Nested Hierarchical Design Application in Production of Ceramic Glazed Floor Tiles

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Abstract — The challenges of using locally available materials in Nigeria to meet the tiles demand that will be affordable and compete favourably with imported products will no doubt not only contribute to our Gross Domestic Product but also meet the yearning of the Federal Government on her local content policy. This necessitated this study to aim at the production of ceramic floor tiles with clays modified with naturally occurring materials. An experimental method was adopted to carry out this research work. Different clay samples were purposively gotten from Mbaukwu town, Anambra State, Nigeria. Rice husk, silt, feldspar, quartz was obtained to serve as modifiers. An elaborate nested experimental design, structured as an analytical hierarchy process, and festooned with three base materials, 4-modifiers, and with replications, facilitated the achievement of the production. The nested design was developed to guide in the optimum combination of materials that will give the best yield of tiles. The base materials were used in combination with the four modifiers at different percentage levels. The tiles produced were subjected to same test in order to ascertain their behavior in terms of weather, resistance to abrasion, compatibility with mortar, water absorption, dilute acid, Sodium Hydroxide and detergent. The experimental tiles produced compete favorably with any foreign product as it was seen to match up with “Vetrified tiles” and “Gomex tile” from Italy and satisfies NIS 427: 2000. Glazed ceramic floor tiles have been successfully manufactured locally using clay and other naturally occurring materials and it has given excellent performance characteristics.

Index Terms — Ceramic, Experimental, Modifiers, Nested Design, Tiles.

I. INTRODUCTION

Despite a teeming market of over 200 million people, a substantial number of ceramic products used in Nigeria are imported. According to [1], the total value of ceramics imported into Nigeria is over $800 million. She purchases more tiles from abroad than any other African nation. The report went further to state Nigeria occupies the 9th position among world’s ceramic consumer and remain the only country among the emerging economies without export of ceramic products. There are abundant natural resources needed for ceramic tiles production in Nigeria [2]. Ceramic glaze production requires the use of various raw materials. These materials mostly are naturally occurring chemical substances called minerals found on the earth and readily available for use but needed to be refined in order to achieve better results. [3] carried out a physiochemical analysis of the clay samples, relatedly, [4] evaluated same samples from Mbaukwu and concluded that the clay has desired properties, and it is suitable for the production of floor tiles. The composition of glazes for tiles requires selections of specific materials which are blended in the right quantities, applied on clay-wares, and fired under proper condition in order to have desired outcome as stated by [5]. The list of raw materials and quantities required to make a particular glaze for a particular firing temperature is known as the recipe. Each of the materials in a glaze recipe contributes component oxide(s) that will end up in the fired glaze. With a nation like Nigeria experiencing significant construction and infrastructural growth, and as economic boom is currently driving the country towards industrialization, the ceramic industry can become a strategic growth market [6]. Although, past research efforts had focused on using clays to produce bricks, pots, refractories and even tiles, none of them provided a true field scientific experimentation on the possibility of the use of clays with other local modifiers to produce glazed floor tiles. Some studies done on the subject area have reported some intriguing and exciting findings [8], [9]. Hierarchically nested designs are appropriate when each of the factors in an experiment is progressively nested within the preceding factor. A nested factor has unique levels within each level of one or more other factors and the allocation of experimental resources in hierarchically nested designs yields more information on factors that are lower in the hierarchy than on those that are higher [10]. Few research studies have so far fitted elaborate nested experimental design to a production process. This study is a novel attempt in the application of hierarchical experimental design to a mix formulation and ceramic tiles production. This study aimed at carrying out proper material selection, developing a nested hierarchical design for optimum combination of materials and carrying out production of the glazed Floor tiles.

II. METHODOLOGY

This is a model used for experiments in which there is an interest in a set of treatment and the experimental units are sub-sampled.

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Fig. 1. Nested Design Model for optimum combination of Materials.

A. Statistical Formulae

Sum of squares for total (SS_T):

$$SS_T = \sum_{i=1}^{l-1} \sum_{j=1}^{k-1} \sum_{l=1}^{\frac{K}{2}} \sum_{m=1}^{\frac{K}{2}} X_{ijkl}^2 - \frac{X^2}{IJKL}$$

Sum of squares for modifier types (SS_A):

$$SS_A = \sum_{i=1}^{l-1} \frac{X^2}{JKL} - \frac{X^2}{IJKL}$$

Sum of squares for modifier levels (SS_B):

$$SS_B = \sum_{j=1}^{k-1} \frac{X^2}{IKL} - \frac{X^2}{IJKL}$$

Sum of squares for percentage per volume of raw materials (SS_C):

$$SS_C = \sum_{l=1}^{l-1} \frac{X^2}{IJKL} - \frac{X^2}{IJKL}$$

Sum of squares for modifier types \( \times \) modifier levels interaction (SS_{AB}):

$$SS_{AB} = \sum_{i=1}^{l-1} \sum_{j=1}^{k-1} \sum_{l=1}^{\frac{K}{2}} \sum_{m=1}^{\frac{K}{2}} X_{ijkl}^2 - \frac{X^2}{IJKL}$$

Sum of squares for modifier types \( \times \) percentage per volume of raw materials interaction (SS_{AC}):

$$SS_{AC} = \sum_{i=1}^{l-1} \sum_{j=1}^{k-1} \sum_{l=1}^{\frac{K}{2}} \sum_{m=1}^{\frac{K}{2}} X_{ijkl}^2 - \frac{X^2}{IJKL}$$

Sum of squares for modifier levels \( \times \) percentage per volume of raw materials interaction (SS_{BC}):

$$SS_{BC} = \sum_{j=1}^{k-1} \sum_{l=1}^{l-1} \sum_{m=1}^{\frac{K}{2}} \sum_{n=1}^{\frac{K}{2}} X_{ijkl}^2 - \frac{X^2}{IJKL}$$

Error sum of squares (SS_E):

$$SS_E = SS_T - SS_A - SS_B - SS_C - SS_{AB} - SS_{AC} - SS_{BC} - SS_{ABC}$$

The performance characteristics of the produced tiles were carried out on different media such as sodium hydroxide, acid to determine their reactions on these media. The effect of heat, detergent, weather, water adsorption, abrasion and compatibility with mortar were also considered. The results obtained are presented.

III. RESULTS AND DISCUSSION

The model developed for this study is depicted as:

$$X_{ijkl} = \mu + \alpha_i + \beta_j + \gamma_k + (\alpha\beta)_j + (\alpha\gamma)_k + (\beta\gamma)_j + (\alpha\beta\gamma)_j + e_{ijkl}$$

where

- \( X_{ijkl} \) – response variable;
- \( i \) – modifier types (4);
- \( j \) – modifier levels (2);
- \( k \) – percentage per volume of raw materials (3);
- \( l \) – replications (2).

A. Experimental Procedure Results

1. Firing Procedures

Samples were first dried at room temperature before taking them outside, under the sun for rapid drying. Measures were taken to curb warpage of the tile samples. This includes placing over/on the tiles a wooden Barton of relative and commensurable weight and laying the textured side of the tiles on a flat paper-masked surface, for cross ventilation. The final drying was done inside the kiln, for relative and uniform drying. The manufactured samples are shown in the PLATES A and B below.
2. **Performance Test of the produced Tiles**

The tests carried out on the produced tiles include Water Adsorption Test, Effect of Detergent, Effect of Dilute acid, Effect of Alkaline Solution, Effect of Weather, Degradation by Heat, Resistance to Abrasion and Compatibility with mortar. These tests on ceramic products are of great importance, as they are under very close watch in the industry. Water absorption level could be regarded as an indication of the level of vitrification/densification and the lower the water absorption, the lower the porosity of the produced tiles. It is also important to have information about the extent of sintering/densification. In the production of standard size ceramic tiles, it is not desired to have a high firing shrinkage which sometimes may depend on the loss on ignition (LOI) of the unfired green structure.

3. **Resistance to Abrasion**

| S/N | Sample Description | Initial Weight (g) | Final Weight (g) | Change in Weight |
|-----|---------------------|--------------------|------------------|-----------------|
| Olamide Tiles | 146.77 | 103.97 | 42.80 |
| Vetrified | 167.89 | 158.07 | 9.82 |
| Gomex Tiles | 153.29 | 148.49 | 4.80 |

Fig. 2. Effect of Water Absorption.

Fig. 3. Effect of Detergent.

Fig. 4. Effect of Dilute Acid.

Fig. 5. Effect of Sodium Hydroxide Solution.

Fig. 6. Effect of Weather.

Fig. 1. Produced Tiles before Firing.

Fig. 2. Produced Tile After Drying and Firing.
4. Compatibility with Mortar

| S/N | Description       | Compatibility     |
|-----|-------------------|-------------------|
| 1.  | Olamide Tiles     | Highly Compatible |
| 2.  | Vetrified         | Highly Compatible |
| 3.  | Gomex Tiles       | Highly Compatible |

TABLE III: SCORING AND RANKING SCHEME FOR SELECTION OF BEST TILES

| Test Criteria           | Scoring and Ranking | Olamide’s Tiles | Vetrified | Gomex |
|-------------------------|---------------------|-----------------|-----------|-------|
| Water Test              |                     | 1               | 2         | 3     |
| Acid Test               |                     | 2               | 3         | 1     |
| Sodium Hydroxide Test   |                     | 2               | 3         | 1     |
| Detergent Test          |                     | 1               | 3         | 2     |
| Weathering Test         |                     | 3               | 1         | 2     |
| Abrasion Test           |                     | 3               | 2         | 1     |
| Total Score             |                     | 12              | 14        | 10    |

From the results of Fig. 2-6, it was observed that; although, an increase in weight was recorded, there was no change in the appearance of the three tiles tested and no swell was recorded. The change in weight observed in the three tiles tested can be traced to the presence of pores on the surface of the tiles. These pores were gradually filled as the detention time in the various medium increases. For water absorption test, the highest change in weight was recorded for Olamide’s tiles (29.63 g) followed by Gomex (25.63 g) and Vetrified (15.91 g). The implication is that the locally manufactured tiles have more pore spaces on the surface compared to commercially available tiles. For acid test, the highest change in weight was recorded for Gomex tiles (26.61 g) followed by Olamide’s tiles (20.28 g) and Vetrified (13.69 g). For sodium hydroxide test, the highest change in weight was recorded for Gomex tiles (26.46 g) followed by Olamide’s tiles (26.41 g) and Vetrified (26.24). For detergent test, the highest change in weight was recorded for Olamide’s tiles (29.43 g) followed by Gomex tiles (22.46 g) and Vetrified (14.66 g) and finally for weathering test, the highest change in weight was recorded for Gomex tiles (0.3 g) followed by Vetrified (0.2 g) and Olamide’s tiles (0.1 g). To select the best tiles based on the various test conducted, a ranking and scoring scheme was done with the tiles having the lowest change in weight given a score of 3 the next 2 and the tile with the highest change in weight given a score of 1. Result of the ranking and scoring scheme is presented in Table III. Based on the result of Tables III, Vetrified was acclaimed the best tile with Olamide’s tiles coming next to it. It is important to note that Vetrified and Gomex tiles are foreign products.

IV. CONCLUSION

Production of ceramic tiles using naturally occurring materials has been successfully achieved in this work. The experimental result shows that tiles produced using naturally occurring materials in Nigeria can compete satisfactorily with the imported ones as evident in the performance evaluation. Nested designs occur when restrictions of cost or experimental procedure require that some factor–level combinations be held fixed while combinations involving other factors are varied and this model has been deployed in achieving a standard product. This has far-reaching implication in encouraging local content policy of the Federal Government of Nigeria.

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