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APPLICATION OF TAGUCHI METHOD FOR OPTIMIZATION IN CERAMIC TILES BODY MATERIALS COMBINATION

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Abstract:

This paper presents an application of the Taguchi optimization technique in determining the optimum raw materials combination for producing green tiles of desired quality characteristics i.e. strength (MoR) and water absorption (%) required for further processing steps. Five main tile body raw materials – clay, dolomite, talc, calcite, and feldspar – were chosen as process parameters and, the performance parameters used for this study were the strength (M.O.R.) and water absorption of the resulting green tile body. An orthogonal array (OA), L27(3,5), and five controllable three level factors were adopted. Manufacturing facility setup was used to carry out experiments and explores the effect of the raw material combinations on the qualities of the final green tile body. Furthermore, the effects of the experimental factors on the selected performance parameters of the produced green tile body were investigated using the analysis of variance approach (ANOVA), thus optimizing the selected parameters. The experimental results indicate that it is possible to produce high performance green tiles by incorporating optimum raw materials combination. Especially, the Taguchi method provides a simple, systematic, and efficient methodology for optimizing raw materials combination.

Keywords: Taguchi Analysis, Design of Experiments (DoE), ANOVA, Ceramic Tile Manufacturing.

1 INTRODUCTION

Ceramic tile is one of the important building materials in present days. Ceramic tile manufacturing is a rapidly growing business in India, which is one of the world's fastest developing countries. Manufacturers are always under pressure to increase performance due to the competitive market environment. Given the features of the manufacturing process for ceramic tiles, quality improvement is becoming increasingly important. The production of ceramic tiles is a flow-style process with several steps of processing. The key stages in the production of ceramic wall tiles include material preparation, shaping (pressing), pre-glaze fire (drying), glaze application, tile printing, post-glaze firing, final inspection and sorting, packaging, and storage. The quality of the finished tile is largely influenced by the quality of the raw materials used and their proper mixing at the start.

Design of experiments (DOE) is a systematic approach to solving an engineering problem in which techniques and concepts are applied during the data gathering stage to ensure the creation of valid, defensible, and supportable engineering findings. Furthermore, all of this is done with the utmost efficiency in terms of engineering runs, time, and money [1, 2, 3, 4].

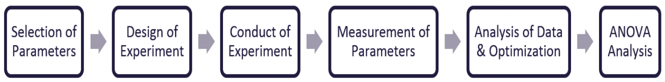
The Taguchi technique is a robust design that involves lowering variation in an experimentation phase. The method's overall goal is to produce a high-quality product at a low cost to the manufacturer. This approach was introduced by Dr. Genichi Taguchi of Japan [10]. This method proposes the use of orthogonal arrays to organise the parameters affecting the process and the levels at which they should be varied; it allows for the gathering of the necessary data to determine which factors have the greatest impact on product quality with the least amount of experimentation, saving resources and time [3]. In Taguchi approach, selecting an appropriate orthogonal array for selected parameters is an important step. [2] In general, each product or process' performance characteristic has to have a nominal or target value. The purpose is to limit the variability in this target value's vicinity. In different operating situations or at different times, the optimal working conditions identified at the end of the experimental investigation should always deliver the same or very close performance value. As a result, the optimization criterion should ensure that the variability in the performance value is minimized [6]. A performance statistic, according to the Taguchi technique, is such an optimization criterion.

Analysis of variance (ANOVA) is a method that investigates and models the relationship between the variables called a response and independent variables and the variables may be one or more[10,11]. The relationships between responses and process parameters are determined, and the validity of these relationships is confirmed using ANOVA [13]. It helps to identify the most important variables affecting the process [1]. On the experimental results, ANOVA is used to differentiate between important and unimportant parameters [2]. The optimum condition is established by examining the principal effects of each factor, which reveal the overall trends of the factors' effects. It becomes easy to estimate the levels of the factors expected to yield the best results once it is known that either a high or low value yields the desired result. Analysis of variance (ANOVA) is a standard statistical procedure for determining the percentage effect of each factor on experimental outcomes [6,9,12].

2 METHODOLOGY

Methodological steps used for this study are shown in below figure 1.

Figure 1: Methodological steps



The Taguchi approach was used to design the experimental protocol in this study. Five main tile body raw materials – clay, dolomite, talc, calcite, and feldspar – were chosen as factors (process parameters) in this study. Furthermore, the responses (performance parameters) used for this study were the strength (M.O.R.) and water absorption of the resulting green tile body. The interaction between the process parameters was ignored, as the Taguchi method can determine the existence or lack of interaction. The values of these parameters are listed in the Table 1 below.

Table 1: Process parameters and design levels.

Level	Factors (Process Parameters)					Response (Performance Parameters)	
	1	2	3	4	5		
	Clay (%)	Dolomite (%)	Talc (%)	Calcite (%)	Feldspar (%)	1	2
1	62	16	9	3	10	Strength (M.O.R.) in Kg/cm2	W. A. (%)
3	68	12	8	5	7		
5	74	14	5	4	3		

For designing experiments, Taguchi suggested using what he referred to as orthogonal arrays [7]. An orthogonal array (OA), $L_{27}(3^5)$, and five controllable three level factors were adopted. Manufacturing facility setup was used to carry out experiments and explores the effect of the raw material combinations on the qualities of the final green tile body. Taguchi analysis was carried out using to explore the effects of the experimental factors on the performance parameters of the produced green tile body, thus optimizing the selected parameters. The presence of optimum conditions was evaluated by including all of the performance statistical values in the analysis, and the optimum conditions were obtained using the MINITAB software.

3 RESULTS & ANALYSIS

1.1 **Experimental Results and S/N Ratio:** The performance characteristic deviation from the target value is commonly measured using a loss function; which is further transformed into a Signal-to-Noise ratio (S/N) to determine the quality of characteristics that are insensitive to noise factors. A higher S/N ratio in combination with a higher factor level suggests a better performance characteristic, and a design project with the highest S/N ratio consistently produces optimal quality characteristics with minimal variance [5,8,14]. Table 2 shows the experimental results and the corresponding S/N ratios. The influence of each selected factor on the quality characteristic (performance parameters) investigated is described in detail below.

Table 2: Experimental Results and S/N Ratio

Exp. No.	Clay (%)	Dolomite (%)	Talc (%)	Calcite (%)	Feldspar (%)	Green Tile Strength (M.O.R.) in Kg/cm2	SNR for Strength (MoR)	W. A. (%)	SNR for W.A. (%)
1	62	16	9	3	10	88	-38.8897	14	-22.9226
2	62	16	9	3	7	86.5	-38.7403	14.5	-23.2274
3	62	16	9	3	3	84	-38.4856	14.7	-23.3463
4	62	12	8	5	10	87.5	-38.8402	14.5	-23.2274
5	62	12	8	5	7	85	-38.5884	15	-23.5218
6	62	12	8	5	3	83	-38.3816	15.3	-23.6938
7	62	14	5	4	10	83.5	-38.4337	16	-24.0824
8	62	14	5	4	7	81	-38.1697	16.5	-24.3497
9	62	14	5	4	3	77.5	-37.786	17	-24.609
10	68	16	8	4	10	86	-38.69	15	-23.5218
11	68	16	8	4	7	84.5	-38.5371	15.3	-23.6938
12	68	16	8	4	3	81.5	-38.2232	15.5	-23.8066
13	68	12	5	3	10	82	-38.2763	16.3	-24.2438
14	68	12	5	3	7	80.5	-38.1159	16.5	-24.3497
15	68	12	5	3	3	77.5	-37.786	17	-24.609
16	68	14	9	5	10	83.5	-38.4337	14.3	-23.1067
17	68	14	9	5	7	82.5	-38.3291	14.7	-23.3463
18	68	14	9	5	3	79.5	-38.0073	15	-23.5218

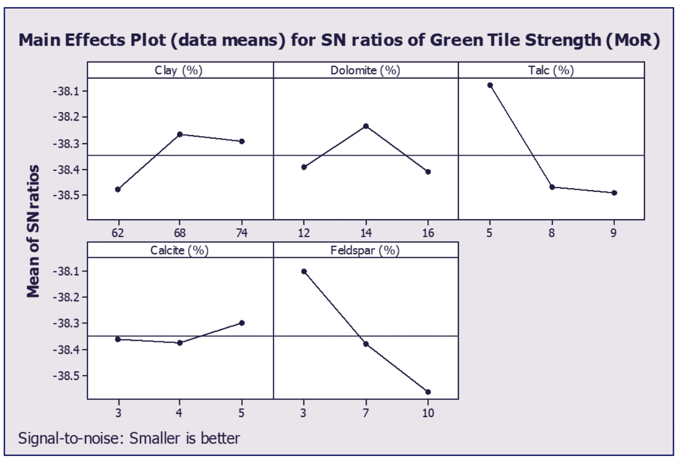
19	74	16	5	5	10	81	-38.1697	17	-24.609
20	74	16	5	5	7	80.5	-38.1159	16.5	-24.3497
21	74	16	5	5	3	78	-37.8419	16	-24.0824
22	74	12	9	4	10	86	-38.69	14.5	-23.2274
23	74	12	9	4	7	84.5	-38.5371	14.7	-23.3463
24	74	12	9	4	3	82.5	-38.3291	15	-23.5218
25	74	14	8	3	10	85.5	-38.6393	15.3	-23.6938
26	74	14	8	3	7	82	-38.2763	15.5	-23.8066
27	74	14	8	3	3	80	-38.0618	15	-23.5218

3.2 Taguchi Analysis: Green Tile Strength V/s Clay (%), Dolomite (%), Talc (%), Calcite (%) and Feldspar (%)

Table 3: Response Table for Signal to Noise Ratios of Strength (MoR)

Level	(%) Clay	(%) Dolomite	(%) Talc	(%) Calcite	(%) Feldspar
1	-38.48	-38.39	-38.08	-38.36	-38.10
2	-38.27	-38.24	-38.47	-38.38	-38.38
3	-38.30	-38.41	-38.49	-38.30	-38.56
Delta	0.21	0.17	0.42	0.08	0.46
Rank	3	4	2	5	1

Figure 2: S/N Response Graph for Green Tile Strength (MoR)



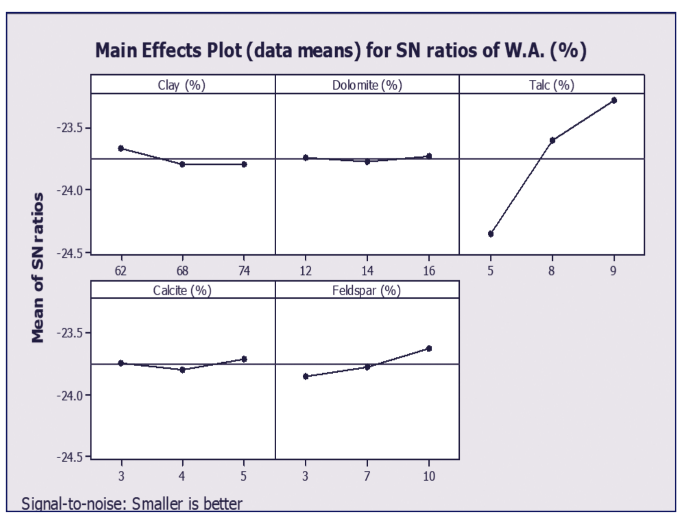
Above figure 2 shows the S/N response graph for green tile strength (MoR). The larger the S/N ratio, the smaller the variance of strength (MoR) around the desired (the-smaller-the-better) value. From above Table and Figure, it can be seen that the feldspar (%) was the most important factor affecting the responses; the maximum value of response was at the highest level of the feldspar (%). Table 2 shows that the Strength (MoR) of the produced green tile ranged between 77.5 and 88 Kg/cm2. Moreover, the highest value of the Strength (MoR) was around 88 Kg/cm2 (Exp. No. 1). The response for Signal to Noise Ratios of Strength (MoR) is summarized in Table 3. As shown in this, Delta is the difference between the highest and lowest characteristic average for a factor is used to calculate the size of the effect. Feldspar is ranked first because it has the highest delta value and is the most important factor affecting tile strength; talc, clay dolomite, and calcite are ranked lower and have decreasing effects on tile strength.

3.3 Taguchi Analysis: Green Tile W. A. (%) V/s Clay (%), Dolomite (%), Talc (%), Calcite (%) and Feldspar (%)

Table 4: Response Table for Signal to Noise Ratios of W.A. (%)

Level	(%) Clay	Dolo-(%) mite	(%) Talc	Calcite (%)	Feldspar (%)
1	-23.66	-23.75	-24.36	-23.75	-23.86
2	-23.80	-23.78	-23.61	-23.80	-23.78
3	-23.80	-23.73	-23.29	-23.72	-23.63
Delta	0.14	0.05	1.08	0.08	0.78
Rank	3	5	1	4	2

Figure 3: S/N Response Graph for Green Tile W.A. (%)



It can be seen from Table 2 that the water absorption of the green tile ranged between 14–17%. In particular, the lowest value of water absorption was 14% and was obtained with sample No. 1. Table 2 also shows the mean S/N ratio at each level of the parameters for water absorption, while above shows the S/N response graph for water absorption. It is evident from Table and Figure 3 that the talc (%) is the most critical factor affecting water absorption; the maximum value of response was at the highest level of talc (%). Figure also indicated that the water absorption decreased with an increase of talc (%).The response for Signal to Noise Ratios of W.A.(%) is summarized in Table 4. As shown in this, Delta is the difference between the highest and lowest characteristic average for a factor is used to calculate the size of the effect. Talc is ranked first because it has the highest delta value and is the most important factor affecting W.A.(%); feldspar, clay calcite and dolomite are ranked lower and have decreasing effects on W.A.(%).

3.4 ANOVA Analysis: ANOVA analysis was carried out to identify significant parameters. The purpose of an analysis of variance (ANOVA) is to determine the contribution of each factor to the product's performance variability [5]. The generated ANOVA table can be helpful to determine which parameters should be controlled to reduce variability. Degree of freedom, sum of squares, mean square, F value, P value and Pooled standard deviation are all key terms in the derived tables.

Table 5: ANOVA for Green Tile's Strength (M.O.R.) – F Ratio & P Value

		Degree of Freedom	Sum of Squares	Mean Square	F-Ratio	Significance Value (P)
Clay (%),	Between Groups	2	22.39	11.19	1.35	0.279
	Within Groups	24	199.28	8.30		
	Total	26	221.67			
Dolomite (%),	Between Groups	2	15.17	7.58	0.88	0.427
	Within Groups	24	206.50	8.60		
	Total	26	221.67			
Talc (%),	Between Groups	2	88.39	44.19	7.96	0.002
	Within Groups	24	133.28	5.55		
	Total	26	221.67			
Calcite (%)	Between Groups	2	2.72	1.36	0.15	0.862
	Within Groups	24	218.94	9.12		
	Total	26	221.67			
Feldspar (%)	Between Groups	2	87.72	43.86	7.86	0.002
	Within Groups	24	133.94	5.58		
	Total	26	221.67			

Table 6: ANOVA for Green Tile's Strength (M.O.R.) – Pooled Std. Dev.

	Level	N	Mean	Std. Dev.	Pooled Std. Dev.
Clay (%),	62	9	84.000	3.317	2.882
	68	9	81.944	2.591	
	74	9	82.222	2.682	
Dolomite (%),	12	9	83.167	3.021	2.993
	14	9	81.667	2.437	
	16	9	83.333	3.279	
Talc (%),	5	9	80.167	2.092	2.357
	8	9	83.889	2.421	
	9	9	84.111	2.534	
Calcite (%)	3	9	82.889	3.389	3.020
	4	9	83.000	2.727	
	5	9	82.278	2.906	

Feldspar (%)	3	9	80.389	2.472	2.362
	7	9	83.000	2.194	
	10	9	84.778	2.412	

From Table 5 and 6, it is evident that feldspar and talc are the main factors affecting strength at a 95% confidence level, because their P-values are less than 0.05, and their pooled standard deviation are 2.362 and 2.357, respectively.

Table 7: ANOVA for Green Tile's W. A. (%) – F Ratio & P Value

		Degree of Freedom	Sum of Squares	Mean Square	F-Ratio	Significance Value (P)
Clay (%),	Between Groups	2	0.312	0.156	0.18	0.834
	Within Groups	24	20.424	0.851		
	Total	26	20.736			
Dolomite (%),	Between Groups	2	0.036	0.018	0.02	0.979
	Within Groups	24	20.700	0.862		
	Total	26	20.736			
Talc (%),	Between Groups	2	17.837	8.917	73.74	0.000
	Within Groups	24	2.902	0.121		
	Total	26	20.736			
Calcite (%)	Between Groups	2	0.081	0.040	0.05	0.954
	Within Groups	24	20.656	0.861		
	Total	26	20.736			
Feldspar (%)	Between Groups	2	0.739	0.369	0.44	0.647
	Within Groups	24	19.998	0.833		
	Total	26	20.736			

Table 8: ANOVA for Green Tile's W. A. (%) – Pooled Std. Dev.

	Level	N	Mean	Std. Dev.	Pooled Std. Dev.
Clay (%),	62	9	15.278	1.015	0.923
	68	9	15.511	0.902	
	74	9	15.500	0.843	
Dolomite (%),	12	9	15.422	0.936	0.929
	14	9	15.478	0.874	
	16	9	15.389	0.973	
Talc (%),	5	9	16.533	0.400	0.348
	8	9	15.156	0.317	
	9	9	14.600	0.320	
Calcite (%)	3	9	15.422	1.001	0.928
	4	9	15.500	0.843	
	5	9	15.367	0.933	
Feldspar (%)	3	9	15.611	0.871	0.913
	7	9	15.467	0.834	
	10	9	15.211	1.023	

From Table 7 and 8, it is evident that talc is the most affecting factor for W.A. at a 95% confidence level, because its P-values is less than 0.05, and its pooled standard deviation is 0.348 which is lowest among all the factors.

4 CONCLUSION

This research presented an application of the Taguchi optimization technique in determining the optimum raw materials combination for producing green tiles of desired quality characteristics i.e. strength (MoR) and water absorption (%) required for further processing steps. Based on the above results and discussion, the following conclusions are drawn:

- The green tiles produced had strength (MoR) ranging from 77.5 and 88 Kg/cm2 and water absorption ranging from 14–17%. These values were comparable to the requirements for green tiles in further manufacturing steps.
- The experimental combinations 1, 4, 16, and 22 were suitable for use as high-performance green tiles material combination. The strength (MoR) of 1, 4, 16, and 22 ranged from 83.5 and 88 Kg/cm2 and is higher than required. Moreover, the water absorption of 4, 16, 19 and 22 ranged from 14–14.5% and was lower than required.
- The raw materials combination - Clay (62%), Dolomite (16%), Talc (9%), Calcite (3%), and Feldspar (10%) yields the optimum performance parameters - Green tile strength in MoR - 88 Kg/cm2 and Water absorption - 14%; which satisfies the desired quality level of green tiles undergoing for further manufacturing steps.
- From the design of experiments and ANOVA analysis, it was found that feldspar and talc are the raw materials which affect the most to green tile strength and water absorption (%); whereas the other materials have little effect on them.
- The experimental results indicate that it is possible to produce high performance green tiles by incorporating optimum raw materials combination. Especially, the Taguchi method provides a simple, systematic, and efficient methodology for optimizing raw materials combination.

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