

**EFFECT OF PARTIAL REPLACEMENT OF FINE
AGGREGATE WITH METAKAOLIN POWDER ON THE
MECHANICAL PROPERTY OF CONCRETE**

BY

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CERTIFICATION

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DEDICATION

This work is dedicated to the Almighty God and my family, whose love and care served as the wind in my back to motivate me and push me forward.

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ACRONYM

MK	-	Metakaolin
PPM	-	Particle Parking Model
SCC	-	Self-compacting Concrete
HSC	-	High Strength Concrete
SCM	-	Supplementary Cementitious Materials
HPCF	-	High Porosity Cement Foams
RCPT	-	Rapid Chloride Permeability Test
PP	-	Polypropylene
MP	-	Macro-polypropylene
SF	-	Silica Fume
HRM	-	High Reactive Metakaolin
RCA	-	Recycled Concrete Aggregate
TCT-LCD	-	Thin Film Transistor Liquid Crystal Display
PET	-	Polyethylene
SP	-	Super Plasticizers
OPC	-	Ordinary Portland Cement

ABSTRACT

The aim of this project is to determine the effects metakaolin powder has on the mechanical properties of concrete when partially replaced at various percentages (**15%**, **20%** and **25%**). The idea behind this study is to assess if metakaolin powder can serve as a suitable substitute for sand as a fine aggregate in terms of responses to various tests. This study seeks to serve as a guide for future research in this field. It also serves to answer the question of why seek substitutes for fine aggregate at all.

The tests required for accomplishing this experiment's objectives are the compressive, flexural, slump and density tests, to determine the compressive strengths, flexural strengths, workability and density, respectively, of various samples been tested. Conventional concrete samples are cast and compared to partially replaced concrete samples to analyze the effects on concrete.

The results for various tests differ showing rises and falls in strengths, slumps and densities. These results are then compared using tables and charts, from which a conclusion is drawn.

The conclusion drawn for workability is that it has a low workability due to the pozzolanic nature of metakaolin powder and its reaction to cement and for the strengths, it is ascertained that concrete samples experience an increase in strength at 15% of partial replacement followed by a decrease at 20% and an increase at 25% indicating a possibility of later strengths at higher percentages but more so at longer periods of curing.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background of study

Concrete, due to its versatility and ready availability, has gradually replaced various competing building materials like wood, solid bricks, and straw. Architects and structural engineers favor these materials because of their perceived durability, low maintenance requirements, and protective qualities. Currently, concrete holds the position of the world's most produced product by volume, estimated at approximately 11 billion tonnes. In Nigeria, construction predominantly relies on concrete due to its cost-effectiveness and use of locally sourced materials.

The production of concrete involves the mixing of cementitious materials, water, and aggregates in specified proportions. This mixture, when placed in a mold and allowed to undergo a hardening process, transforms into a solid mass referred to as concrete, maintaining the shape it had when poured. The hardening results from a chemical reaction between water and cement, a process that extends over a considerable period, making concrete stronger with time. Hardened concrete can be likened to artificial stone, where smaller particles fill the voids left by larger particles and cement fills the voids within aggregates. It is crucial to use the correct type and quantity of materials.

The aggregate component in concrete constitutes around 60–75% of the total volume. The inclusion of aggregates in concrete decreases drying shrinkage and enhances various properties. Despite being the least expensive per weight unit, aggregates contribute significantly to the overall weight. Globally, aggregate consumption falls within the range of 8–12 billion (Kumar et al., 2012). Aggregates are categorized as fine and coarse and can be sourced naturally or produced artificially. Given the vital role of concrete in

structural construction, the aggregate content should possess substantial strength for structural purposes.

In response to the growing environmental imperative to minimize waste and address the global recycling challenge, the concrete industry has implemented diverse strategies. These include the substitution of fine aggregate, coarse aggregate, or cementitious binders with alternative materials.

The demand for fine aggregate is particularly high due to increasing urbanization and the continuous requirement for infrastructure development. However, the persistent use and production of fine aggregate contribute to ecological imbalances such as landscape degradation, compromised land stability, water pollution, and atmospheric pollution. Therefore, the partial replacement of fine aggregate holds significant importance for the construction sector. It serves as a viable alternative that aligns with environmental considerations and contributes to the enhancement of concrete.

This specific experimental initiative aimed to explore the utilization of metakaolin as a partial substitute for fine aggregate. Concrete specimens were cast with **M20**, **M30**, and **M40** grades, incorporating varying replacement percentages of metakaolin—**15%**, **20%**, and **25%**. The specimens were subjected to wet curing for different durations, including **7 days**, **14 days**, and **28 days**.

Metakaolin stands out as a pozzolanic product with diverse specific characteristics. It comes in various types and grades, with purity being a determinant of its binding capacity or the presence of free lime. Certain varieties also display unique reactivity. As an advantageous admixture for concrete and cement applications, metakaolin imparts favorable engineering properties to the resulting concrete. The pozzolanic reaction is believed to initiate early and persists over a period ranging from 7 to 28 days.

This particular study expatiates on metakaolin as a material, the effects on concrete mixes through given tests as well as the procedures of said tests. The results of the partially replaced concrete is then compared with the performance of conventional concrete to find a conclusion.

1.2 Statement of problem

Kaolinite is a gentle, earthy mineral, typically white, classified as a dioctahedral phyllosilicate clay. It results from the chemical weathering of aluminum silicate minerals like feldspar. On the other hand, metakaolin is created through controlled thermal treatment (calcination) of kaolin, rendering a more stable version of the aforementioned mineral. It serves as a potential substitute for fine aggregate, aiming to reduce construction costs and mitigate the environmental impact associated with sand processing. Additionally, its influence on the mechanical properties of hardened concrete is being explored through partial replacement at varying metakaolin percentages.

1.3 Aim and objectives

The objective of this undertaking is to assess the impact of substituting a portion of fine aggregate with metakaolin powder on the mechanical characteristics of solidified concrete. This evaluation will be conducted by achieving the outlined goals below:

- i. To determine the workability of fresh concrete.
- ii. To determine the density of hardened concrete.
- iii. To determine the compressive strength of hardened concrete.
- iv. To determine the flexural strength of hardened concrete.

1.4 Scope of study

The examination involves comparing concrete compositions where fine aggregate is partially substituted with metakaolin at different rates (**15%**, **20%**, and **25%**) to traditional concrete. The goal is to understand the impact on mechanical properties. Various tests and procedures, including the slump test, are necessary to evaluate the workability of both conventional and partially replaced concrete. The casting of concrete into cube and beam moulds (using various apparatus such as head-pans, trowels, shovels, etc., while taking proper safety precautions) to form cubes and beams respectively. These cubes and beams are then weighed using the weighing balance and measured, using a tape measure to determine their density (**kg/m³**). A compression testing machine and flexure strength testing machine is used to determine compressive strength (**N/mm²**) for cubes (**100×100×100**) mm and flexural strength (**N/mm²**) for beams (**1000×66×127**) mm for both control (concrete with 0% replacement) and partially replaced concrete followed by a comparison of results.

All examinations were conducted within the Structural Laboratory located in the Civil Building of the Faculty of Engineering at the University of Benin, situated in Benin City, Edo State.

1.5 Justification of study

The findings of this research will inform individuals in the construction sector about how metakaolin influences the mechanical features of concrete when applied as a partial replacement for fine aggregate. Additionally, it raises awareness within the industry regarding the potential use of metakaolin as an eco-friendly alternative for fine aggregate, contributing to both environmental well-being and cost-effectiveness.

CHAPTER TWO

2.0 LITERATURE REVIEW

The rise of high-performance concrete has underscored the essential requirement for additives, encompassing both chemical substances and supplementary cementing materials, aimed at enhancing concrete properties. The global progress in concrete improvement is evidenced by the continual refinement of these additives (Murthy et al., 2012). Consequently, supplementary cementitious materials (SCMs) have become an integral aspect of high-performance concrete mix design, encompassing natural materials, by-products, and industrial residues from various manufacturing processes. Numerous endeavors have been undertaken to formulate sustainable binders by incorporating SCMs as partial substitutes for cement in concrete. These include materials like slag, fly ash (FA), palm oil fuel ash (POFA), silica fume (SF), rice husk ash (RHA), ground granulated blast furnace slag (GGBFS), metakaolin (MK), and others. These SCMs are commonly employed as pozzolanic materials in concrete, showcasing a significant capacity to enhance mechanical properties.

SCMs are important and necessary components for modern concrete structures by produce high-performance concrete. (Aitcin, 2011) The mortar and concrete properties, both in fresh and hardened cases, can be enhanced by cement composed of mixtures of Portland cement with these other additives, which have been used in more and more concrete projects (Zongjin, 2011). The examination outcomes revealed enhancements in strength, resilience, and longevity. The most effective replacement proportion for metakaolin and fly ash was identified as 7.5%. They reported that the compressive strength of high-performance concrete containing 7.5% of metakaolin was 12% higher than the normal concrete. (Kannan and Ganesan, 2012) investigated the effects of rice husk ash,

metakaolin and their combinations when used as replacement for blending component in cement. The characteristics of mortar incorporating blended cement were examined, covering aspects like physical and chemical properties, setting time, compressive strength, and saturated water absorption. Metakaolin is used in the development of self-compacting concrete (Poon et al., 2001), (Basu, 2003), (Patil and Kumbhar, 2012), (Dvorkin et al., 2012) and it has given the good results.

Metakaolin distinguishes itself from other Supplementary Cementitious Materials (SCMs), such as fly ash, silica fume, and slag, by not being a by-product of an industrial process. It is intentionally manufactured for a specific purpose under controlled conditions. The production of metakaolin involves heating kaolin, a prevalent natural clay mineral, to temperatures ranging from 650-900°C. This calcination process breaks down the structure of kaolin, eliminating bound hydroxyl ions. The outcome is a disorder among alumina and silica layers, resulting in a highly reactive, amorphous material with pozzolanic and latent hydraulic reactivity. This material is well-suited for various cementing applications. When used as a partial replacement for Portland cement, metakaolin may improve both the mechanical properties and the durability of concrete (Ankur and Deepa, 2011). Development and construction of different structures are directly associated with civil engineering construction of any structure needs construction material like sand, stones, bricks, cement, concrete, steel, glass, and wood, etc. There is a substantial need for these materials within the construction sector to facilitate sustainable development. This involves the utilization of renewable resources to conserve natural resources and mitigate environmental pollution. Keeping this in mind reuse and recycle of waste material from the demolished building site is needed. Finding an alternative replacement for natural fine aggregate and coarse aggregate has been inattention of many scholars and researchers

recently. Different materials have been tried already such as glass waste, wooden waste, plastic, and other waste materials.

Based on the existing literature, there are varying opinions regarding the optimal quantity of metakaolin as a favorable substitute material in high-strength concrete (HSC) production. Several researchers have noted a notable enhancement in both mechanical and durability properties of high-strength concrete through partial cement replacement with metakaolin. However, there is a significant research gap concerning the determination of the efficiency factor of metakaolin, an aspect that has been established for self-compacting concrete. Past studies have affirmed the positive impact of metakaolin on concrete strength. This underscores that the strength of HSC is primarily influenced by water/cement ratios and the levels of metakaolin replacement. As a result, this study is designed to address these research gaps.

Initially, specimens under control conditions will be created with diverse water/cementitious ratios ranging from 0.50. Concurrently, specimens will be prepared with partial replacements using metakaolin at levels of 15%, 20%, and 25%. Subsequently, an in-depth evaluation will be conducted on the impact of key variables influencing compressive strength. Extensive use of fine aggregates in construction will eventually run out Nigeria's supply and might lead to increase in prices (Hainin, et al., 2012). Hence, it is imperative to identify a suitable alternative for fine aggregates to mitigate this issue. The exploration of metakaolin as a potential partial replacement for fine aggregate in concrete production has been instigated by the challenges associated with the availability of fine aggregate. The utilization of supplementary cementitious material like metakaolin concrete can compensate for environmental, technical and economic issues caused by cement production.

(Ubojiekere E. Obunwo et al., 2018) The study explores the impact of metakaolin on the fresh properties and compressive strength of high-strength self-compacting concrete (SCC). The particle packing model (PPM) was employed for the concrete mix design, with the primary goal of eliminating voids in SCC. Metakaolin (MK) was utilized as a substitute for cement at three incorporation ratios: 5%, 10%, and 15%, coupled with varying water-to-cementitious ratios of 0.25, 0.30, 0.35, and 0.40. The mixes were formulated to achieve both self-compatibility and high compressive strength. Multiple workability tests, including slump flow, L-box, Funnel, and J-ring, were conducted. Compressive strength measurements were taken at 7, 14, and 28 days of wet curing. The findings indicated the adequacy of the mix design method for proportioning SCC mixtures with cement and metakaolin. All fresh state properties met the criteria outlined by EFNARC (2005). The highest compressive strength of 69.6MPa was achieved in concrete incorporating metakaolin, demonstrating a significant enhancement in compressive strength for all mixtures. A similar trend was observed in all the concrete mixes and there was progressive increase in compressive strength as metakaolin inclusion level increased.

(Hamdy, et al., 2017) carried out an experimental investigation on the mechanical behavior of high strength concrete made with high percentages of metakaolin and hybrid fibres with volume fractions of 0.25% and 0.5%. A total of 315 standard test samples, comprising 189 cubes and 126 cylinders, were fabricated and distributed across three groups, each containing 105 specimens. Each dataset was derived from the average outcomes of three test specimens. The metakaolin (MK) percentage remained constant across all groups (10%, 15%, 20%, 30%, 40%, and 50%), relative to the weight of cement. Findings indicated the feasibility of producing High Strength Concrete (HSC) with a substantial metakaolin content. The combined influence of hybrid fibers and metakaolin

revealed that the optimal proportion of MK is 15% across all testing periods. In addition, there was a significant gain in split tensile strength due to Metakaolin and hybrid fibres.

(Rathan, et al., 2013) formulated a simplified mix design procedure for HSC by combining BIS and ACI code methods of mix design. Using this information, a desired compressive strength of 60 MPa was determined. In the compressive strength assessment, three cubes were examined for each experimental mix combination at curing intervals of 1, 7, 14, 28, and 56 days. It was observed that the strength of concrete blended with metakaolin increases as the incorporation ration of metakaolin increases at all the curing ages.

(Kasini, et al., 2012) studied the influence of metakaolin (MK) on the compressive strength development of the concrete, the metakaolin samples investigated were obtained from four different sources in Czech Republic. Portland cement was substituted with Metakaolin at rates of 5%, 10%, 15%, and 20% in concrete production. To establish a basis for comparison, a control mix devoid of any admixture was also created. The compressive strength evolution of the concrete was assessed at intervals of 3, 7, 28, and 90 days. It was concluded that metakaolin incorporated concretes, 15% was observed to be the optimal replacement level for the concrete compressive strength for 28 and 90 days of curing.

(Ramezaniyanpour and Bahrami, 2012) studied the response of concrete mixtures containing local metakaolin in terms of compressive strength, water penetration, absorptivity, salt ponding, Rapid Chloride Permeability Test (RCPT) and electrical resistivity subject to 7, 28, 90 and 180 days of curing. Portland cement was substituted with metakaolin at various percentages: 0% (representing a control mix without metakaolin), 10%, 12.5%, and 15% by mass. The mixes were formulated with water-to-cement (w/c) ratios of 0.35, 0.4, and 0.5, while maintaining a consistent binder content of

400 kg/m³. Findings indicated that High-Strength Concrete (HSC) blended with metakaolin (MK) exhibited a notable increase in compressive strength compared to the control mixture (0% MK) as the curing duration progressed. In addition, according to the salt ponding and RCPT tests, it was observed that metakaolin significantly enhances the resistance to chloride penetration compared with the control mixture.

(Dhinakaran, 2012) studied the strength increases by MK concrete is effective only at the early age of concrete and in the long term the strength increase is only marginal. The rise in compressive strength was more pronounced in MK concrete, particularly at higher water-cement ratios (0.4 and 0.5), making it more suitable for elevated w/cm ratios. Through the research, the optimal MK percentage was identified as 10% for all w/cm ratios except 0.32, where the optimal percentage was 15%. While MK concrete exhibited a substantial early-age strength increase, beyond 28 days, the increase became less than 10%. The maximum compressive strength of 59.25 N/mm² was achieved at a 0.4 w/cm ratio with 10% MK. The addition of MK led to a reduction in pH values, though the reduction was negligible, as the pH values remained above 11.5, ensuring the maintenance of steel (reinforcements) in a passive state. The chloride ion penetration depth for MK concrete was significantly lower than that of control concrete. The minimum reduction rates for chloride penetration depth in MK-admixed concrete were determined as 78%, 38%, 25%, and 25% for w/cm ratios of 0.32, 0.35, 0.40, and 0.50, respectively. The maximum rate of reduction was observed as 95% for 0.32 and 0.3 ratios.

(Nova John, 2013) investigated the cement replacement levels were 5%, 10%, 15%, 20% by weight for metakaolin. The strength development of all concrete mixes containing metakaolin exceeded that of conventional concrete. The mix with a 15% metakaolin content demonstrated superior performance compared to others. Increasing metakaolin content up to 15% enhanced compressive strength, split tensile strength, and

flexural strength. These results advocate for the use of metakaolin as a pozzolanic material for partial cement replacement in high-strength concrete production. The addition of metakaolin led to faster early-age strength development in concrete, attributed to its pozzolanic activity. The compressive strength of HGC increased by 10.13%, 14.24%, and 22.90% with the addition of metakaolin at 4%, 6%, and 8%, respectively, compared to control concrete specimens of HGC. The variation in RCPT values in HGC for different proportions of metakaolin blended concrete indicated a decrease in concrete permeability with an increase in metakaolin percentage. The values of rapid chloride permeability of HGC decreased up to 1450 coulombs, 1548.67 coulombs, and 1684.70 coulombs for 4%, 6%, and 8% metakaolin, respectively, compared to control concrete specimens. The percentage reduction in permeability values in coulombs was 48.57%, 51.88%, and 56.43% for metakaolin content of 4%, 6%, and 8%, respectively.

Utilization of metakaolin as a pozzolanic material in mortar and concrete studied by (Sabir et.al., 2001). They stated that incorporating metakaolin into concrete and mortar contributes to the early strength development. Additionally, they highlighted its significant enhancement of resistance to water transportation and the diffusion of detrimental ions, thereby preventing matrix degradation.

An attempt has been made by (Hemant et al., 2011) to use industrial wastes like activated fly ash, iron oxide and metakaolin as supplementary cementitious materials in various proportions. By incorporating mineral admixtures such as fly ash (30%), metakaolin (10%), and iron oxide (2%) with OPC cement, five distinct concrete mixtures were formulated. These mixtures were then utilized to assess the compressive strength of concrete cubes at 3, 7, 14, 28, and 56 days. The findings suggested that achieving concrete cost-effectiveness was feasible through a 42% replacement of cement with varying proportions of mineral admixtures. High performance concrete was prepared by partial

replacement of Ordinary Portland Cement (OPC) with metakaolin and fly ash by (Muthu priya et al., 2011).

(Khatib et al., 1996) investigated the porosity and pore size distribution of cured Ordinary Portland Cement-Metakaolin paste. Mixtures with varying proportions of metakaolin (0%, 5%, 10%, and 15%) were formulated with a consistent water-to-binder (w/b) ratio of 0.55. The specimens underwent moist curing for durations ranging from 3 days to 365 days. The intruded pore volume and the pore structure were determined by mercury intrusion porosimeter. (Khatib et al., 1998) in their research said that the partial replacement of cement with metakaolin is investigated in terms of resistance of metakaolin mortar to Sodium Sulphate (Na_2SO_4) solution and some specimens are cured in water. Results on strength, pore size distribution, porosity, are reported.

(Frais et al., 2000) The authors present findings from a study that explores the impact of metakaolin (MK) on the microstructure of pastes blended with MK. Pastes containing 0%, 10%, 15%, 20% and 25% of MK were prepared at a constant water/binder ratio of 0.55 and cured at 200°C for hydration periods from 1 to 360 days.

(Nabil M. Al-Akhras, 2006) this study investigates the effect of metakaolin (MK) replacement of cement on the durability of concrete to sulfate attack. The study examined three replacement levels of MK: 5%, 10%, and 15% relative to the weight of cement. Other experimental factors considered included the water-to-binder ratio (0.5 and 0.6), the initial period of moist curing (3, 7, and 28 days), the type of curing (moist and autoclaving), and air content (1.5% and 5%). After the specified initial moist curing period, concrete specimens were immersed in 5% sodium sulfate solution for a total period of 18 months.

(Rafat Siddique et al., 2010) an investigation dealing with the effect of metakaolin (MK) on the near surface characteristics of concrete are presented in this work. A control concrete having cement content 450kg/m^3 and w/c of 0.45 was designed.

(Dinakar et al., 2011) examined High Reactive Metakaolin (HRM) for high strength and high-performance concrete. According to him, materials like fly ash, silica fume, and GGBS, classified as Supplementary Cementing Materials (SCMs), have seen a growing utilization in recent times as substitutes for cement. They help obtain both higher performance and economy.

(Beulah et al., 2012) this paper presents an experimental investigation on the effect of partial replacement of cement by metakaolin by various percentages; 0%, 10%, 20%, and 30% on the properties of high-performance concrete, when it is subjected to hydrochloric acid attack.

(Vikas Srivastava et al., 2012) this study deals with the addition of some pozzolanic materials, the various properties of concrete; workability, durability, strength, resistance to cracks and permeability can be improved. The objective of this study is to assess the mechanical properties of cement partially replaced with metakaolin in varying proportions (0%, 10%, 15%, 20%, 25%, and 30%) for M70 grade concrete. The investigation includes the evaluation of compressive strength, split tensile strength, flexural strength, and stress-strain curve of MKC at a 15% replacement subjected to temperatures of 100°C , 200°C , 300°C , 400°C , and 500°C . The mix proportions were determined by partially replacing OPC with 0%, 10%, 15%, 20%, 25%, and 30% of MK. Cement may be pure Portland cement, or it made from Portland cement mixed with other materials that also have cementitious properties such as supplementary cementing materials.

(Zhiguang Shi et al., 2015) conducted the experiment on effect of metakaolin and sea water on performance and microstructure of concrete. In the study, metakaolin (MK) was utilized in the range of 0–6 wt%. The addition of 5% MK resulted in a 33% increase in compressive strength at 28 days, and when mixed with seawater, the increase was 22%. The combined use of both metakaolin and seawater led to a substantial enhancement, with a 52% increase in compressive strengths. The pore structure was refined under both conditions.

(Adel Al Menhosh et al., 2016) studied the effect of metakaolin additive and polymer admixture on the concrete strength properties. Various combinations involving two distinct polymers, metakaolin, and recycled fiber reinforcement were employed in this investigation. It was determined that incorporating 5% of the optimized polymer and replacing 15% of cement with metakaolin results in an optimal concrete mix concerning both strength and durability. Existing literature indicates a significant focus on research related to supplementary materials for cement and aggregates, with limited exploration into the non-destructive evaluation of metakaolin concrete. This study endeavors to contribute to the understanding of metakaolin as a pozzolanic material and its influence on the mechanical properties of concrete. Although the workability of the concrete experiences a slight reduction, notable improvements in strength and a reduction in concrete weight are observed. Finding a partial replacement for sand with demolition waste as an aggregate without altering the properties of the conventional concrete is effectively studied and utilized so that it can contribute towards environmental problems and solid waste management.

(Lakshmi and Nivedhitha, 2015) did experiments and investigated the changes in compressive strength, flexural strength and tensile strength by replacing the natural fine aggregate and natural coarse aggregate with the recycled fine and coarse aggregate.

Various substitutions were implemented, with 10%, 20%, and 30% of natural fine aggregate and coarse aggregate being replaced by recycled fine and coarse aggregate. Concrete tests were conducted, and the outcomes were analyzed. It was observed that the compressive and tensile strength exhibited improvement specifically with a 20% replacement of both fine and coarse aggregate with recycled aggregate. And the flexural strength was decreasing with the increase in percentage replacement of natural fine aggregate and coarse aggregate.

(Hamdy, et al., 2017) carried out an experimental investigation on the mechanical behavior of high strength concrete made with high percentages of metakaolin and hybrid fibres with volume fractions of 0.25% and 0.5%. A total of 315 standard test specimens (189 cubes and 126 cylinders) were manufactured and grouped into three sets, each containing 105 specimens. The data for each group was derived from the average results of 3 test specimens. The percentage of metakaolin (MK) was consistent across all groups (10%, 15%, 20%, 30%, 40%, and 50%) relative to the weight of cement. The findings indicated that High Strength Concrete (HSC) could be achieved with a high volume of metakaolin. The synergistic impact of hybrid fiber and metakaolin indicated that the optimal dosage of MK is 15% across all testing ages. In addition, there was a significant gain in split tensile strength due to metakaolin and hybrid fibre.

(Rathan, et al., 2013) formulated a simplified mix design procedure for HSC by combining BIS and ACI code methods of mix design. With this in mind, a desired compressive strength of 60 MPa was established. The compressive strength test involved evaluating three cubes for each trial mix combination at curing ages of 1, 7, 14, 28, and 56 days. It was noted that the concrete's strength improved with the increase in the incorporation ratio of metakaolin at all curing ages.

2.1 Concrete

Concrete stands out as an exceptionally versatile and extensively employed construction material globally. Its strength, durability, low maintenance requirements, fire resistance, and adaptability to various sizes and shapes, ranging from colossal structures to small stepping stones, contribute to its popularity. A crucial factor that underscores these benefits is its cost-effectiveness compared to alternative materials. Examining its composition, concrete is formulated with four key components and they include;

- i. Water
- ii. Fine aggregate
- iii. Coarse aggregate
- iv. Cement

Elements that are readily obtainable from nature serve as the fundamental building blocks for the world's infrastructure. Among these elements, cement is the sole ingredient in concrete that possesses any intricacy. Cement plays a vital role in various construction materials, including grout, mortar, stucco, and concrete.

Each component in concrete has a specific function, with cement playing a crucial role in transforming concrete from a liquid to a solid state. Unlike drying, cement curing involves a chemical process called hydration, where water becomes an integral part of the cured concrete. Inadequate water can prematurely halt the hydration process, preventing the concrete from attaining its full strength. Interestingly, concrete can be placed and cured entirely underwater, achieving comparable or even enhanced setting and hardening compared to dry placement. Cement acts as a binding agent, filling the spaces between fine and coarse aggregates and holding the other elements together. While aggregates constitute the majority of concrete volume, contributing to cost savings, they also enhance

structural properties by boosting strength and minimizing shrinkage during the concrete curing process.

While the basic concrete recipe involves only four ingredients, the intricacy lies in the precise selection of quantities and properties of these elements. The process of crafting a specific concrete formula is termed mix design. Water plays a crucial role in shaping concrete characteristics during mix design. Increased water content facilitates smoother concrete flow, aiding easy placement into forms. However, this enhanced workability comes at the expense of concrete strength due to over-dilution of cement, making it less effective in binding all constituents together. Fluctuations in water content can significantly impact workability, strength, appearance, and other concrete attributes.

2.1.1 Cement

Cement serves as a binding agent in construction. When combined with water, it is mixed with materials such as fine or coarse sand for mortar or plaster, and with sand and stone for a concrete mix. Ordinary Portland Cement (OPC) is the most frequently used type. It is classified as hydraulic, signifying that once it sets, the curing process persists even underwater.

The manufacturing of cement initiates with the extraction of limestone, serving as the fundamental component. To generate various types of cement, the chemical characteristics of limestone are modified by incorporating corrective minerals like silica, alumina, and iron. This blend is finely powdered, subjected to heat, rapidly cooled, and later milled with gypsum, limestone, fly ash, or slag to yield cement.

2.1.2 Ordinary Portland Cement

(Rahman, 2018) Ordinary Portland Cement, OPC is one of the most widely used type of cement. In 1824, Joseph Aspdin named it Portland Cement due to its resemblance

in color and quality to Portland stone, a white-grey limestone found on the island of Portland, Dorset.

2.1.3 Properties of OPC

Table 2.1: Properties of Ordinary Portland Cement

S/N	PROPERTIES	VALUES
1	Specific Gravity	3.12
2	Normal Consistency	29%
3	Initial Setting Time	65mins
4	Final Setting Time	275mins
5	Fineness	330kg/m
6	Soundness	2.5mm
7	Bulk Density	830 – 1650kg

Source; (Rahman, 2018)

2.1.4 Uses of OPC

(Rahman, 2018)

- i. It is used for general construction purposes where special properties are not required such as reinforced concrete buildings, bridges, pavements, running of tests and where soil conditions are normal.
- ii. Used for most concrete masonry units.

2.1.5 Advantages of OPC

- i. It has great resistance to cracking and shrinkage but has less resistance to chemical attacks.
- ii. Initial setting time of OPC is fast, it is recommended in projects where props are to be removed early.
- iii. Curing period of OPC is short, it is recommended where curing cost is prohibitive.

2.1.6 Disadvantages of OPC

- i. It cannot be used for mass concreting as it has high heat of hydration.
- ii. It has a low durability.
- iii. It produces a concrete with low cohesion, thereby making concrete pumping difficult.
- iv. It has a lower fineness, hence has higher permeability and as a result it has lower durability.

2.1.7 Curing

It involves maintaining optimal moisture and temperature within concrete after placement to ensure continuous cement hydration until the desired properties are sufficiently developed. In simple terms, it's about retaining moisture and heat during the hydration or reaction of concrete. Additionally, it serves to protect the concrete surface, keeping it moist and thereby prolonging or allowing the hydration process to proceed. This final step is crucial in concrete production, aiding concrete in reaching its maximum potential and achieving full strength.

2.1.8 Hydration

When cement comes into contact with water, it undergoes an exothermic reaction called hydration, which is the fundamental process through which concrete attains its strength. The release of heat resulting from this exothermic reaction is referred to as the heat of hydration.

It is approximated that, on average, 23% of water by the weight of cement is needed for the chemical reaction with Portland Cement compounds. Additionally, 15% of water by the weight of cement is necessary for gel formation, and 38% of water by the weight of cement is required for the complete hydration of cement. An increase in the water-cement (w/c) ratio leads to the creation of more voids by water, potentially resulting in subpar concrete and a reduction in strength.

2.1.9 Bleeding

Bleeding in freshly mixed concrete is the phenomenon in which excess water in the mixture rises to the surface as a result of the settling of denser solid components like cement. While a certain amount of bleeding is typical, an excessive amount can pose challenges.

2.2 Fine Aggregate

Fine aggregates serve as small-sized filler materials in construction. These particles, passing through a 4.75mm sieve and retained on a 0.075mm sieve, contribute to concrete composition. Examples of fine aggregates used in concrete encompass materials such as sand, stone screenings, burnt clays, cinders, fly ash, among others.

2.3 Coarse Aggregate

Coarse aggregates serve as larger-sized filler materials in construction, with particles that remain on a 4.75mm sieve. Examples encompass stone chips (fragmented stones), gravels, pebbles, granite, and similar materials.

2.4 Water

The precise amount of water utilized in concrete production plays a pivotal role in determining its strength and durability. The quantity of water significantly influences concrete properties; higher water content corresponds to decreased strength and durability. Excessive water leads to increased voids in the concrete, rendering it porous. Porosity allows harmful gases and chemicals from the atmosphere and soil to infiltrate the concrete through its pores, causing deterioration.

Concrete work with elevated water content is prone to ingredient segregation, resulting in a non-homogeneous mixture and diminished strength. Additionally, excess water tends to surface during compaction, causing bleeding. This phenomenon makes the concrete surface porous, weaker, and less resistant to wear. Increased water content in concrete contributes to shrinkage cracks. The recommended water content for a bag of cement should ideally fall within the range of 20 to 27 liters, depending on concrete exposure conditions.

Optimal water usage results in a cohesive, denser, and impervious concrete.

2.5 Kaolin

Kaolinite, classified as a clay mineral, possesses the chemical formula $\text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4$. It holds significance as an industrial mineral, and geological formations abundant in kaolinite are referred to as either kaolin or china clay.

2.6 Metakaolin

(Patel, 2019) Metakaolin is recognized as a premium-quality pozzolanic substance. Widely employed as a mineral admixture today, metakaolin contributes to enhancing the performance and cost-effectiveness of concrete. Unlike some alternatives, it is not a by-product of industrial processes or entirely natural but is intentionally produced from high-quality kaolin.

(Muralinathan, et al., 2018) Metakaolin is derived through the calcination of pure or refined kaolinite clay at temperatures ranging from 650°C to 850°C . Following the completion of the burning process, it undergoes proper grinding to achieve the desired fineness, enhancing various strengths and property parameters of cement mortar and concrete. Kaolin clay serves as the raw material for metakaolin, and kaolinite clay is a fine, white mineral.

Metakaolin comprises active silica and alumina, similar to other mineral admixtures. It reacts with calcium hydroxide at room temperature, forming calcium silicate hydrate (C-S-H) gel. This reaction increases concrete density, reduces porosity, decreases permeability, and enhances concrete durability. When used in concrete, metakaolin acts as a filler, penetrating the voids between cement particles, resulting in a more impermeable concrete.

2.6.1 Advantages of Metakaolin

- i. Use of metakaolin in concrete accelerates the initial setting time of concrete.
- ii. It helps in development of the early age strength of concrete which allows the early removal of formwork and thus enhances the production rate.
- iii. Metakaolin consumes calcium hydroxide thereby preventing the reaction of alkali-silica. Use of metakaolin increases the resistance to sulphate attack, chemical attack and freeze and thaw action.
- iv. It reduces drying shrinkage and efflorescence.
- v. It improves water-tightness and impermeability of concrete hence is safe for using in water retaining structure, off-shore structure, etc.
- vi. It can increase the residual strength of refractory concrete after firing.
- vii. It increases the strength and durability of concrete.
- viii. It is a green option, an ecofriendly building material.
- ix. It is cost effective as compared to other admixtures.
- x. Compared to other mineral admixtures, it is easily and abundantly available in the market.

2.6.2 Disadvantages of Metakaolin

- i. Use of metakaolin reduces workability of the concrete due to its fineness; hence it becomes necessary to use water reducers or air entraining admixtures to achieve the desired workability.
- ii. High quality control to enhance performance can be tasking.
- iii. Better quality of materials to enhance performance may cost more than the lower quality.

2.7 Partial Replacement

Partial replacement in concrete is the switching out of portions of certain constituents of concrete with different materials (metakaolin) to get a desired conclusion. To determine said conclusion, tests are carried out on a given type of concrete with varying portions of switched materials and the results gotten are then compared to conventional concrete mixes to find out the effects, from which a conclusion is drawn.

Partial replacement is also carried out to save on construction costs as well as being used as an eco-friendly way of disposing waste. The tests become necessary to understand the effects these materials would have on concrete properties, be they positive or negative to ascertain if they are to be utilized or abandoned.

This research explores the mechanical characteristics of concrete manufactured through the partial substitution of fine aggregate with a substance identified as metakaolin, (see 2.2.1).

CHAPTER THREE

3.0 METHODOLOGY

3.1 Materials and Methods

The materials used for this investigation are as follows:

- i. Cement
- ii. Aggregates
- iii. Water
- iv. Metakaolin

3.1.1 Cement

The brand of cement used for the experiments and tests is known as Ordinary Portland Cement, OPC, 42.5N grade manufactured by Dangote, procured from a local cement retailer located at Isiohor, Benin City, transported to the Civil Laboratory, University of Benin and stored properly.

3.1.2 Aggregates

This can be divided into:

- i. Fine aggregate
- ii. Coarse aggregate

3.1.3 Fine Aggregate

Fine aggregates, which serve as small-sized filler materials in construction, are crucial. The prescribed fine aggregate, typically sand, should be of a quartz, whitish variety

and devoid of silt. The sand grains must exhibit an angular shape, with approximately spherical forms, while elongated and flattened grains should be present in minimal or negligible quantities. The specified sand should pass through a 2mm BS sieve and be retained on a 90Micron BS sieve. It has a specific gravity of 2.68 and falls within Grading Zone II, according to BS: 2386 (Part - 3): 1963.

Fine aggregate, the river sand is a locally available material. Samples used in experiment were procured at Isiohor, Benin City and transported to the Civil Laboratory, University of Benin.

3.1.4 Coarse Aggregate

Granular materials with irregular shapes, such as granite, fall under the category of coarse aggregates. Aggregates whose size are greater than 4.75mm are coarse aggregates.

The coarse aggregate used was procured at Isiohor, Benin City and transported to the Civil Laboratory, University of Benin.

3.1.5 Grading

Aggregate grading refers to the determination of the aggregate size employed in construction projects, as demonstrated in this experiment. In well-graded concrete, a mix of two or more aggregate sizes, such as 20mm and 12mm for coarse aggregate, is utilized to enhance bonding. In contrast, poorly graded concrete relies on single-size aggregates, leading to insufficient bonding induced by the cement paste, resulting in weakened and easily breakable concrete.

The classification of aggregates follows BS code 383, designating sizes below 4.75mm as fine aggregate and those above as coarse aggregate. The gradation of aggregates adheres to the fineness modulus method outlined in the BS standard. This

involves passing aggregates through sieves, specifically 20mm and 12mm sieves, to classify their sizes. Based on the aggregate gradation, we learn that:

- i. We can choose the right aggregates for construction.
- ii. The smaller size of aggregates gives a larger surface area which provides good bonding to the material and increases the strength of the concrete.
- iii. It helps to find the flaky and irregular shape aggregates which are not suitable for concrete that decreases the strength of the concrete.
- iv. The bonding between the aggregates is not good when the single size of aggregates is used in concrete.
- v. To determine the quality of the aggregates.

3.1.6 Water

Potable water and non-potable water (from a borehole; a source that rid of impurities that would negatively affect the results) was used in the mixing and curing of concrete. Even though drinkable water, with its known and regulated chemical composition, is the preferred choice for mixing and curing concrete, its limited availability led to its non-utilization during the experiment.

Potable water is water that is fit for human consumption.

3.1.7 Metakaolin

The raw material from which metakaolin is derived is known as kaolin clay. Metakaolin is gotten from the calcination of kaolin. It is highly reactive, due to its fineness and chemical composition. It has a particle size of about 3 Microns.

Metakaolin used in the experiments was procured from Edo North, Okpella.

3.2 Equipment Used

The following are the major machines used in the course of the experiment:

- i. Slump Test Apparatus
- ii. Vibrating Table
- iii. Concrete Strength Testing Machine
- iv. Flexure Strength Testing Machine
- v. Weighing Balance
- vi. Concrete Moulds
- vii. Concrete Mixer

3.2.1 Slump Test Apparatus

These are the tools utilized in conducting the slump test to assess the workability of a concrete mixture. They include:

- i. Slump cone
- ii. Base
- iii. Tamping rod
- iv. Brushes
- v. Trowel
- vi. Measuring tape



Fig. 3.1 Slump Test Apparatus

3.2.2 Vibrating Table

A vibrating table is a tool utilized to assist in the consolidation of substances, such as concrete, within receptacles like molds. The vibratory motion facilitates the close arrangement of materials and items, causing them to settle and minimize product volume. Additionally, it aids in expelling trapped air from concrete during the compaction process. It improves product quality and productivity.

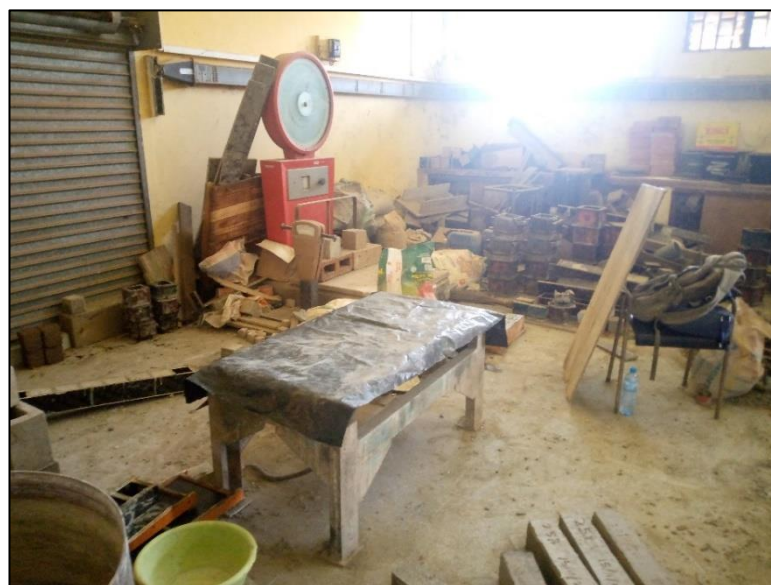


Fig. 3.2 Vibrating Table

3.2.3 Concrete Strength Testing Machine

This apparatus is employed for assessing the compressive strength of concrete cubes by subjecting them to crushing, wherein force is applied until the point of failure is reached.



Fig. 3.3 UTM

3.2.4 Flexural Strength Testing Machine

This equipment is created for assessing the flexural strength of concrete beams. The design ensures optimal stiffness across its operational spectrum. The application of force is achieved through the downward motion of the piston. An additional feature includes a spacer to accommodate the testing of beams of varying sizes.



Fig. 3.4 Flexural Strength Testing Machine

3.2.5 Weighing Balance

This is an apparatus employed for measuring mass or weight, offered in various sizes with diverse weighing capabilities, and serves as a crucial instrument in settings such as laboratories. It was used in the weighing of samples in kilogram, (kg) before mixing as well as the weighing of concrete cubes before crushing/testing for compressive strength.



Fig. 3.5 Weighing Balance

3.2.6 Concrete Moulds

(Paun, 2022) Once the concrete mixture is complete, it transforms into a robust and enduring material suitable for various applications. Prior to the drying and hardening process, the concrete can be molded into diverse shapes. Concrete molds or forms, which are empty containers, serve the purpose of shaping the final appearance of the solidified concrete. They can be made of wood or other materials. In the case of this experiment they are made of wood (marine board).



Fig. 3.6 Concrete Cube Mould



Fig. 3.7 Concrete Beam Mould

3.2.7 Concrete Mixer

A concrete mixer is a machine that uniformly blends cement, aggregates, and water to create concrete. This concrete mixer employs a rotating bowl and a mechanical mixing system to thoroughly blend the ingredients.



Fig. 3.8 Concrete Mixer

3.3 Experimental Work

This involves the various processes considered in the carrying out of this experiment.

They are as follows:

- i. Concrete Mix Design
- ii. Mixing, Casting, Demoulding, Curing and Testing for Concrete Cubes and Beams

3.3.1 Concrete Mix Design

The formulation of a concrete mix is the procedure of determining the appropriate ratios of cement, sand, and aggregates to attain the desired strength in construction. This process comprises a series of steps, computations, and estimations to determine the mix

proportions. The concrete mix design of this experiment was done to find out an estimation for the amount of materials to buy.

The advantages of the concrete mix design lie in offering the estimated material proportions, making the casting of concrete cost-effective to achieve the desired strength.

Using the concrete design forms and BRE Concrete Mix Design Method, I was able to determine approximate values for materials of the grades of concrete being worked on (M20, M30 and M40).

0-20

Concrete mix design form

Stage	Item	Reference or substitution	Values																							
1	1.1 Characteristic strength	Specified	20 N/mm^2 or 28 days																							
	1.2 Standard deviation	Fig 3	Proportion coefficient 5 N/mm^2																							
	1.3 Mean	C1	$\mu = 1.64 \times 5 + 20 = 28.2$ N/mm^2																							
	1.4 Target mean strength	Specified	20 N/mm^2																							
	1.5 Characteristic strength	Specified	42.5/52.5 N/mm^2																							
	1.6 Aggregate type, coarse	Table 2, Fig 4	Crushed (angular) / Crushed (rounded)																							
	1.7 Free water/cement ratio	Table 2, Fig 4	0.56 Use the lower value																							
	1.8 Maximum free-water/cement ratio	Table 2, Fig 4																								
2	2.1 Slump or Veeb time	Specified	Slump 30-60 mm or Veeb time 3-6 s																							
	2.2 Maximum aggregate size	Specified	20 mm																							
	2.3 Free water content	Table 3	170 kg/m^3																							
3	3.1 Cement content	C3	170 kg/m^3 \times 0.56 = 340 kg/m^3																							
	3.2 Maximum cement content	Specified																								
	3.3 Minimum cement content	Specified																								
	3.4 Modified free-water/cement ratio	Table 3, Fig 4	use 3.14 \times 3.3 / 3.1 = 340 kg/m^3																							
4	4.1 Relative density of aggregate (SDA)		2.6 known/assumed																							
	4.2 Concrete density	Fig 5	2350 kg/m^3																							
	4.3 Total aggregate content	C4	2350 - 340 - 170 = 1820 kg/m^3																							
5	5.1 Grading of fine aggregate	Percentage passing 600 μm sieve	50 %																							
	5.2 Proportion of fine aggregate	Fig 6	26 %																							
	5.3 Fine aggregate content	C5	0.36 \times 1820 = 655 kg/m^3																							
	5.4 Coarse aggregate content	C5	1820 - 655 = 1165 kg/m^3																							
<table border="1"> <thead> <tr> <th>Quantities</th> <th>Cement (kg)</th> <th>Water (kg or litres)</th> <th>Fine aggregate (kg)</th> <th>Coarse aggregate (kg)</th> </tr> <tr> <td></td> <td></td> <td></td> <td>10 mm</td> <td>20 mm</td> <td>40 mm</td> </tr> </thead> <tbody> <tr> <td>per m^3 (to nearest 5 kg)</td> <td>340</td> <td>170</td> <td>655</td> <td>1165</td> <td></td> </tr> <tr> <td>per total mix of 0.026 m^3</td> <td>12.34</td> <td>6.34</td> <td>23.58</td> <td>41.74</td> <td></td> </tr> </tbody> </table>				Quantities	Cement (kg)	Water (kg or litres)	Fine aggregate (kg)	Coarse aggregate (kg)				10 mm	20 mm	40 mm	per m^3 (to nearest 5 kg)	340	170	655	1165		per total mix of 0.026 m^3	12.34	6.34	23.58	41.74	
Quantities	Cement (kg)	Water (kg or litres)	Fine aggregate (kg)	Coarse aggregate (kg)																						
			10 mm	20 mm	40 mm																					
per m^3 (to nearest 5 kg)	340	170	655	1165																						
per total mix of 0.026 m^3	12.34	6.34	23.58	41.74																						
<small>Notes in brackets are optional limiting values (marked) (checked from Section 7). Concrete strength is expressed in the area (N/mm²) (N/mm² = 1 MPa) (N/mm² = 100 psi). The characteristic strength (N/mm²) is the mean strength plus 1.64 times the standard deviation (N/mm²) based on the substituted surface by number.</small>																										
(Source: Building Research Establishment)																										
<p>15% \Rightarrow 3.54</p> <p>20% \Rightarrow 4.72</p> <p>25% \Rightarrow 5.90</p>																										

Fig. 3.9 Concrete Mix Design Form

3.3.2 Casting, De-moulding, Curing and Testing for Concrete Cubes and Beams

Concrete cube samples were prepared in accordance with M20, M30 and M40 concrete mix design calculations with cement/water ratio, 0.5. To investigate compressive strength using concrete cube samples, molds with dimensions of 100 x 100 x 100mm were fabricated. These were then subjected to curing periods of 7, 14, and 28 days, followed by testing using a concrete strength testing machine to determine the mean compressive strength for each respective period. A total of 108 concrete cube samples were generated for this research: 27 for the control group (0%) and 27 for each percentage replacement (15%, 20%, and 25%) of a single grade, distributed across various curing periods (3 cubes for each day of the grading and percentages).

Table 3.1 Cubes Cast Scheduling

Curing Period	7DAYS	14DAYS	28DAYS
Grades & Percentages	Number of Cubes Cast		
M20/0%	3	3	3
M30/0%	3	3	3
M40/0%	3	3	3
M20/15%	3	3	3
M20/20%	3	3	3
M20/25%	3	3	3
M30/15%	3	3	3

M30/20%	3	3	3
M30/25%	3	3	3
M40/15%	3	3	3
M40/20%	3	3	3
M40/25%	3	3	3
TOTAL	108 CUBES CAST		

Same goes for concrete beam samples, prepared in accordance with M20, M30 and M40 concrete mix design calculations with cement/water ratio, 0.5. To investigate the flexural strength of concrete beam samples, molds with dimensions of 1000 x 66 x 127mm were created. These molds were cured for a period of 28 days and then subjected to flexural strength testing using a specialized machine to determine the mean flexural strength at the end of the 28-day curing period. A total of 6 concrete beam samples were generated for the research, comprising 3 for the control group (0%) and 3 for each percentage replacement in M20 (15%, 20%, and 25%).

Table 3.2 Beams Cast Scheduling

Curing Period	28DAYS
Grades & Percentages	Number of Beams Cast
M20	1
M30	1
M40	1
M20/15%	1
M20/20%	1
M20/25%	1
TOTAL	6 BEAMS CAST



Fig. 3.10 Mixing of Concrete (Head-pan)

Concrete is blended through manual means or using a concrete mixer, constituting a mix of cement, water, coarse aggregates, fine aggregates, and admixtures, such as metakaolin. The proportions of these components, measured in kilograms, influence the properties of the final hardened concrete. The weight proportions are determined through a concrete mix design, accounting for a 10% allowance for potential human error. Dry ingredients are mixed, and water is gradually added until the concrete achieves workability. Adjustments to the mixture may be necessary due to the type of aggregate used, aiming for the right workability and addressing errors or wastages in the lab, such as power shortages for mixers or vibrating tables. The casting process involves cleaning and properly oiling the molds for easy demolding. Molds are securely tightened before casting, minimizing gaps to prevent slurry leakage after compaction. Careful procedures are followed in batching, mixing, and casting. Weights of cement, coarse aggregate, fine aggregate, water, and admixtures are measured first. Hand mixing or use of a concrete mixer bowl ensures thorough blending of cement and aggregates until a uniform color is achieved. Admixtures and coarse aggregate are then added and mixed, followed by a careful addition of water in stages to prevent bleeding that might impact the concrete's strength formation.

The clean and oiled mold was placed on the vibrating table for each category and filled in three layers. Vibrations ceased when the cement slurry surfaced on the mold's top. These specimens remained in the mold for the initial 24 hours at ambient conditions. Careful de-molding followed to prevent edge breakage, and specimens were then placed in a tank at ambient temperature for curing. After de-molding, cubes were submerged in water for 7 days, 14 days, and 28 days. The same procedure applied to beams, with the beams placed in water for 28 days after de-molding.

For the calculation of cement and fine aggregate strength, a uniform mix was achieved. Concrete compressive strength cubes (100 x 100 x 100mm) and flexural strength beams (1000 x 66 x 127mm) were used as hardened specimens. These specimens were tested at 7 days, 14 days, 28 days, and 28 days, respectively, to obtain failure loads for all cubes and beams. The compressive and flexural strength are then calculated using formulas (see 4.3.1 and 4.4.1).

3.4 Tests and Analysis

The following are tests and analysis used to determine the objectives of this experiment (the last three are carried out on hardened concrete, while the first is carried out on fresh concrete):

- i. Slump Test
- ii. Compressive Strength Test
- iii. Flexural Strength Test
- iv. Density Test

3.4.1 Slump Test

The concrete slump test is conducted to assess the workability of laboratory-prepared concrete mixes. This test, recognized by standards like ASTM C143 in the United States, IS: 1199 – 1959 in India, and EN 12350-2 in Europe, is a cost-effective and straightforward method offering immediate results. The slump value of concrete is commonly utilized to determine workability, reflecting the water/cement ratio. However, numerous factors, such as material properties, mixing techniques, air content, timing, admixture dosage, etc.,

influence the concrete slump value. The test should be performed in a location devoid of vibration or shock.

3.4.2 Procedures of the Slump Test

- i. Prepare the mould by cleaning its internal surface and applying lubricating oil.
- ii. Position the mould on a smooth, flat, horizontal, and non-porous base plate.
- iii. Fill the mould with the concrete mix in approximately 3-4 equal layers.
- iv. Tamp each layer with 25 strokes from the rounded end of the tamping rod, ensuring uniformity across the cross-section of the mould. Subsequent layers should penetrate into the underlying layer.
- v. Use a trowel to remove excess concrete and level the surface.
- vi. Clean any mix or water that may have leaked between the mould and the base plate.
- vii. Lift the mould gently from the concrete in an upward vertical direction.
- viii. Measure the slump as the difference between the height of the mould and the highest point of the tested specimen.

3.4.3 Types of Slump Test Results

- i. **True Slump:** This is the only measurable slump in the examination. The measurement is taken from the top of the cone to the top of the concrete after cone removal.
- ii. **Zero Slump:** This signifies an extremely low water/cement ratio, resulting in dry mixes.

- iii. **Collapsed Slump:** This signals an excess water/cement ratio, meaning the concrete mix is too wet or has high workability, rendering the slump test inappropriate.
- iv. **Shear Slump:** This suggests an inconclusive result, necessitating a retest of the concrete.

3.4.4 Compressive Strength Test

This is a mechanical examination gauging the utmost compressive force a material can withstand before breaking. The specimen, shaped like a cube, undergoes compression between the platens of a compression testing machine through a gradually applied load. Compression tests were conducted on every cast cube at intervals of 7, 14, and 28 days. Each cube was crushed on the specified dates, and the average crushing value was documented. The apparatus was operated by a laboratory technician.

3.4.5 Procedures of the Compressive Strength Test

- i. The test was conducted immediately after taking samples out of the curing tank and weighing samples. The machine was then turned on and its gauge were set to zero.
- ii. The cube samples due for crushing were taken out of the curing tank and was then placed at the middle of the machine
- iii. The top screw was then lowered to hold the given sample in place, firmly.
- iv. The compression machine then starts exerting compressive force on the cube sample, such that the cube is crushed at a particular load in kilonewtons (kN), the dial gauge rising to a point, pausing and then falling after crushing the sample. The

figure the dial pauses at is recorded as the maximum compression load or failure load

- v. Sample is then discarded after noting readings. Failure load is then used to calculate the compressive strength of the sample.

3.4.6 Flexural Strength Test

The flexural test assesses the force needed to bend a beam subjected to point loading. Typically, this information helps in choosing materials for components that need to withstand loads without deformation, or in this context, understanding the impact of specific admixtures on the behavior of concrete beams.

3.4.7 Procedures of Flexural Strength Test

- i. The examination was performed on the sample right after removal from the curing environment to avoid surface drying, which can decrease flexural strength.
- ii. The sample was subsequently positioned on the loading points. Care was taken to prevent the hand-finished rough surface of the specimen from coming into contact with the loading points to ensure precise results.
- iii. The loading points is placed in a way that both 10mm from the edges and the two-point load is then lowered on to the beam and at the point of failure, the deflection of the gauge is then read to find out its failure load.

3.4.8 Density Test

The density of conventional concrete falls within the bracket of 2,200-2,600kg/m³.

3.4.9 Procedures of Density Test

- i. This is carried out by measuring the weight (kg) of the samples using weighing balance (cubes or beams).
- ii. The weights are then used to calculate the density, see **Eq. (4.1)**.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION OF RESULTS

4.1 Mix Design

The concrete mix design was determined following the BRE Concrete Mix Design Method, utilizing the concrete mix design form (see Fig. 3.9) and tables from the BRE mix design handbook. To achieve the specified compressive strength, an estimated value for the water/cement (w/c) ratio (0.5) was calculated for a suitable test age (28 days). Quantities for cement, water, coarse aggregate and fine aggregate are derived which are then used to calculate the amount of concrete to fit into various moulds volumes per trial mix.

The quantities are as follows;

For M20

Cement - 340kg

Water - 190kg

Fine Aggregate - 655kg

Coarse Aggregate – 1165kg

For M30

Cement - 396kg

Water - 190kg

Fine Aggregate - 635kg

Coarse Aggregate – 1129kg

For M40

Cement - 380kg

Water - 190kg

Fine Aggregate - 641kg

Coarse Aggregate – 1139kg

4.2 Slump Test

The slump test was conducted on different concrete grades, including those with partial replacements at various percentages. It was performed in accordance with BS 12350- 2: 2009.

The results are as shown below;

Table 4.1 Slump Test Results for Cubes Cast

DESCRIPTION	SLUMP (mm)
M20/0%	18
M30/0%	13
M40/0%	15
M20/15%	10
M20/20%	18
M20/25%	15
M30/15%	13

M30/20%	19
M30/25%	14
M40/15%	10
M40/20%	13
M40/25%	15

4.2.1 Slump Test Discussion for Cubes Cast

Using **Table 4.1**, the control cube for M20 concrete gives a slump of 18mm, in comparison when partially replaced by metakaolin at 15% replacement the slump is shown to reduce to 10mm indicating an increased cementitious nature of concrete mix, then at 20% replacement for M20 concrete the slump increases to 18mm same as the control reducing its cementitious property and last at 25% replacement for M20 concrete the slump decrease again to 15mm, seeming to be at its lowest workability and highest cementitious nature at 15%.

The control cube for M30 concrete gives a slump of 13mm, in comparison to its partially replaced metakaolin percentages, 15% is the same at 13mm, 20% increases to 18mm and 25% shows a minimal increase of 15mm. This shows no increase or decrease at 15%, a decrease in cementitious nature of the mix and an increase in workability and a little increase at 25%, showing its highest workability at 20%.

The control cube for M40 concrete gives a slump of 15mm, in comparison to its partially replaced metakaolin percentages, 15% is given as 10mm, 20% increases to 13mm and 25% increases to 15mm. This shows a decline in workability for 15% and then a steady increase in slump and workability for 20% and 25%. The highest workability is at 15%.

All slumps for cubes cast fall in the range of true slump. This is well suited for the cubes cast as the lower the slump found the greater the compressive strength, they are referred to as dry mixes and are mostly used for road and pavement construction.

Table 4.2 Slump Test Results for Beams Cast

DESCRIPTION	SLUMP (mm)
M20	38
M30	40
M40	39
M20/15%	37
M20/20%	40
M20/25%	40

4.2.2 Slump Test Discussion for Beams Cast

From the results shown in **Table 4.2**, it can be seen that the slump results for the control of M20, M30 and M40 are in 38mm, 40mm and 39mm respectively, all giving true slumps indicating a low degree of workability.

Using only M20 for the comparison of partially replaced percentages, 15% slump is 37mm, 20% is 40mm and 25% is 40mm. This shows a decrease in slump and workability for only 15%, it is the sample with the lowest slump. The results for beams cast are suitable for beams construction.

4.3 Compression Test

The cubes were subjected to a compressive strength test at 7, 14, and 28 days, following the guidelines outlined in BS 1881-116.

4.3.1 Formulas Used for Compressive Strength and Density

Density is given as;

$$\rho(kg/m^3) = \frac{m(kg)}{v(m^3)} \quad \text{Eq. (4.1)}$$

Where, ρ = Density of cube

m = Mass of cube

v = Volume of cube = $0.001m^3$

Mass of the cube is gotten used the weighing balance, while volume of the cube is given as;

$$v = l \times b \times h \quad \text{Eq. (4.2)}$$

Where, l = length of the cube

b = width of the cube

h = height of the cube

which is $(100 \times 100 \times 100)$ mm

Compressive strength is given as;

$$F(N/mm^2) = \frac{P(N)}{A(mm^2)} \quad \text{Eq. (4.3)}$$

Where F = Compressive Strength

P = Applied Load or Failure Load

A = Cross-sectional Area of the Cube

Failure load is gotten by reading the gauge of the compressive strength machine at the point of failure, while the cross-sectional area of the cube, A, is given as;

$$A = side \times side \quad \text{Eq. (4.4)}$$

Sides are the measurement of the cube sides using a measuring tape, i.e. 100mm

Note;

$$\text{Average Density} = \frac{\text{Density of M1} + \text{Density of M3}}{2} \quad \text{Eq. (4.5)}$$

$$\text{Average Comp. Strength} = \frac{\text{Comp. Strength of M1} + \text{Comp. Strength of M3}}{2} \quad \text{Eq. (4.6)}$$

The results are as follows;

Table 4.3 Control Cubes M20/0%

Curing days	Sample	Weight (kg)	Density (kg/m ³)	Failure load (kN)	Compressive Strength (N/mm ²)	Average density (kg/m ³)	Average Compressive Strength (N/mm ²)
7	M1	2.434	2434	130	13	2436	14.5
7	M3	2.438	2438	160	16		
14	M1	2.390	2390	220	22	2433	25
14	M3	2.476	2476	280	28		
28	M1	2.496	2496	310	31	2431	32
28	M3	2.365	2365	330	33		

$$\text{Total Average Comp. Strength of M20/0\%} = \frac{14.5 + 25 + 32}{3} = 23.8 \text{ N/mm}^2 \quad \text{Eq. (4.7)}$$

Table 4.3 shows a steady decrease in density and increase in compressive strength with increasing maturity of given samples. For 7 days the density is at 2436kg/m³ and a compressive strength of 14.5N/mm², for 14 days the density is at 2433kg/m³ and a compressive strength of 25N/mm² and for 28 days the density is at 2431kg/m³ and a compressive strength of 32N/mm².

Table 4.4 Partial Replacement Cubes M20/15%

Curing days	Sample	Weight (kg)	Density (kg/m ³)	Failure load (kN)	Compressive Strength (N/mm ²)	Average density (kg/m ³)	Average Compressive Strength (N/mm ²)
7	M1	2.456	2456	180	18	2420	17.3
7	M3	2.383	2383	165	16.5		
14	M1	2.452	2452	290	29	2441	28.8
14	M3	2.429	2429	285	28.5		
28	M1	2.362	2362	410	41	2402	38
28	M3	2.441	2441	350	35		

$$\text{Total Average Comp. Strength of M20/15\%} = \frac{17.3+28.8+38}{3} = 28.03\text{N/mm}^2$$

Eq. (4.8)

Table 4.4 shows a steady decrease in density and increase in compressive strength with increasing maturity of given samples. For 7 days the density is at 2420kg/m³ and a compressive strength of 17.3N/mm², for 14 days the density is at 2441kg/m³ and a compressive strength of 28.8N/mm² and for 28 days the density is at 2402kg/m³ and a compressive strength of 38N/mm².

Table 4.5 Partial Replacement Cubes M20/20%

Curing days	Sample	Weight (kg)	Density (kg/m ³)	Failure load (kN)	Compressive Strength (N/mm ²)	Average density (kg/m ³)	Average Compressive Strength (N/mm ²)
7	M1	2.390	2390	170	17	2432	16.7
7	M3	2.474	2474	163	16.3		
14	M1	2.462	2462	370	37	2485	34.5
14	M3	2.507	2507	320	32		
28	M1	2.547	2547	380	38	2535	36
28	M3	2.522	2522	340	34		

$$\text{Total Average Comp. Strength of M20/20\%} = \frac{16.7+34.5+36}{3} = 29.1\text{N/mm}^2$$

Eq. (4.9)

Table 4.5 shows a steady increase in density as well as one in compressive strength with increasing maturity of given samples. For 7 days the density is at 2432kg/m³ and a compressive strength of 16.7N/mm², for 14 days the density is at 2485kg/m³ and a compressive strength of 34.5N/mm² and for 28 days the density is at 2535kg/m³ and a compressive strength of 36N/mm².

Table 4.6 Partial Replacement Cubes M20/25%

Curing days	Sample	Weight (kg)	Density (kg/m ³)	Failure load (kN)	Compressive Strength (N/mm ²)	Average density (kg/m ³)	Average Compressive Strength (N/mm ²)
7	M1	2.494	2494	100	10	2516	12.5
7	M3	2.536	2538	150	15		
14	M1	2.417	2417	280	28	2405	29
14	M3	2.392	2392	300	30		
28	M1	2.491	2491	360	36	2507	34
28	M3	2.523	2523	320	32		

$$\text{Total Average Comp. Strength of M20/25\%} = \frac{12.5+29+34}{3} = 25.2\text{N/mm}^2$$

Eq. (4.10)

Table 4.6 shows a steady decrease in density for 7 and 14 days' maturity consecutively and an increase at the latest maturity of 28 days and a steady increase in compressive strength with increasing maturity of given samples. For 7 days the density is at 2516kg/m³ and a compressive strength of 12.5N/mm², for 14 days the density is at 2405kg/m³ and a compressive strength of 29N/mm² and for 28 days the density is at 2507kg/m³ and a compressive strength of 34N/mm².

Table 4.7 Comparing M20 Compressive Strength Results

Maturity	Control (N/mm ²)	M20/15% (N/mm ²)	M20/20% (N/mm ²)	M20/25% (N/mm ²)
7	14.5	17.3	16.7	12.5
14	25	28.8	34.5	29
28	32	38	36	34

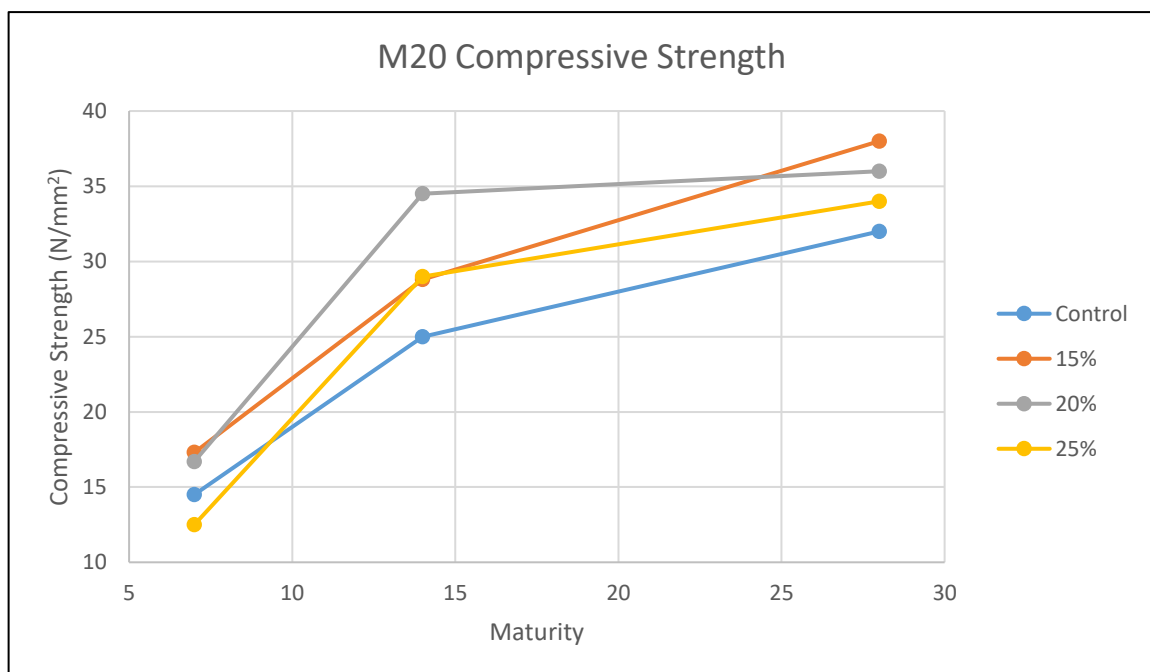


Fig 4.1 Comparison of M20 Compressive Strength Results

4.3.2 M20 Compressive Strength Test Discussion

Using **Fig 4.1**, at 7 days, the control acting as a reference, 15% has the highest compressive strength followed closely by 20% and 25% been the lowest well under the compressive strength of the control. At 14 days, the compressive strengths for 15% and 25% are nearly the same now above that of the control but the highest well above them all is that of 20%. At 28 days, the highest of the compressive strengths is 15% followed by 20% and then 25% all above that of the control.

I can surmise that 15% metakaolin partially replaced M20 concrete causes a spike in compressive strength for the earliest maturity of 7 days and is most appropriate to work with as it produces a much higher compressive strength in the long term.

Table 4.8 Control Cubes M30/0%

Curing days	Sample	Weight (kg)	Density (kg/m ³)	Failure load (kN)	Compressive Strength (N/mm ²)	Average density (kg/m ³)	Average Compressive Strength (N/mm ²)
7	M1	2.498	2498	240	24	2486	21
7	M3	2.473	2473	180	18		
14	M1	2.450	2450	285	28.5	2445	28
14	M3	2.439	2439	275	27.5		
28	M1	2.420	2420	320	32	2460	31.8
28	M3	2.500	2500	315	31.5		

$$\text{Total Average Comp. Strength of M30/0\%} = \frac{21+28+31.8}{3} = 26.9\text{N/mm}^2 \quad \text{Eq. (4.11)}$$

Table 4.8 shows a decrease in density for 7 and 14 days, followed by an increase at 28 days and increase in compressive strength with increasing maturity of given samples. For 7 days the density is at 2486kg/m³ and a compressive strength of 21N/mm², for 14 days the density is at 2445kg/m³ and a compressive strength of 28N/mm² and for 28 days the density is at 2460kg/m³ and a compressive strength of 31.8N/mm².

Table 4.9 Partial Replacement Cubes M30/15%

Curing days	Sample	Weight (kg)	Density (kg/m ³)	Failure load (kN)	Compressive Strength (N/mm ²)	Average density (kg/m ³)	Average Compressive Strength (N/mm ²)
7	M1	2.522	2522	140	14	2520	17
7	M3	2.517	2517	200	20		
14	M1	2.538	2538	200	20	2552	15.8
14	M3	2.565	2565	115	11.5		
28	M1	2.548	2548	210	21	2497	24
28	M3	2.445	2445	270	27		

$$\text{Total Average Comp. Strength of M30/15\%} = \frac{17+15.8+24}{3} = 18.9\text{N/mm}^2$$

Eq. (4.12)

Table 4.9 shows an increase in density for 7 and 14 days, followed by a decrease at 28 days and a decrease in compressive strength for 7 and 14 days, followed by an increase at 28 days. For 7 days the density is at 2520kg/m³ and a compressive strength of 17N/mm², for 14 days the density is at 2552kg/m³ and a compressive strength of 15.8N/mm² and for 28 days the density is at 2497kg/m³ and a compressive strength of 24N/mm².

Table 4.10 Partial Replacement Cubes M30/20%

Curing days	Sample	Weight (kg)	Density (kg/m ³)	Failure load (kN)	Compressive Strength (N/mm ²)	Average density (kg/m ³)	Average Compressive Strength (N/mm ²)
7	M1	2.496	2496	210	21	2510	22
7	M3	2.524	2524	230	23		
14	M1	2.419	2419	235	23.5	2423	23.1
14	M3	2.426	2426	226	22.6		
28	M1	2.527	2527	300	30	2505	25.5
28	M3	2.482	2482	210	21		

$$\text{Total Average Comp. Strength of M30/20\%} = \frac{22+23.1+25.5}{3} = 23.5\text{N/mm}^2$$

Eq. (4.13)

Table 4.10 shows a decrease in density for 7 and 14 days, followed by an increase at 28 days and a steady increase in compressive strength with increasing maturity of given samples. For 7 days the density is at 2510kg/m³ and a compressive strength of 22N/mm², for 14 days the density is at 2423kg/m³ and a compressive strength of 23.1N/mm² and for 28 days the density is at 2505kg/m³ and a compressive strength of 25.5N/mm².

Table 4.11 Partial Replacement Cubes M30/25%

Curing days	Sample	Weight (kg)	Density (kg/m ³)	Failure load (kN)	Compressive Strength (N/mm ²)	Average density (kg/m ³)	Average Compressive Strength (N/mm ²)
7	M1	2.470	2470	200	20	2484	18.5
7	M3	2.498	2498	170	17		
14	M1	2.493	2493	270	27	2479	26.8
14	M3	2.464	2464	265	26.5		
28	M1	2.332	2332	315	31.5	2362	30.8
28	M3	2.391	2391	300	30		

$$\text{Total Average Comp. Strength of M30/25\%} = \frac{18.5+26.8+30.8}{3} = 25.4\text{N/mm}^2$$

Eq. (4.14)

Table 4.11 shows a steady decrease in density and increase in compressive strength with increasing maturity of given samples. For 7 days the density is at 2484kg/m³ and a compressive strength of 18.5N/mm², for 14 days the density is at 2479kg/m³ and a compressive strength of 26.8N/mm² and for 28 days the density is at 2362kg/m³ and a compressive strength of 30.8N/mm².

Table 4.12 Comparing M30 Compressive Strength Results

Maturity	Control (N/mm ²)	M30/15% (N/mm ²)	M30/20% (N/mm ²)	M30/25% (N/mm ²)
7	21	17	22	18.5
14	28	15.8	23.1	26.8
28	31.8	24	25.5	30.8

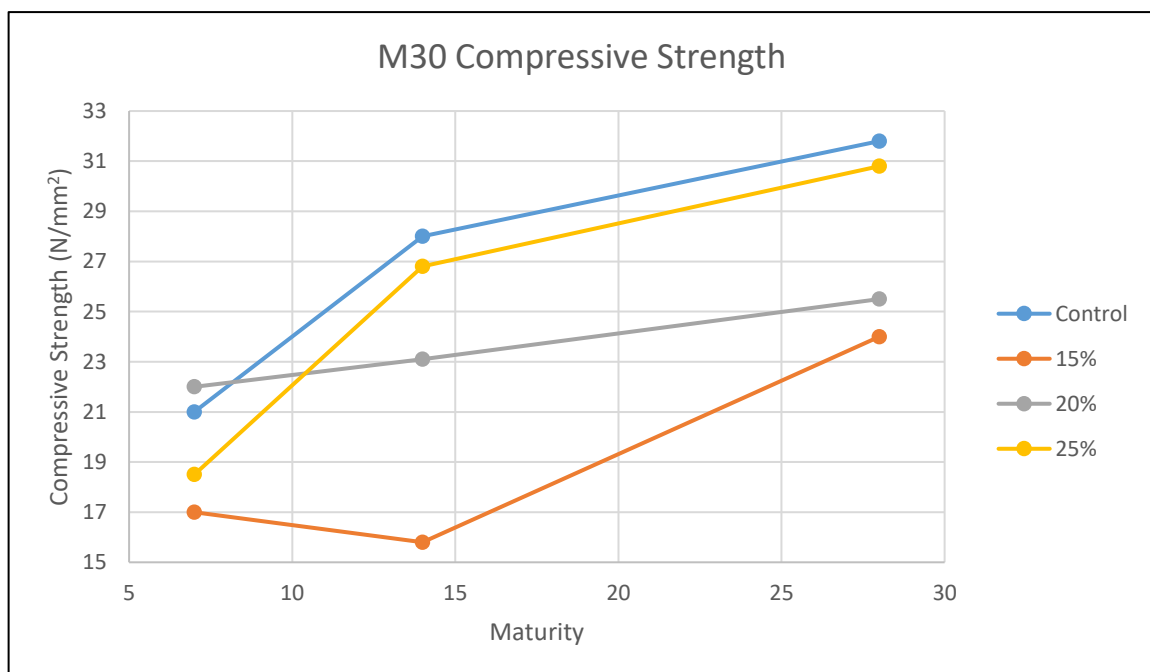


Fig. 4.2 Comparison of M30 Compressive Strength Results

4.3.3 M30 Compressive Strength Test Discussion

Using **Fig 4.2**, at 7 days, the control acting as a reference, 15% has the lowest compressive strength, with 25% above it, both under that of the control and 20% slightly above the control. At 14 days, the compressive strength for 15% goes even lower with 20% well above it followed by 25% all of which are below the control. At 28 days, the highest of the compressive strength is 25% followed by 20% and then 15% all below that of the control.

The curve of progress across various maturity with the most similarity to that of the control is 25%, staying slightly under the control from 7 days to 28 days.

Table 4.13 Control Cubes M40/0%

Curing days	Sample	Weight (kg)	Density (kg/m ³)	Failure load (kN)	Compressive Strength (N/mm ²)	Average density (kg/m ³)	Average Compressive Strength (N/mm ²)
7	M1	2.500	2500	220	22	2486	21.5
7	M3	2.472	2472	210	21		
14	M1	2.245	2245	315	31.5	2373	30.8
14	M3	2.501	2501	300	30		
28	M1	2.465	2465	340	34	2468.5	33.8
28	M3	2.472	2472	335	33.5		

$$\text{Total Average Comp. Strength of M40/0\%} = \frac{21.5+30.8+33.8}{3} = 28.7\text{N/mm}^2 \quad \text{Eq. (4.15)}$$

Table 4.13 shows a decrease in density for 7 and 14 days, followed by an increase at 28 days and a steady increase in compressive strength with increasing maturity of given samples. For 7 days the density is at 2486kg/m³ and a compressive strength of 21.5N/mm², for 14 days the density is at 2373kg/m³ and a compressive strength of 30.8N/mm² and for 28 days the density is at 2468.5kg/m³ and a compressive strength of 33.8N/mm².

Table 4.14 Partial Replacement Cubes M40/15%

Curing days	Sample	Weight (kg)	Density (kg/m ³)	Failure load (kN)	Compressive Strength (N/mm ²)	Average density (kg/m ³)	Average Compressive Strength (N/mm ²)
7	M1	2.422	2422	145	14.5	2396	13.8
7	M3	2.369	2369	130	13		
14	M1	2.406	2406	160	16	2388	25.5
14	M3	2.370	2370	95	9.5		
28	M1	2.416	2416	120	12	2422	13.5
28	M3	2.427	2427	150	15		

$$\text{Total Average Comp. Strength of M40/15\%} = \frac{13.8+25.5+13.5}{3} = 17.6\text{N/mm}^2$$

Eq. (4.16)

Table 4.14 shows a decrease in density for 7 and 14 days, followed by an increase at 28 days and an increase in compressive strength for 7 and 14 days, followed by a decrease at 28 days. For 7 days the density is at 2396kg/m³ and a compressive strength of 13.8N/mm², for 14 days the density is at 2388kg/m³ and a compressive strength of 25.5N/mm² and for 28 days the density is at 2422kg/m³ and a compressive strength of 13.5N/mm².

Table 4.15 Partial Replacement Cubes M40/20%

Curing days	Sample	Weight (kg)	Density (kg/m ³)	Failure load (kN)	Compressive Strength (N/mm ²)	Average density (kg/m ³)	Average Compressive Strength (N/mm ²)
7	M1	2.426	2426	150	15	2324	14.5
7	M3	2.222	2222	140	14		
14	M1	2.223	2223	85	8.5	2339	14.3
14	M3	2.455	2455	200	20		
28	M1	2.411	2411	300	30	2407	24
28	M3	2.402	2402	180	18		

$$\text{Total Average Comp. Strength of M40/20\%} = \frac{14.5+14.3+24}{3} = 17.6\text{N/mm}^2$$

Eq. (4.17)

Table 4.15 shows a steady increase in density and a decrease in compressive strength for 7 and 14 days, followed by an increase at 28 days. For 7 days the density is at 2324kg/m³ and a compressive strength of 14.5N/mm², for 14 days the density is at 2339kg/m³ and a compressive strength of 14.3N/mm² and for 28 days the density is at 2407kg/m³ and a compressive strength of 24N/mm².

Table 4.16 Partial Replacement Cubes M40/25%

Curing days	Sample	Weight (kg)	Density (kg/m ³)	Failure load (kN)	Compressive Strength (N/mm ²)	Average density (kg/m ³)	Average Compressive Strength (N/mm ²)
7	M1	2.390	2390	190	19	2416	18.5
7	M3	2.441	2441	180	18		
14	M1	2.428	2428	240	24	2446	23.5
14	M3	2.464	2464	230	23		
28	M1	2.540	2540	310	31	2431	28.5
28	M3	2.321	2321	260	26		

$$\text{Total Average Comp. Strength of M40/25\%} = \frac{18.5+23.5+28.5}{3} = 23.5\text{N/mm}^2$$

Eq. (4.18)

Table 4.16 shows an increase in density for 7 and 14 days, followed by a decrease at 28 days and a steady increase in compressive strength with increasing maturity of given samples. For 7 days the density is at 2416kg/m³ and a compressive strength of 18.5N/mm², for 14 days the density is at 2446kg/m³ and a compressive strength of 23.5N/mm² and for 28 days the density is at 2431kg/m³ and a compressive strength of 28.5N/mm².

Table 4.17 Comparing M40 Compressive Strength Results

Maturity	Control (N/mm ²)	M40/15% (N/mm ²)	M40/20% (N/mm ²)	M40/25% (N/mm ²)
7	21.5	13.8	14.5	18.5
14	30.8	25.5	14.3	23.5
28	33.8	13.5	24	28.5

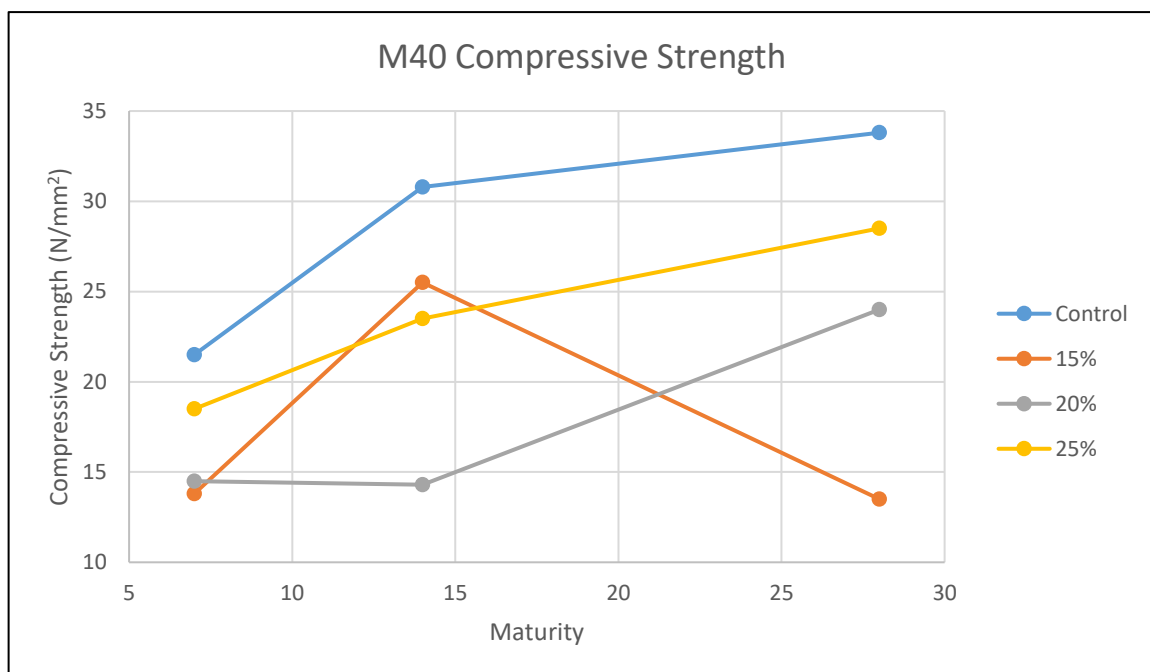


Fig 4.3 Comparison of M40 Compressive Strength Results

4.3.4 M40 Compressive Strength Test Discussion

Using **Fig 4.3**, at 7 days, the control acting as a reference, 15% has the lowest compressive strength, with 20% slightly above it followed by 25% well above them both, with all below the control. At 14 days, the compressive strength for 20% is at its lowest, followed by 25% well above followed by 15% slightly above, all of which are below the control. At 28 days, the highest of the compressive strength is 25% followed by 20% and then 15% by a large margin all below that of the control.

The curve of progress that is most erratic is that of 15% following a zigzag motion from low to high to low, the curve for 25% shows a steady increment and the curve for 20% shows a slight decrease then an increase at the latest maturity.

4.4 Flexural test

The cubes were subjected to a flexural strength test after being cast and left to cure for 28 days. The testing procedure adhered to the guidelines outlined in BS EN 12390-4.

4.4.1 Formulas used in the determination of flexural strength and density

Density is given as;

$$\rho(kg/m^3) = \frac{m(kg)}{v(m^3)} \quad \text{Eq. (4.19)}$$

Where, ρ = Density of beam

m = Mass of beam

v = Volume of beam = $0.0083m^3$

Mass of the beam is gotten used the industrial weighing scale, while volume of the beam is given as;

$$v = l \times b \times h \quad \text{Eq. (4.20)}$$

Where, l = span of the beam

b = width of the beam

h = height of the beam

which is (1000×66×127) mm

If force is applied at two points towards center of sample, flexural strength is given as;

$$\sigma(\text{N/mm}^2) = \frac{PL}{bd^2} \quad \text{Eq. (4.21)}$$

Where σ = Flexural Strength

P = Applied Load or Failure Load

L = Span of the Beam

b = Breadth/Width of the Beam

d = Depth/Height of the Beam

It is known as *Four Point Test Equation*.

Failure load is gotten by reading the gauge of the flexural strength testing machine at the point of failure, while the breadth and depth of the beam, b and d, are given by the measurement of the beam using a measuring tape, i.e. 1000mm.

The results are as follows;

Table 4.18 Control Beams

Curing days	Description	Weight (kg)	Density (kg/m ³)	Failure load (kN)	Flexural Strength (N/mm ³)
28	M20	20.1	2398	1.6	1.91×10^{-4}
28	M30	21	2505.4	3.2	3.82×10^{-4}
28	M40	20	2386.1	3.3	3.94×10^{-4}

Table 4.18 shows the various densities and flexural strength of the various grades of concrete all on the same maturity of 28 days. For M20 at 28 days the density is at 2398kg/m³ and a flexural strength of 1.91×10^{-4} N/mm², for M30 at 28 days the density is at 2505.4kg/m³ and a flexural strength of 3.82×10^{-4} N/mm² and for M40 at 28 days the density is at 2386.1kg/m³ and a compressive strength of 3.94×10^{-4} N/mm².

Table 4.19 Partial Replacement Beams for M20

Curing days	Description	Weight (kg)	Density (kg/m ³)	Failure load (kN)	Flexural Strength (N/mm ³)
28	M20/15%	21	2505	1.6	1.91×10^{-4}
28	M20/20%	21.5	2565	2.5	2.98×10^{-4}
28	M20/25%	19.5	2326	1.8	2.15×10^{-4}

Table 4.20 Comparing M20 Flexural Strength Results

Maturity	M20 Control	M20/15% (N/mm ³)	M20/20% (N/mm ³)	M20/25% (N/mm ³)
28	1.91×10^{-4}	1.91×10^{-4}	2.98×10^{-4}	2.15×10^{-4}

Table 4.20 shows the flexural strengths of the various partially replaced concrete beams in comparison to the control, all grades, M20 are on the same maturity of 28 days. For M20 control at 28 days the flexural strength is at $1.91 \times 10^{-4} \text{N/mm}^2$, for M20/15% at 28 days the flexural strength is at $1.91 \times 10^{-4} \text{N/mm}^2$, for M20/20% at 28 days the flexural strength is at $2.98 \times 10^{-4} \text{N/mm}^2$ and for M20/25% at 28 days the flexural strength is at $2.15 \times 10^{-4} \text{N/mm}^2$.

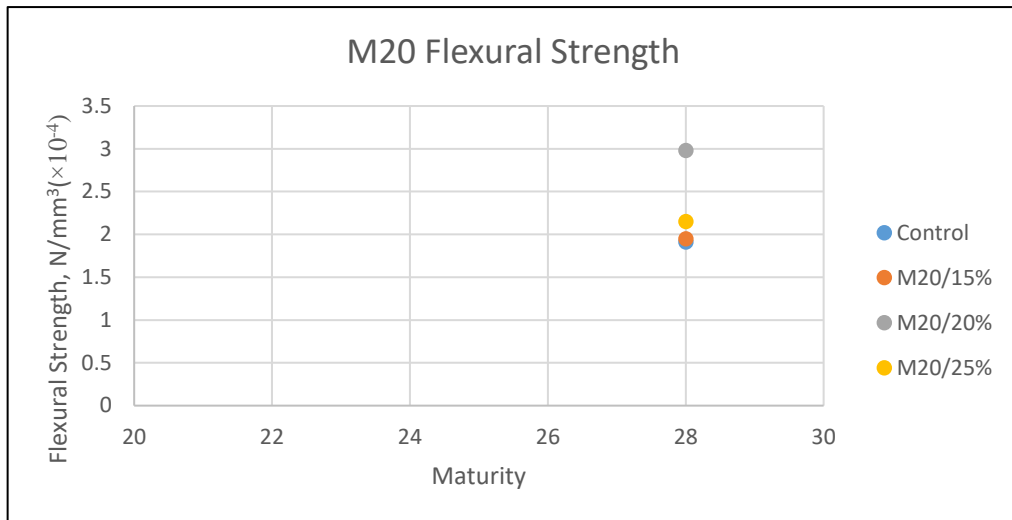


Fig 4.4 Comparison of M20 Flexural Strength Results

Fig. 4.4 shows that the flexural strengths for control and partially replaced M20/15% are the equal followed by M20/25% and M20/20%, all at a maturity of 28 days with M20/20% having the highest flexural strength. This shows that with the partial replacement of fine aggregate with metakaolin, the highest flexural strength is at 20%.

CHAPTER FIVE

5.0 CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

The findings suggest that the most significant enhancement in compressive strength is observed at a 15% replacement level for M20 at both the earliest and latest maturity periods. For M30, the compressive strength of the control mix surpasses that of the partial replacement percentages, except at the earliest maturity period where 20% replacement exhibits the highest strength. In the case of M40, the compressive strength of the control mix remains higher than the partial replacement percentages across all levels.

The results indicate that the most substantial increase in flexural strength is observed at a 20% partial replacement.

Overall, the results imply that metakaolin may serve as a suitable replacement, as its influence on the mechanical properties of hardened concrete shows slight variations, often tending towards an overall increase in the strength of the cast concrete.

5.2 Recommendations

For better results to ascertain an increase in compressive strength, so as to determine if metakaolin can serve as a suitable substitute for fine aggregate, I recommend testing for longer periods of curing, as it may be able to achieve later peaks in compressive strength as seen in results.

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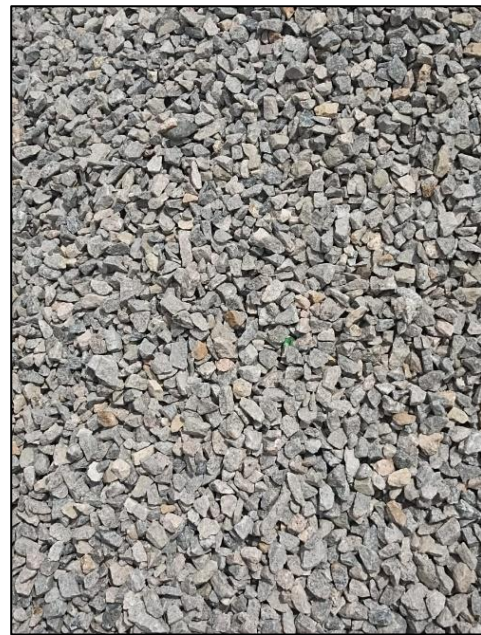
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APPENDIX



Degree of workability	Slump (mm)
Very low	0-25 mm
Low	25-50 mm
Medium	50-100 mm
High	100-175 mm
Very high	collapsed