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Modelling Porosity Permeability of Ceramic Tiles using Fuzzy Taguchi Method

https://doi.org/10.1515/chem-2018-0117
received January 31, 2018; accepted June 8, 2018.

Abstract: Taguchi experiment design in quality development studies, is an approach to engineering that supports research and development, product design and product development activities by enabling fewer trials of experiments to determine the best combinations of inputs that affect the outcome. In this study, the factors affecting the porosity were studied in a firm that produces ceramic tile. There were 6 factors considered to be important in total and 2 levels in each factor. L8 orthogonal array were used during the experiment design, which proposes 8 experiment types with different factor levels. The results of the experiments were analyzed so that important factors were determined. Significance of factors were tested by ANOVA and 4 of them were found to be significant. These factors were fuzzified by assessing the factors using linguistic expressions and then triangular fuzzy numbers. A model with 4 inputs and 1 output was built and 34 rules were generated for this model. The developed model was shown to be a useful approach in modeling the porosity permeability of ceramic tiles.

Keywords: Fuzzy Taguchi; Experiment Design; ANOVA Analysis; Porosity Permeability.

PACS: 07.05.Mh, 07.05.Fb, 91.60.Np, 02.70.Rr

1 Introduction

Taguchi method was developed by Genichi Taguchi as a process improvement technique in the 1950s [1]. Taguchi method is an experimental design and optimization method based on parameter design, system design and tolerance design. It is commonly used to perform statistical analysis of collected data within quality assurance systems. Taguchi experiment design is an approach in engineering that supports product design and product development activities by enabling less trials of experiments to determine the most effective combinations of input values that yield better outcome [2].

There are various studies on the application of the Taguchi method in different areas. Savaşkan et al. aimed at finding the cost and quality benefits of maximizing the process parameters and increasing the life of the drill bits, based on the importance of drilling in the metalworking industry [3].

Baynal used the Signal to Noise (S/N) ratio in order to eliminate the bulge and slickness at the head of the products and to make the weight and dimensions close to the target values. By doing experiments with 3 levels of 13 factors (L27) in the study, it provided equipment, energy and labor savings as well as improved weight of produced parts [4].

Öztop investigated the impact rate and interactions of extrusion speed, temperature of the extrusion, rate of extrusion and profile of the die guide distance over the profile temperature, punch force and die surface pressure, which are decisive on die lifetime in aluminum extrusion process, using the Taguchi experiment design method. He determined the most important factors using the L8 orthogonal array [5].

Kiani et al. studied Zn (II) removal from aqueous solution using halloysite nanotubes. They found the optimum conditions for adsorption capacity and removal percent with Taguchi method using 4 levels of 5 control factors (L16) which are pH, contact time, adsorbent mass, temperature and initial concentration of Zn (II) [6].

Fuzzy Logic is a method for optimization which used in several engineering problems. This method can be used in Civil Engineering, Mechanical Engineering, Industrial Engineering, Chemical Engineering etc. Ibadov used Fuzzy Sets for determining the risk factors

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in the construction projects [7]. Adali et al. used Fuzzy for selecting the optimal shift numbers in a paint factory [8]. Erdem used Fuzzy analytical hierarchy process for personnel selection in IT companies [9]. Toklu determined the customer loyalty levels by Fuzzy multi criteria decision making approaches [10]. Akinrotimi and Oladele used fuzzy logic to classify patients with typhoid fever disease in five different severity by generating explainable rules for diagnosis [11]. Srivastava et al. implemented fuzzy logic to predict the rainfall using temperature and humidity as parameters [12].

Jenatabadi et al. combined fuzzy analytical hierarchy process and Taguchi method to determine a pattern for willingness to pay characteristics of public transportation users based on their satisfaction [13]. Ngo et al. combined fuzzy theory with Taguchi method to optimize in fly cutting process and applied to hobbing process [14].

Ethical approval: The conducted research is not related to either human or animal use.

2 Problem Definition

In this study, tile production process of a ceramic company was analyzed. Tile is a construction material used for floor and wall coating in closed and open areas regardless of shape and size. Decorative tile consists of four parts in structural aspect; mass, liner, glost and decor. The raw materials in the mass are shaped by pressing, plastic extrusion or casting at normal room temperature after being processed through grinding, sieving and mixing processes. The shaped body is then cooked at high temperature [15].

Porosity has a great importance in ceramics. Porosity is defined as the ratio of the amount of water that the tile can contain to the weight of the tile, expressed in percentage [15]. Low degree of porosity is a desirable condition for ceramic materials. Low porosity indicates good quality of ceramics. For this reason, the factors affecting the porosity of tiles are examined and the most important factors are determined using the Taguchi experiment design method. After the factors with the greatest effect on the porosity are determined, a fuzzy model is suggested to calculate the porosity for any value of these factors.

3 Suggested Model

There are 6 factors that affect the porosity of tiles. Engineers in the factory may prefer one of two levels of value for each factor, during operations. Therefore, normally, 2^6 combinations of experiment is required in order to find out the most effective factor levels. However, with the Taguchi experimental design, using L8 orthogonal array that proposes only 8 experiment combinations will be sufficient to analyze effective combinations of factor levels. The factors affecting the porosity, as well as their level values given in Table 1.

Table 1: Factors and their level values that affects the porosity.

Factors		Level 1	Level 2
A	Alcali ratio	3%	6%
B	Grain size of mud	10μ	20μ
C	Size distribution of mass	>250μ rate 80%	>250μ rate 90%
D	Pressure of press	250 bar	300 bar
E	Furnace temperature	1100°C	1200°C
F	Firing time	35 min.	40 min.

Table 2: L8 orthogonal array and observed values.

	Factors and their levels						Observed values (%)			
Exp.	A	B	C	D	E	F	1	2	3	4
1	3	10	80	250	1100	35	14	16	16.3	17.2
2	3	10	80	300	1200	40	11.2	10	10.8	11.5
3	3	20	90	250	1100	40	19.2	18.7	19	18
4	3	20	90	300	1200	35	8.3	9.1	7.9	8.9
5	6	10	90	250	1200	35	1.1	0.7	1	1.3
6	6	10	90	300	1100	40	5	5.4	5.5	5.4
7	6	20	80	250	1200	40	2	2.5	2.1	2.3
8	6	20	80	300	1100	35	4.6	4.8	4.8	4.5

The L8 orthogonal array was generated with the help of the Minitab program and the experiments were performed according to the experiment combinations proposed by this array. Experiments were repeated 4 times for each combination. L8 orthogonal array and observed values of the experiments given in Table 2.

4 Application

The signal to noise (S/N) ratio indicates variability of response values relative to the target value under different noise conditions. S/N ratio of factors given in Figure 1. Since the best result can be obtained with lowest porosity,

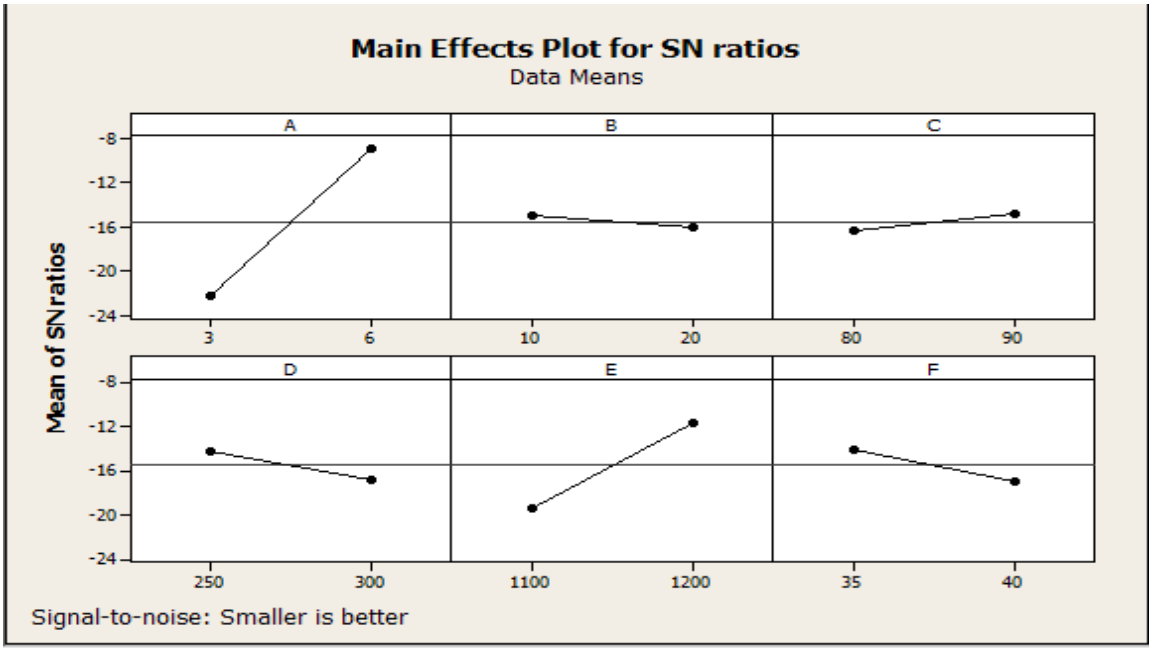

Figure 1: S/N ratios of factors.

Table 3: ANOVA test results.

Source	DF	Seq. SS	Adj. SS	Adj. MS	F	P
A	**1**	**831.30**	**831.30**	**831.30**	**1428.32**	**0.000**
B	1	0.58	0.58	0.58	0.99	0.329
C	1	0.00	0.00	0.00	0.00	0.982
D	1	35.49	35.49	35.49	60.98	0.000
E	1	240.35	240.35	240.35	412.97	0.000
F	1	24.68	24.68	24.68	42.40	0.000
Error	25	14.55	14.55	0.58		

the "smaller is better" approach was used to calculate the S/N ratio. The greatest levels in the S/N ratio graph indicate the best values of factors to obtain better porosity. It is seen that among all the factors, the most effective factors on the porosity are A and E. On the other hand, the effect of using different levels of factor B or C is close to zero. Factors D and F seem to have small effect on porosity.

The results of the ANOVA test performed on the Minitab program are given in Table 3. Values of P less than 0.05 denote that related factor significantly affects the porosity. For this reason, the fuzzification process was performed on factors A, D, E and F, which were found to be effective in ANOVA.

The values of factors found to be significant in the ANOVA test were fuzzified by classifying the values into linguistic expressions as "very low", "low", "medium", "high" and "very high". Then, these expressions were transformed into triangular fuzzy numbers within range of lower and upper limits. Linguistic rules were formed between these expressions and porosity.

34 rules related to the porosity model with 4 inputs and 1 output were established. Some of these rules are given below:

1. If the alkali ratio is low and the press pressure is not high and the furnace temperature is low and the firing time is not high, then the porosity is high.
2. If the alkali ratio is low and the press pressure is not high and the furnace temperature is low and the firing time is high, then the porosity is very high.

⋮

34. If the alkali ratio is high and the press pressure is high and the furnace temperature is high and the firing time is high, then the porosity is very low.

5 Conclusion

The linguistic expressions and rules treated with the defuzzification process using the Matlab program to obtain crisp results. At this stage, unlike in Taguchi method, the porosity value can be calculated for any value of each factor in the interval between two levels, as well as for all value combinations of all factors.

The effect of the A and E factors, which are the most effective on the porosity is shown in Figure 2. Porosity is

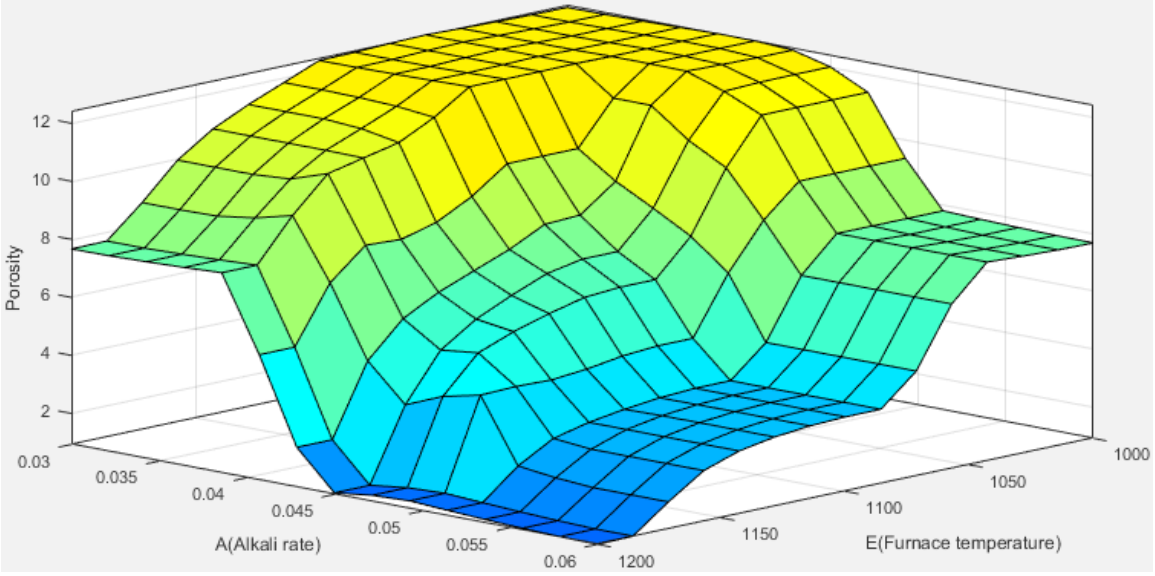

Figure 2: Effect of A (Alkali rate) and E (Furnace temperature) to porosity.

very low at the blue region and gets higher as the region color turns to yellow.

Integrating fuzzy logic into Taguchi method enables the decision maker to apply enhanced analysis. This approach could be used in any Taguchi implementation in different areas.

Acknowledgements: We would like to thank Ind. Eng. Lütfiye Hamamcı for providing the data necessary to carry out this study.

Conflict of interest: Authors state no conflict of interest.

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