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Effects of Metakaolin as a Pozzolanic Material on Chloride Ingress in Concrete

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Abstract

The use of supplementary cementitious materials as cement partial replacement has emerged as a successful strategy in producing green, less energy-intensive and environmentally friendly concrete. This study investigates the effects of metakaolin as a pozzolanic material on chloride ingress in concrete. Cement was partially replaced with metakaolin at 5, 10, 15 and 20%, using a mix ratio of 1:2:4 and a water-cement ratio of 0.5. Density, Compressive strength, flexural strength, water absorption and abrasion resistance tests were carried out. Metakaolin is a filler material in concrete and improves concrete's strength and functional performance. The maximum compressive strength at 28 days was the control, which achieved 28.9, 27.6 and 26.6 N/mm^2; and that of flexural strength achieved 4.37, 4.22 and 3.97 N/mm^2 for concrete cured in H_2O, NaCl and HCl medium respectively. At later stages of 56 and 90 days, concrete produced with metakaolin at 5 and 10% cement replacement gave better strength. The findings show that metakaolin improves concrete's water absorption and abrasion resistance. Chloride significantly affects the performance of concrete. HCl is more deleterious to concrete than NaCl. In conclusion, metakaolin is suitable as a pozzolan in the production of concrete; its usage at a lower volume of cement replacement will help reduce cement utilization in concrete production, thereby reducing the global warming contributed by the exploration and production of cement. 10% Metakaolin (MTK) is the optimum percentage in concrete which is recommended to produce strong, dense, and durable concrete.

1.0. Introduction

Reinforced concrete structures like buildings, bridges, and aqueducts are susceptible to deterioration when exposed to aggressive environments, which affects their durability due to chloride permeability. The extent of this exposure often determines the structure's serviceability and safety [1]. An environment is classified as aggressive when it contains harmful substances like chemicals or other conditions that degrade concrete and its reinforcements. Pollution from air, water, and soil intensify this issue by increasing the concentration of damaging chemicals such as acids, bases, and salts. This reduces the concrete's durability, and can result in premature deterioration or failure [2]. Concrete, a porous material, allows ions to diffuse through its pore solution to balance concentration differences, including chloride ions at the surface, leading to chloride ingress [3] [4]. Corrosion is one of the predominant deteriorations in reinforced concrete caused by the formation of expansive products and crystallization of salt in concrete pores as a result of chloride ingression [5], which reduces the cross-sectional area of steel bars, thereby decreasing the load-carrying capacity of structures [6]. The presence of portlandite, Ca $(OH)_2$, in concrete prevents the corrosion of steel reinforcement by forming a thin passive protective film of iron oxide on the surface of the reinforcement [7]. However, due to the porous nature of concrete, the presence of water and oxygen can accelerate the corrosion rate when exposed to critical chloride concentrations. Chloride ions penetrate the surface layer of the steel reinforcement and break down the passive protective film, a process known as de-passivation, once the chloride concentration exceeds a critical threshold value [5] [8]. This increases the electrical conductivity of the concrete, reduces its alkalinity, and consequently leads to steel corrosion [3] [9] [10]. As corrosion occurs, the extension volume of the steel reinforcement can be as high as two to six times the original steel volume, which produces an increasing expansive pressure on the interfaces between concrete and reinforcements. Afterwards, tensile stress loss leads to surface cracking, delamination, spalling of concrete, a decrease of the transverse-sectional reinforcement area, and loss of the bond between the concrete and steel reinforcement [11] [12].

Chloride ingress serves as a threat to infrastructure in the construction industry, thereby facilitating a need for corrosion protection and maintenance methods for reinforced concrete (RC), especially in marine environments [13]. One widely adopted approach in the construction industry is the addition of supplementary cementitious materials (SCMs) or pozzolans into reinforced concrete to enhance the concrete's strength, durability, and resistance to biological deterioration, making them effective in reducing chloride ingress and protecting reinforcement from chloride attack [14]. Pozzolans can be defined as siliceous and aluminous material, although not cementitious, but in finely divided and in the presence of water, can react with Calcium hydroxide at room temperature to form compounds with cementitious properties, such as Calcium Silicate Hydrates (CSH) and Calcium Aluminate Hydrate (CAH) [15]. This reaction increases the pH, and due to their fine particle size, provides a protective layer that fills pores and refines the microstructure internally and reduces concrete permeability, thereby increasing the durability of structures exposed to saline and aggressive environments [5] [14]. To achieve this, cement can be partially replaced with supplementary cementitious materials (SCMs) such as fly ash, Metakaolin, rice husk ash, silica fume, waste glass, volcanic ash and blast furnace slag [9] [16] [17] [18] [19] [20] [21] [22]. These materials contain high silica content contributing to their pozzolanic activity and characteristics that determine the degree of reactivity in pozzolans [15] [23]. This method improves the longevity and strength of structures exposed to saline environments while promoting environmental and economic benefits by minimizing carbon emissions during construction [24] [25] [15].

However, Nigeria faces a shortage of these materials in commercial quantities due to the absence of coal-fired power and steel plants. Nevertheless, Nigeria possesses abundant reserves of kaolin clay [$Al_2Si_2(OH)_4$] across numerous regions [19]. According to data from the Raw Materials Research and Development Council (RMRDC), an estimated reserve of 3 billion metric tons of high-quality kaolinite clay is available in various Nigerian localities [20] [21]. This Kaolin clay can be processed into Metakaolin, a highly reactive pozzolanic material, by calcining kaolin at high temperatures (600-850 °C) for about one hour to twelve hours [26]. The calcination of kaolin clay transforms it into Metakaolin ($Al_2Si_2O_5$ or AS_2), resulting in the elimination of water ions present in the kaolinite clay and the formation of alumina (40% - 45%) and amorphous silica (50% - 55%), the two primary chemical components present in pozzolans [27]. Concrete containing Metakaolin can improve the resistance to chloride ingress and freeze-thaw damage compared to concrete without SCMs [28]. This research, therefore, assesses the effect of Metakaolin as a pozzolanic material on the chloride ingress of concrete.

2. Materials and Methods
2.1 Materials
The materials for this research include coarse aggregate, fine aggregate, Cement, Metakaolin, Sodium chloride (NaCl), Hydrochloric acid (HCl) and water. Potable water was used to mix and produce concrete specimens. Portland cement (PC) of grade 42.5N was used for the purpose of this research. The coarse aggregate of 12mm size gotten from quarry site in Oluku, Benin City, Edo State. River sand from Oluku, Benin City that was in saturated surface dry condition which passes through 5mm sieve size was used for the production of concrete. The Kaolin clay used for this research was sourced from Ikpeshi community in Akoko-Edo Local Government Area of Edo State.

2.1.1 Curing Media
The concrete samples were cured by completely immersing them into three different curing media: water (H_2O), NaCl, and HCl. A 2.5% concentration of NaCl and HCl, each with 50 litres of water, was used. This means that, for every 50000g of clean water, 1250g of chemical was used as a 2.5% concentration. The 1250g of chemical and 50000g of water were poured into a 100-litre capacity bowl. A 100-litre capacity bowl allowed specimens to be placed and appropriately cured without overflow.

2.2 Methods
The study used a water-cement ratio of 0.5 and a 1:2:4 mix proportions. Beam specimens (100 ×100 × 500 mm) were used for flexural strength and tested for 28, 56 and 90 days, while 100 x 100 x 100 mm cube specimens were used for density, compressive strength, water absorption and abrasion test. Compressive strength tests were carried out for 7, 14, 28, 56, and 90 days, while abrasion resistance and water absorption were tested for 28, 56, and 90 days. The percentage of metakaolin varies from 0 to 20 % with an increment of 5% used in the concrete as supported by [29] [30] [31]. Table 1 depicts the standard test methods followed for carrying out various experimental program.

Table 1: Test Method Adopted in the Experimental Program

Test Description	Specification
Specific Gravity	BS EN 1097-6 [32]
Setting Time and Consistency	BS EN 196-3 [33]
Slump Test	BS EN 12350-2 [34]
Density	BS EN 12390-7 [35]
Compressive Strength	BS EN 12390-3 [36]
Flexural Strength	BS EN 12390-6 [37]
Water Absorption	BS EN 13755 [38]
Abrasion Resistance	BS EN 1338 [39]

3. Results and Discussion
3.1 Specific Gravity of Materials
Table 2 shows the specific gravity of materials. Fine aggregate was determined to be 2.65 which falls within the specified range of 2.4 to 2.9 specified by [32] for specific gravities of fine aggregate. Coarse aggregate was determined to be 2.74; the result falls within the specified range of the specific gravity of rocks used as aggregate, which ranges between 2.6 and 2.8 [32]. The specific gravity of Metakaolin (MTK) was determined to be 2.44; this value is close to the work done by [40], who reported a value of 2.50, and that of [23], who reported a value of 2.46. The result determined in this research is consistent with previous research.

Table 2: Specific Gravity of the Materials

Materials	Specific Gravity
Fine Aggregate	2.65
Coarse Aggregate	2.74
Metakaolin	2.44

3.2 Chemical Composition of Metakaolin

The chemical composition of metakaolin used for this research indicated that the silica, alumina and iron contents sum up to 96.02% as presented in Table 3, and satisfies requirement by [41] which state that for a material to be a pozzolan the summation of Aluminum Oxide (Al_2O_3), Silicon Oxide (SiO_2) and Iron Oxide (Fe_2O_3) must be 70.0 % minimum. This means that metakaolin satisfies the chemical requirement for N-class pozzolana. The result is also close to the findings of [42] and [43], who achieved 91.15% and 96.88% respectively. [44] stated that the oxide content of SiO_2 and K_2O can lower the heat evolution in concrete.

Table 3: Chemical Composition of Metakaolin

Elements	% Composition
Aluminum Oxide (Al_2O_3)	42.86
Silicon Oxide (SiO_2)	51.92
Iron Oxide (Fe_2O_3)	1.24
Potassium Oxide (K_2O)	0.31
Calcium Oxide (CaO)	0.11
Sodium Oxide (Na_2O)	0.17
Magnesium Oxide (MgO)	0.14
Vanadium Oxide (V_2O_5)	0.002
Manganese Oxide (MnO)	0.08
Titanium oxide (TiO_2)	0.15
Loss of Ignition	2.36

3.3 Setting Time Test

Figure 1 and 2 present the setting time and consistency tests for Portland cement (0% replacement) and percentage replacement of Portland cement with Metakaolin (5, 10, 15 and 20%). This aligns with findings from [33] [45] and conform to the result by [46], showing that cement replacement with MTK takes longer time to set compared to 0% replacement. [47] reported that the delay in both initial and final setting times can be attributed to the negative surface charge of MTK which attract and bind the released calcium ions needed for early hydration reactions in the paste leading to reduced availability of these ions for the formation of calcium silicate hydrate (CSH), thereby slowing down the hydration rate.

3.4 Workability Test

Figure 3 below shows the workability test (slump) for concrete produced with PC/MTK at 0, 5, 10, 15 and 20%. The result shows that the slump value decreases with an increase in MTK. According to [48], the values of the five different mixes indicate that the degree of workability ranges from medium to low. The slump value decreases as the percentage of cement replaced with MTK increases. [49] recorded that the slump decrease could be attributed to the fine particle size of MTK that increase the surface area of the cementitious materials within the concrete mix, leading to higher water demand. This increased surface area allows more water to be absorbed by the concrete resulting in reduced concrete slump.

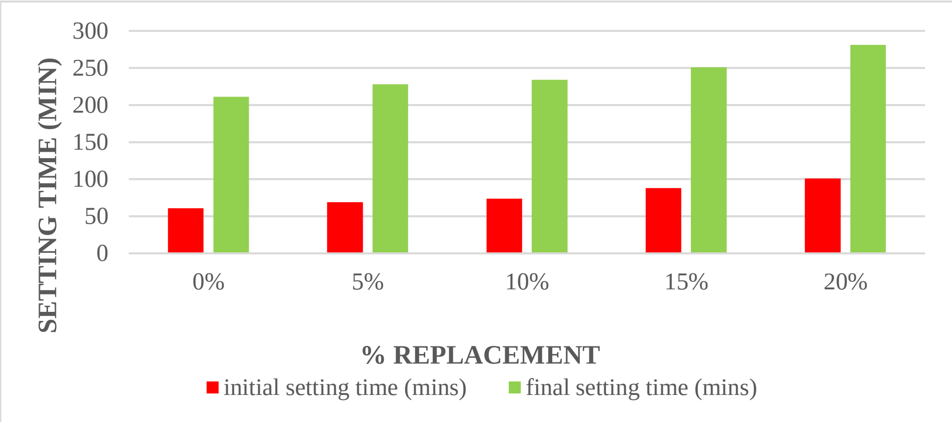

Figure 1: Initial and final setting time of PC/MTK

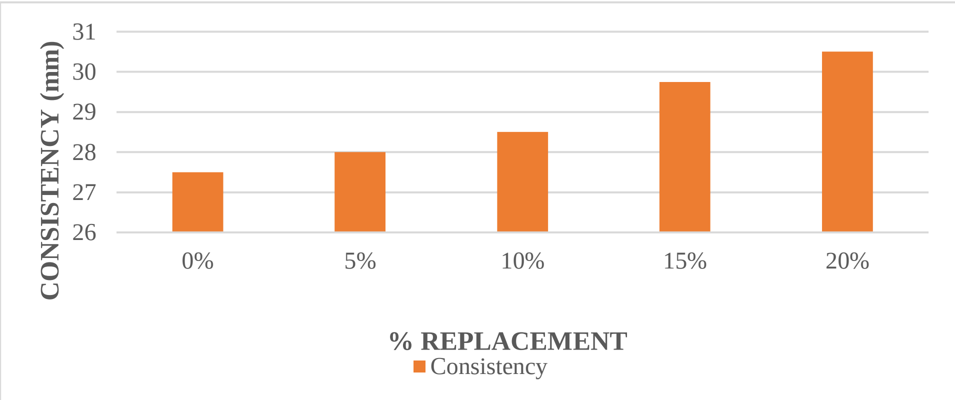

Figure 2: Consistency Test of PC/MTK

3.5 Density of Concrete

Figures 4, 5, and 6, shows the results of the density test carried out on concrete produced with PC/MTK at 0, 5, 10, 15 and 20%. Concrete cubes with 0% replacement initially exhibit higher density at 28 days of curing. Beyond 28 days, concrete with MTK tends to show increased density which may be due to the formation of dense and compact structure of concrete by the additional hydration products from the pozzolanic reaction of metakaolin.

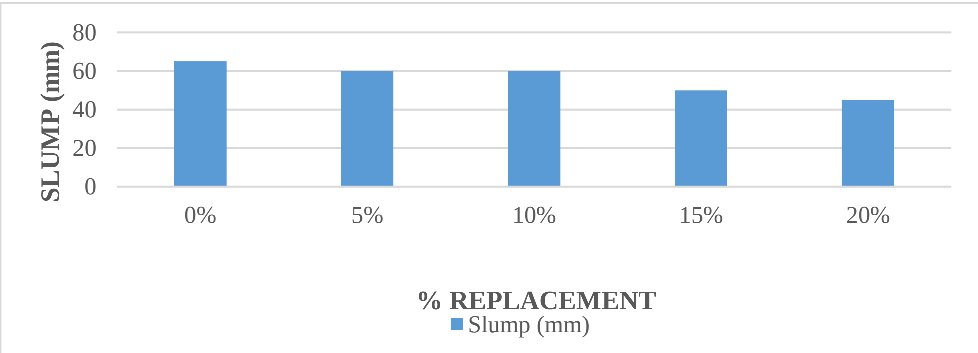

Figure 3: Workability test of concrete produced with PC/MTK

The filler effect of finer particles of metakaolin also contribute to the enhancement in density values by reducing the pore structure of concrete mixes [50] [51]. Figure 4 shows the density test results for PC/MTK concrete samples cured in water (H_2O) and weighed at 7, 14, 28, 56 and 90 days. The density of concrete samples ranges from 2420 kg/m^3 to 2565 kg/m^3 increasing with longer curing periods. Concrete with 0% MTK shows higher density compared to other percentage replacement, while beyond 28 days, 5% and 10% MTK concrete samples show increased density. Concrete samples with a density higher than 2600kg/m^2 are called higher density concrete samples [24]. The values obtained exceeded the 2400 kg/m^3 expected at 28 days' hydration period for a normal-weight concrete.

Figures 5 shows the density test results for PC/MTK concrete samples cured in sodium chloride ($NaCl$) medium and weighed at 7, 14, 28, 56 and 90 days. The density of concrete cube varies from 2410 kg/m^3 to 2525 kg/m^3, and it increase with curing period. Concrete with 0% MTK shows higher density period up to 28 days, while beyond 28 days, the 5% and 10% MTK replacement samples exhibit higher densities. The density values obtained exceeded the 2400 kg/m^3 at 28 days' hydration period for a normal-weight concrete.
Figure 6 presents the result of PC/MTK concrete samples cured in hydrochloric acid (HCl) medium and weighed at 7, 14, 28, 56 and 90 days. The density of concrete cube samples varies from 2405 kg/m^3 to 2480 kg/m^3, which increase with increase in curing period. Concrete with 0% MTK shows higher density at an early age, but as the curing days' increase, concrete with 10% MTK shows the highest density in the acid medium. The density of concrete increases with longer curing periods, and concrete samples with densities higher than 2400kg/m^2 at 28 days are classified as normal-weight concrete [52].

3.6 Compressive Strength of Concrete
Figure 7 shows the compressive strength of concrete with PC/MTK at 0, 5, 10, 15 and 20%, cured in H_2O and tested at 7, 14, 28, 56 and 90 days. It was observed that compressive strength increased with increase in curing period for all concrete specimens, and strength decreased with an increase in the proportion of supplementary cementitious materials. The highest compressive strength at 28 days was observed with the control concrete with 28.9 N/mm^2. At 90 days, 5% and 10% metakaolin in concrete as cement replacement gave improved strength of 30.8 N/mm^2 and 31.4 N/mm^2 respectively, beyond control concrete with 30.6 N/mm^2. Control concrete gave better strength at an early age up to 28 days, however, at later stages of curing beyond 28 days, concrete containing MTK at 5% and 10% gave improved strength index beyond the control. This increase in strength may be attributed to the presence of pozzolanic materials in the concrete mix, as demonstrated by [53] [54]. The result also aligns with the findings of [52] [55], who noted that although aggressive environments affect the strength properties of concrete, the C-S-H formation in pozzolanic concrete at later stages helps develop strength and reduce damage in chemical environments. The observed strength improvement results from the formation of additional C-S-H gel as a result of the pozzolanic reaction between MTK and CaOH [56] [57] [58]. Notably, 20% MTK has the least strength, which is likely due to insufficient moisture in the environment hindering the continued concrete hydration process.

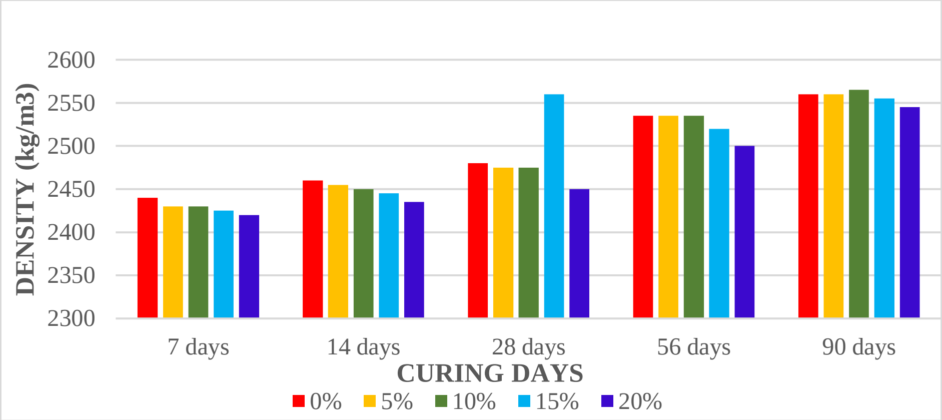

Figure 4: Density of Concrete Cured in Water

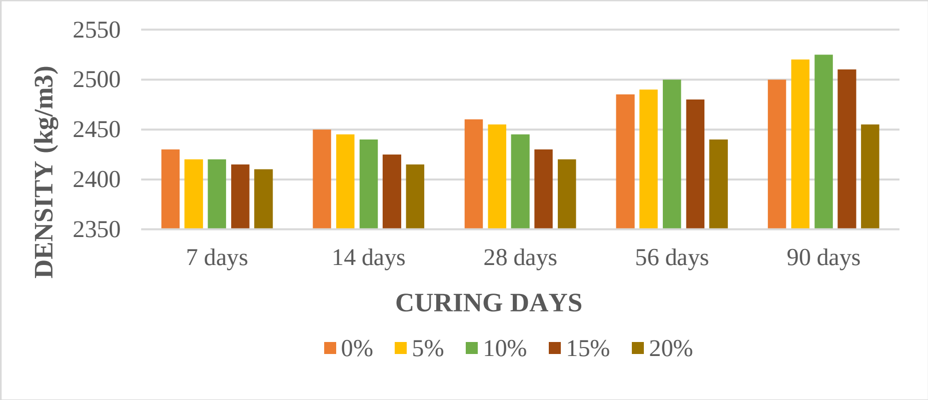

Figure 5: Density of Concrete Cured in NaCl

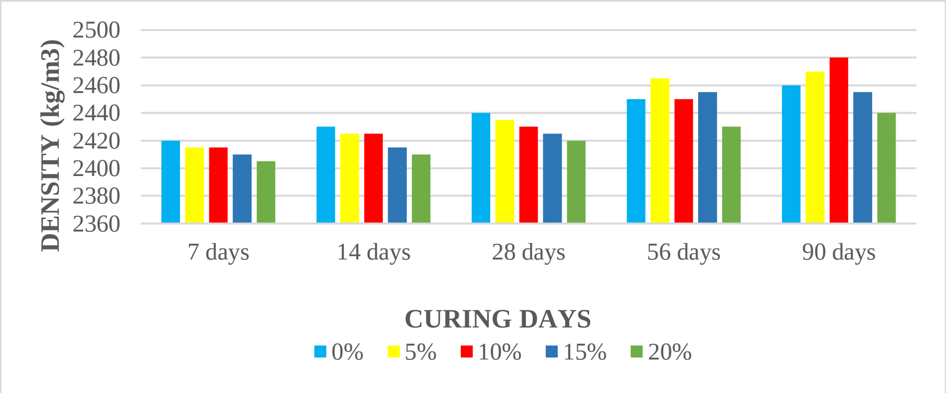

Figure 6: Density of concrete Cured in HCl

Figure 8 shows the compressive strength of PC/MTK concrete samples cured in NaCl, which increases with an increase in curing period. The highest compressive strength at 28 days was observed with the control concrete with 27.6 N/mm^2. At 90 days, 5% and 10% metakaolin in concrete as cement replacement gave improved strength of 29.1 N/mm^2 and 29.6 N/mm^2 respectively, beyond control concrete with 28.5 N/mm^2. This result aligns with the findings of [52]

[55], who noted that although aggressive environments affect the strength properties of concrete, the C-S-H formation in pozzolanic concrete at later stages helps develop strength and reduce damage in chemical environments.

Figure 9 shows the compressive strength of PC/MTK concrete cured in HCl, which also increases with the curing period. The highest compressive strength at 28 days was observed with the control concrete with 26.6 N/mm^2. At 90 days, 5% and 10% metakaolin in concrete as cement replacement gave improved strength of 27.8 N/mm^2 and 28.8 N/mm^2 respectively, beyond control concrete with 27.6 N/mm^2. Metakaolin concrete exhibits reduced strength in chemical environments compared to specimens cured in water [59] [60]. As noted in [61], although aggressive environments affect concrete strength development, the increased strength of Metakaolin concrete reduces the impact of strength loss in such environments. The faster reaction rate of pozzolanic blends accelerates the filling of pore spaces with hydration products and reduces chloride ion diffusivity, leading to higher strength development and limiting the entrainment of harmful chemicals in concrete [62] [63].

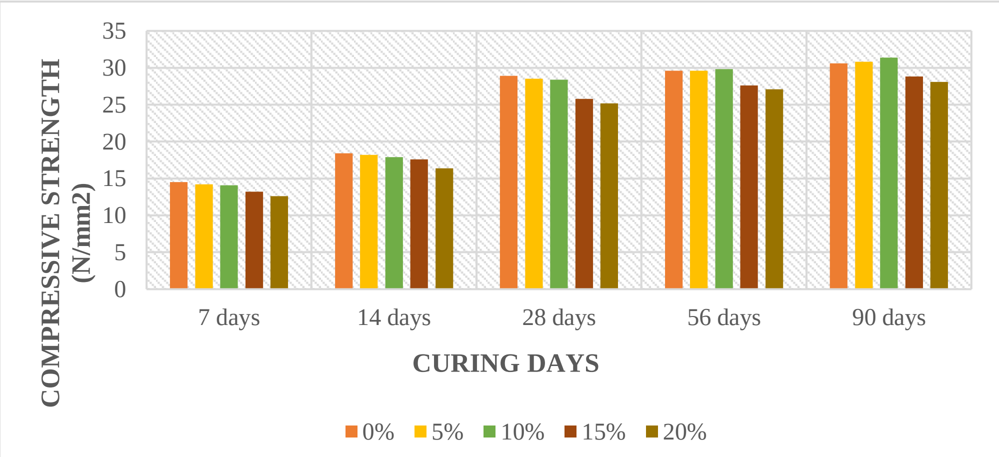

Figure 7: Compressive strength of concrete Cured in water

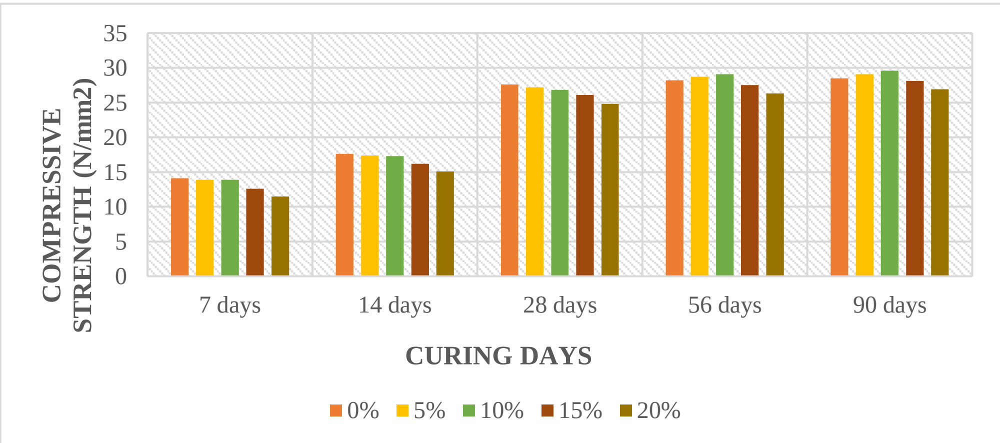

Figure 8: Compressive strength of concrete cured in NaCl

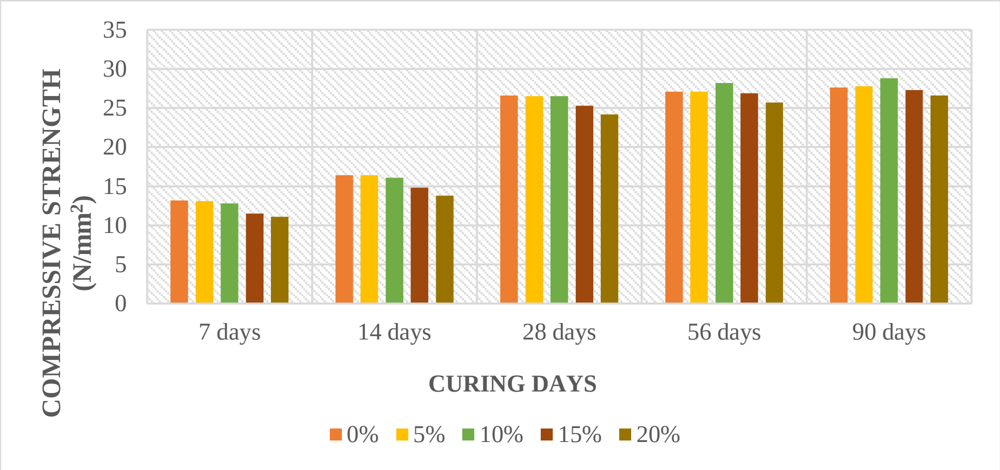

Figure 9: Compressive strength of concrete cured in HCl

3.7 Flexural Strength

Figure 10 shows the flexural strength of concrete produced with PC/MTK at 0%, 5%, 10%, 15% and 20%, cured in water (H_2O) and crushed at 28, 56 and 90 curing days. At 28 days, the results show that 0% MTK replacement achieved flexural strength of 4.37 N/mm^2 while 5% and 10% replacement attained 4.35 N/mm^2, respectively. At 90 days, 0% cement replacement with MTK achieved a flexural strength of 4.93 N/mm^2; 5% and 10% replacement attained 4.95 N/mm^2 and 4.97 N/mm^{2,} respectively. From the result of the findings, it shows that pozzolanic concrete has improved strength at later stages of curing, this is however related to the findings of [52] who stated that concrete with MTK replacement exhibit higher flexural strength at later curing stages. This can be attributed to the development of a refined pore structure and a denser, thinner interfacial transition zone (ITZ) between the binding phase and the aggregate. MTK enhances bonding between the concrete ITZ, resulting in a smaller proportion of weaker area which in turn enhances the flexural strength [64].

Figure 11 shows the flexural strength of concrete produced with PC/MTK cured in NaCl, and crushed at 28, 56 and 90 curing days. From the results, 0% replacement achieved flexural strength of 4.22 N/mm^2, while 5, 10, 15 and 20% replacement attained 4.17 N/mm^2, 4.15 N/mm^2, 3.93 N/mm^2 and 3.87 N/mm^2 respectively at 28 days. At 90 days, 0% MTK cement replacement achieved 4.59 N/mm^2, 5, 10, 15 and 20% replacement attained 4.67 N/mm^2, 4.70 N/mm^2, 4.45 N/mm^2, and 4.33 N/mm^{2,} respectively.

Figure 12 shows the flexural strength of concrete produced with MTK as cement partial replacement between 0 – 2-% at intervals of 5%, cured in HCl, and crushed at 28, 56 and 90 curing days. The result shows that 0% MTK replacement achieved flexural strength of 3.95 N/mm^2, 5, 10, 15 and 20% replacement attained 3.91 N/mm^2, 3.84 N/mm^2, 3.68 N/mm^2 and 3.61 N/mm^2 respectively at 28 days. At 90 days' the flexural strength for 0% MTK cement replacement achieved 4.43 N/mm^2, while 5, 10, 15 and 20% replacement attained 4.47 N/mm^2, 4.51 N/mm^2, 4.41 N/mm^2, and 4.22 N/mm^2 respectively.

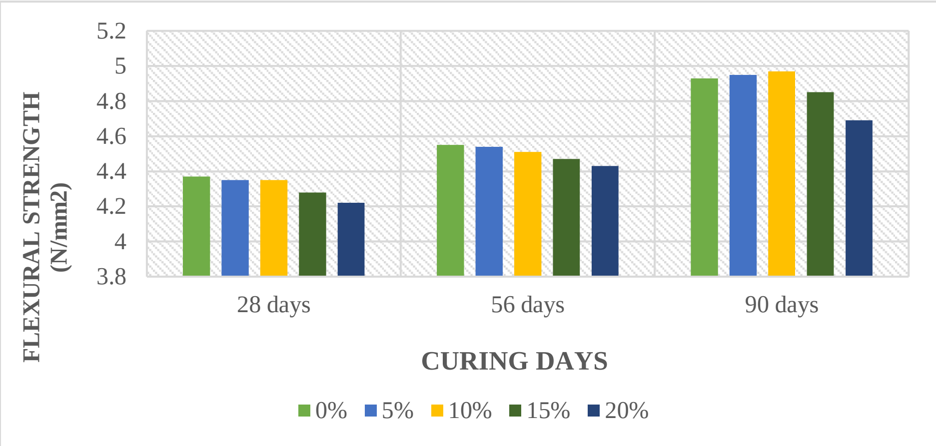

Figure 10: Flexural strength of concrete cured in water

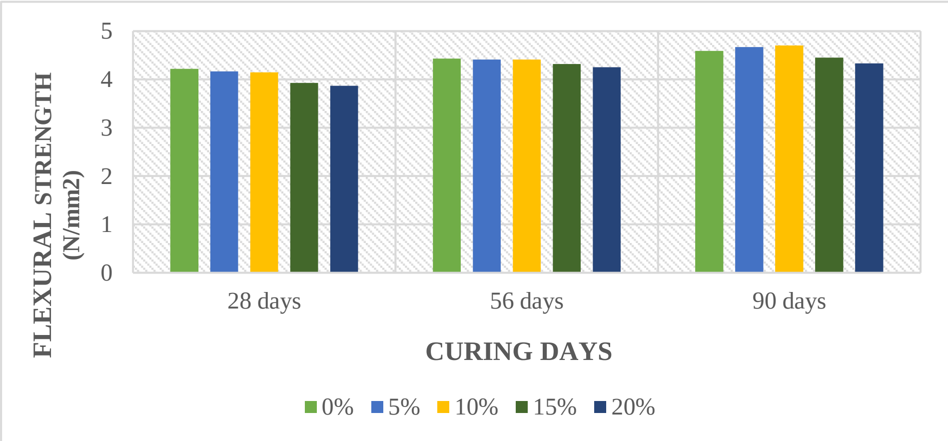

Figure 11: Flexural strength of concrete cured in NaCl

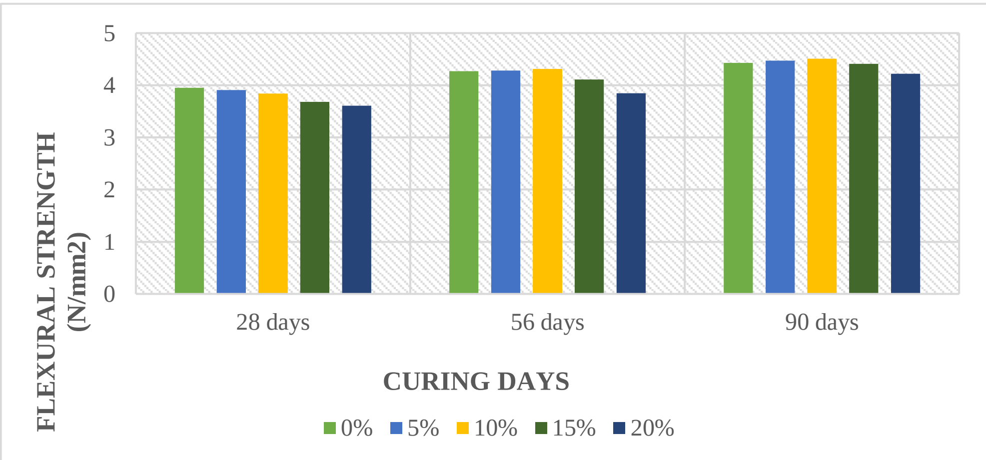

Figure 12: Flexural strength of concrete cured in NaCl

3.8 Water Absorption Test

Figures 13, 14 and 15 show the water absorption test results of concrete produced with Metakaolin at 0%, 5%, 10%, 15% and 20%, cured in water, NaCl and HCl and tested at 28, 56 and 90 days. The degree of absorption of concrete in the three-curing media satisfies the assertion made by [65], which states that the average absorption of the concrete specimens should not exceed 5%. The absorption level of concrete samples decreased with increasing curing age, with 0% replacement absorbing more curing agents than 5% and 10% replacements. This can be attributed to the pozzolanic reaction of MTK combined with filler effect resulting in reduced concrete porosity and sorption as curing continues [66]. Rate of water absorption is particularly important for concrete's durability [24], as it can predict the material's ability to resist chloride ingress and corrosion. Specimens with higher percentages of Metakaolin content absorbed more of their curing medium. However, concrete with a water absorption capacity of less than 10% is considered good [67].

In the water curing medium, as presented in figure 13, at 28 days, control concrete gave better reduction in absorption than other cement replacement level. The absorption level of concrete samples also decreased with increasing curing age. At 90 days, the 0% replacement absorbed 1.86% curing agent, while the 5% and 10% cement replacements absorbed 1.88% and 1.89%, respectively. As curing age increases the rate of absorption reduces in the concrete samples.

Concrete samples cured in NaCl, with 0% MTK replacement of cement at 28 days gave better reduction in absorption than other cement replacement level. At 90 days, control concrete absorbed 2.04%, while 5% and 10% replacement absorbed 1.97% and 1.99% respectively. This indicates that the 5% and 10% of replacements absorbed less curing agent than 0% of replacements at later stages of curing.

The level of absorption of concrete samples reduced with an increase in curing age. At 28 days control concrete gave better reduction in absorption than other cement replacement level. Concrete samples with 0% replacement absorbed 2.13%, while 5% and 10% replacement absorbed 2.11% and 2.10% at 90 days for concrete cured in HCl. HCl-cured concrete samples absorbed more curing agents than those in other curing mediums. HCl is more deleterious to concrete sample compared to NaCl and H_2O curing medium.

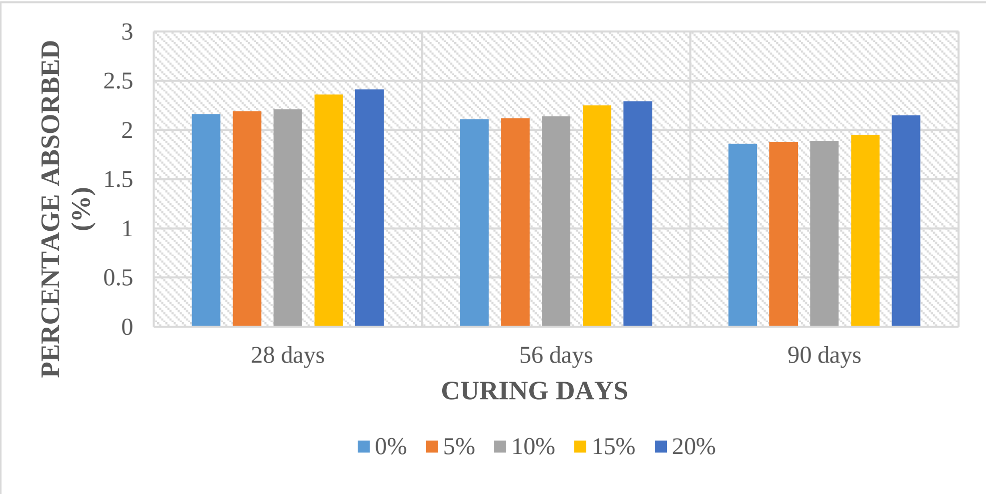

Figure 13: Average water absorption of concrete cured in water

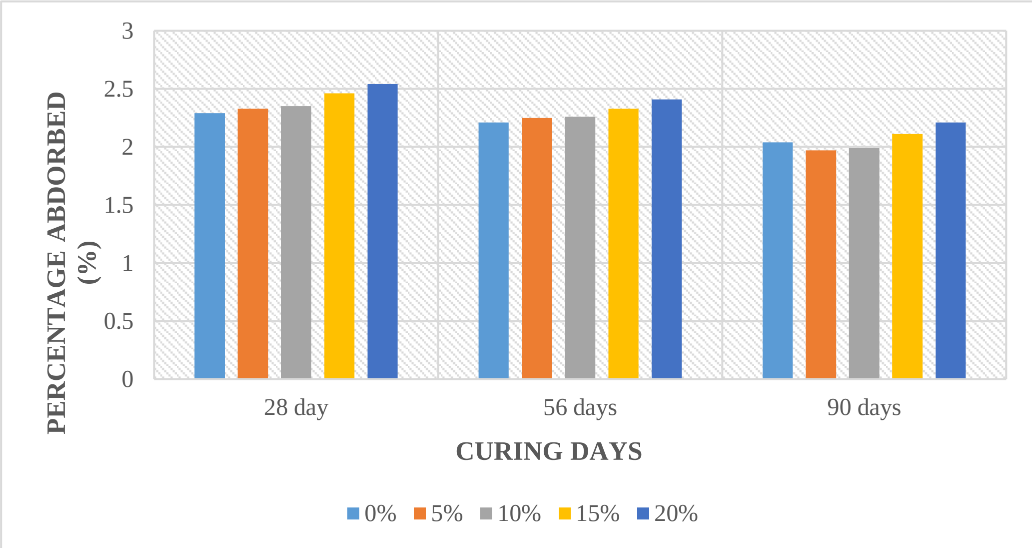

Figure 14: Average water absorption of concrete cured in NaCl

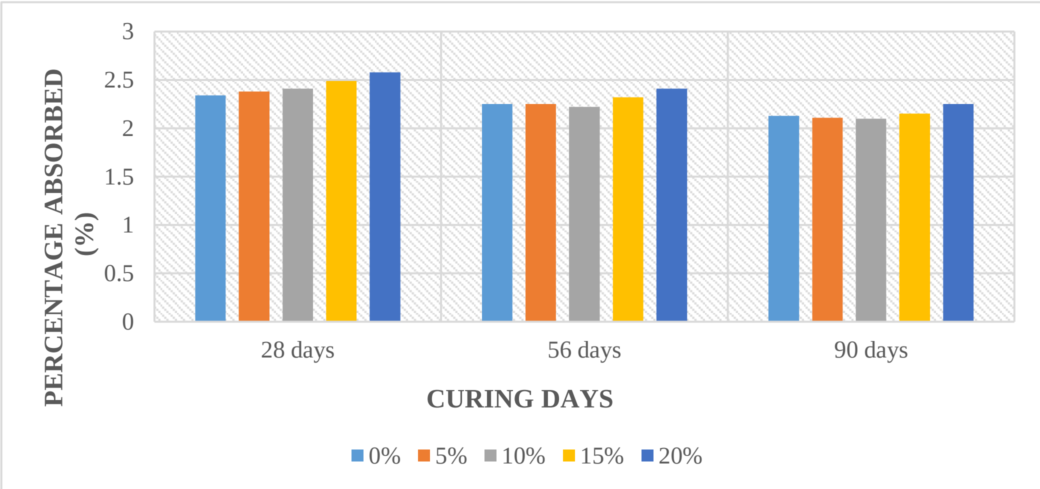

Figure 15: Average water absorption of concrete cured in NaCl

3.9 Abrasion Test

Figure 16 presents the abrasion resistance of concrete produced with Metakaolin as partial cement replacement at 0, 5, 10, 15 and 20%, cured in water (H_2O) and tested at 28, 56 and 90 days. At 28 days of curing 0% and 5% gave improved abrasion resistance than any other cement replacement level. There was an observed weight loss in the concrete samples at higher cement replacement levels. At 90 days, 0% replacement had the same weight loss of 0.04% with 5% and 10% cement replacement with metakaolin. Thus, the 5% and 10% MTK replacements resisted abrasion better, while higher percentage of replacements resulted in greater weight loss. This trend can be observed across all curing ages. Abrasion resistance is a vital durability property especially in structures subjected to wear or surfaces exposed to friction that could cause damage. The findings of this study align with earlier research [68] [69] [70], which indicates that pozzolanic concrete exhibits increased abrasion resistance which can primarily be attributed to the increase in compressive strength resulting from increased maturity of concrete due to pozzolanic reaction of MTK with increased curing age by having reduced depth of wear [68]

Figure 17 presents the abrasion resistance of concrete produced with PC/MTK at 0, 5, 10, 15 and 20%, cured in NaCl and tested at 28, 56 and 90 hydration periods. At 28 days of curing, 10% gave improved abrasion resistance of 0.11% than any other cement replacement level. There was weight loss in the concrete samples at higher cement replacement levels. The 0% replacement had the same weight loss of 0.05% as the 5% and 10% replacements, which both had 0.05% at 90 days. Thus, 5% and 10% replacements resisted abrasion impact better, while higher replacement levels resulted in greater weight loss.

Figure 18 presents the abrasion resistance of concrete produced with Metakaolin as partial cement replacement, cured in HCl and tested at 28, 56 and 90 days. At 28 days of curing 0%, 5% and 10%, have same abrasion resistance value of 0.13%. The 0% replacement had a weight loss of 0.09%, while the 5% and 10% replacement, had slightly lower weight losses of 0.08% at 90 days. Thus, 5% and 10% replacements resisted abrasion better.

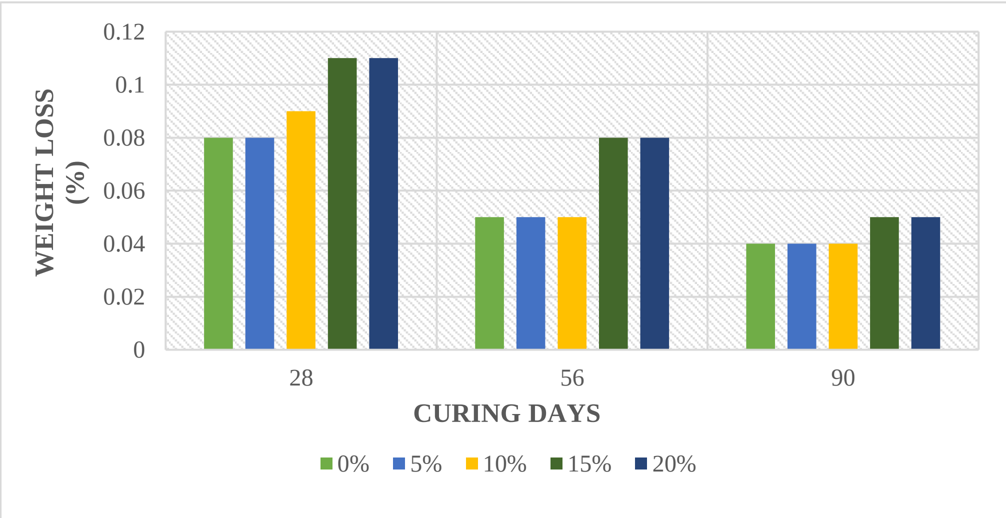

Figure 16: Abrasion resistance of concrete cured in water

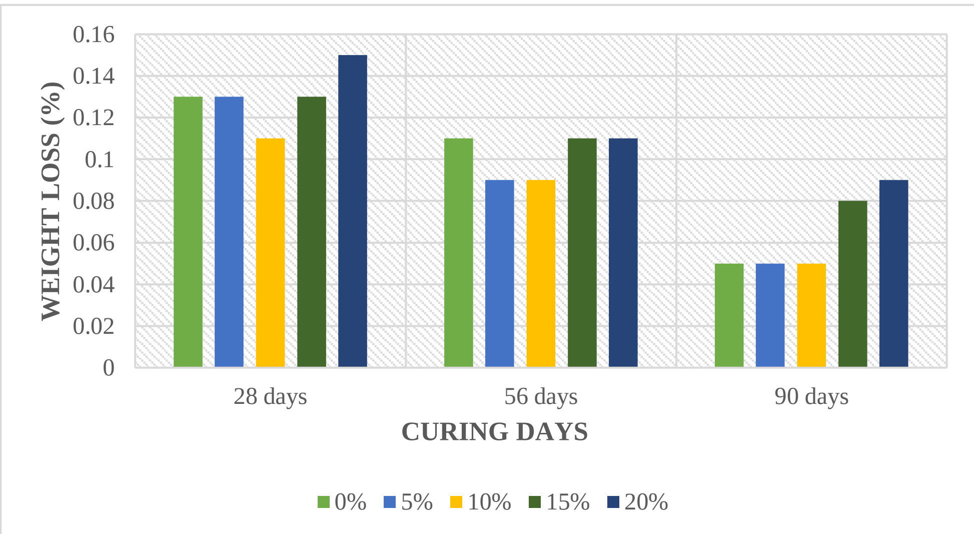

Figure 17: Abrasion resistance of concrete cured in NaCl

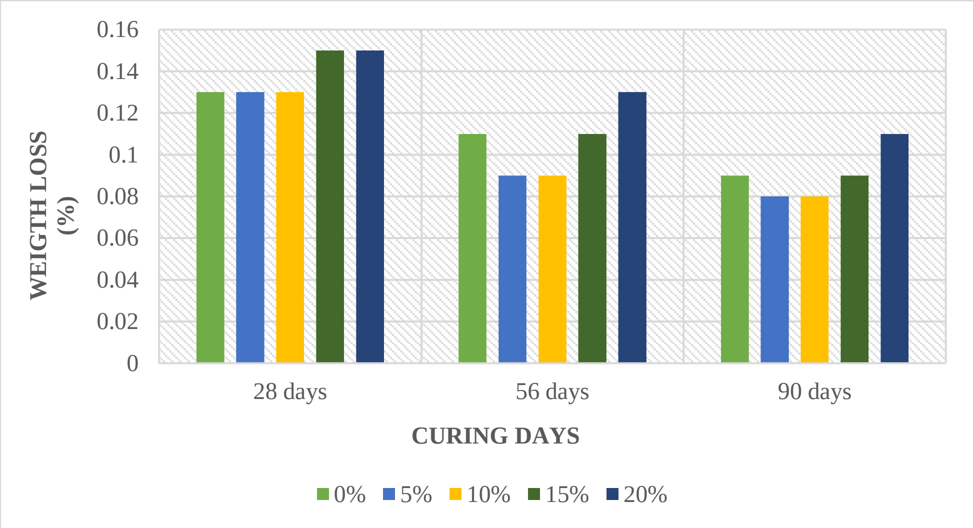

Figure 18: Abrasion resistance of concrete cured in HCl

4. Conclusion and Recommendations

The chemical properties of metakaolin (MTK) were investigated, and the result showed that MTK has SiO_2, Al_2O_3, and Fe_2O_3 percentage sum up to 96.02%, which meets the minimum chemical requirements of an excellent pozzolan. The chemical analysis of MTK showed that it satisfied the ASTM 618-05 requirement as a pozzolanic material. The workability of the concrete shows that an increase in MTK beyond 10% reduces the workability of concrete. The density of concrete increases with the curing period. There was more density loss in control concrete samples than in 5% and 10% Metakaolin concrete samples in the aggressive medium at a higher curing stage. The result indicated that concrete produced with Metakaolin at a lower replacement level significantly improves concrete's strength and durability. 0% control concrete has higher strength at 28 days, but at later stages of curing, 5% and 10% pozzolanic concrete have a higher strength index. The flexural strength results revealed that concrete at all replacement levels met the expected 4.0N/mm^2 flexural strength at 28 days for concrete cured in water but a higher drop below standard in the chemical medium. Concrete samples made with up to 10% of pozzolanic material have high abrasion resistance and are less absorptive in a chemical environment. Metakaolin as cement replacement up to 20% has potential for applications in mass concrete. The results indicate a potential use of Metakaolin in concrete production for structural and non-structural purposes. It is recommended that metakaolin as cement replacement up to 10% is beneficial through improving concrete's durability and physical and mechanical properties and protecting the environment from pollution compared to conventional concrete.

1. For general construction projects requiring high workability and finish quality, 10% MTK replacement level is optimal. This improves concrete strength, durability and density with a satisfactory workability. Beyond 10%, workability reduces which will affect the placement and finishing of the concrete.
2. Metakaolin as partial cement replacement in concrete mix should be evaluated in diverse environmental conditions and elevated temperature and extended to 120, 180, 360 or possibly 720 curing days to further determine the pozzolanic ability and long-term durability.

3. Due to its availability and viability, the research recommends using Metakaolin to replace cement in concrete production.
4. Research should be carried out on the effects of admixtures on the properties of Metakaolin that may improve the curing of pozzolans in general and water-enhancing admixture due to the high absorption of the pozzolans.
5. Concrete mixtures with 5% to 10% MTK are highly recommended for structures exposed to chemical or aggressive environments. This is due to the reduced water absorption properties and increased resistance of water transport in the metakaolin concrete thereby enhancing durability even in harsh conditions.
6. An intensive microstructural assessment of the interfacial zone of concrete produced with metakaolin should also be carried out.

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