

## Impact of Suitable Replacement of Granite-Particles on Interlocking Tiles

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### Abstract

To investigate the impact of alternative replacement of granite-particles in the production of interlocking tiles. Aggregate mixes of homogeneously mixed raw materials was used for production of experimental interlocking tiles. The mortar method was used for casting purposes. Produced interlocking tiles were cured and treated for twenty-eight days before the physical and mechanical tests were conducted. For improved mechanical strength, an optimum mix of granite particles to lateritic soil to silica sand of 2:1:1 is recommended for suitable replacement for granite particles in the production of interlocking tiles. A simple model that relates the granite particles/cement ratio to water/cement ratio for interlocking tiles was determined, with a coefficient of correlation and standard error of estimate of 0.85 and 0.65 respectively. The investigation had shown that cheaper and easily available raw materials, such as lateritic soil and silica sand may be used as suitable replacement for granite particles in the production of interlocking tiles with acceptable properties. Developed model that relates the granite particles/cement ratio to water/cement ratio for interlocking tiles would be very useful for control studies or production purposes.

*Keywords:* interlocking tiles, aggregate mixes, granite particles, mechanical strength

### 1. Introduction

The abundant natural resources available in the environment offer a wide range of possibilities in the development of products that competes favourably with existing products with suitable alternatives of raw materials. Enhanced characteristics features or cheaper products could be achieved in many instances, especially when cheaper materials and manufacturing processes are engaged. Since 1999 the present evolving democratic dispensation in Nigeria have been accompanied with increased infrastructural development, and the usage of interlocking tiles have been found to be increasing in recently constructed building structures both for private and public purposes.

Tiles are usually applied in different areas such as building floors, warehouse, museum, art galleries, building walls, commercial garage, hall, factory e. t. c. [1]. They are structural or decorative items used to cover floors, roofs and walls. "It could also be extended to include small flat pieces of surfacing material that is not ceramic, such as carpet, wood, stone or cork [2]. In the past, interlocking tiles has been used to improve the outward appearance of building projects. Their unique feature is that they are simple to place together as they easily fit into one another. They are produced in different sizes, shapes, colours and patterns. They are made from bricks, ceramics, glass and concrete materials [3]. Interlocking tiles are loosely laid and do not

need any adhesives. In fact they can be removed or placed as the need arises. They are durable and easy to clean. And the fact that they can be removed and replaced easily helps to ensure that no dirt or dust particles accumulate below the surface [4]. Though with several advantages, interlocking tiles have a disadvantage that the mating ends where these tiles merged is visible, hence, liquid such as water or some chemicals may seep down the line between the mating parts. This mainly occurs in open air garage, kitchens, hospitals and some factories where water is liable to be distributed over the floor [5]. The core material mostly used to produce interlocking tiles in Nigeria is granite particles, otherwise known as stone dust (pulverized granite). The word granite comes from the Latin granum, which means a grain, in reference to the coarse-grained structure of such a crystalline rock. Granite is a common and widely occurring type of intrusive, felsic, igneous rock [6]. The average density of granite is 2.75 g/cm<sup>3</sup> [7]. The aggregated materials of interlocking tiles are usually bound together with cement. Cement is basically a binder which sets and hardens independently, and can bind other materials together when hydrated [8]. Interlocking tiles are originated from the south-east Asia seashore; they are made from natural materials and are produced by moulding together natural stones which when cut to size, are made into a mesh [9]. Presently, interlocking tiles are predominantly produced from small granite-particles known as stone dust, usually sourced from quarry site after several industrial processes and long distance transportation. Hence, quite expensive compared with other building construction materials such as gravel, sand and lateritic soil.

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The present study investigates suitably-cheaper and easily available raw materials for granite particles replacement in the production of interlocking tiles. The appropriate material-mix, physical and mechanical properties of experimentally produced interlocking tiles are being examined and compared with those produced by conventional means.

## 2. Methodology

### 2.1 Materials

Specimens of experimental interlocking tiles were produced from various mixes of granite-particles (stone dust), cement, silica sand, and lateritic soil. The mixture proportions and amount of lateritic soil and silica sand addition are presented in Table 1. The quantity of each batch of material-mix, were used to produce pieces of specimens of experimental interlocking tiles investigated for 10% and 15% cement content respectively. Experimental tests results were compared with those from field samples which were discovered to be produced with an average cement content of 15.17%.

**Table 1:** Aggregate mix of experimentally produced interlocking tiles

| Water/cement ratio | Granite particles/cement ratio | Lateritic soil (%) | Silica sand (%) |
|--------------------|--------------------------------|--------------------|-----------------|
| 2.30               | 3.35                           | 33.50              | —               |
| 2.20               | 3.40                           | 17.00              | 17.00           |
| 2.00               | 3.50                           | —                  | 35.00           |
| 1.53               | 2.07                           | 31.00              | —               |
| 1.47               | 2.10                           | 15.75              | 15.75           |
| 1.33               | 2.17                           | —                  | 32.50           |

### 2.2 Production process of experimental interlocking tiles

The aggregate mixes of each batch of experimentally produced tiles were homogeneously mixed together according to the proportions outlined in Table 1. The inner surfaces of the moulds used to cast the tiles were lubricated with a mixture of engine oil and diesel. The mortar method which involves the preparation of cement soup was used for casting purposes. Prepared mortar was first of all poured into the lubricated moulding containers and allowed to even out on the inner surfaces before the aggregate mixes were poured. The casted products were left for twenty-four hours to set properly before they were removed from the moulds. After production, the interlocking tiles were cured by watering for seven days and dried in-door (or under shield) for two weeks. After which it was left for another three days under atmospheric conditions before sun-dried for 4 days. This indicates that the produced interlocking tiles were treated for twenty eight days to attain adequate strength and form before the physical and mechanical tests were conducted on the tiles.

### 2.3 Physical properties tests of experimental produced interlocking tiles

#### 2.3.1 Measurement of water absorption

The mass of each specimen tested was first determined by weighing on a weighing balance and their values recorded, as the dry mass,  $M_d$ . Each specimen was then submerged in cold water for about 24 hours, after which the specimens were taken out of the water and their surfaces wiped with a piece of cloth to remove excess water. The new mass was determined by weighing and recorded as the saturated mass,  $M_s$ . The percentage water absorbed, otherwise known as “water absorption” were then calculated by using the relation [10]:

$$A = \frac{M_s - M_d}{M_d} \times 100\% \quad (1)$$

where, A = water absorption

#### 2.3.2 Saturation coefficient

This is the maximum amount of water the interlocking tiles can absorb, and it is determined by the expression [11, 12].

$$C_s = \frac{M_1 - M_d}{M_2 - M_d} \times 100\% \quad (2)$$

where,

$M_1$  = saturated weight within the first 24 hours

$M_2$  = saturated weight after 5 days

$M_d$  = dry weight of specime

#### 2.3.3 Measurement of drying shrinkage

Test specimens were first submerged in water for four days and their mass were determined as the saturation mass  $M_s$ . The Specimens were then oven dried until constant mass was attained. The mass of the specimens were then taken after they were removed from the oven and cooled at room temperature. The mass recorded after being oven dried was  $M_f$ . The drying shrinkage defined as the difference between the masses when saturated and when dried to a constant mass was then determined by the expression [13, 14]:

$$S_d = \frac{M_s - M_f}{M_f} \times 100\% \quad (3)$$

#### 2.3.4 Bulk density

Test specimens were dried to constant mass after curing, and the dry mass,  $M_d$  was determined. The bulk density, B ( $\text{g}/\text{cm}^3$ ), of a specimen is the quotient of the dry mass divided by volume of the specimen. The volume, V was determined from the surface dimensions, and physical geometry of the specimen. The bulk density was then calculated by the relation [10]:

$$B = \frac{M_d}{V} \quad (4)$$

### 2.4 Mechanical properties tests of experimental produced interlocking tiles

### 2.4.1 Flexural strength test

The flexural strength, expressed in terms of modulus of rupture, is given in MN/m<sup>2</sup> (MPa), and can be calculated as follows [15]:

(i) If the specimen broke within the middle third of the span length, the following equation applies:

$$R = \frac{PL}{bd^2} \quad (5)$$

where,

R = modulus of rupture, MPa  
 P = maximum applied load, N  
 L = span length, mm  
 b = average width of specimen, mm  
 d = average depth of specimen, mm

(ii) If the specimen broke outside the middle third of the span length by not more than 5% of the span length, the modulus of rupture can be calculated as follows:

$$R = \frac{3Pa}{bd^2} \quad (6)$$

where,

R = modulus of rupture, MPa  
 P = maximum applied load, N  
 a = distance, mm between the line of fracture and the nearest support, measured along the center line of the bottom surface of the beam  
 b = average width of specimen, mm  
 d = average depth of specimen, mm

### 2.4.2 Compression test

The compressive strength for each specimen was determined as the quotient of the average breaking force to the area of impact and is given by the relation [10]:

$$C_s = \frac{P_c}{A_c} \quad (7)$$

where,

CS = compressive strength of the specimen, MPa  
 PC = the average load on the specimen at failure, N  
 AC = calculated area of the bearing surface on the test specimen, mm<sup>2</sup>.

## 3. Results and discussion

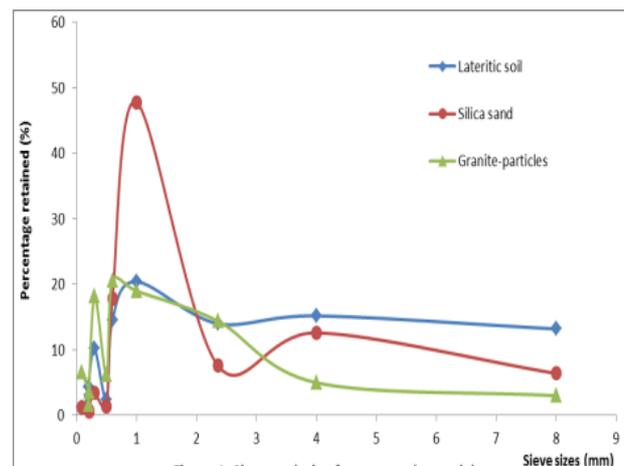
### 3.1 Physical properties of materials

The physical properties of the aggregated materials used in the production of experimental interlocking tiles investigated were determined as presented in Table 2. These comprises of colour, specific gravity, moisture content, the sieve analysis which indicates the maximum mass retained on sieve, the

mesh size of occurrence, and the grain fineness number respectively. Naturally occurring raw materials used for production purposes could be generally variable due to the as-received or processed conditions. Table 2 shows that the lateritic soil used had a specific gravity of 2.06 and moisture content of 5.00%, while the silica had a specific gravity of 2.38 and moisture content of 6.25%, and the granite particles had a specific gravity of 2.51 and moisture content of 2.50%. Generally, the specific gravity of solid and broken granite is given as 2.69 and 1.65 [16]. The maximum mass retained, mesh size of occurrence, and the grain fineness number of the raw materials are given as lateritic soil: 20.40%, 1.00 mm and 46.59, silica sand: 47.80%, 1.00 mm and 40.65, and granite particles: 20.60%, 0.60 mm and 62.25 respectively. The sieve analysis of the aggregated materials shown in Figure 1 reveals that the amounts of the materials retained within the 1.00 mm sieve size was lateritic soil-57.6%, silica sand-73.4% and granite particles-77.6%. Hence, 1.00 mm sieve was found adequate to produce the experimental interlocking tiles for maximum material utilisation accordingly.

**Table 2:** Physical properties of raw materials used to produce experimental tiles

| Physical Properties                | Lateritic soil | Silica sand | Granite-particles |
|------------------------------------|----------------|-------------|-------------------|
| Colour                             | Reddish brown  | Light Brown | Ash               |
| Specific gravity                   | 2.06           | 2.38        | 2.51              |
| Moisture Content (%)               | 5.00           | 6.25        | 2.50              |
| Maximum mass retained on sieve (%) | 20.40          | 47.80       | 20.60             |
| Mesh Size of occurrence (mm)       | 1.00           | 1.00        | 0.60              |
| Grain fineness number              | 46.59          | 40.65       | 62.25             |



**Fig.1:** Sieve analysis of aggregated materials

### 3.2 Water absorption, saturation coefficient and dryness shrinkage of interlocking tiles

The water absorption and dryness shrinkage respectively dropped from 21.26 to 11.51% and 21.54 to 11.90% as the granite particles/cement ratio increases from 2.07 to 2.17 and water/cement ratio reduces from 1.53 to 1.33 for 15% cement content as shown in Figure 2. The figure also shows

that water absorption and dryness shrinkage respectively dropped from 23.73 to 12.51% and 24.25 to 12.71% as the granite particles/cement ratio increases from 3.35 to 3.50 and water/cement ratio reduces from 2.30 to 2.00 for 10% cement content respectively. Furthermore, the water absorption and dryness shrinkage of the average from field samples was 12.76% and 11.95% at granite particles/cement ratio of 4.74 and water/cement ratio of 1.00. Higher cement content resulting in reduced porosity and improved hardenability was responsible for reduced water absorption and dryness shrinkage in the tiles.

The dryness shrinkage of experimental tiles was slightly higher than values of the water absorption at an average of 1.72% while that from field samples was 6.30%. This is an indication that the capacity of interlocking tiles to loose water is almost equivalent to the capacity to absorb water. The figure clearly reveals that the saturation coefficient of the tiles were almost independent of the material aggregate in the mixtures. The average value of the saturation coefficient for the experimental tiles was slightly higher than that from field samples. And these were obtained as 95.48% and 90.92% respectively. It was observed from Table 1 and Figure 2 that higher content of lateritic soil in tiles mixtures also accounted for higher water absorption and dryness shrinkage respectively which is an indication of the higher attraction of clay for water.

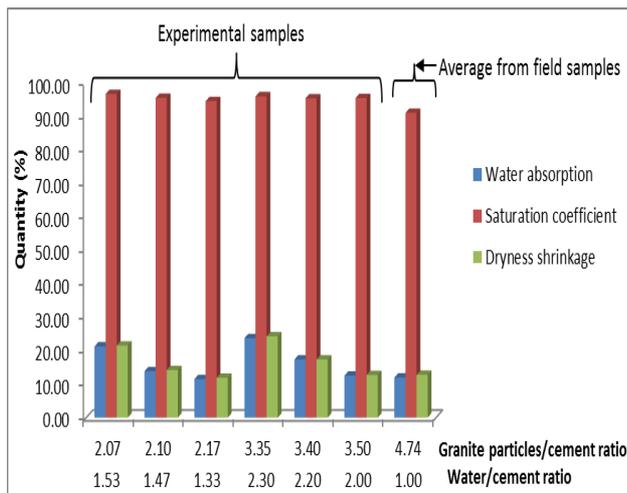


Fig. 2. Water absorption, saturation coefficient and dryness shrinkage and dryness shrinkage of interlocking tiles

### 3.3 Bulk density of interlocking tiles

Table 1 and Figure 3 shows that aggregate mixes without the addition of lateritic soil had nearly the same value of bulk density, at a granite particles/cement ratio of 2.17 and 3.50 respectively. Figure 3 shows that the when equal amount of lateritic soil and silica sand were used in tiles production, higher value of bulk density (2.03 g/cm<sup>3</sup>) was obtained at a granite particles/cement ratio of 2.10 compared with a bulk density of 1.88 g/cm<sup>3</sup> at a granite particles/cement ratio of 3.40. The higher bulk density experienced at a granite particles/cement ratio of 2.10 was as a result of cement content of 15% in the tiles compared with 10% for the 3.40 granite particles/cement ratio. The specific gravity of cement mortar is about 2.16 [16], which are higher than the specific gravity of lateritic soil given as 2.06 in Table 2. On the contrary, lower bulk density of 1.78 g/cm<sup>3</sup> was experienced at a granite particles/cement ratio of 2.07 at a cement content

of 15% in the tiles compared with 1.90 g/cm<sup>3</sup> at a granite particles/cement ratio of 3.35 at a cement content of 10% when only lateritic soil was added to the tiles mixtures. The mass of the granite particles clearly accounts for the bulk densities experienced at this instant.

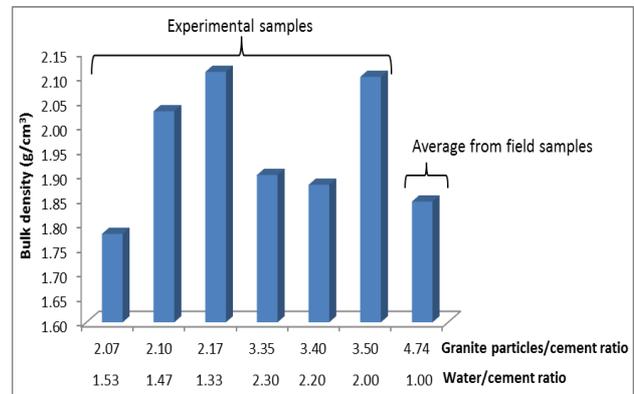


Fig. 3. Bulk density of interlocking tiles

### 3.4 Modulus of rupture and compressive strength of interlocking tiles

The modulus of rupture and compressive strength of the experimental interlocking tiles were found to increase from 0.39 to 1.34 MN/m<sup>2</sup> and 6.37 to 7.27 MN/m<sup>2</sup>, as the granite particles/cement ratio increases from 2.07 to 2.17 and water/cement ratio reduces from 1.53 to 1.33 for 15% cement content as shown in Figure 4. Similarly, the modulus of rupture and compressive strength of the experimental interlocking tiles increases from 0.22 to 0.36 MN/m<sup>2</sup> and 4.97 to 6.73 MN/m<sup>2</sup>, as the granite particles/cement ratio increases from 3.35 to 3.50 and water/cement ratio reduces from 2.30 to 2.00 for 10% cement content respectively.

The mechanical properties, namely the modulus of rupture and compressive strength of experimental interlocking tiles were generally increasing with increasing granite particles/cement ratio and with reducing water/cement ratio. Tiles mixes with higher cement content resulted in higher mechanical properties. The average compressive strength of interlocking tiles from field samples was obtained as 12.86 MN/m<sup>2</sup> at granite particles/cement ratio and water/cement ratio of 4.76 and 1.00 respectively, and average cement content of 15.17%. Results shown in Figure 4 also reveal that the compressive strength of interlocking tiles is enhanced with reduced water/cement ratio, despite equivalent cement content in tile mixtures.

The best mechanical strength of experimentally produced tiles were obtained respectively for both 15% and 10% cement content in tiles mixtures when 32.50% silica sand was added to tile mixtures at a granite particles/cement ratio of 2.17 and water/cement ratio of 1.33; and when 35.00% silica sand was added to tile mixtures at a granite particles/cement ratio of 3.50 and water/cement ratio of 2.00 respectively. This indicates that lateritic soil has the tendency to weaken the mechanical strength of interlocking tiles, and as such, should be used with caution. For better mechanical strength, an optimum mix of granite particles to lateritic soil to silica sand of 2:1:1 is recommended for suitable replacement for granite particles in the production of interlocking tiles.

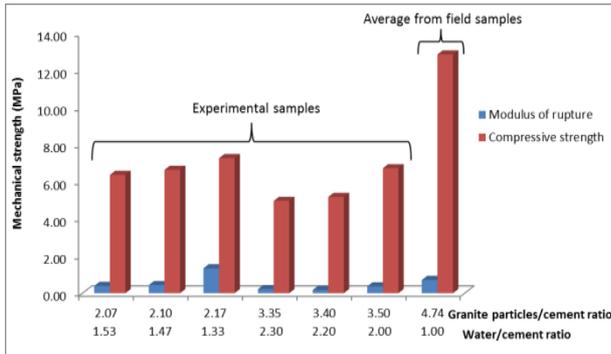


Fig.4: Modulus of rupture and compressive strength of interlocking tiles

### 3.5 A simple model to relate granite particles/cement ratio to water/cement ratio.

A simple model that relates the granite particles/cement ratio to water/cement ratio for interlocking tiles was developed from the mixture proportions given in Figures 2 to 4. The model curve is shown in Figure 5. The simple model that relates the granite particles/cement ratio to water/cement ratio is therefore given as:

$$y = 4.871x^2 - 16.451x + 15.958 \quad (8)$$

where,

y = granite particles/cement ratio  
 x = water/cement ratio

The coefficient of correlation and standard error of estimate of the model is given as 0.85 and 0.65 respectively. The model given by equation (8) can be used to estimate the granite particles/cement ratio for a given water/cement ratio accordingly. By differentiating equation (8), the minimum point was determined as x = 1.69 and y = 2.07. Hence, in general, a water/cement ratio and granite particles/cement ratio of 1.69 and 2.07 is recommended for interlocking tiles.

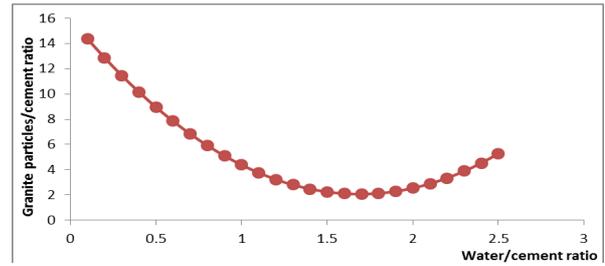


Fig.5: Model of granite particles/cement ratio in relation to water/cement ratio

### 4. Conclusion

Results revealed that the capacity of interlocking tiles to loose water is equivalent to the capacity to absorb water. Increase of lateritic soil content in tiles mixtures results in increased water absorption and dryness shrinkage. Increased cement content accounted for increase in the bulk density of interlocking tiles when equal amount of lateritic soil and silica sand were used in tiles production. When only lateritic soil was added to the tiles mixtures, the mass of the granite particles was the determining factor of the bulk densities of interlocking tiles.

The mechanical properties, namely the modulus of rupture and compressive strength of experimental interlocking tiles were generally increasing with increasing granite particles/cement ratio and with reducing water/cement ratio. Tiles mixes with higher cement content resulted in higher mechanical properties. For improved mechanical strength, an optimum mix of granite particles to lateritic soil to silica sand of 2:1:1 is recommended for suitable replacement for granite particles in the production of interlocking tiles.

A simple model that relates the granite particles/cement ratio to water/cement ratio for interlocking tiles was determined as:  $y = 4.871x^2 - 16.451x + 15.958$ . The model has a coefficient of correlation and standard error of estimate of 0.85 and 0.65 respectively

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