the CFPR are described below. (Kuo and Lu, 2013)(Wang, 2013).

(1) Multiplicative preference relations

The matrix $\mathbf{A} \subset X \times X$, $\mathbf{A} = [a_{i,j}]$, represents the multiplicative preference relations for a set of X criteria, where $a_{i,j}$ represented the ratio of preference intensity of criterion x_i to criterion x_j. The ratio of preference intensity with a scale from 1 to 9 suggested by Saaty (1980) is employed in this study to measure the relative impacts of critical factors on fire safety equipment installation performance. Herein, $a_{i,j} = 9$ indicates that x_i is absolutely important compared to x_j; $a_{i,j} = 1$ indicates equal importance between criteria x_i and x_j; $a_{i,j}$ = 1/9 indicates that x_i is less absolutely important compared to x_j. Preference relation matrix $\boldsymbol{A}$ is typically assumed to be multiplicative reciprocal as presented as Eq. (1).

$$a_{i,j} \cdot a_{j,i} = 1, \forall i, j \in \{1, \cdots, n\} \quad (1)$$

(2) Fuzzy preference relations

The fuzzy preference relation $\mathbf{P} \subset X \times X$ for a set of criteria X is a fuzzy set with a membership function μ_p: $X \times X \rightarrow [0, 1]$. The preference relation is represented by matrix $\boldsymbol{P} = [p_{i,j}]$, where $p_{i,j} = \mu_p(x_i, x_j)$. Herein, $p_{i,j}$ is interpreted as the level of preference for criterion x_i over x_j. If $p_{i,j}$ = 1/2, it means that x_i and x_j are equally important (i.e., $x_i \sim x_j$); $p_{i,j}$ = 1 indicates that x_i is absolutely important/preferred to x_j; $p_{i,j}$ > 1/2 shows that x_i is more important/preferred to x_j, i.e., ($x_i \succ x_j$). In this case, the preference matrix, $\boldsymbol{P}$, is usually assumed to be additive reciprocal as in Eq. (2)

$$p_{i,j} + p_{j,i} = 1, \forall \mathrm{i}, \mathrm{j} \in \{1, \cdots, \mathrm{n}\} \quad (2)$$

(3) Consistent fuzzy preference relations

A set of alternatives $X = \{x_1, \cdots, x_n\}$ and $x \in X$ are associated with reciprocal multiplicative preference relations $\boldsymbol{A} = [a_{i,j}]$ for $a_{i,j} \in [1/9, 9]$. Then, Eq. (3) can be used to obtain the corresponding reciprocal fuzzy preference relation $\boldsymbol{P} = [p_{i,j}]$ for $p_{i,j} \in [0, 1]$ associated with A:

$$p_{i,j} = g(a_{i,j}) = \frac{1}{2} \cdot (1 + \log_9 a_{i,j}) \quad (3)$$

Here, $\log_9 a_{i,j}$ is used to transfer $\boldsymbol{A} = [a_{i,j}]$ to $\boldsymbol{P} = [p_{i,j}]$, because $a_{i,j}$ is between 1/9 and 9. Additive transitivity, with the relationships as in Eqs. (4) and (5), is one of the suggested properties to explore the consistent reciprocal fuzzy preference relation $\boldsymbol{P} = [p_{i,j}]$ (Herrera-Viedma et al., 2004).

$$p_{i,j} + p_{j,k} + p_{k,i} = \frac{3}{2}, \forall i < j < k \quad (4)$$

$$p_{i,(i+1)} + \cdots + p_{j,i} = \frac{j - i + 1}{2}, \forall \mathrm{i} < \mathrm{j} \quad (5)$$

(4) Determining the priority of risk factors

After obtaining the $n-1$ preference intensity ratio $\{a_{1,2}, a_{2,3}, \cdots, a_{n-1,n}\}$ of criteria/alternative $X = \{x_1, \cdots, x_n, n \geq 2\}$ from the experts' judgments as in Eq. (1),then Eq. (5) can be employed to construct a fuzzy preference relation for the set of n−1 values $\{p_{1,2}, p_{2,3}, \cdots, p_{n-1,n}\}$. Then the other preference relation values for decision matrix $\boldsymbol{B} = \{p_{i,j} \mid \wedge_{i<j} \ p_{i,j} \notin \{p_{1,2}, p_{2,3}, \cdots, p_{n-1,n}\}\}$, will be obtained using Eqs. (2), (4) and (5). However, when Eqs. (4) and (5) are used to calculate preference relation values all the necessary elements in the decision matrix $\boldsymbol{P}$ may not lie within [0, 1]; some may lie within [−a, 1+a], where $a = |\min\{\boldsymbol{B} \cup \{p_{1,2}, p_{2,3}, \cdots, p_{n-1,n}\}\}|$. In this case, the transformation function $\boldsymbol{P'} = f(p)$, displayed in Eq. (6), should be employed to develop the consistent reciprocal fuzzy preference relation matrix $\boldsymbol{P'}$. This transformation process can remain the decision matrix with reciprocity and additive consistency

$$f: [-a, 1 + a] \rightarrow [0, 1], f(x) = \frac{(x + a)}{(1 + 2a)} \quad (6)$$

This method is utilized to assess the relative impacts on project performance of the risk factors. The obtained assessment decision matrix, $\boldsymbol{P'} = (p'_{i,j})$, shows the consistent reciprocal relation. Eqs. (7) and (8) can now be applied to determine the multiplicative preference relations matrix associated with the relative impacts of risk factors on project performance

$$a'_{i,j} = 9^{(2 \times p'_{i,j} - 1)} \quad (7)$$

$$A' = [a'_{i,j}] \quad (8)$$

(5) Determining relative impact on project performance

The last step is calculating the weight of each criterion by Eqs. (9) and (10).

$$x_{i,j} = a'_{i,j} \Big/ (\sum_{i=1}^{n} a'_{i,j}) \quad (9)$$

$$W_i = \left(\prod_{j=1}^{n} x_{i,j}\right)^{\frac{1}{n}} / \sum_{i=1}^{n} \left(\prod_{j=1}^{n} x_{i,j}\right)^{\frac{1}{n}} \quad (10)$$

2.3 Taguchi Methods

The Taguchi method has been widely used in engineering analysis. This method dramatically reduces the number of tests by using orthogonal arrays provides a simple, efficient and systematic approach to specifying the optimum cutting parameters in the manufacturing process. (K. Palanikumar, 2011)(I. Asilturk, H. Akkus, 2011)

The Taguchi method uses a loss function to calculate the deviation between the experimental values and the desired values. This loss function is further converted into a signal–noise (S/N) ratio (η). (I. Asilturk, H. Akkus, 2011)(O. Koksoy, Z.F. Muluk, 2004)

Normally, there are three kinds of quality characteristics in the analysis of the S/N ratio, namely the lower-the-better, the higher-the-better, and the nominal-the-best(A. Gupta, H. Singh, A. Aggarwal, 2011).

3. Research Method

There were two phases of the research process of this study.

The main purpose of the first phase was to select factors. And there were two parts in this phase. In the first part, the Delphi method was applied. The experts were interviewed to obtain the process factors with influences on the response values. In the second part, the CFPR method was applied, to determine the relatively important process factors based on the experts' experiences.

The second phase aimed to obtain a better combination of screen printing parameters and verify the experiments. There were two parts in this phase. In the first part, the Taguchi method was applied. The experiments were designed based on the important process factors determined using the CFPR method and the data obtained from the experiments were collected. In the second part, the verification experiment was conducted. The combination of parameters found using the Taguchi method was used in the experiment and the obtained data were compared with those obtained based on engineers' standard combination of parameters, in hopes that the results were better.

4. Research result

4.1 Select factors

4.1.1 Identifying Relevant Factors Using the Delphi Method

Step 1: Defining the problem and determining the response variable

This study aimed to improve the uniformity of ink print thickness. According to the literature review and the interviews with the experts from the industry, the quality of a printed product is good if the thickness is uniform, leading to rather stable line impedance with low variations, in other words rather stable electric conductivity. Thus, this study defined the response variable of the experiments as the thickness standard deviation of the same product.

Step 2: Selecting experts to explain issues related to the problem

According to Step 1, the focus of this study was on improving the ink print thickness uniformity. The experts selected to be interviewed were mainly professionals of the screen printing process, including PCB manufacturing technicians, printing ink manufacturer personnel, and printing ink salesmen. The experts were visited individually for an interview and their opinions were collected.

Step 3: Questionnaire design and handing out

After interviewing the experts, this study summarized 13 process factors which could influence the research subject, namely mesh number, mesh tension, snap-off distance, whether to raise plate, squeegee angle, squeegee deviation, squeegee pressure, speed of squeegee travel, number of printing, squeegee hardness, squeegee blade, squeegee length, squeegee and thickness. The questionnaire was designed based on these factors. Then the questionnaire was handed out to the experts.

Step 4: Questionnaire retrieval and data analysis

The retrieved questionnaires were organized the factor sums and quartile deviations (QDs) were calculated. The sums were used to rank the factors and the QDs represented the degrees of concentration of the experts' opinions on the factors, as shown in Table 4.1.

Then the QDs were used to determine whether the experts' opinions were concentrated based on the method proposed by Holden et al. According to Table 4.1, the experts' opinions were highly concentrated ($0<QD\leq0.6$) for 10 (76.92%) of the factors and moderately concentrated ($0.6<QD\leq1$) for 3 (23.07%) of the factors. For over 85% of the factors, the experts' opinions were moderately or highly concentrated. That means the Delphi questionnaire survey could end here.

Lastly, based on the 80/20 rule, this study removed the rather unimportant factors. According to Table 4.1, the sum of the scores of all 13 factors was 451. And the sum of the scores of the top 10 factors was 368, 81.59% of the sum of all 13 factors. However, the factor rates of squeegee length (#10) and squeegee thickness (#11) were close, so this study decided to exclude squeegee length (#10) and keep the top 9 factors as the basis for the follow-up hierarchical structure construction using CFPR.

4.1.2 Determining Important Process Factors Using CFPR

Step 1: Constructing the objective hierarchical structure

The objective hierarchical structure was constructed based on the relevant process factors obtained using the Delphi method. This study categorized the factors into two constructs: gauge parameters and printer parameters. Figure 4.1 shows the objective hierarchical structure.

Step 2: Questionnaire design and handing out

Based on the objective hierarchical structure, a questionnaire was designed and handed out to the experts who were asked to fill it.

Step 3: Calculating relationship matrices

There was no issue of inconsistency when the CFPR method was applied. Thus, the questionnaire survey only had to be conducted once. After the questionnaires were retrieved, according to the calculation steps, the corresponding relationship matrices and weights were obtained. First of all, the values of the multiplicative relations (Table 4.2) from the retrieved questionnaires were transformed into values of the fuzzy relations using equation (3). Then, based on the transitivity of addition (equation (4) and equation (5)), the remaining values of the fuzzy relations were obtained. Then, equation (6) was applied to transform the fuzzy preference relation matrices into consistent fuzzy preference relation matrices. Finally, equation (7) was applied to transform the consistent fuzzy preference relation matrices into multiplicative preference relation matrices used to calculate weights.

Table 4.1 Delphi Questionnaire result

Factors	Absolutely important (5)	Important (4)	Fair (3)	Not Important (2)	Less absolutely important (1)	SUM	Quartile Deviation	Percentage (%)	Rank
mesh number	7	2	1			46	0.38	10.20%	1
speed of squeegee travel	2	6	2			40	0	8.87%	2
squeegee pressure	2	4	4			38	0.5	8.43%	3
mesh tension	1	5	4			37	0.5	8.20%	4
number of printing	3	2	4	1		37	0.88	8.20%	5
squeegee hardness	1	6	2	1		37	0.38	8.20%	6
squeegee blade	2	4	3	1		37	0.5	8.20%	7
squeegee angle	2	4	1	2	1	34	0.88	7.54%	8
snap-off distance	1	3	4	2		33	0.5	7.32%	9
squeegee length	1	1	4	4		29	0.5	6.43%	10
squeegee thickness	1	3	2	2	2	29	1	6.43%	11
whether to raise plate	1	1	4	2	2	27	0.5	5.99%	12
squeegee deviation	2		3	3	2	27	0.5	5.99%	13

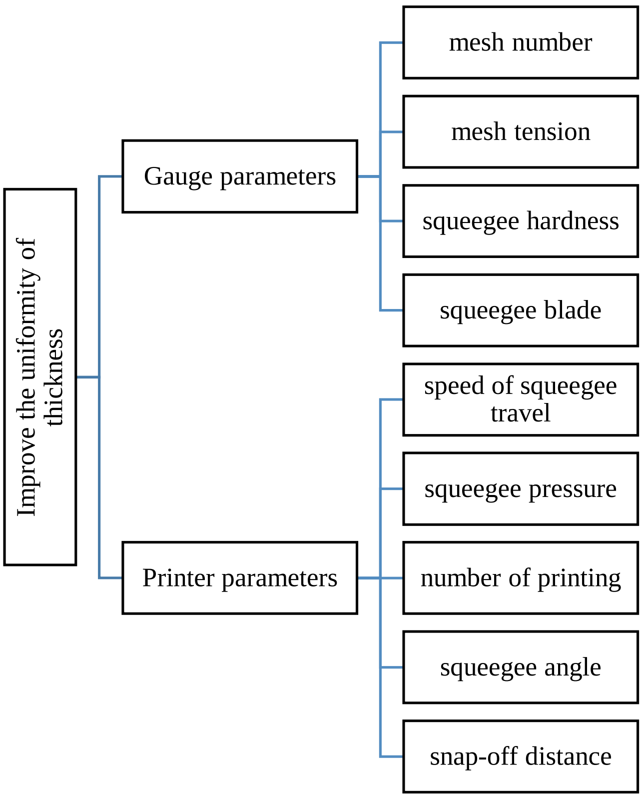

Figure 4.1 Objective hierarchical structure

Table 4.2 The values of the multiplicative relations (Gauge parameters)

	A：B	B：C	C：D
Expert 1	4	0.142857143	1
Expert 2	7	0.25	5
Expert 3	1	1	1
Expert 4	9	0.2	0.333333333
Expert 5	7	0.2	1
Expert 6	3	0.333333333	3
Expert 7	7	1	1
Expert 8	5	1	1

A：mesh number, B：mesh tension, C：squeegee hardness, D：squeegee blade

Step 4: Determining important factors

Equation (10) was applied to calculate the weight, then the factor loadings were calculated for the purpose of ranking, as shown in Table 4.3.

Lastly, this study removed the rather unimportant factors based on the 80/20 principles. As shown in Table 4.3, the total percentage of the weights of the top 6 factors was 82.28%. Thus, this study used the top 6 factors as the control factors for the Taguchi experimental design. However, due to the partner manufacturer's equipment problem squeegee blade (#3) could not be used as in input variable for the experiments. Therefore, this study include squeegee angle (#7) as one of the control factors for the follow-up Taguchi experimental design.

Table 4.3 Weights of factors (all of the constructs)

Factors	Weight	Rank
mesh number	0.2301	1
squeegee hardness	0.142132	2
squeegee blade	0.131156	3
speed of squeegee travel	0.124077	4
number of printing	0.104562	5
squeegee pressure	0.090528	6
squeegee angle	0.070701	7
mesh tension	0.066887	8
snap-off distance	0.039856	9

4.2 Obtain a better combination of screen printing parameters and verify the experiments

4.2.1 Experimental Design Using the Taguchi Method and Collecting Data

Step 1: Designing and conducting experiments and collecting data

The printer used in this study was the FP-6060SL printer by Hanky and Partners (Taiwan) Ltd., All the experiments were conducted in the same place. For factors not used as the control factors, the corresponding parameters were fixed. For example, the thread diameter was 0.035mm, the mesh tension was 22N, the snap-off distance was 3mm, the temperature was 22 degrees, and the humidity was 50~60%.

This study aimed to improve the uniformity of the print thickness. Thus, the response variable in this study was the standard deviation of the thickness. 46 spots of each printed product were selected randomly to measure the print thickness and the standard deviation was calculation. In this case, the thickness was more uniform if the standard deviation was smaller. And the important process factors, selected using the CFPR method, were then used as the control factors for the Taguchi experiments.

First, the factor levels were set based on the discussion with field engineers who operated the printer. According to the engineers, the squeegee pressure was controlled using the increase in pressing down distance. Thus, this study used the increase in pressing down distance to represent the squeegee pressure. Table 4.4 summarizes the factor levels.

Then, based on the number of factors and their levels, at least 11 experiments needed to be conducted (2 factors with 2 levels and 4 factors with 3 levels, with the degree of freedom being 2+8=10). The only orthogonal arrays that could meet this condition were $L_{36}(2^3\times3^{13})$ and $L_{36}(2^{11}\times3^{12})$. Thus, this study chose the L_{36} $(2^3\times3^{13})$ orthogonal array as the basis to design the experiments.

Step 2: Analyzing the factor effects and obtaining the better combination of factor levels of the Taguchi method

The S/N ratios of the Taguchi experiments from the previous step were calculated. Table 4.5 shows the results.

Table 4.4 The factor levels

mesh number	280, 330
squeegee hardness	70, 80
squeegee angle	70, 75, 80
speed of squeegee travel (mm/s)	50, 70, 100
number of printing	1, 2, 3
increase in pressing down distance (mm)	0.5, 0.75, 1

Table 4.5 S/N ratio

No.	1	2	3	4	5	6	7	8	9
S/N ratio	-3.22019	0.38132	1.35271	2.16981	2.04372	5.18011	2.26418	6.05853	-1.92559
No.	10	11	12	13	14	15	16	17	18
S/N ratio	2.71039	0.25268	2.87399	2.36427	0.32669	-0.27438	2.74183	0.17554	5.40724
No.	19	20	21	22	23	24	25	26	27
S/N ratio	1.36419	1.34985	2.51138	1.0726	2.74578	-1.99903	1.92772	4.10714	-1.57808
No.	28	29	30	31	32	33	34	35	36
S/N ratio	5.70115	5.93336	5.03726	5.31353	3.1251	4.14512	2.64818	3.59802	5.09112

Then, the effects of the factors on the S/N ratios were calculated, and the results are shown in Table 4.6. According to the calculation results, the control factors, ranked by their effects, were increase in pressing down distance, squeegee angle, squeegee hardness, speed of squeegee travel, number of printing, and mesh number. The better combination of levels was: mesh number = 330, squeegee hardness = 80, squeegee angle = 80, speed of squeegee travel = 50, number of printing = 2, and increase in pressing down distance =1.

Lastly, ANOVA was performed with the factors. The results are shown in Table 4.7. According to the study by Fowlkes et al., a factor is not significant when the relevant F<1, and is significant when F>4. Thus, this study selected only the significant factors and the combination became: squeegee hardness = 80, squeegee angle = 80, and increase in pressing down distance =1.

4.2.2 Performing Confirmatory Experiments

After obtaining a better combination of parameters using the Taguchi Method, the combinations of parameters obtained from Taguchi Method was then input into the confirmatory experiments and the post-test data were collected. Table 4.8 shows the experiment results for the combinations of parameters obtained from Taguchi Method.

According to Table 4.8, the Taguchi method reduced the standard deviation by 19.07%, proving that the method proposed by this study was effective, and only needed to adjust 6 process factors to perform the experiments.

Table 4.6 The effects of the factors on the S/N ratios

	mesh number	squeegee hardness	squeegee angle	speed of squeegee travel (mm/s)	number of printing	increase in pressing down distance (mm)
Level 1	2.2098	1.6441	1.4822	2.5081	2.1944	0.5314
Level 2	2.4	2.9658	1.6785	2.2548	2.4145	2.5409
Level 3			3.7541	2.1518	2.3058	3.8425
Diff.	0.1902	1.3217	2.272	0.3563	0.2201	3.3111
Rank	6	3	2	4	5	1

Table 4.7 ANOVA

	df	Sum of squares	Mean Square	F	Contribution rate
mesh number	1	0.325431	0.325431		
squeegee hardness	1	15.72156	15.72156	5.900883	6.51%
squeegee angle	2	38.03511	19.01756	7.13799	16.32%
speed of squeegee travel (mm/s)	2	0.807015	0.403508		
number of printing	2	0.290753	0.145377		
increase in pressing down distance (mm)	2	66.78387	33.39193	12.53322	30.66%
Error	25	78.505	3.1402		
Error (merge)	30	79.9282	2.664273		46.52%
SUM	35	200.4687			

Table 4.8 Experiment results

	result 1	result 2	result 3	result 4	result 5	average
standard combination	0.706423	0.686657	0.665579	0.706423	1.037695	0.760555
Taguchi Methods	0.589768	0.620503	0.556038	0.631309	0.67994	0.615512

Standard combination of parameters: mesh number =280, squeegee hardness =70, squeegee angle =75, speed of squeegee travel (mm/s) =100, number of printing =1, increase in pressing down distance (mm) =0.6.
Taguchi Methods of parameters: mesh number =330, squeegee hardness =80, squeegee angle =80, speed of squeegee travel (mm/s) =50, number of printing =2, increase in pressing down distance (mm) =1.

5. Conclusions and Suggestions

5.1 Conclusions

This study aimed to improve the uniformity of thickness and proposed a systematic method to find a combination of screen printing process parameters. This method was performed in two phases.

The first phase was to select factors. This study adopted the Delphi method and the CFPR method to select factors. According to the results of the Delphi method, 9 process factors were selected, which were mesh number, speed of squeegee travel, squeegee pressure, mesh tension, number of printing, squeegee hardness, squeegee blade, squeegee angle, and snap-off distance. The CFPR method further selected 6 among them, which were mesh number, speed of squeegee travel, squeegee hardness, squeegee pressure, number of printing, and squeegee angle.

The second phase was to obtain a better combination of screen printing parameters and verify the experiments. According to the experiment results, the Taguchi method reduced the standard deviation by 19.07%

5.2 Suggestions

1. This study only using Taguchi method to find the combination of parameters. metaheuristics can be tried, such as the Harmony Search and the Genetic Algorithm. Moreover, the method proposed by this study can also be applied in other engineering related issues.
2. The methods applied by this study to select factors were the Delphi method and the CFPR method, which were based on the experts' subjective opinions. In the future, if there are enough experiment data, it is suggested that factors can be selected using more objective methods such as PCA and correlation coefficients.

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