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EXPERIMENTAL INVESTIGATION OF THE DURABILITY PROPERTIES OF CONCRETE PRODUCED WITH METAKAOLIN AS PARTIAL REPLACEMENT OF CEMENT

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ABSTRACT

The research investigates the durability properties of concrete produced with metakaolin (MTK) as partial replacement of cement. Cement was partially replaced by metakaolin at 5% to 30% at an interval of 5%. Physical properties of materials were tested. A 100 x 100 x 100mm cube was used for density, compressive strength, water absorption and abrasion resistant test, while, 100mm x 200mm cylinder was used for split tensile strength, at a mix ratio of 1:2:4 with 0.5 w/c ratio, and cured at 7, 14, 28, 56 and 90 days under different curing conditions. Result shows that the density of concrete increase as the curing ages of concrete increases. The highest compressive strength of concrete at 28days was at 0% control which achieved 28.2 N/mm^2 and 27.6 N/mm^2, while, 10% has the highest strength of 32.1 N/mm^2 and 31.1 N/mm^2 at 90 days for concrete cured in H_2SO_4 and $MgSO_4$ respectively. 10% MTK concrete has reduce absorption capacity of 11.34, 11.17% and 6.57% in H_2O, H_2SO_4 and $MgSO_4$ respectively, as compared to that of control concrete, and has improve resistance to abrasion in aggressive environment. Chemicals significantly affect the strength of concrete. $MgSO_4$ is more deleterious to concrete than H_2SO_4. In conclusion, metakaolin is a suitable pozzolana for use in the production of concrete, at lower volume of replacement will enhance the reduction of cement usage in concretes, thereby reducing the production cost and environmental pollution from exploration and production of cement. 10% MTK is the optimum percentage in concrete, therefore, it was recommended to produce a strong, dense and durable concrete which can be used both in normal and aggressive chemical environments.

Keywords: Abrasion Resistance, Compressive Strength, Durability Properties, Metakaolin, Split Tensile Strength, Water Absorption

INTRODUCTION

The construction industry, due its scale and function have a significant impact on the environment. Concrete is the most widely used construction material in the world and it is inherently environmentally friendly, whereas Portland cement, which is a major material in concrete production, is coherently important but not environmentally friendly. According to Mohammad (2010) the most essential ingredient of concrete is cement which contribute to the construction industry and its product impact negatively on the environment. The exploration of raw materials needed in the production of cement and the cement production itself emits carbon dioxide in large quantity to the surroundings which leads to environmental pollutions. It was estimated that the annual production of concrete is estimated to 12 billion tons of concrete, and it utilizes about 1.6 billion tons of Portland cement (Agboola, *et al.,* 2020a). Thus, on an estimated average, we can assume that approximately 1 ton of concrete is produced each year for everybody in the world. PC is currently under discussion, not only for its cost but also for its environmental effects during manufacture. 900 kg of CO_2 are produced for the manufacturing of every ton of cement (Mahasenan, *et al.,* 2003). The amount of CO_2 produced in concrete is directly proportional to the amount of cement used in the concrete mix. Thus, the production of 1 Ton of PC supposes the consumption of 1.5 Tons of quarry material, energy consumption of 5.6 Gj/Ton and an emission of nearly 0.9 Ton of CO_2, representing 5% of total anthropogenic CO_2 emission (Reddy *et al.,* 2006; O'Rourke *et al.,* 2009; Juenger *et al.,* 2011). Of all the pollutants in the cement manufacturing industry, CO_2 gas emission is the most prevalent. This particular pollutant is produced in three distinct processes: one is produced by the de-carbonation of limestone in the calcining process; the other is produced by the kiln fuel combustion and the last is produced by the vehicles in the cement manufacturing plant and that produced by the vehicles used in the distribution of the already manufactured cement (The Cement Sustainability Initiative, 2007).

Harley (2007) noted that concrete utilized by the construction industries throughout the world is as double as total of all other building materials like, glass, wood, steel, plastic and aluminum utilized. It is most utilized construction material due to its versatility, availability of its constituents, and performance in terms application, usage flexibility, strength, durability, impermeability etc. As a composite material it is the most widely used in the construction of buildings and other infrastructures. For this reason, concrete is the most common material used in construction, and it is second only to water as the most utilized substance in the world. However, there is a concern to more understanding and to improve its properties. One way to make the construction industry more compatible with the requirements of sustainable development would be to use as much concrete as possible, but with the least amount of Portland cement as possible. The target of sustainability is to keep lives safe for the foreseeable future by adequate care and support of the current activities without damaging the ecological balance (Agboola, *et al.,* 2023). The problems posed by carbon dioxide emission from cement production concrete and other achievable and desirable properties of concrete have led to research on cement alternative that will partially or completely replace cement in the concrete construction industry (Agboola, *et al.,* 2022a). The current trend is to reduce the amount of Portland cement used in the production of concrete with Supplementary

Cementitious Material (SCM) which is affordable and available to improve desirable properties of concrete (Agboola *et al.*, 2020c). Ways to reduce the amount of Portland cement in concrete is to introduce the use of supplementary cementitious materials. Supplementary cementitious material, also known as pozzolan, was defined by ASTM C125-06 (2006) as a siliceous and aluminous or siliceous material that, when finely divided and in the presence of moisture, will react chemically with calcium hydroxide at room temperature to form compounds that have cementitious properties. In other words, pozzolan is a siliceous material that has little or no cementitious value on its own. Natural and artificial cementitious materials is used to reduce amount of cement in concrete production. Natural cementitious materials include, volcanic ash, clay and shales, diatomaceous earth, volcanic tuffs and pumicites etc. while artificial cementitious material include rice husk ash, guinea corn husk ash, fly ash, blast furnace slag, silica fume, rice husk ash, metakaolin, surkhi, wood ash etc. Joergensen (2014) claims that using pozzolana in place of cement in the manufacturing of concrete minimizes heat generation during the hardening process and enhances the performance of specific properties as well as the durability of the finished concrete structures. The focus of this work is on metakaolin, an artificial pozzolan that is readily available and reasonably priced. Concrete's strength properties when combined with metakaolin are already showing promise.

Research have shown that pozzolanas can produce concrete with properties in form of normal concrete at ages even beyond 28 days. Pozzolanic reactions are chemical reactions that take effect between silica and calcium hydroxide in the presence water to produce calcium silicate hydrates(C-S-H) that aid strength development in concrete. This C-S-H creates a relatively high-density microstructure that increases strength, lowers concrete permeability and increases its resistance to chemical attack (Osei and Jackson, 2012). Accordingly, concrete can be relatively made strong but not durable (Agboola, *et al.,* 2020b). Concrete structures are currently built in chemical and highly polluted urban and industrial areas, deleterious sub soil, active and aggressive marine environment, water in coastal areas and many other hostile and harmful conditions where other materials of construction are found not to be durable (Shetty, 2009). Nagesh (2012) asserts that lifetime service in concrete is synonymous with durability and goes on to say that concrete's durability is defined as its capacity to function adequately under exposure conditions for the desired amount of time while requiring the least amount of maintenance. According to Shetty (2009), researchers and designers of concrete in the past focused too much on compressive strength while ignoring other characteristics of the material, such as durability. It is now understood, however, that the degree of aggression in the environment that concrete is exposed to, plays an equally vital role in determining the quality of the material; concrete compressive strength alone is not enough. Strength and durability must thus be carefully taken into account throughout both the research and design phases. This research work therefore assesses the effect of metakaolin on the durability properties of concrete.

MATERIALS AND METHODS

This section gives the detailed description of all the materials used in the experimental programme and the method used for conducting the various tests. The specimens were prepared and tested according to the relevant British Standards (BS).

Research Materials

Materials used in this research include the following: Cement, metakaolin, coarse aggregates, fine aggregate, water, $MgSO_4$, H_2SO_4.

Cement

Portland Limestone Cement was used for this research as the main binder, and it satisfies the minimum requirement as provided by BS 12 (1996). The Portland Limestone Cement brand was that of Dangote.

Metakaolin

The kaolin clay used to produce the metakaolin used in this research was obtained from Alkaleri local government in Bauchi state, Nigeria. The kaolin was grounded to powder using a stone crusher then pound with metal mortar and pestle to fine powder. The kaolin powder was fired (calcined) in the laboratory at a controlled temperature of 700^0C in a kiln (furnace) and maintained for an hour, and the resultant metakaolin was brought out and allowed to cool at room temperature produced a highly reactive alumino-silicate material rich in silica and alumina. After cooling, the resultant metakaolin powder was sieved through a 15um sieve.

Coarse aggregate (CA)

The coarse aggregate was obtained from suppliers in Bauchi town. Sieve analysis was carried out in accordance with BS 933 part 1(1997) to distribute the aggregate into various sieve sizes. The aggregate required comprises of 20mm as its maximum and 5mm as its minimum size and they are used in the Saturated Surface Dry (SSD) condition.

Fine aggregate (FA)

River sand was obtained from suppliers in Bauchi town and used for the experiment. It was kept in the SSD condition prior to use in the laboratory. Sieve analysis in accordance with BS 933 part 1(1997) was carried out to distribute the particles in their required sieve sizes, remove impurities and bigger size aggregates.

Water

Portable water fit for drinking was used in this research for mixing and production of the concrete specimens.

Curing Media

The concrete samples were cured by completely immersing them into three different curing media of water (H_2O), $MgSO_4$, H_2SO_4. 2.5% concentration of H_2SO_4 and $MgSO_4$ each with 50 liters of water was used. This means that, for every 50000g of clean water, 1250g of chemical was used as 2.5% concentration. The 1250g of chemical and 50 liters of water was poured in a 100-litre capacity bowl. A 100-litre capacity bowl was used to allow specimens be placed and cured properly without overflow.

Laboratory Tests

Laboratory tests carried out on the aggregates include particle size distribution, specific gravity, bulk densities and void.

Sieve Analysis

The sieve analysis for fine aggregate and coarse aggregate was carried out in accordance with BS 812-103 (1990). This was done to determine the grading of the aggregates.

Specific Gravity

In determining the specific gravity, a pycnometer (a vessel of 1 liter capacity with a metal conical screw top and a 5mm diameter hole at its apex, giving a water tight connection), tray, scoop, drying cloth and weighing balance were used. The test procedure was carried out in accordance to with BS 812-1377 (1970). The specific gravity was calculated using equation below.

$Gs = \frac{(C-A)}{(B-A)(D-A)}$

Where: A is the weight of empty density bottle and it is stopper which it was clean and dried

B is the weight of empty density bottle plus water

C is the weight of empty density bottle plus sample

D is the weight of empty density bottle plus water and sample

Bulk Density

In determining the bulk density and void for fine aggregate, coarse aggregate and metakaolin, a weighing balance, metal cylinder of 7dm^3 capacity, scoop, straight edge, tamping rod of 16mm diameter and a drying duster (towel) were used. This was determined in accordance with BS 812: Part 2 (1995). The bulk density was calculated using equation below.

$Bd = = \frac{M2- M1}{V}$

Where: M_1 is the weight of empty container

M_2 is the weight of container plus Sample

V is the volume of container

Moisture Content of Materials

1000g of coarse aggregates (coarse and fine aggregate) was weighed using weighing balance and recorded as A, the material was then poured on a wide metal plate, spread and put inside an electric oven for 24hours at 105^{0}C. After 24hours the aggregates were removed from the oven and allowed to cool down at room temperature, after cooling the aggregates were weighed again and recorded as B. The same procedure was applied for 500g of metakaolin and the moisture contents determined in accordance to BS 812-109 (1990). Moisture content was calculated using the equation below.

$Mc= \frac{A- B}{B}\ x\ 100$

Density Test

This was carried out prior to crushing of the concrete specimen. At the end of each curing period, the concrete specimens were weighed using an electric weighing machine balance. Density is calculated as mass of concrete specimen in (kg) divided by volume of concrete cube (m^3) and expressed in kg/m^3. Density tests were conducted on 100x100x100mm cube specimens in accordance with BS EN 12390-7 (2000).

Compressive Strength Test of concrete

The compressive strength tests were conducted in accordance with BS EN 12390-3 (2009). Cube specimen of 100 x 100 x 100mm were prepared. All the cube specimens were removed from the molds after 24 hours of casting and cured by total immersion in H_2SO_4, and $MgSO_4$ until the testing age, cubes were removed from curing medium and allowed to drip off and be at saturated surface dry condition before being tested for strength. Compressive strength test was carried out on the cube specimens at curing age of 7, 14, 28, 56 and 90 days. The cement was replaced with metakaolin at 5% to 30% at 5% interval.

Split Tensile Strength Test

In order to assess the tensile characteristics of concrete samples with metakaolin (MTK) as partial replacement of cement, the splitting tensile strength was conducted on 100 x 300mm concrete cylinder specimens in accordance with the provision of BS EN 12390-6 (2009). The splitting strengths were determined on 600KN Avery Denison Universal Testing machine at a loading rate of 120KN/min until failure.

The split tensile strength Fct in N/mm^2 was computed using the equation below.

$Fct = \frac{2F}{\pi \times L \times d}$

Where;

F is the maximum load in (KN)

L is the average measured length in (mm)

d is the average measured diameter in (mm)

The tensile splitting strength is expressed to the nearest 0.05 MPa.

Abrasion resistance test

This test was conducted at the curing ages of 28, 56 and 90 days on concrete containing 0%, 5%, 10%, 15%, 20%, 25% and 30% metakaolin and cured in water and chemical. Abrasion resistance is used to measure the resistance of concrete to surface wear by abrasion. It is aimed at determining the abrasion resistance of a material through sliding or scraping, thus causing a wearing down by friction. Gupta and Gupta (2012) explained that abrasion value should not be more than 30% for wearing surface and 50% for other surfaces. The initial weight of each concrete sample was determined before brushing and recorded as W1, after which a weight of 3.5kg was mounted and tightly fixed to the wire brush. The brush was used to stroke the surface of concrete specimen 60 times at equal speed, then the specimen was re-weighed while the value was recorded as W2. The relation used to determine abrasion resistance of the concrete sample is given as:

Abrasion Resistance = $AR = \frac{W1-W2}{W2}\ x\ 100$

Where W_1 = Initial weight of a concrete specimen

W_2 = Final weight of a concrete specimen

Water Absorption Capacity Test

This test was conducted at the curing ages of 28, 56 and 90 days on concrete containing 0%, 5%, 10%, 15%, 20%, 25% and 30% metakaolin in accordance with BS 1881-122:(1983). Specimens were tested for absorption capacity, and on each day of testing, three cubes each were placed in the electric oven to dry the specimens at 105^{0}C for 72 hours. The specimens were removed from the oven and allowed to cool at room temperature before determining the initial weight which was recorded as (W_1). The final weight was determined after the concrete specimen has been immersed in water for 30 minutes. It was removed and dried with a piece of cloth; re-weighed and recorded as (W_2). The equation below was used to compute the absorption capacity for the specimens as:

Water Absorption Capacity= $WA = \frac{W2-W1}{W1}\ x\ 100$

Where: W_1 = Weight of the concrete sample after oven dry

W_2 = Weight of the saturated surface dry concrete sample

Quantities of Concrete Constituents

Table 1: Quantities of Concrete Constituents at Various Replacement of Cement with Metakaolin

Sample	Cement	MTK	CA	FA	Water
Control (0%)	420	0.0	1079	661	210
5%	399	21	1079	661	210
10%	378	42	1079	661	210
15%	357	63	1079	661	210
20%	336	84	1079	661	210
25%	315	105	1079	661	210
30%	294	126	1079	661	210

RESULTS AND DISCUSSION

Sieve Analysis

Figure 1, present the graph for sieve analysis of fine aggregate which shows that the percentage of fines passing through sieve 600micron sieve size which is 28.0% which is within the range of 15 – 34 specified by BS 882:1992 indicating that the aggregate is within the range of Zone 1**.** Figure 2, present the grading curve for coarse aggregates with 20mm nominal size. It can be seen that aggregate fall between zones 1 and 4. This means that the aggregate is suitable for general construction work.

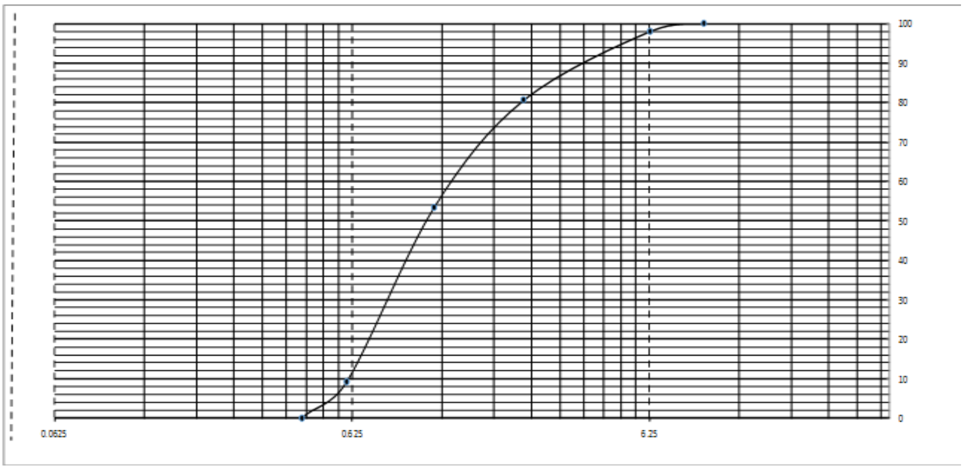

Figure 1: Sieve Analysis Graph Showing Well Graded Fine Aggregate

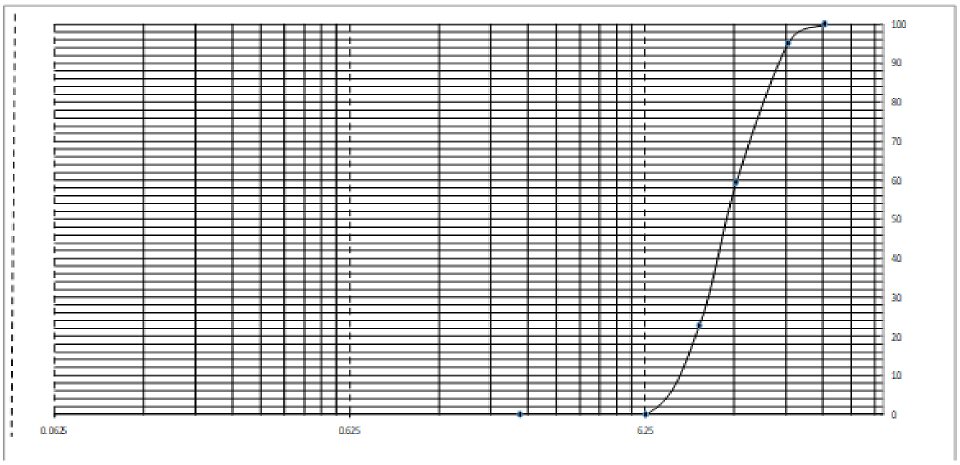

Figure 2: Sieve Analysis Graph Showing Coarse Aggregate

Physical properties of Materials

The physical properties of materials used in the research is presented in Table 2. The result shows that specific gravity of fine aggregate is 2.62, for coarse aggregate is 2.72, while that of metakaolin is 2.46. The result shows that compacted and un-compacted bulk density of fine aggregate is 1518 and 1359 respectively. The compacted and un-compacted bulk density of coarse aggregate is 1736 and 1406 respectively. In addition, the compacted and un-compacted bulk density of metakaolin is 1106 and 946 respectively. The moisture content of coarse aggregate is 0.6%, that of fine aggregate is 5.15% and that of metakaolin is 0.46%. However, the test shows that the aggregate used is in conformity with standard as ACI E1-99 (2001) specified that the moisture content of coarse aggregates should be within 0 to 2% and that for fine aggregates should be within 0 to 10%.

Table 2: Physical properties of Materials

Materials	Bulk Density (Kg/m³)		Specific Gravity (g)	Moisture Content (%)
	Compacted	Uncompacted		
Fine Aggregate	1518	1359	2.62	5.15
Coarse Aggregate	1736	1406	2.72	0.6
Metakaolin	1106	946	2.46	0.46

Density of Concrete

Figure 3, presents the result on density of concrete produced with metakaolin as partial replacement of cement and replaced at 5% to 30% by weight of cement cured in H_2SO_4 curing conditions. The result shows the effect at various curing ages from 7days to 90 days. Density of metakaolin - cement concrete and that control concrete ranges from 2420 to 2540 kg/m^3. Considering the lowest value of concrete density reported in this study, it is higher than the density of conventional concrete of 2400 kg/m^3 according to (Kazjonovs *et al.*, 2010); and comparable to the reported value of earlier investigators (Agboola, *et al.*, 2020c), for pozzolanic concretes. At early stages, say 7 to 28days concrete produced with metakaolin has reduced density as compared to the control concrete. Reduction in density is as a result of metakaolin having a higher specific area as compared to cement (Ahmad *et al.*, 2022; Al-Hashem, *et al.*, 2020). Lower concrete density is achievable with metakaolin when considering massive concrete construction. At 56days, concrete produced with 10% percentage replacement of cement with metakaolin have higher density as compared to the control concrete.

Figure 4 presents the results on density of concrete produced with metakaolin as partial replacement of cement and replaced at 5% to 30% by weight of cement cured in $MgSO_4$ curing conditions. Density of metakaolin - cement concrete and control concrete ranges from 2405 to 2500 kg/m^3. Considering the lowest value of concrete density reported in this study, it is higher than the density of conventional concrete of 2400 kg/m^3 according to (Kazjonovs *et al.*, 2010); and comparable to the reported value of earlier investigators (Agboola, *et al.*, 2020c), for pozzolanic concrete cured in magnesium sulphate environment. At early stages, say 7 to 28days concrete produced with metakaolin has reduced density as compared to the control concrete, while at 56days concrete produced with 0%, 5% and 10% percentage replacement of cement with metakaolin have same density, while at 90 days of curing, 5% and 10% metakaolin in concrete as cement replacement gave higher density beyond the control concrete. Concrete produced with natural pozzolana as partial cement replacement has lower density than control concrete samples due to result of diluted action of pozzolanic material (Azad, *et al.*, 2020; Reddy, & Rao, 2019; Al-Zboon & Al-Zou'by, 2015; Mouanda, *et al.*, 2022; Saraya, 2014; Valipour, *et al.*, 2014; Rashad, 2013; Memon, *et al.*, 2012; Siddique, 2011).

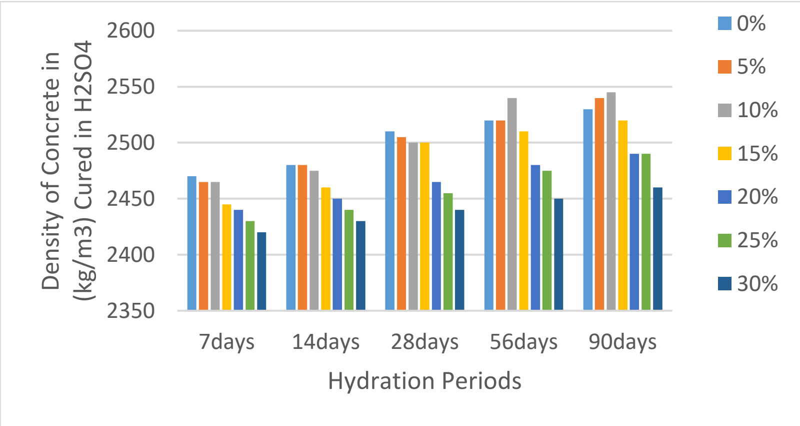

Figure 3: Density of MTK Concrete Cured in H_2SO_4

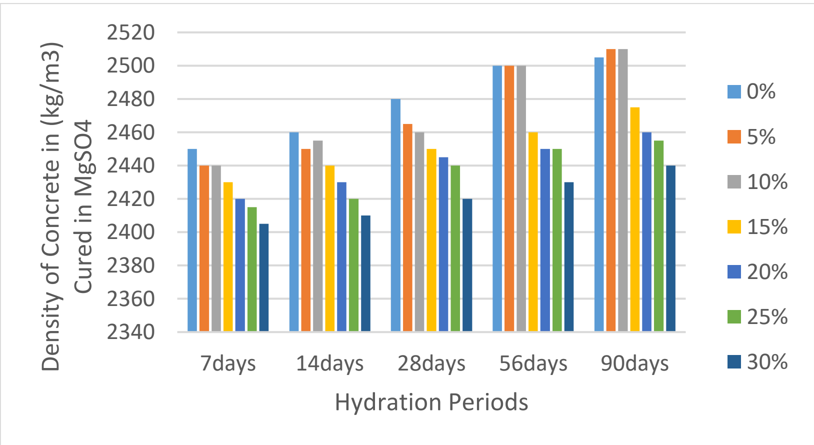

Figure 4: Density of MTK Concrete Cured in $MgSO_4$

Compressive Strength of Metakaolin-Concrete

Figure 5, present the result on the compressive strength of concrete produced with MTK as partial replacement of cement at levels of 5%, 10%, 15%, 20%, 25%, and 30%, with a water cement ratio of 0.5 cured in H_2SO_4 medium, at 7 days, 14 days, 28 days, 56 days and 90 days respectively; At 28 days curing period the compressive strength result indicated that control concrete exhibited the highest compressive strength as compared to all cement replacement levels and shows an increase in strength of 0.35%, 0.35%, 3.55%, 9.57%, 14.18% and 27.66% beyond 5%, 10%, 15%, 20%, 25% and 30% levels. At 90 days curing, 5%, 10% and 15% shows higher strength as compared to the 0% control concrete with an increase of 2.87%, 4.98% and 0.97% respectively. The control concrete has high strength at early stage up to 28 days as compared to cement replacement levels in concrete, but at later stages 5%, 10% and 15% shows better strength index as compared to the control concrete even in acid medium. The strength of concrete with and without pozzolanic material, increase with increase in curing age. The pozzolanic concrete produced in this study indicated best dosage at 10%, which shows better performance beyond 28 days of curing than all other concrete produced. Also, at later stages of curing, say 90 days, 15% cement replacement level shows better strength performance than the control concrete. 20% to 30% replacement level in concrete shows lesser strength performance as compared with the control concrete. The result from this study is in line with the study of Senhadji *et al*. (2012) that at an early age pozzolanic materials lowers the strength of concrete samples. The study is also supported by (Alishah & Razaei, 2021; Ahmad, Mohaisen, Adekunle, Al-Dulaijan, & Maslehuddin, 2019) that pozzolanic materials reaction in concrete production aid high improved strength than control concrete at longer ages.

Figure 6 present the result on the compressive strength of concrete produced with MTK as partial replacement of cement at levels of 5%, 10%, 15%, 20%, 25%, and 30%, cured in $MgSO_4$ medium, at 7 days, 14 days, 28 days, 56 days and 90 days respectively. At 28 days curing period, compressive strength indicated that control concrete exhibited the highest compressive strength than all cement replacement levels and has increase in strength of 0.72%, 0.36%, 7.61%, 11.91%, 18.48% and 34.42% beyond 5%, 10%, 15%, 20%, 25% and 30% metakaolin as cement partial replacement. At 90 days curing, 5%, 10% and 15% shows higher strength with an increase of 2.63%, 5.07 and 1.66% respectively. While control concrete shows an increase in strength of 6.08%, 11.82%, and 19.26%, respectively, beyond 20% 25% and 30% cement replacement with metakaolin in magnesium aggressive medium. The control concrete has high strength at early stage up to 28 days as compared to cement replacement levels in concrete, but at later stages 5%, 10% and 15% shows better strength index as compared to the control concrete even in aggressive medium. The strength of concrete increase with increase in curing age. The findings are supported by Senhadji et al. (2012) that at an early age, pozzolanic concrete has lowers strength, but at later stages of curing, the pozzolanic reaction aids in more strength development than the control concrete (Alishah & Razaei, 2021; Vijay & Reddy, 2021; Laidani, *et al*., 2020; Ahmad, *et al*., 2019; Rehman, *et al*., 2019; Trumer, *et al*., 2019; Photisan, 2018; Sicakova, *et al*., 2017; Makhloufi, *et al*., 2015; Akbar, *et al*., 2013; Karakurt & Topcu, 2011). The amorphous silicate matrix in pozzolana actively reacts with portlandite to form a secondary C–S–H gel which mainly improves the strength of the final hydrated cement matrix, which is mostly dependent on the hydration reaction of pozzolana and cement phase (Oumnih, *et al*., 2019; Lemonis, *et al*., 2015; Rashad, 2013). In addition, Valipour *et al.* (2014) and Walker and Pavía (2011) reported that the compressive strength of concrete with natural pozzolana increases with decreasing pozzolanic particle size. Also, Homayoonmehr *et al.* (2021) and Reddy and Reddy (2021) found that pozzolana improves compressive strength of concrete and its performance depend mainly on the chemical composition and fineness or filling ability of the pozzolana. Furthermore, Khan *et al.* (2017) reported that improvement of strength by partial replacement of cement with pozzolana in concrete mostly result from cement hydration effect, pozzolanic reaction effect between amorphous silica and cement hydration product $Ca(OH)_2$, and filler effect of pozzolanic particles, and all the aforementioned factors significantly play a crucial role in improving the strength, and durability of concrete.

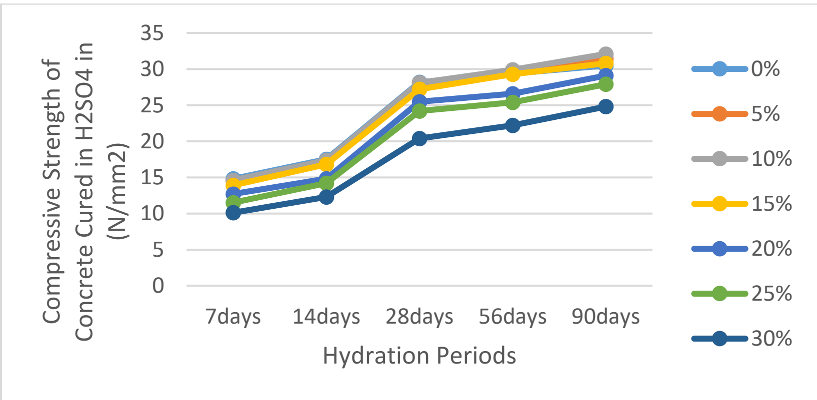

Figure 5: Compressive Strength of MTK Concrete Cured in H_2SO_4

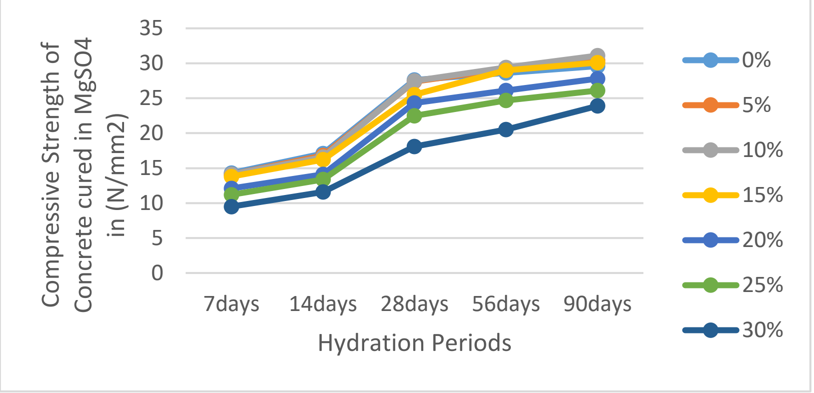

Figure 6: Compressive Strength of MTK Concrete Cured in $MgSO_4$

Split Tensile Strength of Metakaolin-Concrete

Figure 7 shows the split tensile strength of concrete produced with metakaolin at 5% to 30% replacement level and cured in H_2SO_4 curing medium. Split tensile strength of concrete attained, is in the range of 1.66 to 2.26 N/mm^2 and 2.32 to 3.14 N/mm^2 at 7days and 28days respectively. The result shows that split tensile strength of concrete increases as curing ages increases. The control concrete has high strength as compared to other percentage cement replacement level at 7days and 28days curing age. At later stages of curing 5%, 10% and 15% present higher strength as compared to the control concrete. It is observed that replacement of cement with metakaolin, up to 15%, shows better split tensile strength than control concrete at later stages. at early curing days there is no much significant impact, but at later stages of curing, there was improve strength through gradual pozzolanic reactions. The use of metakaolin enhances the split tensile strength performance of concrete. According to Priyanka, *et al.* (2018) and Shiau, *et al.* (2018), the use of natural pozzolana in concrete mixture significantly improves the splitting tensile strength compared to concrete control mixture.

Figure 8 shows the split tensile strength of concrete produced with metakaolin at 5% to 30% replacement level and cured in $MgSO_4$ curing medium. Split tensile strength of concrete attained, is in the range of 1.47 to 2.15 N/mm^2 and 2.19 to 2.90 N/mm^2 at 7days and 28days respectively. The result shows that split tensile strength of concrete increases as curing ages increases. The control concrete has high strength as compared to other percentage cement replacement level at 7days and 28days curing age. At later stages of curing 5%, 10% and 15% present higher strength as compared to the control concrete. It is observed that replacement of cement with metakaolin, up to 15%, shows better split tensile strength than control concrete at later stages in $MgSO_4$ aggressive environment. 10% metakaolin in concrete was most inclusive to get maximum split tensile strength of concrete having 0.50 water to cement ratio.

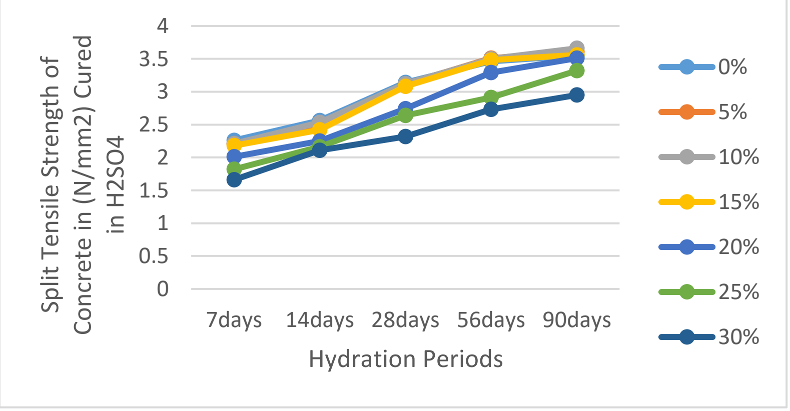

Figure 7: Split Tensile **S**trength of MTK Concrete Cured in H_2SO_4

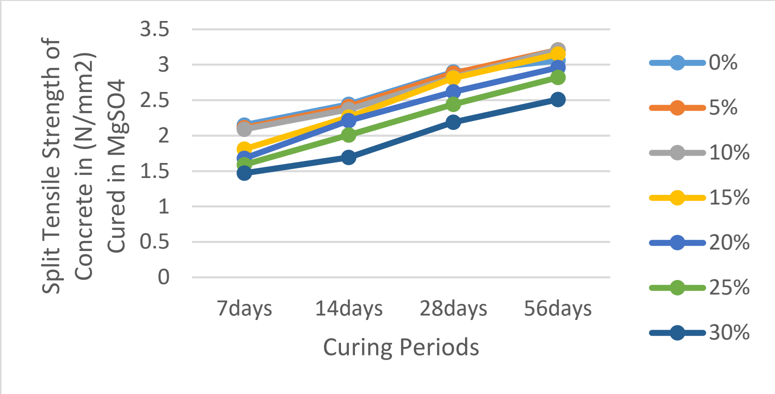

Figure 8: Split Tensile Strength of MTK Concrete Cured in $MgSO_4$

Water Absorption Test of Metakaolin-Concrete

Figure 9, presents the water absorption test of metakaolin concrete specimens cured and tested at 28, 56 and 90 days of curing. The level of absorption of concrete samples reduced with increase in curing days. At 28 days, 0% control concrete have same value with 15% cement replacement level with metakaolin absorbing 2.29% but absorbed more curing agent than 5% and 10% replacement of cement which have 2.26% and 2.23% respectively, while other cement replacement level of 15%, 20%, 25% and 30% absorbs more curing agent than the control concrete. At 56 days, control concrete absorbed more curing agents of 2.02% than 5% and 10% cement replacement with metakaolin which both absorbed 2.01%, while other cement replacement level absorbed more curing agent. At 90 days, 5% and 10% cement replacement have reduced level of absorption as compared to the control concrete. This means that 5% and 10% replacement absorbed less amount of curing agent than 0% control concrete. The degree of water absorption of concrete produced in this study tally with the findings of Pitroda and Shah (2014) which stated that the average absorption of the concrete specimens shall not be greater than 5%. However, all cement replacement level and control concrete cured in water gave water absorption level less than 5%. Water absorption is the crucial measure of water penetration through concrete pores (Bao, *et al.*, 2020; Zhang & Zong, 2014; Wang & Ueda, 2011; Castro, *et al.*, 2011; Liu, *et al.*, 2011), which can show the existence of pores in the concrete matrix that allow penetration of water and other hazardous chemicals and hence, can cause concrete durability issues.

Figure 10, shows the water absorption test of metakaolin concrete specimens cured in H_2SO_4 and tested at 28, 56 and 90 curing days. The level of absorption of concrete samples reduced was curing days increases. 0% control concrete absorbed 2.33% curing agent and have higher value for absorption than 5% and 10% replacement of cement with metakaolin with each absorbing 2.31% and 2.32% respectively, at 28days, while other cement replacement level of 15%, 20%, 25% and 30% absorbs more curing agent than the control concrete. At 56 days, concrete samples with 0% replacement have 2.12% absorption rate and absorbed more curing agents than 5% and 10% cement replacement with metakaolin which absorbed 2.06% and 2.05% respectively, while other cement replacement level have higher absorption rate. At 90 days, 5% and 10% cement replacement absorbed less curing agent than the control and all other cement replacement level. Replacement of cement up-to 10% with metakaolin in concrete, present better absorption capacity than the control specimen. The degree of absorption of concrete tally with the findings of Pitroda and Shah (2014) which stated that the average absorption of the concrete specimens shall not be greater than 5%. However, all cement replacement level and control concrete gave water absorption level less than 5% in H_2SO_4 medium. Metakaolin as cement replacement up-to 10% in concrete perform better than control concrete in H_2SO_4 curing medium. The use of natural pozzolana in cement composite enhances the densification of cement slurries that protects the penetration of water (Bechar & Zerrouki, 2018; Zeyad, *et al.*, 2022). The reduction of water absorption is very crucial for the improvement of the durability of concrete especially in construction work where there is contact with water like dams, bridges, culverts and aggressive environment like harmful chemical in soils.

Figure 11, presents the water absorption test of metakaolin concrete specimens cured in $MgSO_4$ and tested at 28, 56 and 90 days of curing. The water absorption of concrete samples reduced with increase in curing days. 0% replacement concrete have same value with 15% cement replacement with metakaolin absorbing 2.42% but absorbed more curing agent than 5% and 10% replacement of cement with metakaolin, which both absorbed 2.38% at 28days respectively, while other cement replacement level of 20%, 25% and 30% absorbs more curing agent than the control concrete. At 56 days, control concrete samples have 2.26% absorption rate and absorbed more curing agents than 5%, 10% and 15% cement replacement with metakaolin which absorbed 2.22%, 2.22% and 2.24% respectively, while other cement replacement level of 20%, 25% and 30% absorbed more curing agent. At 90 days of curing, 5% and 10% cement replacement level absorbed less curing agent compared to control concrete and other cement replacement level. This means that 5% and 10% replacement absorbed less amount of curing agent than 0% the control concrete. The degree of absorption of concrete tested in this study tally with the findings of Pitroda and Shah (2014) which stated that the average absorption of the concrete test specimens shall not be greater than 5%. However, all cement replacement level and control concrete gave water absorption level less than 5% in $MgSO_4$ curing medium. Metakaolin as cement replacement up-to 10% in concrete perform better than control concrete in $MgSO_4$ curing medium. The addition of natural pozzolana decreases water absorption in concrete (Chakkamalayath, *et al.*, 2020; Samimi, *et al.*, 2017; Mohseni, *et al.*, 2017), which is as a result of pozzolana having a finer particle than cement which can make concrete denser, and this consequently, improve concrete microstructure and durability (Masood, *et al.*, 2020; Nagrockiene & Girskas, 2016; Ahmad, *et al.*, 2011).

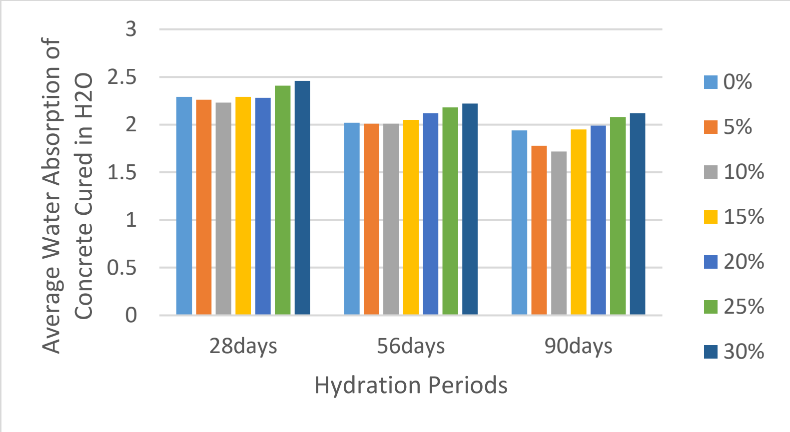

Figure 9: Water Absorption Test of MTK Concrete Cured in H_2O

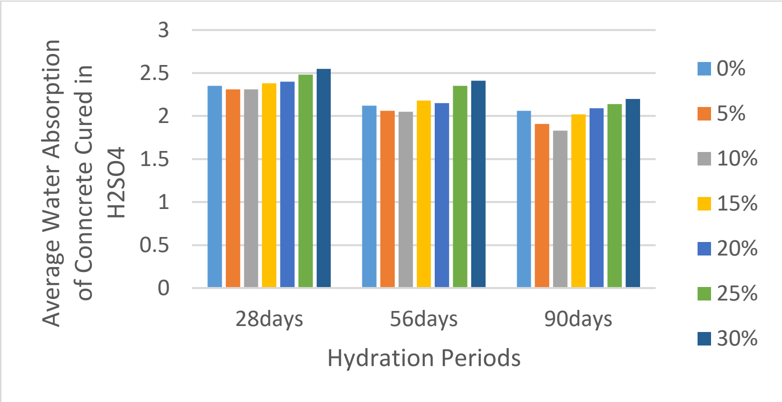

Figure 10: Water Absorption Test of MTK Concrete Cured in H_2SO_4

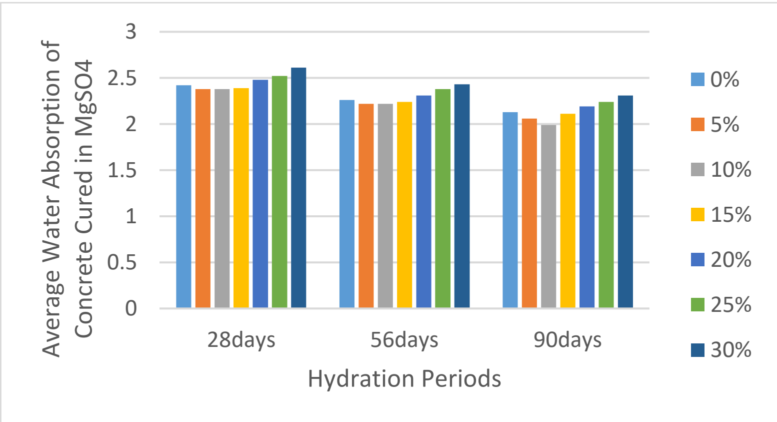

Figure 11: Water Absorption Test of MTK Concrete Cured in $MgSO_4$

Abrasion Resistance of Metakaolin Concrete

Figure 12, presents the abrasion resistance of concrete produced with metakaolin, cured in H_2O and tested at 28-, 56- and 90-days curing periods. At 28 days curing period concrete sample with 0%, 5%, 10% cement replacement has same loss in weight of 0.08%, while other replacement level has higher loss of weight. At 56 days curing period, concrete samples with 0%, 5%, 10% and 15% replacement has same loss in weight of 0.04%, lower than at 20%, 25% and 30% cement replacement having 0.12%, 0.12% and 0.13% respectively. At 90 days curing period, concrete samples with 0%, 5%, 10% and 15% replacement has same loss in weight of 0.04%, lower than at 20%, 25% and 30% cement replacement having 0.08%, 0.08% and 0.12% respectively. This means that 0%, 5% 10%, and 15% replacement were more resistant to abrasion and have lower weight loss percentage when subjected to water curing medium. Metakaolin as replacement of cement in concrete aid in reducing the wearing of concrete. The blinding of natural pozzolana in a concrete can increase durability of concrete specimen (Aravindhraj, & Sapna, 2016; Masood, *et al.*, 2020; Lee, *et al.*, 2021; Andrade, *et al.*, 2021). Figure 13, shows the abrasion resistance of concrete produced with metakaolin, tested at 28, 56 and 90 days and cured in H_2SO_4. At 28 days curing period concrete sample with 5%, 10% has same loss in weight of 0.12%, and have less loss in weight as compared to the control concrete which have 0.13% loss in weight. At 56 days curing period, concrete samples with 0% and 20% replacement have same loss in weight of 0.11%, higher than at 5%, 10% and 15% cement replacement having 0.08%, 0.08% and 0.09% respectively. At 90 days curing period, concrete samples with 0% and 15% have same loss of weight of 0.08%, which is higher than 5% and 10%, with 0.04% loss of weight respectively, while other cement replacement level of 20%, 25% and 30% has weight loss of 0.09%, 0.11% and 0.13% respectively. This means that 5% and 10% replacement were more resistant to abrasion and have lower weight loss percentage than 0% replacement when subjected to hydrogen sulphate curing medium. Metakaolin as replacement of cement in concrete aid in reducing the wearing of concrete in acid medium, this is due to metakaolin having finer particles than that of cement which can make concrete denser, consequently, improve concrete durability and microstructure. The micro-filling ability of metakaolin due smaller particle size in the concrete matrix aid in more densification of the concrete and improved microstructure which consequently enhance the durability of concrete and also increase abrasion resistant effect of concrete.

Figure 14, presents the abrasion resistance of concrete produced with metakaolin, tested at 28, 56 and 90 days and cured in $MgSO_4$. At 28 days curing period, concrete sample with 0%, 5%, 10% and 15% has same loss in weight of 0.16%, while cement replacement levels of 20%, 25% and 30% has higher loss in weight. At 56 days curing period, concrete samples with 0% and 15% replacement have same loss in weight of 0.13%, but higher than that of 5% and 10% cement replacement with both having 0.11%, while other cement replacement levels of 20%, 25% and 30% has higher loss in weight. At 90 days curing period, concrete samples with 0%, 20% and 25% replacement has same loss in weight of 0.11%, but higher than that of 5% and 10% cement replacement all having 0.08%, 15% cement replacement level has 0.09%, while 30% cement replacement level has higher loss in weight of 0.13%. This means that 5% and 10% replacement were more resistant to abrasion than 0% replacement when subjected to magnesium sulphate curing medium. Metakaolin as replacement of cement in concrete aid in reducing the wearing of concrete in $MgSO_4$ medium. Loss in weight for the concrete samples cured in $MgSO_4$ were higher than those cured in water (H_2O) and in H_2SO_4. $MgSO_4$ solution has high deteriorating effect on concrete product.

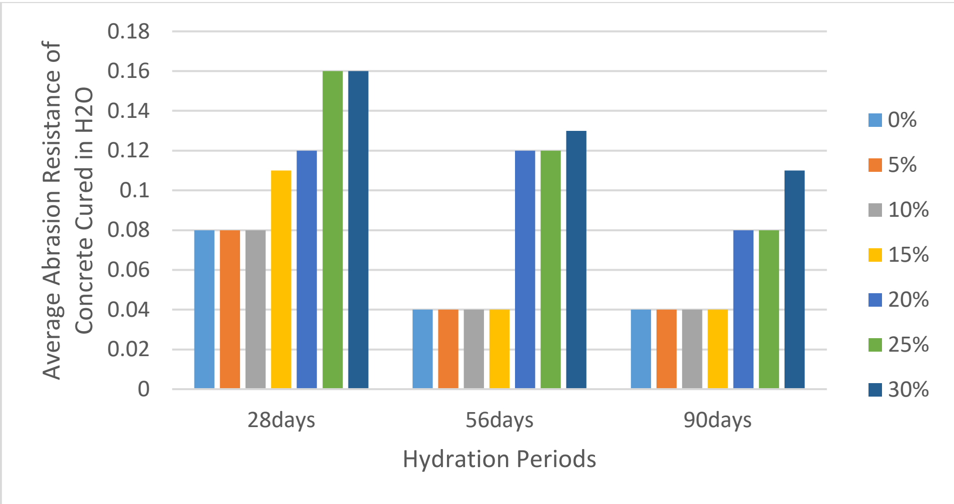

Figure 12: Abrasion Resistance Test of MTK Concrete Cured in H_2O

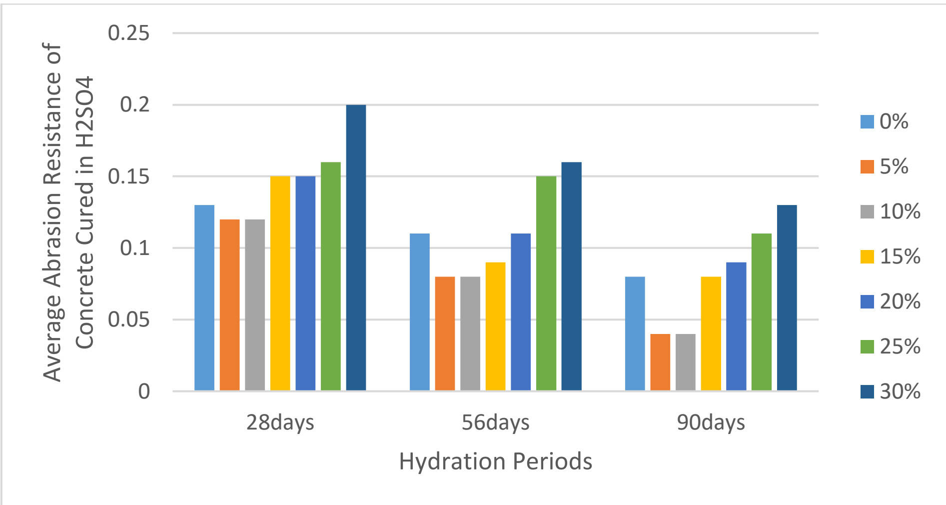

Figure 13: Abrasion Resistance Test of MTK Concrete Cured in H_2SO_4

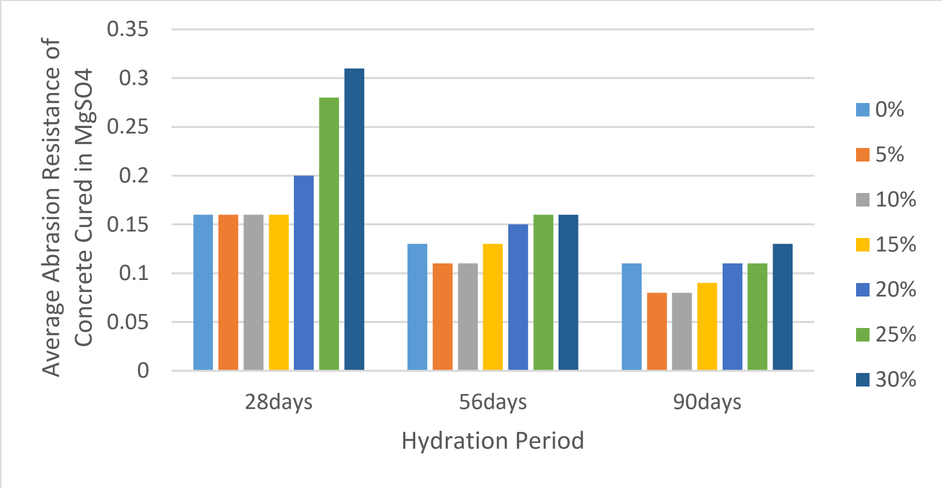

Figure 14: Abrasion Resistance Test of MTK Concrete Cured in $MgSO_4$

CONCLUSION

Density of concrete is increased with an increase in curing period. There was more loss of density in control concrete samples than in 5% and 10% metakaolin concrete samples at higher curing period, in chemical aggressive medium. The maximum compressive strength at 7 days and 28 days was the control concrete. It was observed up-to 10% replacement of cement with metakaolin there was increase in the strength of concrete at later stages of 56 and 90 days. Compressive strength of concrete increase at higher curing ages and metakaolin as cement replacement up-to 10% withstand chemical environment better and gave higher strength than the control concrete in both curing media of $MgSO_4$ and H_2SO_4. Split tensile strength of concrete produced with metakaolin up-to 10% as cement replacement improved significantly. The addition of metakaolin in concrete significantly reduces water absorption, by blocking capillary voids and making denser concrete microstructure, which is mainly through the pozzolanic reaction of metakaolin and cement. The decreased water absorption capacity of metakaolin concrete shows that concrete produced with metakaolin will be more durable than normal concrete when subjected to chemical aggressive environment. Concrete samples made with pozzolanic material up-to 10% have high resistance to abrasion and less absorption in chemical environment. Metakaolin concrete reduces the porosity of concrete, that is mainly due to the pozzolanas micro-filling ability and active reactivity with portlandite to form C–S–H. Hence, C–S–H potentially aid in improving the strength and durability of concrete. Replacement of cement up-to 20% by metakaolin has reduced compressive strength range only marginally, and therefore it still has potential for applications in flexible and rigid pavements and mass concrete. The metakaolin replaces cement up to 30% on the basis of the weight of cement in this experiment. The results indicate a potential use of metakaolin in concrete production for structural and non-structural building material. Despite a decline in the strength of concrete with the addition of metakaolin at higher percentage, the loss of concrete compressive strength by adding 30% MTK is only about 30-40% in aggressive medium. The addition of 30% MTK yields acceptable strength of concrete for non-structural purposes. Generally, metakaolin as cement replacement up-to 20% is beneficial through improving durability, physical, and mechanical, properties of concrete in addition to protecting the environment from pollution compared to conventional concrete.

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