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The Effects of Aggregate Sizes on Strength and Permeability of Pervious Concrete Blended with Metakaolin

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Abstract
Pervious concrete is a sustainable pavement material characterized by its high permeability, and it is increasingly adopted as an effective solution for storm water management in urban infrastructure by preventing flooding possibilities on our pavements and increasing water recharge to the underground. A major challenge lies in balancing its strength and permeability especially when partially replacing Portland Limestone Cement with supplementary cementitious materials for economic and environmental sustainability. This study investigates the combined effects of coarse aggregate size variation and partial substitution of Portland limestone cement with metakaolin, highly pozzolanic calcined clay, on the mechanical and permeability properties of pervious concrete. Concrete mixes were produced using three coarse aggregate gradations: 9.5-16, 16.5-20 and 20.5–25 mm. Aggregate properties were established through sieve analysis, water absorption and specific gravity test. For each of the size ranges, control mixes with 100% PLC and modified mixes with 10% metakaolin replacing cement by weight were prepared. A constant water–binder ratio of 0.35 and a binder aggregate ratio of 1:4 were recast. Workability tests (slump and compacting factor) were used to assess fresh concrete behavior. Mechanical properties were evaluated through permeability test, compressive and flexural strength tests and density assessments. These tests were conducted at 7, 28, and 56 days respectively to monitor the effects on the different aggregate sizes and partial substitution of PLC with metakaolin over time. Sieve analysis confirmed the classification of coarse aggregate into the specified size ranges of 9.5-16, 16.5-20 and 20.5-25 mm. Slump values, ranged from 18-24 mm and 14-20 mm for the control and metakaolin modified mixes. Compacting factor values for all concrete mixes ranged from 0.68 to 0.82. The 9.5-16.0 mm mixes has compressive strength values, ranged from 9.78-16.44 MPa (Control mix) and 9.33-15.78 MPa (Blended mix) as against 9.11-16 Mpa, 8.67-15.33 Mpa in 20.0mm size range and 8.44-15.11 Mpa, 8-14.67 Mpa in 25.0 mm aggregate size range. It is recommended that 16.5-20 mm aggregate size range be used in pervious concrete where both strength and permeability are required. A 10% metakaolin replacement is also recommended to improve long-term strength.

Keywords: Compacting factor, Compressive strength, Flexural strength, Slump, Permeability.

Introduction
Construction labour constitutes the largest unit of human resources on any given project. Human resource is the most variable, uncontrollable and important element in production (Brent and Leighton, 2014). The success of any construction project is largely hinged on the labour productivity. Due to its importance, productivity is one of the most frequently discussed topics in the construction industry. Attar *et al.,* (2012) stated that delay and project cost overrun is caused by poor productivity of labour. Thus, managing labour factor can be greatly beneficial to construction budget.

Introduction
Concrete is by far the most versatile and widely used construction material worldwide. It can be modified to satisfy a wide range of performance specifications, unlike other building materials, such as natural stone or steel, which are being used as procured. Concrete is a composite material which is made up of various constituents, the properties and characteristics of the composite are functions of the constituent materials'

properties as well as the various mix proportions (Mehran and Majid, 2019). Tensile strength of concrete is much lower than its compressive strength, which makes concrete to be typically reinforced with steel bars, in which case it is known as reinforced concrete (Mehran and Majid, 2019). Pervious concrete is a unique kind of concrete with high porosity that reduces the water runoff from particular site and moves the water to recharge groundwater (Osuolale *et al.,* 2019). Pervious concrete has little aggregate and sufficient cementitious paste to coat coarse aggregate particles on preserving the interconnectivity of voids which drains quickly.

It is used in residential streets, parking areas, pedestrian walkways, areas with light traffic and greenhouses (Sadiq and Atoyebi, 2015). It is an important application to protect water quality. The proper use of pervious concrete is recognized by the United States environmental protection agency for providing storm-water management pollution control (Osuolale *et al.,* 2019). The advantage of pervious concrete over normal cement concrete further extend to water treatment by pollution removal, less need for curbs and storm sewers, better skid resistance in pavements, and a good recharge mechanism to local aquifers (Mujed *et al.,* 2014).

Pervious concrete is a type of concrete which consist of coarse aggregate, Portland limestone cement and water. Absence of fine aggregate defines its difference from the convectional concrete, its single sized aggregates are bonded together with cement-water paste (Adesanya and Ejeh, 2014), which resulted into a concrete with highly interconnected voids which allows rapid percolation of water through it in its function states. Pervious concrete has void ratio ranging from 15 to 40% depending on its application. It is also different to the conventional concrete with lower unit weight, higher permeability, and lower compressive strength (Akinwumi, 2016). Therefore, to overcome these difficulties, pervious concrete is considered a best management practice because of its capability to reduce excessive storm-water runoff (Adewole *et al.,* 2014). The case study on Evaluation of Structural Performance of Pervious Concrete in Construction (Ajamu et al., 2012), two coarse aggregate sizes 9.38 and 18.75 were used and Portland Limestone cement used as binder with high porosity values. The aim of this study is to determine the aggregate size variation and substitution of PLC with metakaolin as a partial replacement at 10% to binder at constant water-cement ratio.

Materials and Methods

The materials used were granite of three (3) different sizes as coarse aggregate; (9.5 – 16.0, 16.5 –20.0 and 20.5 – 25.0mm), and Dangote brand of Portland Limestone Cement of 32.5 grade was used, Also, metakaolin was used as pozzolanic material in partial replacement to Portland Limestone cement at 10% for concrete mix on each aggregate size after been calcinated in a muffle furnace from its drying state to a temperature of 700℃ and grinded to fine, (Rafat and Juvas, 2009). 10% PLC was substituted for metakaolin blended cement to avoid a denser concrete mix and not adversely influence the concrete workability (Osuolale et al., 2019)

The granite was obtained from construction sites in Ogbomoso, situated in the South-western part of Nigeria. Water was obtained locally also in Ogbomoso land. The kaolin clay was sourced from mining sites in Ekiti state, the southwestern part of Nigeria (Lat. 7° 47′ 57″, Long. 4° 29′ 06″) and transformed into metakaolin at a temperature of 700ºC for 1hr using muffle furnace, the temperature 700ºC being the most reactive and was more evident in both flexural and compressive strength. The metakaolin was later inter-ground with Portland Limestone (PLC) clinker at the factory; Lafarge, Sagamu, Ogun-State, Nigeria to produce metakaolin blended cement.

Cement

The cement used was Portland Limestone Cement. It was sourced from Ogbomoso Area, Oyo State, Nigeria and conformed to the requirement of BS EN 197 (2000).

Coarse Aggregate
The coarse aggregate used for this study was granite and locally sourced from Ogbomoso, Oyo State, Nigeria. The impurities were removed and conformed to the requirements of BS 882 (1992).

Water
The potable water was used in all the mixes in accordance with the requirement of water concreting and curing as specified by BS 3148 (1980).

Metakaolin
The kaolin clay sourced from mining sites in Ekiti state (Lat. 7° 47′ 57″, Long. 4° 29′ 06″) and transformed into metakaolin at a temperature of 700^{o}C to achieve high reactive temperature and making it ideal for use in high performance concrete, for 1hr using muffle furnace, the metakaolin was later inter-ground with Portland Limestone (PLC) clinker at the factory; Lafarge, Sagamu, Ogun-State, Nigeria to produce metakaolin blended cement.

Preparation and Casting
The concrete mix ratio used was 1:4 with 0.35 water-binder ratio for a considerably cohesive and stiffen concrete mix, with the absence of fine aggregate. The 150 x 150 x 150 mm^3 cube specimens was produced, hardened, cured and tested for compressive strength, density test and the 150 x 150 x 450 mm^{3}of Flexural Specimens was tested in accordance with BS 1881: part 116:1970 and BS 1881: part 117:1983. Using Vary – Denison Universal Testing Machine at Geotechnics and Structural Laboratory, Ministry of Work and Transport Osogbo, Osun State. The concrete produced from three (3) different sizes of granite samples obtained were experimented on fresh and hardened concrete tests.

Sieve Analysis
Sieve analysis was used in determining the particle size distribution of the coarse aggregates, analysis carried out on the coarse aggregates so as to obtain the three size ranges of coarse aggregate sizes: 9.5 – 16.0, 16.5 – 20.0 and 20.5 – 25.0mm. This was done by sieving the aggregates in accordance with the provisions of BS 812: (Part 1) – 1985. The distribution ratio for the sieve analysis was determined using Equation 1: (Gurnani *et al*., 2023)

$$Distribution\ Ratio = \frac{Percentage\ passing\ No.200 \times 100\%}{Percentage\ passing\ No.36} \qquad (1)$$

Specific Gravity Test
Sieve analysis was used in determining the particle size distribution of the coarse aggregates, analysis carried out on the coarse aggregates so as to obtain the three size ranges of coarse aggregate sizes: 9.5 – 16.0, 16.5 – 20.0 and 20.5 – 25.0mm. This was done by sieving the aggregates in accordance with the provisions of BS 812: (Part 1) – 1985. The distribution ratio for the sieve analysis was determined using Equation 1: (Gurnani *et al*., 2023).

$$Gs = \frac{M_2 - M_1}{(M_4 - M_1)(M_3 - M_2)} \qquad (2)$$

Where:
Gs = Specific Gravity of granite
M_1 = Mass of Specific Gravity Bottle
M_2 = Mass of Specific Gravity Bottle + Granite
M_3 = Mass of Specific Gravity Bottle + Granite + H_2O
M_4 = Mass of Specific Gravity Bottle + H_2O (water)

Workability Test on Pervious Concrete

Testing for the workability of the pervious concrete, both on control and partial replacement of PLC with metakaolin mixes was conducted by filling the fresh concrete into the slump cone placed vertically on non-porous fat metal surface and held down in position. The cone was filled in three layers and each layer was compacted 25times with a tempering rod 16 mm in diameter and 800 mm long. Thereafter, slump cone was removed vertically and the height of the concrete slump was determined by measuring the different between the cone height and the concrete slump and also compacting factors were carried out on fresh concrete using compacting factor test equipment in accordance with BS EN 12350-4, compacting factor was computed according to Equation 3

$$CF = \frac{W2 - W1}{W3 - W1} \quad (3)$$

Where, W_1 is weight of empty cylinder, W_2 is weight of empty cylinder plus partially compacted concrete and W_3 is weight of empty cylinder + fully compacted concrete.

Compressive Strength Test

The compressive strength is a measure of the concrete's ability to resist loads which tend to crush it. The pervious concrete specimens was produced and made ready for compressive strength test according to ASTM C39M-21. The test verifies that the concrete components meet required strength standard and project specifications, it helps in structures design by determining the load carrying capacity and durability of materials like concrete, compressive strength also revealed the hidden weaknesses in the material that might not be apparent from other test of concrete. The mould used was made of non-absorbent material and substantial enough to hold their compact form during the placing of concrete specimens, a standard mould used was 150mm in diameter and 150mm in length, moulds were water tight and the base plate was at right angle to the mould axis. A round straight steel rod of 16mm in diameter and 600mm in length was used as tamping rod after filling the mould with concrete, using shovel, trowel and scoop.

A moist storage tank capable of accommodating specimens at favorable temperature maintaining a moist condition in which free water is maintained on the surfaces of the specimens was used for sample's curing; the samples were after collected and tested for compressive strength test. The area of the specimen was measured and cross-sectional areas estimated. Compressive strength test on pervious concrete was carried out in accordance with BS 1881-108:1983, compressive testing machine (CTM) of 3000 KN capacity was used to compress the specimens in the laboratory. The cubes were placed on the spring balance to determine the weight of the cube and the results were recorded, the specimen was placed between the loading surfaces of CTM with the axis of the specimens aligning properly and the load was applied slowly and continuously to opposite side of the specimen until the specimen fractured and failed, the crushing load was determined and the crushing load recorded, the cube specimens was tested for compressive strength at ages of 7, 28 and 56 days of curing. The density of concrete was gotten from the weight of sample divided by the volume of concrete cube. The compressive strength of the specimen was calculated by dividing the maximum load attained during compression test by the cross-sectional area of the specimen. This was determined using Equation 4: (Ajamu et al., 2012)

$$Compressive\ Strength\ (MPa) = \frac{failure\ load \times 1000}{gross\ area\ of\ cube} \quad (4)$$

Concrete cubes produced with 100% PLC for control mixes and 10% metakaolin blended cement concrete mix is shown in Figure 1. The compressive strength testing procedure is shown in Figure 2, which includes pouring fresh concrete into moulds to form cubes, which are then cured and tested.

Figure 1: Pervious concrete cubes **Figure 2:** Compressive strength test of pervious concretes

Flexural Strength Test on Pervious Concrete

The flexural test of pervious concrete was investigated to evaluate the strength of concrete in a slab. Flexural strength test reveals the ability of mass concrete slab to withstand failure in bending (Raheem, 2012). The specimen is prepared by filling the mould 150 x 150 x 450 mm with pervious concrete and tamped 35 times in three layers respectively. The test was carried out according to two points loading in accordance with IS 516-1959. The specimen was later demoulded after 24 hours and tested at 14, 28 and 56 curing age respectively. The test specimen of size 450 x 150 x 150 is supported on the rollers of the testing machine, load applied on specimen gradually without shock and increase continuously at a rate such as the stress increases at approximately 7kg/cm/min till the point of failure in accordance to IS 5816-1999. The flexural strength of pervious concrete was determined using Equation 5: (Sujeet *et al*. 2018).

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

Where:
Fr = Flexural strength of concrete (in MPa). b = Width of specimen d = Failure point, depth of the specimen
L = Length of Specimen
P = Maximum load applied (N)

Permeability Test on Pervious Concrete

The test was initiated by allowing water to flow through the pervious concrete sample until the water in the standpipe reaches a given lower level, a constant time of 15secs was allowed for the water to fall from one head to another in the standpipe, the standpipe was refilled and the test repeated thrice for each sample under falling head for water permeability to improve the accuracy of the results. The time it takes for the water level to decrease between two specific points were taken and recorded. The coefficient of water permeability (K) was computed in accordance to ASTM D2434 using Equation 6: (Ajamu *et al*., 2012).

$$K = \frac{2.303aL}{A(t_2-t_1)}\log h_1/h_2 \quad (6)$$

Where:
K= Permeability coefficient
a = Cross-Sectional area of the pipe in diameter,
A = Cross section area of the specimen
L= The height of pervious concrete sample
(t_2-t_1) = Time taken for water to fall from one level to another, by (15secs)
h_1 = Upper water level,
h_2= Lower water level

Results and Discussion

A. Sieve Analysis of Coarse Aggregate

Figure 3 illustrates the particle size distribution curve for the coarse aggregates. The plotted grading curves for the three coarse aggregate size ranges were superimposed on a single chart to allow for direct comparison. From the chart, it was observed that the 9.5-16.0 mm size group exhibited the highest percentage passing across all sieve sizes. This indicates a finer gradation with more aggregate particles falling into the smaller sieve categories. Such a distribution tends to produce tighter packing with reduced void content, which may lower permeability but improve strength due to increased inter particle contact.

In contrast, the 16.5-20.0 mm size range showed a moderately steep grading curve, indicating a more balanced distribution. This gradation may offer a compromise between permeability and mechanical strength, as it allows for adequate void content while still maintaining inter particle contact. The 20.5-25.0 mm aggregate group displayed the lowest percentage passing, especially at the finer sieve sizes, highlighting its coarser nature. This group contained the largest proportion of large aggregate particles, resulting in greater void content and hence better permeability, although potentially at the expense of compressive strength due to reduced contact surfaces between particles.

The comparison of the three grading curves confirms that none of the aggregates are continuously graded, which is appropriate for pervious concrete. Continuous (well-graded) aggregates are typically avoided in pervious concrete applications because they reduce the void content necessary for water flow. Instead, the use of uniformly or narrowly graded aggregates is preferred to maintain the interconnected pores required for permeability.

The particle size distributions obtained from the analysis are therefore consistent with the design philosophy of pervious concrete. According to BS 882:1992, the aggregates used in this study can be classified as graded coarse aggregates, which are suitable for concrete production. The standard allows for defined ranges of aggregate gradation, and all three groups fall within acceptable limits. Furthermore, the absence of fines (i.e., material passing the 2.36 mm sieve or retained in the pan) confirms the cleanliness of the aggregates, reducing the risk of clogging the voids in pervious concrete and minimizing excess water demand during mixing.

The superimposed grading curve reinforces the understanding that aggregate gradation has a profound effect on the structure and function of pervious concrete. The distinct shape and position of each curve provide insights into the void structure that each size group will contribute to the concrete matrix. While finer aggregates may improve strength, coarser ones promote permeability. This makes it necessary to carefully select the aggregate size group that aligns with the specific performance targets of the pervious concrete, particularly when using supplementary cementitious materials like metakaolin, which can alter workability and hydration characteristics.

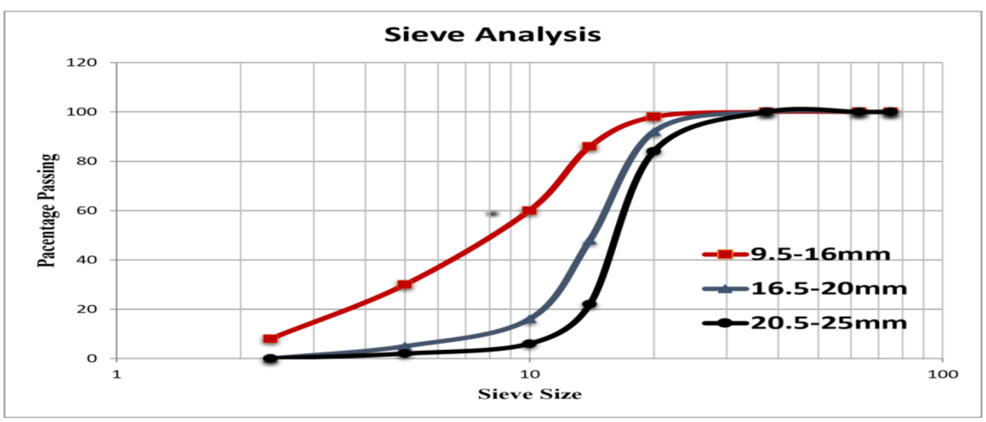

Figure 3: Particle size distribution curve for the coarse aggregates

B. Specific Gravity of Coarse Aggregate

The specific gravity results obtained from this study indicated denser and stronger aggregates, making the aggregate a better aggregate in respect to quality and potential strength in concrete and construction performance. Aggregate type, sizes and composition, significantly affected the density and specific gravity of aggregate, the presence and size of pores within the aggregate particles influenced water absorption capacity of aggregate and its overall specific gravity. The test value obtained as presented in Table 1, the results revealed the evaluations of physical properties of coarse aggregates used in this study and also helps in selecting appropriate coarse aggregate for pervious concrete production, construction, performance and durability.

Table 1: Specific gravity of coarse aggregate

Item	Specific Gravity
9.5-16mm	2.62
16.5-20mm	2.67
20.5-25mm	2.70

The specific gravity of the coarse aggregates results in table 1 shows the range value to be 2.62 to 2.70. Specific gravity tests were conducted on three coarse aggregate size ranges, 9.5-16.0 mm, 16.5-20.0 mm, and 20.5-25.0 mm in accordance with BS 812-2. The specific gravity of the 9.5-16.0 mm aggregate was found to be 2.62, which falls within the typical range for natural aggregates (2.50 to 3.00). This indicates that the aggregate is of good quality and is expected to have moderate density and water absorption capacity. These characteristics can influence the permeability and strength of pervious concrete, particularly in mixes designed for sustainable storm-water management.

For the 16.5-20.0 mm size range, the specific gravity increased slightly to 2.67, suggesting a denser aggregate with potentially lower porosity. This may result in a slightly lower void ratio when used in concrete, which could enhance compressive strength but reduce permeability. The 20.5–25.0 mm aggregate exhibited the highest specific gravity of 2.70, indicating a very dense and low-porosity material. Aggregates of this size and density are expected to produce pervious concrete with improved structural strength but may lead to reduced interconnected voids and lower permeability. This tradeoff is a key focus of the current study, as understanding how specific gravity varies across aggregate sizes helps in selecting the optimal range that meets both strength and permeability requirements. These specific gravity values provide essential input for concrete mix design, particularly in achieving the research objective of identifying how aggregate size influences the strength and permeability characteristics of pervious concrete made with metakaolin-blended cement.

C. Specific Gravity of Cement and Metakaolin

In this study, the specific gravity of the Portland Limestone Cement (PLC) and metakaolin used was found to be 3.15 and 2.50 respectively as shown in Table 2. This value falls squarely within the standard range of specific gravity for PLC, confirming the cement's suitability for use in concrete production. An average specific gravity 3.15 is considered standard for mix design, with values widely outside this range potentially indicating issues of moisture content or inadequate fineness and coarseness of cement clinker.

Table 2: Specific gravity of cement and metakaolin

Item	Specific Gravity
Cement (PLC)	3.15

Metakaolin	2.50

The specific gravity of cement results shown in Table 2, having value of 3.15 indicates that the cement is of high purity, free from adulterants or excessive porosity that could compromise the concrete's strength and hydration characteristics. A standard specific gravity helps ensure proper hydration and the development of calcium silicate hydrate (C-S-H), which is essential for achieving the desired compressive strength and durability in pervious concrete. For the metakaolin used in this research, a specific gravity of 2.50 was determined. This value is consistent with standard ranges reported for high reactivity metakaolin, suggesting a finely calcined and reactive pozzolanic material. In accordance with the standard coarse aggregate test BS 812-2-1995. Metakaolin has a lower specific gravity than cement due to its amorphous structure and high silica and alumina content, which result from the dehydroxylation of kaolinite clay. The lower density means that when metakaolin is blended with cement, it can reduce the overall specific gravity of the binder system. This alteration in density must be carefully considered in mix proportioning to maintain the desired concrete volume and mechanical balance.

D. Workability Test on Fresh Pervious Concrete

There are two tests that were considered on the workability of pervious concrete when in fresh state, for this study, slump test and compacting factor test were carried out and the results are presented in Table 3 and Table 4.

i. Slump Test on Concrete

The slump test is a fundamental method for assessing the workability or consistency of fresh concrete before it sets. It provides an indication of how easily a concrete mix can be mixed, handled, placed, and compacted without segregation. This is especially significant when evaluating the effects of using supplementary cementitious materials like metakaolin, and varying coarse aggregate sizes, as they influence the water demand, cohesion, and flow properties of concrete.

The Table 3 shows the slump values of the fresh concrete for both the control mix and metakaolin modified mix across the aggregate sizes considered. The control mixes, containing only PLC without metakaolin showed moderate to low workability, with slump values in the range of 18-24 mm depending on the aggregate size. The concrete with 9.5-16 mm aggregates showed the highest slump of 24 mm, indicating relatively better flow and ease of placement due to a denser packing and higher surface area, which enhances cohesion. As the aggregate size increased to 16.5-20 mm, the slump value slightly reduced to 21 mm, and further decreased to 18 mm with the 20.5-25 mm aggregates. This pattern reflects the general trend that larger aggregate sizes reduce workability, owing to increased internal friction and reduced surface area for paste bonding. When 10% of the cement was replaced with metakaolin, a noticeable reduction in slump values was observed across all sizes. The metakaolin modified mix with 9.5-16 mm aggregate had a slump of 20 mm, indicating a slight reduction in workability compared to the control (24 mm). For 16.5-20 mm, the slump reduced to 17 mm, and for 20.5-25 mm, it dropped further to 14 mm.

This reduction is attributed to the high surface area and pozzolanic reactivity of metakaolin, which increases water demand and stiffens the mix, thereby reducing flowability. Although slump is measured immediately after mixing, these results are also significant when considered alongside the curing periods of 7, 28, and 56 days. Each fresh concrete batch tested for slump was cast into cubes intended for strength testing at these time intervals, reinforcing the need for consistent workability during fresh handling across all ages of assessment. From the results, it can be inferred that both aggregate size and metakaolin content influence the workability of concrete. Smaller aggregate sizes promote higher slump due to better cohesion and lower internal friction, while larger aggregates contribute to lower workability. Meanwhile, the inclusion of 10% metakaolin slightly compromises the mix’s fluidity but is still within acceptable limits for hand placement and low slump applications such as pervious concrete. Importantly, despite the reduction in slump values with metakaolin addition, all mixes maintained a true slump behavior, indicating uniformity and no signs of segregation or shear slump.

This phenomenon is crucial for structural performance and validates the suitability of the mix proportions adopted, especially considering that concrete from each batch will undergo compressive strength testing after 7, 28, and 56 days of curing, demanding consistent fresh-state quality. The control mixes serve as a reference for normal concrete behavior, while the metakaolin blended mixes demonstrate the influence of pozzolanic materials on fresh concrete workability. The concrete mix of 10% metakaolin substitution reduces slump slightly, it remains within workable limits, especially when combined with an optimized water binder ratio of 0.35. The curing days (7, 28, and 56) guide the sampling volume and structure of the testing regime, ensuring that each mix's fresh state consistency directly supports the expected hardened state performance analysis.

ii. Compacting Factor Test on Concrete

The compacting factor test is a vital tool in assessing the workability of fresh concrete, particularly for mixes with low workability that are not effectively evaluated using the slump test alone. The results of the compacting factor test shown in Table 4, displayed a trend that aligns closely with the slump values obtained earlier, highlighting a clear relationship between both methods of workability assessment. As a pozzolanic material with high surface area and fine particle size, metakaolin increases the water demand of the mix and contributes to early stiffening. Although the water binder ratio remained constant at 0.35, the presence of metakaolin limited the fluidity and flow-ability of the mix, reducing its ability to compact easily under gravity or mechanical effort. The control mixes, without metakaolin inclusion, its compacting factor values ranged from 0.82 to 0.72, as seen in Table 4, the value decreases with an increase in aggregate size range.

The compacting factor test thus reinforces the findings from the slump test, revealing how aggregate size and metakaolin content influence the fresh properties of concrete. The highest compacting factor of 0.82 was observed in the control mix using 9.5-16 mm aggregates, which also had the highest slump value (24 mm). This indicates superior workability due to better packing and higher surface area of smaller aggregates, leading to increased paste coverage and cohesion. As the aggregate size increased to 16.5-20 mm and 20.5-25 mm, the compacting factors decreased to 0.78 and 0.72 respectively, with corresponding slump values of 21 mm and 18 mm. These results suggest that larger aggregates tend to reduce workability due to greater internal friction and lower surface area for binder coating.

In the metakaolin admixture mixes, a consistent reduction in compacting factor values was observed across all aggregate sizes when compared to their control counterparts. For the 9.5-16 mm mix with 10% metakaolin, the compacting factor dropped to 0.78, slightly lower than the control mix, while the slump value was also lower (20 mm compared to 24 mm). Similarly, for the 16.5-20 mm and 20.5-25 mm aggregate sizes, compacting factors reduced to 0.74 and 0.68 respectively, alongside slump values of 17 mm and 14 mm. These reductions reflect the influence of metakaolin on fresh concrete behavior as a good pozzolanic material. Smaller aggregates consistently produced higher workability and compacting factors, while larger aggregates led to a reduction in workability due to increased resistance to compaction. Moreover, while the inclusion of metakaolin slightly compromised the ease of compaction, the values remained within acceptable limits for low slump applications such as pervious concrete, where high fluidity is not the primary concern. The observed trends between slump and compacting factor values show a direct relationship, validating the consistency and reliability of the workability measurements obtained in this study. These insights provide a strong foundation for further analysis of the hardened properties of the concrete at the 7, 28, and 56-day curing stages, where the strength and durability characteristics will be assessed in relation to the fresh concrete behavior.

Table 3: Slump test values

Aggregate Size (mm)	Mix Type	Average Slump (mm)

9.5 – 16	Control Mix	24.0
16.5 – 20	Control Mix	21.0
20.5 – 25	Control Mix	18.0
9.5 – 16	Metakaolin Mix (10%)	20.0
16.5 – 20	Metakaolin Mix (10%)	17.0
20.5 – 25	Metakaolin Mix (10%)	14.0

Table 4: Compacting factor test values

Aggregate Size (mm)	Mix Type	Average Slump (mm)	Compacting Factor
9.5–16	Control	24	0.82
9.5–16	Metakaolin (10%)	20	0.78
16.5–20	Control	21	0.78
16.5–20	Metakaolin (10%)	17	0.74
20.5–25	Control	18	0.72
20.5–25	Metakaolin (10%)	14	0.68

E. Compressive Strength Test

The compressive strength development of the pervious concrete mixes produced across the three coarse aggregate sizes shows consistent and insightful trends when observed over the curing ages of 7, 28, and 56 days for both the control and metakaolin modified concrete mixes. The compressive strength test results gotten and illustrated in Figure 4, Figure 5 and Figure 6, reflect the evolution of strength over time and the influence of aggregate size and metakaolin content on the concrete's mechanical behavior**.** The aggregate size range 9.5-16 mm concrete produced exhibited the highest compressive strength across all curing periods. The control mix began with strength of 9.78 MPa at 7 days and progressed to 16.44 MPa at 56 days, as it is illustrated in Figure 4. The metakaolin blended mix, although initially lower at 9.33 MPa, caught up over time and almost equal the control at 56 days with 15.78 MPa.

This pattern indicates that while metakaolin may delay early strength gain due to its pozzolanic nature, its contribution to long-term strength is evident, particularly in mixes with smaller aggregate sizes that allow better paste aggregate interaction and compaction. A similar trend was observed with the 16.5-20 mm aggregate size as shown in Figure 5, though with slightly reduced strength values due to the increase in aggregate size. At 7 days, the control and metakaolin mixes recorded compressive strengths of 9.11 MPa and 8.67 MPa respectively. By 28 days, the values rose to 13.78 MPa (control) and 13.11 MPa (metakaolin), and by 56 days, the control mix slightly outperformed the metakaolin again, recording 16.0 MPa versus 15.33 MPa.

This slight difference confirms the effectiveness of metakaolin's pozzolanic reaction over time and reinforces the benefit of longer curing durations for mixes incorporating metakaolin. Although the strength difference between the mixes is less pronounced than in the 9.5-16 mm series, the trend remains consistent. The largest aggregate size range of 20.5-25 mm, the compressive strength values were the lowest among the three groups, likely due to increased void content and reduced surface area for binder interaction (Kwabena, and Morteza, 2023). The bar chart in Figure 6 illustrated that the control mix recorded 8.44 MPa at 7 days, increasing to 15.11 MPa at 56 days, while the metakaolin mix progressed from 8.0 MPa to 14.67 MPa over the same period. The compressive strength charts illustrate a consistent relationship, smaller aggregate sizes lead to higher strengths due to improved packing and bonding, while metakaolin improves long-term strength regardless of aggregate size.

The trends validate the effectiveness of using a 10% metakaolin replacement in pervious concrete, particularly when combined with an optimized water binder ratio of 0.35 and adequate curing duration. These results align with previous findings. For instance, Rama and Shanthi, (2023) observed that a 10% metakaolin replacement could slightly reduce compressive strength at early ages but improve long-term performance due to continued pozzolanic activity. Similarly, (Kwabena, and Morteza, 2023) emphasized the importance of aggregate gradation in influencing concrete strength, noting that smaller aggregates offer better contact and dispersion within the binder matrix, which improves load distribution and crack resistance.

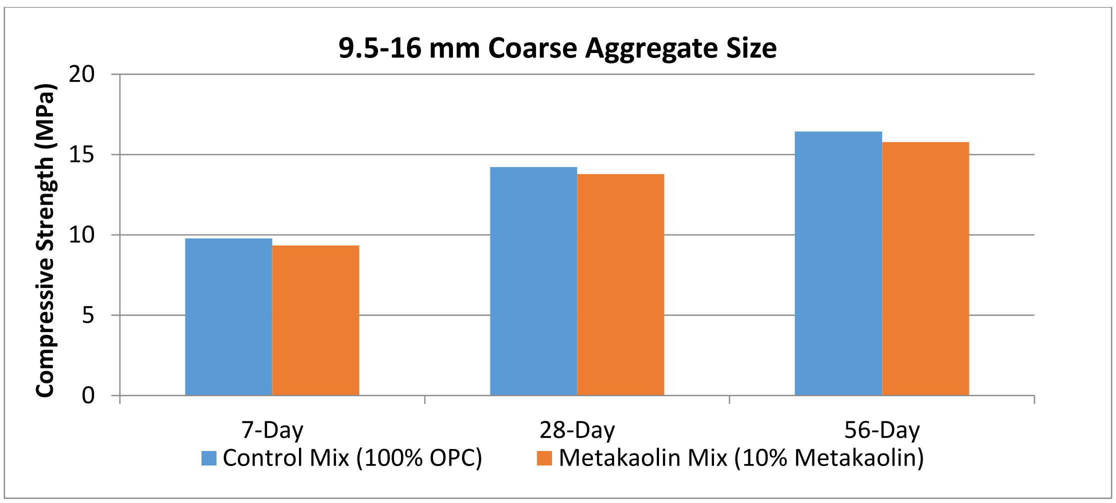

Figure 4: Compressive Strength of 9.5-16 mm coarse aggregate size pervious concrete cubes

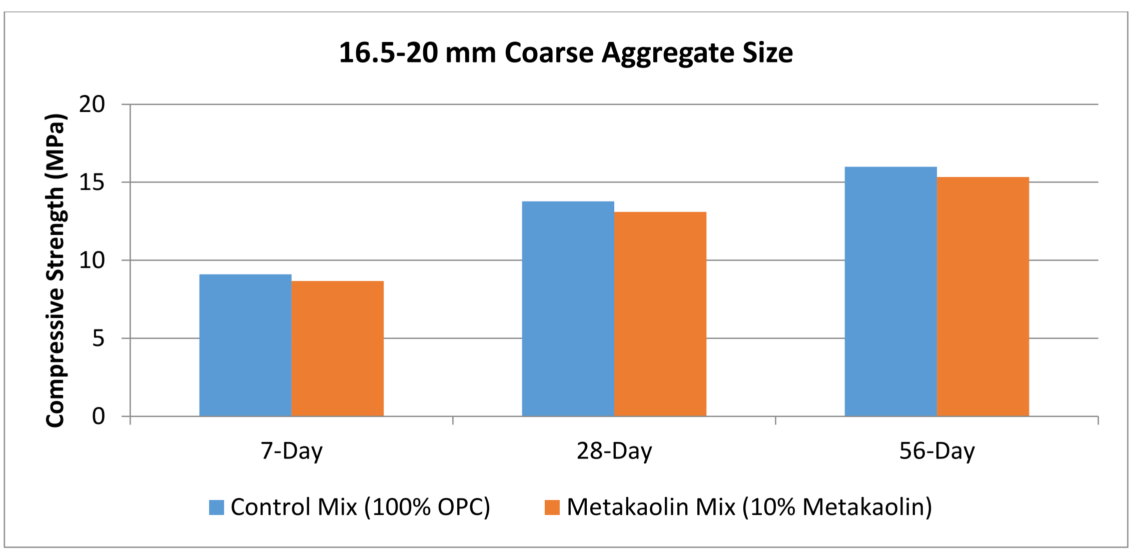

Figure 5: Compressive Strength of 16.5-20 mm coarse aggregate size pervious concrete cubes

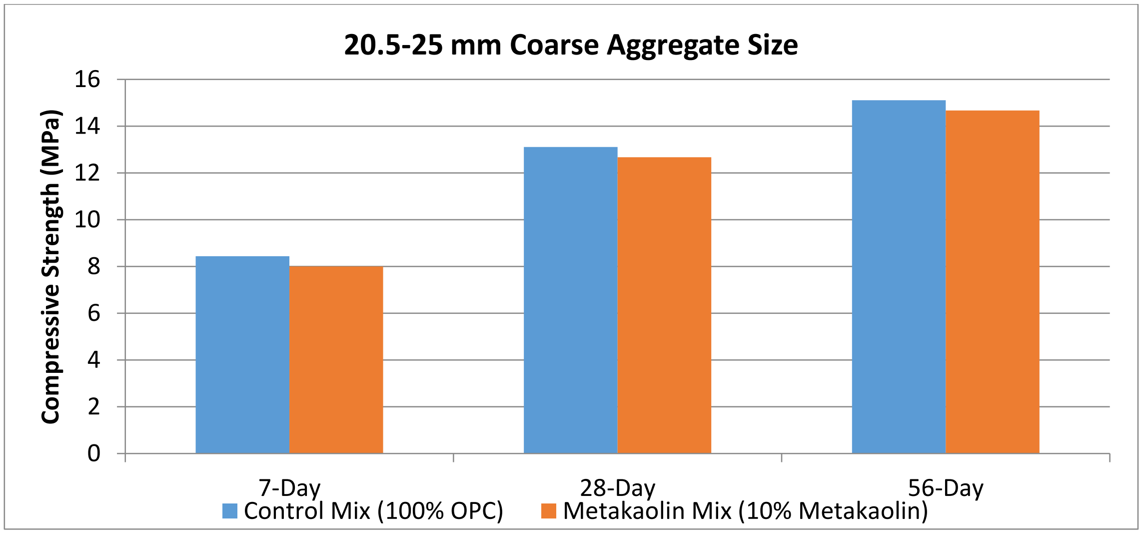

Figure 6: Compressive Strength of 20.5-25 mm coarse aggregate size pervious concrete cubes

F. Flexural Strength Test

The flexural strength test was carried out to evaluate the pervious concrete beam's ability to resist bending or flexural stresses under load. The test revealed concrete performance under load. It is particularly essential for pervious concrete, where the void structure influences the strength and water percolation, concrete beams were tested across three coarse aggregate size ranges: 9.5-16 mm, 16.5-20 mm, and 20.5-25 mm, with the results presented. From the results obtained, the flexural strength results demonstrated that both finer aggregates and metakaolin inclusion contributed positively to the tensile behavior of pervious concrete. This implies a potential trade-off when selecting coarse aggregate size for permeability versus mechanical integrity. Future design optimization would need to strike a balance depending on the intended functional priorities of the pavement or structural system.

The results of the flexural strength test presented in figure 7, 8, and 9, revealed important trends regarding the influence of aggregate size, curing age, and metakaolin inclusion on the tensile resistance of pervious concrete. The flexural strength generally improved with increased curing duration across all mixes, reflecting the continued hydration and progressive strength gained typical of cementitious systems. In figure 7, the smallest aggregate size range of 9.5-16 mm, both the control and metakaolin mixes showed the highest flexural strength values among all aggregate categories. The control mix recorded 1.60 MPa at 7 days, rising to 1.95 MPa by 56 days. In comparison, the metakaolin mix outperformed the control at every curing age, reaching 1.73 MPa, 2.00 MPa, and 2.13 MPa at 7, 28, and 56 days respectively.

This enhancement is attributed to the pozzolanic reaction of metakaolin, which not only densifies the paste matrix but also improves bond development between the binder and coarse aggregate surfaces. Furthermore, the smaller aggregate size likely resulted in a more continuous matrix with fewer large voids, hence increasing tensile integrity and improving resistance to bending stress. Figure 8 shows the flexural behavior of concrete made with 16.5-20 mm coarse aggregate range. A slightly lower flexural strength was observed compared to the 9.5-16 mm group. Control mixes attained 1.47 MPa at 7 days and improved to 1.87 MPa at 56 days. Similarly, metakaolin mixes achieved 1.65 MPa, 1.91 MPa, and 2.04 MPa at 7, 28, and 56 days respectively. Though slightly lower than the finer aggregates, these values still demonstrate the beneficial role of metakaolin in flexural strength development.

The reduced strength relative to smaller aggregates can be linked to increased void content and less effective stress transfer across the concrete section, as coarser aggregates typically result in higher porosity in pervious concrete. The largest aggregate size range of 20.5-25 mm consistently produced the lowest flexural strength values as shown in figure 9. The control mix reached 1.33 MPa at 7 days, increasing to 1.73 MPa at 56 days, while the metakaolin mix attained 1.51 MPa, 1.78 MPa, and 1.91 MPa over the same curing intervals. Despite the strength improvement due to metakaolin incorporation, the relatively larger and more irregular internal voids characteristic of coarse aggregates contributed to a reduced ability to resist tensile stress under flexure. This result confirms the inverse relationship between aggregate size and tensile performance in pervious concrete due to weaker interfacial bond areas and increased discontinuities in the paste-aggregate skeleton.

Comparing across all aggregate sizes, it is evident that flexural strength performance follows the trend, 9.5-16 mm > 16.5-20 mm > 20.5-25 mm, irrespective of the mix type or curing duration. Additionally, metakaolin consistently enhanced flexural strength, underlining its efficiency as a supplementary cementitious material in improving mechanical properties, especially in tensile-critical applications. The effect of curing time was also significant, with the most substantial gains occurring between 7 and 28 days, then tapering off slightly by 56 days a pattern consistent with strength gain curves in cement based materials. The flexural strength results demonstrated that both finer aggregates and metakaolin inclusion contribute positively to the tensile behavior of pervious concrete. This implies a potential trade-off when selecting coarse aggregate size for permeability versus mechanical integrity. Future design optimization would need to strike a balance depending on the intended functional priorities of the pavement or structural system.

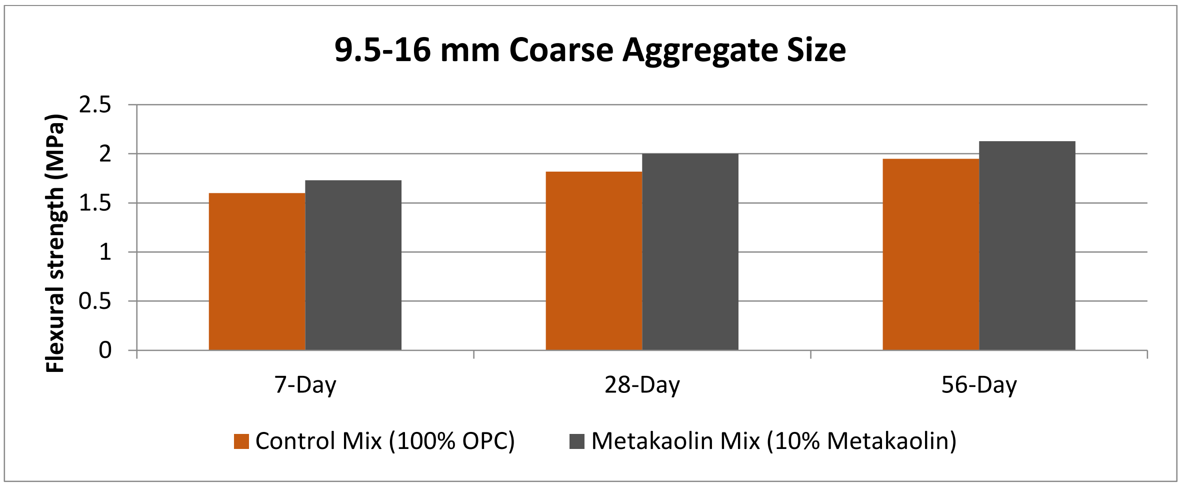

Figure 7: Flexural strength of 9.5-16 mm coarse aggregate size concrete cubes

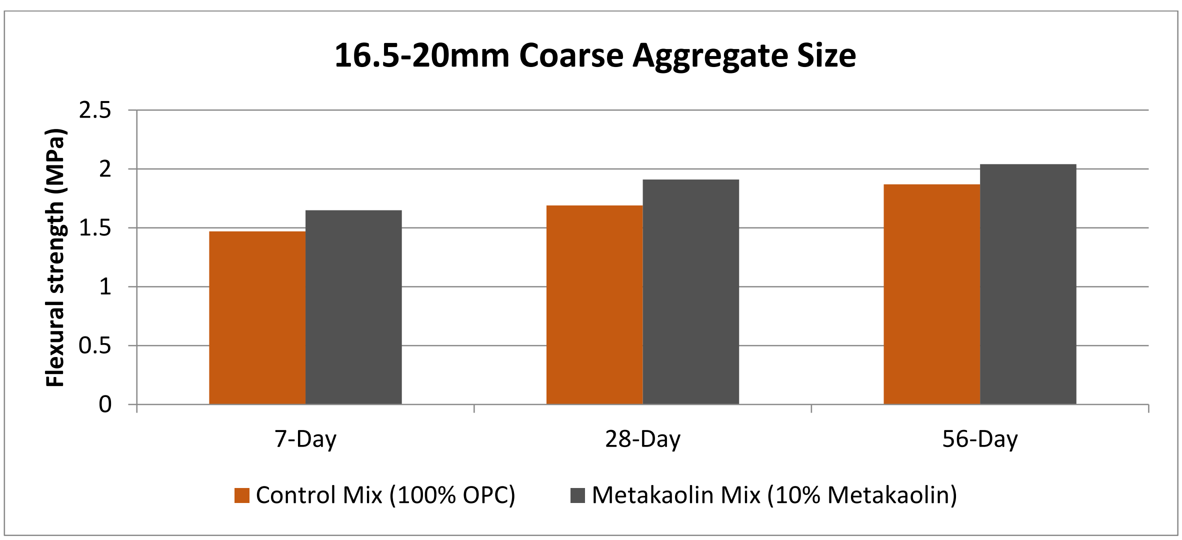

Figure 8: Flexural strength of 16.5-20 mm coarse aggregate size concrete cubes

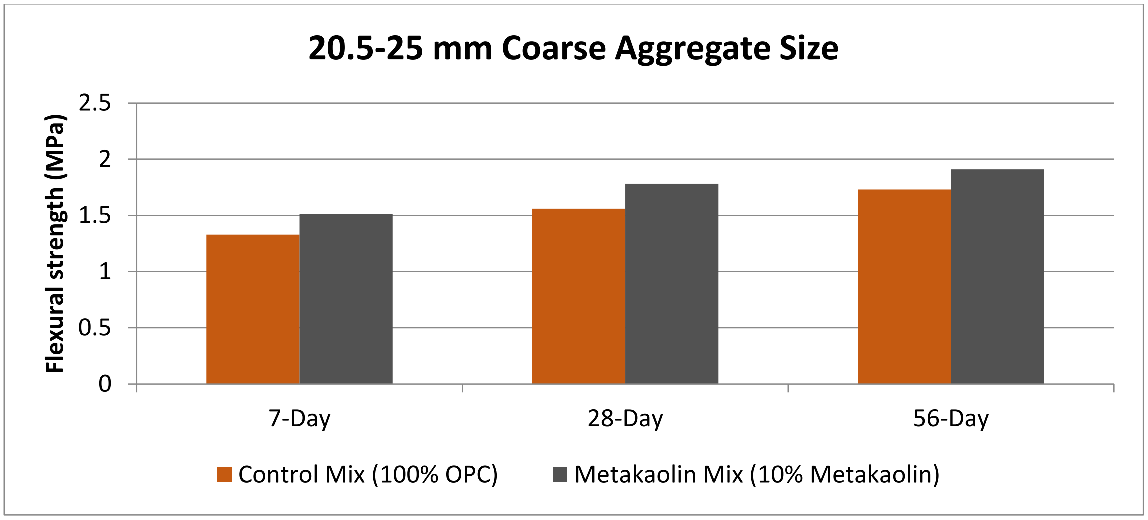

Figure 9: Flexural strength of 20.5-25 mm coarse aggregate size concrete cubes

G. Permeability Test of Pervious Concrete

Across all aggregate sizes, the control mixes consistently showed higher permeability values than their metakaolin-modified counterparts, this trend is attributable to the densifying effect of metakaolin, which refines the pore structure and reduces the interconnected voids that facilitate water passage. In figure 10, the 9.5-16 mm aggregate size, the control mix exhibited permeability values ranging from 6.8 mm/s at 7 days to 5.5 mm/s at 56 days, while the metakaolin-modified mix ranged from 6.2 mm/s to 4.8 mm/s over the same period. These results confirm the trend that smaller aggregate sizes produce tighter inter-particle packing, leading to reduced void channels and thus lower permeability. The decrease in permeability with age is due to continued hydration and void refinement as the cementitious materials solidify the matrix, especially under the influence of metakaolin’s pozzolanic activity.

The medium-sized aggregates (16.5–20 mm), has its permeability increased relative to the smaller aggregate mixes in figure 11. Control mixes achieved 9.5 mm/s at 7 days, reducing to 7.9 mm/s at 56 days, while metakaolin modified mixes decreased from 8.6 mm/s to 6.9 mm/s. This aggregate size appears to strike a reasonable balance between strength and permeability, as seen in previous compressive and flexural strength results. The interconnected voids here are larger than in the smaller aggregate mixes but still controlled enough to provide a relatively stable structure. This makes this size range particularly promising for applications requiring both drainage and moderate strength. The largest aggregate size (20.5–25 mm) produced the highest permeability values overall as shown in figure 12, the control mix achieved 13 mm/s at 7 days, settling at 11 mm/s by 56 days, while the metakaolin mix ranged from 11.8 mm/s to 9.5 mm/s. This is consistent with the expected behavior where larger aggregates increase void content and decrease surface area for paste bonding, thus allowing water to flow more freely. However, the metakaolin mixes still reduced permeability by approximately 1.5–2 mm/s across the curing period due to their pore-filling and densifying characteristics.

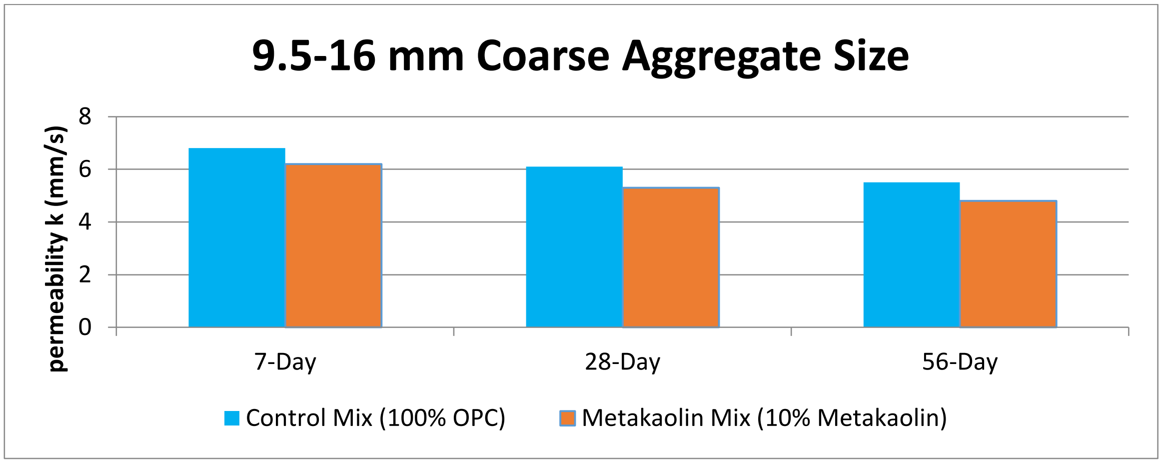

Figure 10: Permeability of 9.5-16 mm coarse aggregate size concrete cubes

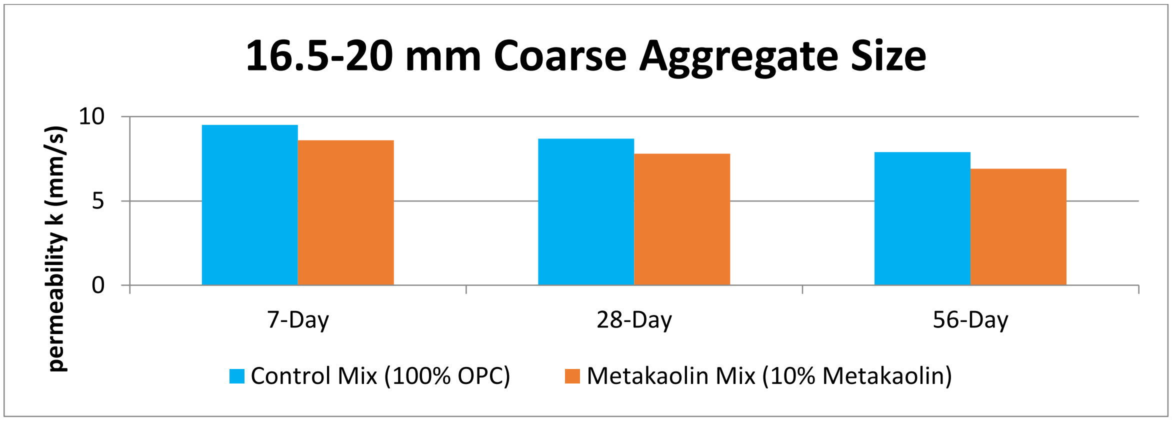

Figure 11: Permeability of 16.5-20 mm coarse aggregate size concrete cubes

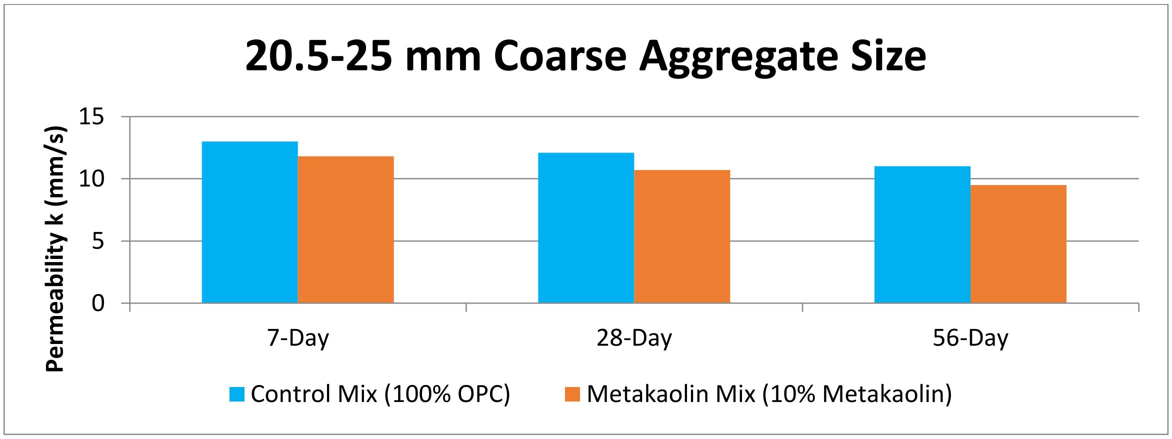

Figure 12: Permeability of 20.5-25 mm coarse aggregate size concrete cubes

Conclusion

Experimental investigations were conducted on metakaolin-blended pervious-concrete mixes to determine their mechanical and hydraulic properties. The optimum pervious-concrete mixes blended with metakaolin were selected from the obtained results of strength and workability. The influence of metakaolin on the mechanical properties of pervious concrete was investigated and the following conclusions presented:

a. The coarse aggregates used in this study were well-characterized. Granite was identified as the aggregate type, and all three size ranges tested (9.5–16 mm, 16.5–20 mm, and 20.5–25 mm) met the requirements of BS 882:1992 for use in structural concrete, indicating their suitability for pervious concrete production.

b. The workability of the fresh concrete, as assessed by slump and compacting factor tests, was found to decrease with increasing aggregate size and the inclusion of 10% metakaolin. Control mixes generally exhibited higher workability than the metakaolin-modified mixes, and mixes with smaller aggregates (9.5–16 mm) had the best workability.

c. Compressive strength, flexural strength and permeability were significantly influenced by aggregate size. Smaller aggregates enhanced strength and density, while larger aggregates improved permeability and less workability. Strength properties increased with curing age. The 16.5–20 mm aggregate size range provided a balanced performance between strength and permeability, exhibited a fantastic coefficient of permeability value without compromising the concrete's strength.

d. The partial replacement of PLC with 10% metakaolin improved the long-term strength and durability of the pervious concrete due to its pozzolanic reaction, though it slightly reduced early-age workability and strength. The optimal performance was achieved with the 16.5–20 mm aggregate size combined with the metakaolin-blended mix, presenting a viable solution for balancing mechanical strength and permeability in sustainable pavement systems.

In the light of the outcome of this study, it is recommended that the use of 9.5–16.0 mm and 16.5–20.0 mm coarse aggregate sizes be prioritized in pervious concrete production, as they demonstrated superior mechanical strength, moderate workability and maintained acceptable permeability. Particularly, the 16.5–20.0 mm aggregate size range offers a favorable balance between strength and drainage performance, making it suitable for structural pervious concrete applications. Additionally, incorporating 10% metakaolin as a partial replacement for Portland Limestone is recommended for long-term strength enhancement in pervious concrete. The study showed that while early-age strength may be slightly lower, metakaolin-enhanced mixes catch up and nearly match or exceed PLC mixes by 56 days, confirming the pozzolanic benefit over time.

Moreover, only one water-binder ratio (0.35) was employed across all mixes. Future studies should consider varying the water-binder ratio to assess its influence on workability, strength development, and permeability, particularly in the presence of pozzolanic materials like metakaolin. Additionally, the introduction of chemical admixtures, such as superplasticizer or water-reducing agents, may further enhance mix performance and should be investigated to understand their interaction with metakaolin and aggregate gradation. Lastly, while the laboratory-based permeability test conducted under standardized conditions was effective, it is recommended that in-situ field testing or simulation under real-world conditions (considering variable load, ambient temperature, and rainfall intensity) be performed to better reflect the drainage behavior and long-term performance of pervious concrete.

Reference

Adesanya D. A., Raheem, A. A. (2009) Development of Corn Cob Ash Blended Cement, *Construction and Building Materials,*23(4):347 352. oi:10.1016/j.conbuildmat.2007.11.013.

Adewole, K. K., Olutoge, F. A., Habib, H. (2014) Effect of Nigerian Portland-Limestone Cement Grades on Concrete Compressive Strength. *International Journal of Civil Environmental Engineering,* 8(1):199-202.

Ajamu, S. O., Jimoh, A. A. and Oluremi, J. R. (2012) "Evaluation of Structural Performance of Pervious Concrete in Construction" *International Journal of Engineering and Technology.* Volume 2, No. 5.ISSN 2049-3444.

Akinwumi, G. (2016) Thermal Properties in Early Age Cracking in Cementitious System Report.*25, A. Bentur, RILEM Publications.*

ASTM C39M-21 Standard Test Method of Determining the Compressive Strength.

BS EN 197-1 (2000) Cement, Composition, Specifications and Conformity Criteria for Common Cements (British Standard).

BS 882 (1992) Specification for Natural Aggregates for Concrete.

BS 812-2 (1995) Method of Determining Properties of Aggregates Used in Construction.

BS 1881: Part 116 (1970) Method of Determining the Compressive Strength of Concrete Cubes.

BS 1881, Part 117 (1983) Method of Determining the Compressive Strength of Concrete Cubes.

BS 1881-108 (1983) Method for Making Test Cubes from Fresh Concrete. Scientific Research Publishing.

BS EN 12350-4 (2019) Testing fresh concrete, Degree of compatibility test, *BSI group, London,* DOI:10.1016/j.clema.2021.100026.

BS 3148 (1980) Specification for methods of Test for water for making concrete, *British Standard Specification London* United Kingdom (1980).

Gurnani, J. H., Priyanka, V., Temghurnikar A, Shital, R., Aniket, W., Rushkesh, B. and Sonal, D. (2023) "Performance of pervious Concrete Made with Black Marble Stone Waste Aggregate" *International Research Journal of Modernization in Engineering Technology and Science.* Volume 05, Issue 02.

IS 5816 (1999) Indian standard code for the *Method of Test for Splitting Tensile Strength of Concrete.*

Kwabena, B. and Morteza, K. (2023) Influence of Calcined Clay Pozzolan and Aggregate Size on the Mechanical and Durability Properties of Pervious Concrete. *Journal of Composite Science (Volume 7 Issue 5, 182 May 1 2023).*

Mehran, K. and Majid, A. (2019) Improvement in Concrete Behavior with Fly Ash, Silica-fume and Coconut Fibres. *Construction and Building Materials, Volume 203 Pg 1-740 (April 10, 2019).*

Mujedu, K. A., Adebara, S. A., and Lamidi, I. O. (2014) The Use of Corn Cob Ash and Saw Dust Ash as Cement Replacement in Concrete Works. *International Journal of Engineering Science,* 3(42):2-8.

Osuolale, O.M., Atoyebi, O.D., and Tunde, O. V. (2019) Experimental Study of the Strength Performance of Sawdust Ash Pervious Concrete. *Journal of Engineering and Applied Science, 14(832):1-8.*

Rafas S. and Juvas K. (2009) Influence of Metakaolin on the Properties of Mortar and Concrete: A review

Raheem, A. A. and Ikotun, B. D. (2020) 'Incorporation of Agricultural Residues as Partial Substitution for Cement Concrete and Mortar- a Review" *Journal of Building Engineering,* Vol.31, 2020, pp. 101-428

Rama, M., and Shanthi, V. M. (2023) Study on Strength, Permeability and Micro-structure of Pervious Concrete Blended with Metakaolin, *Jordan Journal of Civil Engineering,* Volume 17.

Sadiq O. M., Atoyebi O. D. (2015) Flexural Strength Determination of Reinforced Concrete Elements with Waste Glass as Partial Replacement for Fine Aggregate. *NSE Technology Trans Journal of Nigeria Society of Engineering;* 49:74-81.

Sujeet, K. S., Shalk, N. G. and Senthil, S. (2018) "Experimental Study on Behavior of Pervious Concrete in Strength and Permeability by Changing Different Parameters" *International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13 No. 6 pp.* 4550-4554.