A Taguchi Method for Safety Design of Artificial Marble Products

Wen-Pai Wang[1], Chung-Shang Chang[2], Yu-Hsiu Lee[1]
[1]Department of Industrial Engineering & Management, National Chin-Yi University of Technology, Taichung, Taiwan, R.O.C.
[2]Department of Industrial Engineering & Management, Chienkuo Technology University, Changhua, Taiwan, R.O.C.
(wangwp@ncut.edu.tw)

Abstract - **Artificial marble products usually include sinks and kitchen equipments. Frequent accidents of consumer injuries caused by fallen sinks have been reported. This study aims to enhance the safety of marble sink by taking into the consideration of not increasing the cost of production and materials, and by applying the parameter design of Taguchi Method in selecting six controllable factors: defoaming time, resin ratio, hardener amount, oven time, oven temperature and amount of transparent glue. Eventually by formulating the optimal combination of production parameters, and by adjusting the raw materials and process, human injuries resulted from broken sink shreds may be avoided. All confirmation experiments conducted by parameter level fall within the confidence interval, indicating the parameter design of this study can actually attain the ultimate goal of product safety by effectively enhancing product quality without increasing any related costs.**

Keywords - **Artificial marble, Taguchi Method, orthogonal arrays, parameter design**

I. INTRODUCTION

Bathroom equipments are one of the necessities of everyday life and are made mostly by artificial marbles. Frequent accidents of bursting apart or falling down of defective, inappropriately installed or misused bathroom equipments, resulting in human injuries or death from broken pieces have been reported over the years. By targeting artificial marble bathroom equipments, the study intends to adjust the manufacturing parameters of artificial marble materials by applying the Taguchi Method. Hopefully, incidents caused by artificial marble products may be lowered to a minimal level, and consumer safety of this product line can be effectively improved.

The object of Taguchi Method is to upgrade the technique of product quality without increasing production cost. In theory, by attaching external plastic housing to prevent lime material from breaking, or using internal steel mesh to avoid irregular cracking, we can increase the designing safety level of artificial marble-related products. Nevertheless, this will raise the production cost and the complexity of production process which will cause much higher selling price of the product due to improvement on the safety, hence reduce the market receptivity of the product. The purpose of this study is to adjust the current material proportion of artificial marbles, so that not only product safety can be enhanced without increasing production cost, but also enables both the manufacturer and customer to enjoy a win-win situation created by quality products.

The main purpose of parameter design is to determine the set parameter value of product or process, so that the sensitivity of noise variables may be reduced to its minimal level. By applying parameter design, we can find an optimal combination set of parameter level, so that the mean value is consistent with the target value, yielding the least variance. By applying the statistic parameter design of Taguchi Method, this study means to adjust the current proportion of product materials and related process parameters, and move one step further to strengthen the hardness of artificial marble, so that it can become resistant to breakage and avoid human hazards.

II. PRODUCTION PROCESS OF ARTIFICIAL MARBLE

The production process of manufacturing artificial marble begins at preparation of required mold. After tape measuring the mold and fixing the molds with small long boards, the mold is then coated with mold-releasing wax. Use a spray gun to spray the transparent glue filled in the plastic shell evenly on the mold. After drying, prepare for filling in other raw materials, and leave them drying for about 1~2 hours (depending on the atmosphere moisture). Coat the mixed main ingredients (including lime powder, resin and hardener) evenly on the whole surface of the mold. Secure the mold with screws. Place the filled mold on the vibrator table for defoaming process. Relocate the defoamed mold at a place with good ventilation for gelatinization. Remove the back mold and the fringe materials. Push the finished product into the oven for baking. Complete the cooled product by sand grinding. Fig. 1 depicts the flow chart of the production process of artificial marble.

III. PARAMETER DESIGN OF TAGUCHI METHOD

There are many success cases of using Taguchi Method to improve the product quality in recent years [1, 2, 3, 4, 5, 6]. The effect of other method (such as transferring of grey rational grade)[7,8,9], is not as significant as Taguchi Method. That is why we have adopted Taguchi Method in this study. We use L_{18} ($2^1 \times 3^7$) design in our experiment. Parameter design is a feasible way in finding the optimal level combination of controllable factors in the experiment.

978-1-4244-4870-8/09/$26.00 ©2009 IEEE

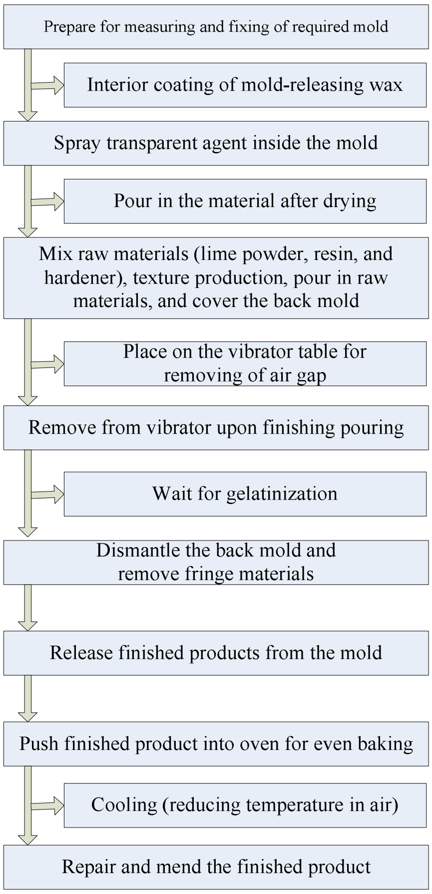

Fig. 1. Production process of artificial marble

The followings are the experimental steps we apply in the parameter design:

Step 1: Defining system goal and range

In order to enhance the safety of artificial marble, the anti-shattering experiment for the products are defined according to individual parameter and level, with each product having a 9cm(length)×9cm(width)×1cm(thickness) dimension. The quality feature data value of the experiment is determined by an iron block of 0.5 kilo in weight, dropping down from various heights, until the artificial marble is broken into shattered pieces (Since "cracking" artificial marble causes no injury to human body, it is the shattered pieces that inflicts hazard upon human, we therefore use breaking as a criteria). In this experiment, we expect to get the longest possible drop distance (i.e., the longer the drop distance, the greater the hardness). And the level combination experiments of each factor are conducted with the longest possible drop distance as the most desirable goal. A consensus has been reached between the researchers and on-site technicians that the shattering phenomenon caused by the artificial marble is mainly resulted from its hardness and brittleness. Therefore, this study intends to extract the controllable parameters from a professional perspective.

Step 2: Selecting response value

Different parameter level combinations will have various dissimilar influences on the variance of quality features (quality feature is response value). In this study, we select the drop distance of iron block as response value, with the larger drop distance representing a better quality (i.e., a greater hardness). Also, the response value indicates that this study is of a LTB (the Large the Better) nature, featuring: (1) Quality feature is continuous and not a negative value, ranging from 0 ~ ∞; (2) Target value is ∞; and (3) No adjusting is needed for the factor.

Step 3: Developing the noise strategy

Noise factor may be generalized into three categories: (1) Unit-to-unit variance: After baking, artificial marble products must be repaired or mended by sand grinding, which whether by machine or by manual, will not result in the unanimity of all products and the thus some defects may be displayed in the repaired part after some usage. This is the reason why sand grinding is listed as one of the product variance of the noise strategy; (2) External noise: All artificial marbles are baked in the oven under an evenly distributed specific temperature. Nevertheless, the expected effect - even distribution of temperature - supposed to be brought forth by the constant temperature is still subject to the influence of changing external temperatures. That is why we are listing the external temperature as an external noise of the noise strategy. (3) Deterioration: It is unavoidable to flush and wash artificial marbles during the using process. The part of which usually be rinsed would crack and even burst because constant dripping wears away the stone; however, It will no result to repaired them. For this reason, we involve water rinse as a factor leads to deterioration.

Step 4: Identifying controllable factors and their levels

Factor A. Defoaming time

Most of the larger air gaps existing within the liquid are eliminated by the vibrator when the liquid materials are poured into the mold, while the smaller air bubble gaps remained intact since the compression process is operated under non-vacuum condition (bubbles contained in each finished are inconsistent). Bubbles do exist in the molded finished product, which will increase the shattering probability of artificial marble. The current defoaming time for manufacturing artificial marble is 5 minutes. Nevertheless, in this study, we have found that the longer processing time taken by the vibrator can reduce the bubbles mixed in the raw materials.

Factor B. Resin ratio (between resin and lime powder)

Current mixing ratio of resin to lime powder for manufacturing artificial marble is 0.4 kilo to 1 kilo. In this study, we consider that the percentage of mixed resin may have an impact on the hardness and brittleness of artificial marble. That is, by enhancing the pulling force of the molecules, the artificial marble is thus prevented from shattering into pieces when falling down to the floor.

Factor C. Amount of hardener agent (corresponding hardener amount to 1 kilo of resin)

Current proportion of resin to hardener for manufacturing artificial marble is 1 kilo to 10 c.c. In this study, we hold that the percentage of hardener may affect the hardness and brittleness of artificial marble. That is, by reducing the amount of hardener, the hardness of artificial marble may be improved, and eventually prevent the artificial marble from shattering into pieces when falling down to the floor.

Factor D. Baking time

Current baking time for manufacturing artificial marble is 75 minutes in summertime, and 90 minutes in wintertime. Since the research period of this study is in summer season, all baking times are based on 75 minutes. In this study, we suggest that the baking time may affect the hardness and brittleness of artificial marble.

Factor E. Baking temperature

Current baking temperature for manufacturing artificial marble is 80℃ in summertime, 75℃ in wintertime. Since the research period of this study is in summer season, all baking temperatures are based on 80℃. In this study, we propose that the baking temperature may have an influence on the hardness and brittleness of artificial marble.

Factor F. Amount of transparent glue

Currently, artificial marble products are manufactured by gun-spraying of transparent glue evenly on the mold, focusing on the even distribution of sprayed glue, but not on the amount of spry glue. While in this study, we consider that the thickness of the external transparent glue of the finished products may have an impact on the cracking (not the shattering) of artificial marble products. After determining the controllable factors, each factor level is set as shown in Table I.

TABLE I
CONTROLLABLE FACTORS AND CORRESPONDING LEVELS

Factor / Level	A	B	C	D	E	F
1	5 min	0.4 : 1	10 cc	65 min	75℃	once
2	10 min	0.5 : 1	9.5cc	75 min	80℃	twice
3		0.6 : 1	9 cc	85 min	85℃	thrice

Step 5: Determining Taguchi's Orthogonal Arrays

The degree of freedom of the six controllable factors taken account in this study is 1 two-level factor, and 5 three-level factors. Therefore, by selecting L_{18} $(2^1 x 3^7)$ orthogonal arrays, the total number of experiment is 18, with each experiment repeating 4 times. Interaction is not being taken into consideration in this study.

Step 6: Execution of experiment and data collecting

Experiments on the above six controllable factors, defoaming time, resin ratio, amount of hardener agent, baking time, baking temperature, amount of transparent glue, followed by repeating four times of each experiment in line with the selected orthogonal arrays, we get a total of 72 pieces of data.

Step 7: Data analysis

By calculating the SN ratio of each experiment listed in orthogonal arrays, we get the following definition:

$$SN_{LTB} = -10 \cdot \log_{10}\left(MSD\right) \quad (1)$$

From there, we therefore get the following larger-the-better quality characteristic formula:

$$SN_{LTB} = -10 \cdot \log_{10}\left(\frac{1}{n}\sum_{i=1}^{n}\frac{1}{y_i^2}\right) \quad (2)$$

The bigger the SN value, the smaller the loss is.

Step 8: Confirmation experiment

According to the above, it is capable of finding the optimal combination of manufacturing parameter levels. Based on obtained results, we implement 3 times of the designed experiment on the remanufactured artificial marble products, which includes 4 runs of each experiment. The outcomes should be consistent with the foregoing optimal manufacturing parameter level combination.

Step 9: Execution results

Upon completion of confirmation experiments, we may choose one optimal set of level combination, which represents the optimal manufacturing parameter level combination referred to in this study.

IV. EXPERIMENTAL ANALYSIS

The SN ratio of each factor is calculated by the response value of every experiment as shown in Table II, and every mean value is displayed as shown in Table III.

As shown in Table III, the optimal level combination of each factor by selecting a bigger SN ratio is $A_1B_3C_3D_2E_1 F_1$. Also, Table IV indicates the result of the Analysis of Variance of SN ratio of each factor. Since the square sums of factors C, D and F are relatively smaller than other factors, they are thus neglected. The resultant net square sums and contribution rates are shown in Table V.

TABLE II
EXPERIMENTAL RESULTS OF SN RATIO

No.	Line								SN
	A	B	C	D	E	F	e	e	ratio
1	1	1	1	1	1	1	1	1	36.2195
2	1	1	2	2	2	2	2	2	34.9277
3	1	1	3	3	3	3	3	3	35.8967
4	1	2	1	1	2	2	3	3	36.4960
5	1	2	2	2	3	3	1	1	37.4433
6	1	2	3	3	1	1	2	2	37.0442
7	1	3	1	2	1	3	2	3	37.1913
8	1	3	2	3	2	1	3	1	36.0737
9	1	3	3	1	3	2	1	2	36.4105
10	2	1	1	3	3	2	2	1	33.2756
11	2	1	2	1	1	3	3	2	32.2753
12	2	1	3	2	2	1	1	3	32.7850
13	2	2	1	2	3	1	3	2	32.5227
14	2	2	2	3	1	2	1	3	32.9829
15	2	2	3	1	2	3	2	1	32.2753
16	2	3	1	3	2	3	1	2	33.2756
17	2	3	2	1	3	1	2	3	35.3614
18	2	3	3	2	1	2	3	1	35.3614

TABLE III
AVERAGE OF SN RATIO AND DIVERSITY

Level \ Factor	A	B	C	D	E	F
1	36.41	34.23	34.83	34.84	35.18	35.00
2	33.35	34.79	34.84	35.04	34.31	34.91
3		35.61	34.96	34.76	35.15	34.73
Diversity	3.06	1.38	0.13	0.28	0.87	0.27

TABLE IV
SN RATIO OF ANOVA

Source	DF	Seq SS	Adj SS	Adj MS	F	P
A	1	42.28	42.28	42.28	36.53	0.01
B	2	5.79	5.79	2.89	2.5	0.162
C	2	0.06	0.06	0.03	0.03	0.973
D	2	0.24	0.24	0.12	0.11	0.899
E	2	2.95	2.95	1.47	1.28	0.345
F	2	0.23	0.23	0.11	0.1	0.905
Error	6	6.9	6.94	1.15		
Total	17	58.53				

TABLE V
SN RATIO OF ANOVA AND CONTRIBUTION

	SS	df	MS	F	**SS*i***	**PC**
A	42.28	1	42.2	67.73	42.19	72.08%
B	5.79	2	5.79	4.64	2.71	4.65%
C	0.06	*	-	-	-	-
D	0.24	*	-	-	-	-
E	2.95	2	2.96	2.37	1.29	2.22%
F	0.23	*	-	-	-	-
Merged	0.54	6	0.09		12.32	21.05%
Sum	58.5	17			58.53	100%

Note: SS*i*: Net sum of squares, PC: Percent contribution

TABLE VI
RESULTS OF CONFIRMATION EXPERIMENT

No	Column						Observation				SN ratio
	A	B	C	D	E	F	1	2	3	4	
1	1	3	3	2	1	1	70	75	75	70	37.1913
2	1	3	3	2	1	1	75	80	80	70	37.6048
3	1	3	3	2	1	1	70	80	65	75	37.1287

According to our previous experience, when $\rho_{err} \leq 15\%$, it is recognized that some of the significant factors have not been neglected in the experiment. However, if $\rho_{err} \geq 50\%$, we may well assume that some of the significant factors have been neglected in the experiment, indicating experimental conditions weren't as good as they should be, or there were big measurement errors [10, 11] occurred in the experiment. Since the resultant, ρ_{err}, is 21.05%, some significant factors may have been neglected. Since in this experiment, theρ_{err} is still falling within the allowable range, and the main object of the experiment is to improve the physical injury caused by the hardness and shattered artificial marble, therefore confirmation experiment may still continue (ρ_{err} is the contribution rate of the error item).

$$\hat{\eta} = \bar{\eta} + (\bar{A}_1 - \bar{\eta}) + (\bar{B}_3 - \bar{\eta}) + (\bar{E}1 - \bar{\eta}) = \bar{A}_1 + \bar{B}_3 + \bar{E}_1 - 2\bar{\eta} = 37.45$$

$$\bar{\eta} = \frac{1}{18}\sum_{i=1}^{18}\eta_i = 34.8788$$

$$\bar{A}_1 = \frac{1}{9}\left[\eta_1 + \eta_2 + \eta_3 + \eta_4 + \eta_5 + \eta_6 + \eta_7 + \eta_8 + \eta_9\right] = 36.411$$

$$\bar{B}_3 = \frac{1}{6}\left[\eta_7 + \eta_8 + \eta_9 + \eta_{16} + \eta_{17} + \eta_{18}\right] = 35.612$$

$$\bar{E}_1 = \frac{1}{6}\left[\eta_1 + \eta_6 + \eta_7 + \eta_{11} + \eta_{14} + \eta_{18}\right] = 35.18$$

$$\alpha = 0.05,\ n_{eff} = \frac{9}{1 + V_A + V_B + V_E} = \frac{9}{1+1+2+2} = 3$$

$$CI_1 = \sqrt{F_{\alpha,1,V_2} \times V_e \times \left(\frac{1}{n_{eff}}\right)} = \sqrt{5.99 \times 0.0913 \times \frac{1}{3}} = 0.427$$

Wherein, V_2 indicates the degree of freedom of merged error variance ($F_{0.05,\,1,6} = 5.99$).

Based on the expected SN ratio and CI_1 value under the optimal conditions, we can calculate the expected range SN ration under the optimal conditions as [37.023 , 37.877] (within 95% confidence interval, the merged error variance listed in the SN Ratio Analysis of Variance Table is 0.0913). Since the purpose of confirmation experiment is to verify the validity of the predicted mean value under the optimal conditions, this experiment has conducted 3 trials confirmation experiments based on the optimal combination of control factor level ($A_1B_3C_3D_2E_1F_1$). As shown in Table VI, a total of 12 pieces of data are acquired by repeating 4 times of each experiment.

$$CI_2 = \sqrt{F_{\alpha,1,V_2} \times V_e \times \left(\frac{1}{n_{eff}} + \frac{1}{r}\right)} = \sqrt{5.99 \times 0.0913 \times \left[\frac{1}{3} + \frac{1}{3}\right]} = 0.604$$

Wherein, r represents number of sample used for the confirmation experiment.

The SN ratio resulted from the previous confirmation experiment is 37.308, the confidence interval of the expected SN ratio is [36.846, 38.054]. The mean value falls within the confidence interval, indicating the accuracy of the confirmation experiment.

Validity of the experiment is analyzed by the following 3 indices:

(1) Overall contribution rate: The SN ratio of the optimal combination of factor level falls within the confidence interval, indicating that both the significant factors, A, B, and E and their corresponding level are accurate. The optimal significant factor level of this experiment is $A_1B_3E_1$, with an overall contribution rate of 78.95%.

(2) Contribution rate of error item (ρ_{err}): According to our previous experience, when $\rho_{err} \leq 15\%$, it is recognized that some of the significant factors have not been neglected in the experiment. However, if $\rho_{err} \geq 50\%$, we may well assume that some of the significant factors have been

neglected in the experiment, indicating experimental conditions weren't as good as they should be, or there were big measurement errors occurred in the experiment. Since the resultant ρ_{err} is 21.05%, therefore no significant factors have been neglected in this experiment.

(3) In our confirmation experiment, the expected SN ratio falls within the confidence interval: mean SN ratio is 37.308, while the confidence interval of the expected SN ratio is [36.846, 38.054], with the mean value falling within the confidence interval. In summing up the conclusion drawn from by the preceding 3 indices, the study is successful. And we get the optimal process parameters of the artificial marble product: factor A - defoaming time is 5 minutes; factor B - resin ratio is 0.6 to 1; factor C - the amount of hardener is 9cc; factor D - baking time is 75 minutes; factor E - baking temperature is 75℃; factor F - the amount of transparent glue is one even spraying; under the condition of ($A_1B_3C_3D_2E_1F_1$), the product quality can be upgraded without any increasing of production cost.

V. CONCLUSION

The purpose of this study is to improve the safety problem caused by broken artificial marble shreds, to find the safe parameter and level of manufacturing artificial marble by applying the Taguchi Method to analysis, and to upgrade product safety without having to increase the cost. That is, to achieve the maximum safety, not the optimal production process (production cost involved) under this parameter level. Lastly, through conducting reproducibility experiment (confirmation experiment), we expect to reach a quality improvement rate up to as high as 13.5%, and to effectively raise the safety of artificial marble products. Nevertheless, unexpected product defects or accidental injuries and death are inevitably resulted from various human behaviors exceeding the designed product functions. For example, uneven pressure borne by the sink due to the accumulated usage time and user's habits may result in the falling down or shattering of sink, hence the user's injuries (feet artery and other vital parts), or death. In light of this, this study, by targeting the property level corresponding to the parameters of various controllable factors, has acquired the optimal combination of parameter level, which not only enables engineering parameter calibration prior to completion of product, but can also acquire a satisfactory safety improvement with the least cost.

ACKNOWLEDGMENT

The research in this paper was partially supported by the National Science Council of Taiwan under grant NSC97-2410-H-167-008-MY2.

REFERENCES

[1] W. Ahmed, E. Ahmed, C. Maryan, M.J. Jackson, A.A. Ogwu, N.Ali, V.F. Neto , and J. Gracio, "Time -modulated CVD process optimized using the Taguchi method," *Journal of Materials Engineering and Performance*., vol. 15, no. 2, pp. 236-241, 2006.

[2] C.W. Chang, and C.P. Kuo, "Evaluation of surface roughness in laser-assisted machining of aluminum oxide ceramics with Taguchi method," *International Journal of Machine Tools and Manufacture*, vol. 47, no. 1, pp.141-147, 2007.

[3] C.S. Chang, H.K Sun, M.C. Tsou, W.L. Pearn, and T.C. Hsia, "Robust Design of a Rifle Muzzle Noise Reducer Based on Taguchi Methods," *Journal of Chung Cheng Institute of Technology*, vol. 34, pp.17-28, 2005.

[4] S. Guharaja, A. Noorul Haq, and K.M. Karuppanan, "Optimization of green sand casting process parameters by using Taguchi's method," *International Journal of Advanced Manufacturing Technology*, vol. 30, no. 11-12. pp. 1040-1048, 2006.

[5] S.J. Kim, K.S. Kim, and H. Jang, "Optimization of manufacturing parameters for a brake lining using Taguchi method," *Journal of Materials Processing Technology*, vol. 136, no. 1-3. pp. 202-208, 2003.

[6] M. Nataraj, V.P. Arunachalam, and K.G. Suresh, "Optimising planer cam mechanism in printing machine for quality improvement using Taguchi method: Risk analysis with concurrent engineering approach," *International Journal of Computer Applications in Technology*, vol. 26, no. 3. pp. 164-173, 2006.

[7] C.S. Chang, R.C. Liao, K.L. Wen, and W.P. Wang, "A grey-based Taguchi method to optimize design of muzzle flash restraint device," *International Journal of Advanced Manufacturing Technology*, vol. 24, no. 11-12, pp. 860-864, 2004.

[8] C.S. Chang, R.C. Liao, K.L. Wen, and W.P. Wang, "Application of Grey-Taguchi Method in the Optimal Design of Rifle Muzzle Noise Reducer. Proceedings of APIEM," in Proc. of 4th Conf. *Asia-Pacific Conference on Industrial Engineering and Management System,* pp.1786-1789, 2004.

[9] F.C. Wu, "Optimising robust design for correlated quality characteristics," *International Journal of Advanced Manufacturing Technology*, vol. 24, no. 1-2. pp. 1-8, 2004.

[10] P.J. Ross, Taguchi techniques for quality engineering. McGraw-Hill, New York, 1995.

[11] D.H.. Wu, and M.S. Chang, "Use of Taguchi method to develop a robust design for the magnesium alloy die casting process.," *Materials Science and Engineering: A* vol. 379, no. 1-2. pp. 366-371, 2004.

[12] J. Antony, and F.J. Antony, "Teaching the Taguchi method to industrial engineers," *Work Study*, vol. 50, no. 4, pp.141-149, 2001.