Strength evaluation of different cement brands in the production of interlocking paving stones

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Abstract. Portland cement remains the most common type generally used throughout the world as a basic ingredient of concrete. Four brands of Portland cement commonly available in Nigeria were investigated through a series of tests conducted to determine their strength characteristics. The study evaluated different cement brands in the production of interlocking paving stones. This study appraised the engineering properties of four cement brands, Dangote 3X Portland Limestone cement, Dangote Falcon kiwi set Portland Limestone cement, Elephant Portland Limestone cement, and Elephant Supaset Portland Limestone cement using sampling to ensure equal representation of various cement brands. Mix ratio 1:4 was used to produce the interlocks and tests such as flexural strength and compressive strength were conducted on 7, 14, 21 and 28 days. The flexural strength was conducted following IS 15658:2006 and the result ranges from 1.79 – 4.48 N/mm². Comparing the results of different brands of cement suggests recommended cement brands to be used in producing interlocks for Residential pathway/public pedestrian path, Residential driveways (light vehicles, commercial vehicles). The compressive strength result for the mix ratio 1:4 ranges from 5.44-15.91 N/mm² and Dangote Falcon had the highest compressive strengths of 15.27 N/mm² and 15.91 N/mm² at 28 and 21 days respectively indicating that it is stronger than other cement brands in the production of interlocking stones. Dangote Falcon and Elephant Supaset are recommended to produce interlocking paving stone on higher compressive and flexural strength.

1. Introduction
Concrete paver pieces are made with concrete essentially comprising of cement, fine aggregates, coarse aggregates (10 mm and below), water, chemical agents, etc. the role of cement is pivotal. Paving stones for outdoor applications because of its unwavering quality and consistency in majestic, although it is used for any sort of environment. Paver piece is utilized in street roads and other construction places. Several sorts of histories have been given by past writings as it was created in Giza, Egypt before 4500
years however, a portion of researchers have said that concrete paver stones started in Holland. It was brought to the notice that after the Second World War, the Europeans began to rebuild their roads by utilizing these sorts of paving blocks. A German Engineer Fritz Von Langsdorff was the individual who developed the shape and presented coloured concrete paver squares [1].

Interlocking paving stones have been hugely utilized worldwide for years as a problem-solving technique for utilizing blocks in areas where the use of conventional pavement is less durable due to environmental issues and operations. Concrete block pavement has become an aesthetically pleasing engineering and economical alternative compared to other types of pavement. The quality, toughness and pleasing surface have made paving stones appealing for many commercial, municipal and industrial places, such as parking areas, pedestrian walks, traffic intersections, container yards and roads [2,3].

Portland cement is typically the main constituent of an interlocking paving stone therefore it determines the strength and understanding of the effect of the cement is required to predict the behaviour of paver under general loading. Portland cement was developed from natural cement made in Britain in the early parts of the nineteenth century, and its name was derived from its similarity in colour and quality of the hardened form of Portland stone, a limestone that was quarried on the isle of Portland of Dorset, England which describes a cement obtained from intimate mixing together calcareous and argillaceous, or other silica-alumina and iron oxide-bearing materials, burning them at a clinkering temperature and grinding the result clinker, [4]. The production of Portland cement, however, originated from a British bricklayer from Leeds called Joseph Aspdin. It was one of his employees (Isaac Johnson) however, who developed the production technique, which resulted in more fast-hardening cement with a higher compressive strength in 1824. Isaac Johnson’s cement was artificial cement similar in properties to the materials known as “Roman Cement”,[5]. Nonetheless, there are numerous cement brands in the Nigerian market, although there are a variety of cement brands this study assesses the qualities of Dangote, Elephant, Ashaka, Unicem and Bua cement in the production of interlocking pavement. The key physical parameters used in classification and comparison of these brands include bulk density, relative density (specific gravity), fineness, setting, time, compressive strength and consistency test. Other parameters such as soundness, the heat of hydration, loss on ignition and chemical composition were not considered because other authors have worked extensively on these parameters.

The collapse of many pavements has partially been a result of the defect in the comprehensive strength of concrete and many pieces of research prove that cement tends to affect concrete strength [6]. This may be as a result of lack of resources or carelessness or negligence or no knowledge on the requirement for various projects such as mix ratio, the mix ratio favourably used in the production of interlocking stones in Nigeria is 1:4 but the compressive strength observed proved to below. With the use of other mix ratios, a higher compressive strength could be achieved which has not been specified for use in producing interlocks in the country [7]. Regardless of the breakthroughs in research on increasing interlocks paving stones compressive strength with various materials ranging from agricultural waste, industrial waste, and several other materials, the partial replacement of certain constituent of the interlock, addition of admixtures etc. it has been observed that these findings are not a match to the strength of cement. The non-availability of manufacturers’ data that may enable the end-users of branded Portland cement to make the best choice prompt this research, taking note that collapsed buildings, pavement failures are often traced to the quality of cement used in the construction process [8]. In highlighting the qualities of the chosen brands of Portland cement, this research will in a vast way aid alleviate some of the identified problems inherent in the choice and to a great extent eliminate the use of inferior quality cement that are in Nigeria.

This study aims to evaluate the strength of different cement brands in the production of interlocking paving stones and the determination of concrete strength. The objectives of this study, therefore, are to determine the compressive strength of interlocking paving stone with different using destructive methods (compression machine), and the flexural strength of the interlocking paving stones and to propose a cement brand using a mix ratio based on compressive and flexural strength results.

2. Materials and Methods
The materials used in the production of interlocking paving stone are Portland cement (Dangote 3x Portland Limestone Cement, Dangote Falcon Kiwi set Portland Limestone Cement, Elephant Portland Limestone Cement and Elephant Supaset Portland Limestone Cement), Quarry dust (stone dust), Water (portable), Engine oil (lubricant) and Interlocking moulds (double tee design). The cement is used as a binder in the production of the interlocking paving stones while the quarry dust served as the aggregate together in a 1:4 mix ratio. Engine oil is used as a lubricant for easy removal of the interlocking stones from the moulds.

2.1 Materials Sourcing
The cement for this project was from a local distributor of cement in Ilorin, Kwara State. The stones' dust and granite chippings were from the Ej unwumi quarry at Illoffa in the Omu-Aran community. The portable water used is from the storage tank behind engineering workshop in Landmark University while the Double Tee moulds and the engine oil used wood was gotten from the concrete laboratory in Landmark University

2.2 Sample preparation
The different cement brands used in the production of interlocks are sieved. The inner surface of the moulds was lubricated with engine oil. After coating the moulds with engine oil, a mixture of cement, quarry dust and water concerning the mix proportions which forms a paste is poured into each mould using hand trowel with the surface level. The mixing of the materials is done manually by using shovels, head pans, and buckets

2.3 Mixing Process
After obtaining the weight of cement and stone dust required, mixing is done manually by adding water to the constituents and thoroughly mixing them. Proportions of the mix are cast and placed into the moulds with the aid of hand trowel. The cast products are then left for 24 hours to set properly before they are removed from the mould. The interlocks were cured by placing them in a curing tank for 7, 14, 21 and 28 days to attain adequate strength and the physical strength and mechanical tests is carried out on the interlocks.

2.4. Curing Method Used (Ponding)
The interlocking paving stone was placed in a curing tank filled with water and left for the number of days to cure. Compressive strength, flexural strength, and Rebound Hammer tests would be carried out at the end of the specific curing days and readings are taken.

2.5 Experimental Test Procedures
The test carried out in the course of the study includes the following-

i. Compressive strength and
ii. Flexural strength

| S/N | Apparatus/Equipment Used          | Number Required |
|-----|-----------------------------------|-----------------|
| 1   | Compression machine               | 1               |
| 2   | Schmidt rebound hammer            | 1               |
| 3   | Hand trowel                       | 1               |
| 4   | Weighing Balance                  | 1               |
| 5   | Wheel Barrow                      | 1               |
| 6   | Shovel                            | 1               |

2.5.1 Compressive strength test on the specimen. The strength was determined by the ability of a material to resist stress without failure. Failure of the interlock was evident due to cracking. During compression,
disintegration often appeared. Strength then was generally referred to in the construction industry because it was relatively easy to measure, and other properties related to the strength can be gotten from the strength data. The machine used for the test was the compression machine.

After the machine was turned on, the area \((25300\text{mm}^2)\) was set and the condition of the machine was checked. The paving stones were placed in the machine and then the crushing process commenced.

2.5.2 Flexural Strength Test. This mechanical testing method measures the behaviour of materials subjected to simple bending loads. Flexural testing involves the bending of a material rather than pushing or pulling, to determine the relationship between bending stress and deflection.

After the machine was turned on, the area \((25300\text{mm}^2)\) is set and the condition of the machine was checked. The paving stones and the steel rods representing the point loads were placed in the machine and then the process began.

![Diagrammatic view of a Suitable Apparatus for Flexural Test by Centre](image)

**Figure 1.** Diagrammatic view of a Suitable Apparatus for Flexural Test by Centre

### 3. Result and Discussion

The purpose of carrying out tests was to evaluate and determine the strength, durability and other properties of the interlocks. Compressive and flexural tests were carried out on the samples of interlocking paving stones after production on each curing day.

#### 3.1 Compressive Strength Test

A compressive strength test was carried out on the interlocking paving stones to determine the compressive strength. The result obtained at 7 days, 14 days, 21 days, and 28 days were shown Table 2 below.

| Cement          | 7 Days (N/mm²) | 14 Days (N/mm²) | 21 Days (N/mm²) | 28 Days (N/mm²) |
|-----------------|----------------|-----------------|-----------------|-----------------|
| Dangote 3x      | 5.44           | 8.54            | 6.62            | 10.26           |
| Dangote Falcon  | 8.49           | 13.12           | 15.91           | 15.27           |
| Elephant Lafarge| 9.72           | 11.38           | 12.42           | 13.09           |
The compressive strength test was conducted according to [9] and the average compressive strength values are presented in Table 2 with results ranging from 5.44-15.91 N/mm². The compressive strength of all the interlocks increased with age as shown in the chart above and maximum compressive strengths were obtained on the 28th day. The compressive strength of Dangote 3X increased and reduced and reduced again through curing ages and attained maximum strength of 10.26N/mm² on the 28th day. Dangote Falcon compressive strength increased as the curing age increased and attained maximum strength of 15.91N/mm² on the 21st day. The Elephant Lafarge compressive strength increased as the curing age increased and attained a maximum compressive strength of 13.09N/mm² on the 28th day. The compressive strength of Elephant Supaset increased as the curing age increased and attained maximum strength of 14.95N/mm² on the 28th day. Dangote Falcon had the highest compressive strength compared to the other cement brands which would be suitable for the production of interlocks based on the results from the figure and table above.

### 3.2 Flexural Strength Test

Flexural strength was carried out on the interlocking paving stones to determine the flexural strength. The result obtained at 7, 14, 21 and 28 days are shown in Table 3.

| Table 3. Average Flexural Strength |
|-----------------------------------|
| Cement                  | 7 Days (N/mm²) | 14 Days (N/mm²) | 21 Days (N/mm²) | 28 Days (N/mm²) |
|--------------------------|----------------|-----------------|-----------------|-----------------|
| Dangote 3X               | 1.79           | 2.33            | 2.33            | 3.85            |
| Dangote Falcon           | 2.51           | 3.05            | 4.12            | 4.48            |
| Elephant Lafarge         | 2.87           | 3.05            | 3.05            | 3.23            |
| Elephant Supaset         | 3.05           | 3.58            | 3.05            | 3.94            |
Figure 3. Average Flexural Strength against Age

Flexural strength test was conducted per [10] and the average flexural strength values are presented in the table above with results ranging from 1.79-4.48 N/mm^2. The flexural strength and all interlock increased with age as shown in the table and chart above and the maximum Flexural strengths were obtained after 28 days. The Flexural strength of Dangote 3X increased as curing ages increased and attained maximum strength of 3.58N/mm^2 on the 28th day. Dangote 3X flexural strength was stable on 14th and 21st days. Dangote Falcon flexural strength increased as the curing age increased and attained maximum strength of 4.48N/mm2 on the 28th day. The Elephant Lafarge Flexural strength increased and attained a maximum compressive strength of 3.23N/mm^2 on the 28th day. Elephant Lafarge Flexural strength was 3.05N/mm^2 on both 14th and 21st days. The flexural strength of Elephant Supaset increased as the curing age increased and attained maximum strength of 3.94N/mm^2 on the 28th day. Dangote Falcon had the highest flexural strength compared to the other cement brands which would be suitable to produce interlocks based on the results from the Figure 3 and Table 3.

4. Conclusion and Recommendation
This study aims to evaluate the strength of different cement brands in the production of interlocking paving stones and the determination of concrete strength. The following conclusions are based on the analyses and discussions.

4.1 Conclusion
Dangote Falcon had the highest compressive strength of 15.91N/mm² and followed closely by Elephant Supaset with a compressive strength of 14.95N/mm² also Elephant Lafarge with a compressive strength of 13.09N/mm² on the 28th day and Dangote 3X with the least compressive strength of 10.26N/mm² on the 28th day. Dangote Falcon had the highest flexural strength of 4.48 N/mm² and followed by Elephant Supaset with a flexural strength of 3.94N/mm² thirdly Dangote 3X with a flexural strength of 3.58N/mm² on the 28th day and finally Elephant Lafarge with a flexural strength of 3.23N/mm² on the 28th day.

4.2. Recommendation
For improved compressive and flexural strength, less material usage and reduced cost of production, Dangote Falcon and Elephant Supaset was recommended for use in the production of interlocking paving stones along with mix ratio 1:4. Although, for increased flexural and compressive strength associated with an increased cost of production granite chippings can be utilized for interlock production. For improved compressive and flexural strength, less material usage and reduced cost of production, the use of mix ratio 1:4 are recommended for use in the production of interlocking paving stones. The effect of various aggregate sizes on the interlocking paving stone should be investigated for heavy traffic areas.

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