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Gum Arabic as an Admixture in Modified Concrete Mixed with Calcined Kaolin

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Abstract

The use of calcined kaolin (CK) as a cementitious material in construction has attracted the interest of various researchers due to its environmental, mechanical, and physical qualities, all of which contribute to the lowering of cement usage. Studies have reported numerous problems associated with its use in concrete, apart from the ecological benefit that CK can provide. For instance, there is an issue of increased water demand due to smaller particle size, which generates much more heat in concrete, which has a detrimental effect on the mechanical and physical properties of concrete. This paper presents the analysis of an investigation aimed at using gum Arabic (GA) as a biopolymer admixture and calcined kaolin as a partial replacement of cement to improve the mechanical properties and durability of concrete. GA proportions ranged from 0 to 1% by weight of cement. Calcined kaolin (CK) was used to replace 5, 10, 15, 20, 25, and 30% of the cement content, respectively. Compressive strength, splitting tensile strength, density, strength loss, and weight loss tests were all performed to validate the structural performance of the modified concrete. The compressive tests, performed after 28 days from the time the mixture was made, demonstrated that the maximum percentage of CK that could replace cement without affecting the mechanical properties of concrete was 20%. Beyond 20%, concrete does not exhibit good compressive strength properties. The results also revealed decreased compressive strength and splitting tensile strength tests as the percentage of CK increased. After 56 days, compressive strength at 5% CK and 10% CK increased slightly by 0.743% and 1.162 %, respectively, compared to the control sample. The inclusion of 0.8%GA increased the compressive strength by 8.94% compared to the control sample (0%CK + 0%GA + 100%OPC) after 56 days. The results of durability tests showed that 0.6% GA had a higher compressive strength than other percentages containing GA.

Keywords: Weight Loss; Mass Loss; Compressive Strength; Splitting Tensile Test; Durability.

1. Introduction

Construction is a global industry that is both significant and ancient, and it predates civilization by thousands of years [1]. Nowadays, construction is the most profitable industry in every market economy. The construction industry uses various materials, including cement, concrete, aggregates, clay, wood, metals, and bricks. The material that is chosen is determined by its properties and cost. Binders are the most frequently used construction material in the industry, out of all other materials. Cement and concrete are two of the most critical binders. The primary binder is Portland cement, which comes in various compositions and constituents [2]. Cement production consumes a significant

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amount of energy and raw materials and contributes approximately 7% of the CO_2 gas responsible for global warming. Nowadays, a variety of supplementary cementitious materials (industrial and agricultural wastes) are used in place of ordinary Portland cement clinker on a partial basis. Because supplemental cementitious materials are not widely available, they cannot be considered a global substitute for cement [3]. Natural resources such as clay (Kaolin), which is high in alumina and silica, have replaced waste materials in recent years. These clays can initiate a pozzolanic reaction when the right conditions exist. Clays are plentiful in nearly every country. Calcined clay (calcined kaolin) is a significant pozzolanic material due to the abundance of kaolinitic clays found worldwide, indicating their potential for usage as supplemental cementitious materials [4]. Calcined clay has a more stable chemical composition than fly ash and slag. This means that clay-mixed cement can be more controlled and predictable.

The effect of calcined kaolin on the mechanical strength of concrete, mainly compressive strength, has been reported inconsistently in the literature at various ages. Calcined kaolin and metakaolin have a significant physical and chemical effect on the compressive strength of concrete. Physically, the result is primarily due to the instantaneous filler effect. The chemical effects are the pozzolanic reaction and the impact on the kinetics of cement hydration during the first 24 hours [5]. Although there are numerous investigations into the use of calcined kaolin in concrete that have been undertaken during the last two decades. Numerous findings have helped researchers better grasp the benefits and drawbacks of calcined kaolin as a partial cement replacement in the mechanical, physical, and durability properties of concrete. Dhandapani et al. [5] investigated concrete's mechanical properties and durability performance with limestone calcined clay Cement (LC3). Findings revealed that for up to 28 days, OPC and limestone calcined clay cement concrete had similar compressive strength evolution in M30 and M50 concrete mixes. A lower binder concentration was required to attain the same goal strength as the limestone calcined clay cement M50. The FA30 concrete mixes had lower early age strength because they used less water to reach equivalent 28th-day strength. Compared to the OPC system, the FA30 and limestone calcined clay cement mixes had a larger increase in compressive strength (from 28 to 365 days). Also, the M30 concretes using FA30 and limestone calcined clay cement had somewhat higher compressive strength than the M50 concretes. The prolonged pozzolanic reaction aids this growth. Rashad et al. [6] conducted a research review that emphasized using calcined kaolin as a source of fresh properties and the ideal content for mechanical strength in traditional cementitious materials. Their findings suggest that when calcined kaolin was added to conventional concrete, the compressive strength, elastic modulus, and chemical resistance increased. The ultra-fine particle size of calcined kaolin decreased the workability of cement and increased heat flow.

Arslan et al. [7] studied the effect of elevated temperatures on the performance of self-compacting mortars composed of calcined kaolin and metakaolin. Findings revealed that adding calcined kaolin to concrete reduced its normal strength. Karatas et al. [8], investigated kaolin and calcined kaolin's effects on self-compacting mortars' durability and mechanical properties subjected to elevated temperatures. The results indicated that when K20 and CK20 aged 28 days were compared to control specimens, 8.42% and 14.65% of the flexural strength loss was detected. The addition of CK to SCMs mixtures decreased compressive strength by approximately 31.94%, 25%, 22.51%, and 24.68%, and by approximately 74.30%, 69.17%, 67.35%, and 68.28% at inclusion rates of 5, 10, and 15, and 20 CK at 600 and 900°C, respectively. A small increase in the compressive strength of SCMs mixtures containing kaolin and calcined kaolin was observed with increasing temperature and content. Calcined kaolin needs more water in concrete because it has microscopic particles. This causes more heat to flow through the cement, which affects workability, setting time, strength, and durability. Calcined kaolin in concrete also has shown low early strengths due to an insufficient reaction of the pozzolana with the free lime (calcium hydroxide) generated from the cement paste to form stable compounds with cementitious properties, resulting in increased strength. Lots of water increases porosity accessible to water and rapid heat evolution due to the high surface area of calcined kaolin, which degrades durability and structural performances. This occurs in concrete due to supplementary cementitious materials and chemical admixtures.

Gum Arabic's effect on concrete, admixtures are used in concrete for a variety of reasons, including preventing water bleeding to the surface, improving the mix's workability, accelerating or delaying the initial setting of the concrete, improving water tightness, producing non-skid concrete, inhibiting the set of cement paste, improving early strength gains, producing a colored surface, and making the concrete more resistant to deterioration caused by repealing [9]. Gum Arabic is one of the admixtures used in concrete to change its characteristics. It is a naturally occurring substance found in the exudates from the trunks and branches of the Acacia Senegal tree. It possesses a low viscosity, emulsifying properties, and long polymer chains referred to as carboxyl acid functional groups (COOH). Elinwa et al. [10] studied gum Arabic as an admixture for cement concrete production. The gum was added to concrete in proportions ranging from 0% to 1%. The following experiments were carried out: compressive strength, water absorption, density and workability. Results indicated that the presence of sepiolite, palygorskite and Mordenite in gum Arabic enhanced the characteristics of concrete. In addition to its micro fibrous structure and distinctive texture, sepiolite also has a high specific surface area due to its composition of magnesium silicate and hydrated magnesium silicate. When combined with little amounts of water, it acts as a binder. Palygorskite is a fibrous aluminium magnesium silicate. Their physicochemical features result from their large surface area, porosity, and excellent thermal resistance, all of which contribute to their attractiveness as an adsorbent. Mordenite has a five-membered chain of silicate and aluminate tetrahedra in its molecular structure. Because of the high proportion of silicon to aluminium atoms, it resists acid attack better than most other zeolites. Mbugua et al. [11] investigated the Effect of Gum Arabic Karroo as a water-reducing admixture in cement mortar. Results revealed that adding gum from Acacia karroo decreased the water-to-binder ratio from 0.61 to 0.48 and boosted mechanical parameters such as compressive strength by 37.03% to control. Additionally, at 0.2%, gum from Acacia karroo exacerbated the slump by 200%. The study concluded that Acacia karroo gum could be utilized to reduce the amount of water in concrete.

Arabic gum has recently been shown to improve fresh and hardened concrete's mechanical and physical properties, making it a potentially viable and environmentally friendly water-saving admixture. Improving the performance of concrete with calcined kaolin at an early stage has become a significant area of interest for a large number of researchers. Additionally, numerous researchers have used gum Arabic to enhance the flow and mechanical properties of concrete, thanks to its chemical properties. Since gum Arabic is significantly less expensive than chemical admixtures, it is a more cost-effective method of improving the structural performance of concrete. The effect of gum Arabic as an admixture in concrete containing calcined kaolin as partial cement replacement on the structural performance and durability of concrete is a novel area of investigation to address the issue of calcined kaolin's high water demand and to enhance its mechanical properties at an early and later age. As a result, the research's primary contributions include the following:

- Investigation of the engineering properties of gum Arabic and calcined kaolin;
- Investigation of the mechanical properties of concrete mixed with gum Arabic as an admixture and calcined kaolin as a partial cement replacement;
- Investigate the durability of concrete containing gum Arabic as an admixture and calcined kaolin as a partial cement replacement when exposed to a 5% sulphuric solution.

2. Materials and Methods

2.1. Methodology Flowchart

Figure 1 summarizes the sequential steps used to accomplish the research objectives.

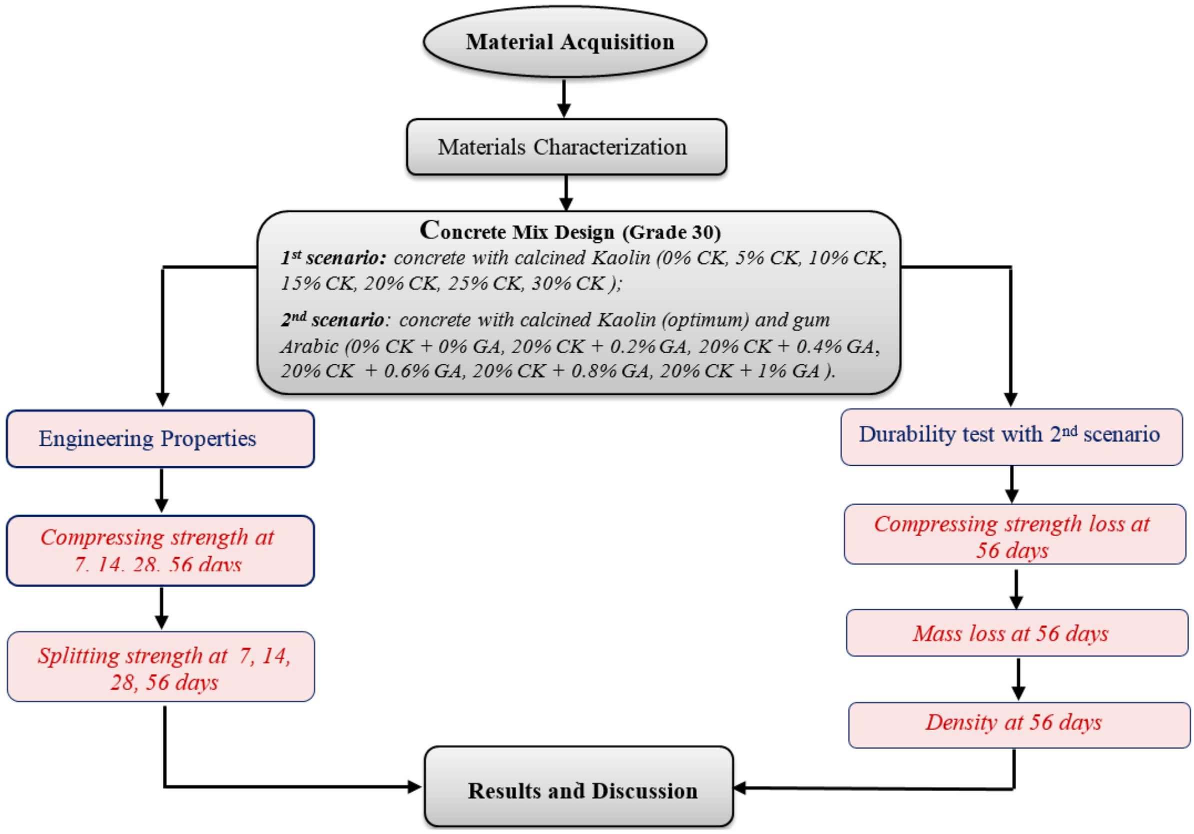


Figure 1. Flow Chart of Methodology Research

2.2. Materials and Acquisition

The materials that facilitated this project's results are Ordinary Portland cement type I 42.5 N, calcined kaolin, gum Arabic, potable water, coarse aggregates of particle size varying between 5-20 mm and the natural river fine aggregates having the maximum length of 4 mm. OPC was supplied from a local manufacturer in Kenya and stored in the Jomo Kenyatta Laboratory at a temperature ranging between 23 ºC and 22 ºC during the specified days to avoid any mechanical or physical quality change. The physical tests carried out are summarized in Tables 1 and 2. Kaolin was bought at the local market in Kenya and was subjected to a calcination temperature of 650 ºC using the furnace to get the calcined Kaolin, as illustrated in Figure 2. Chemical composition components revealed that 650 ºC was the perfect temperature used to burn Kaolin.

Table 1. Physical properties for OPC type I 42.5 N

Property	Results	Standard
Specific gravity	3.10	BS4550
Normal consistency (%)	34	BS4550
Initial setting time (min)	120	BS4550
Final setting time (min)	260	BS4550
Finenes (%)	2.33	BS4550
Loss on ignition @ 900 ºC	4.48	

Table 2. Chemical composition for OPC type I 42.5 N

Component	Percentage (%)
Al_2O_3	5.454
S_iO_2	24.619
Fe_2O_3	2.741
P_2O_5	0.439
SO_3	2.964
K_2O	0.607
CaO	62.741
TiO_2	0.193

The burnt Kaolin's particle distribution size and physical properties are illustrated in Figure 3, Table 3 and 4. The coarse and fine aggregate physical tests are summarized in Tables 5 and 6. The local company supplied gum Arabic; the chemical composition is summarized in Table 7.

Table 3. Chemical composition for calcined kaolin

Component	Percentage (%)
Al_2O_3	14.043
S_iO_2	71.781
Fe_2O_3	5.504
P_2O_5	0.212
SO_3	0
K_2O	4.583
CaO	0.461
TiO_2	0.33

Table 4. Physical properties for calcined kaolin (CK)

Property	Results	Standard
Specific gravity	2.54	ASTMC188
Normal consistency (%)	44	ASTMC188
Fineness (%)	1.5	ASTMC188
Loss on ignition 900 ºC	0.72	-
Moisture	0.5	BS812

Table 5. Physical properties for fine aggregates

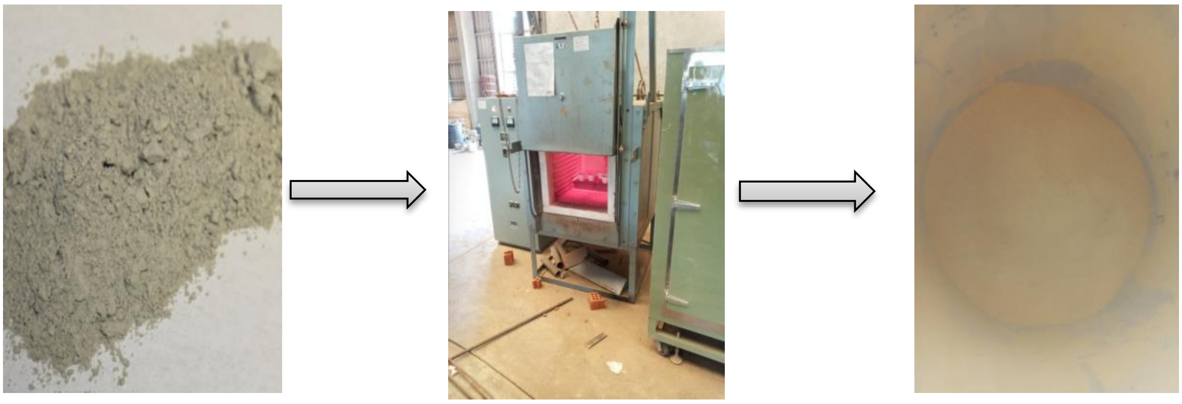
Property	Results	Standard
Specific gravity	2.65	BS812-108
Loose density (kg/m3)	1071	BS812-2
Bulk density (kg/m3)	1151	BS812-2
Water absorption (%)	0.503	BS812-107
Moisture content (%)	3.414	BS812-109
Fineness modulus	2.79	BS812-103
Silt content (%)	1.87	BS EN 197

Table 6. Physical properties for coarse aggregates

Property	Results	Standard
Specific gravity	2.67	BS812-108
Loose density (kg/m^3)	1213	BS812-2
Bulk density (kg/m^3)	1317	BS812-2
Water absorption (%)	2.96	BS812-107
Moisture content (%)	2.01	BS812-109
AIV (%)	7.26	BS812-112
ACV (%)	16.74	BS812-110

Table 7. Chemical composition for GA

Component	Percentage (%)
Sr	0.12
Cu	0.003
MgO	24.414
K_2O	15.251
CaO	56.935
TiO_2	0.334



(A) Grounded kaolin **(B) Calcination phase** **(C) Calcined Kaolin**

Figure 2. Processing of calcined Kaolin

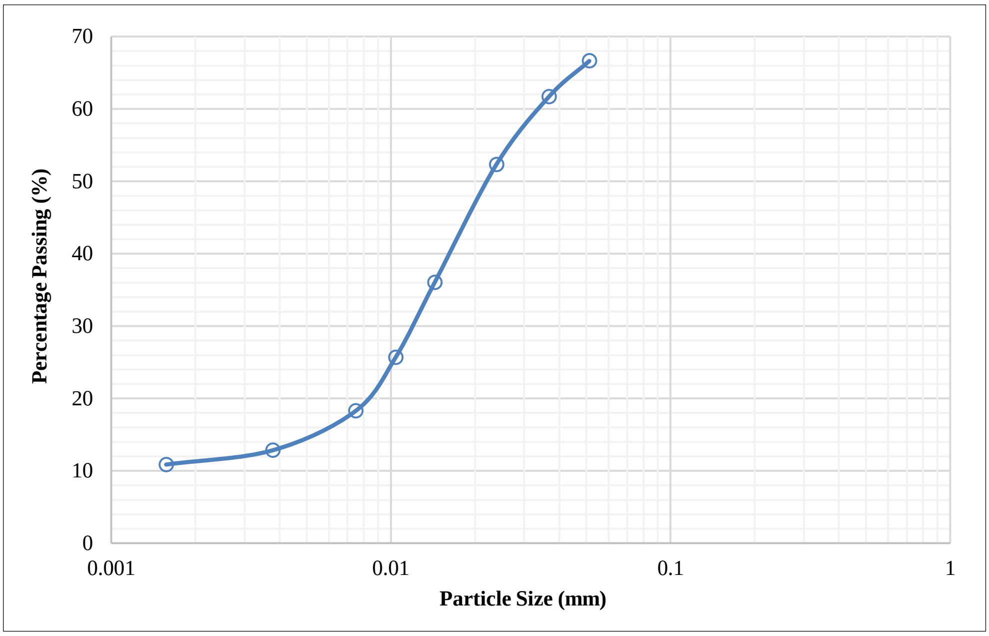


Figure 3. Particle distribution size of calcined kaolin

2.3. Evaluation of the Natural Pozzolana

The pozzolanic activity of natural pozzolans. To offset the drawbacks of the low early strengths of cement containing pozzolans, achieving the ASTM C618-2003 standards for natural pozzolana is essential. The potential quality of calcined kaolin was assessed using two methods: mechanical and chemical. The X-ray fluorescence test confirmed that Pozzolana samples are siliceous in composition. The principal oxide concentration (SiO_2, Al_2O_3, Fe_2O_3) exceeded the ASTM requirement of 70%. The mechanical approach revealed that the strength activity index was 78.536% at 7 days and 81.526% at 28 days, as shown in Table 8. This study determined that the calcined Kaolin utilized in this work met ASTM requirements and was suitable for usage as a partial cement replacement.

Table 8. Evaluation of the natural pozzolana for calcined kaolin

ASTM C618-2003 requirements	Class N	Calcined Kaolin
$SiO_2 + Al_2O_3 + Fe_2O_3$	Min 70	91.328
Loss on ignition	Max 10	0.72
Moisture content	Max 5	0.5
Sulfur trioxide SO_3	Max 5	0
Strength activity index after 7 days	Min 75	78.536
Strength activity index after 28 days	Min 75	81.526

2.4. Testing Procedure

The design of the concrete mix was completed initially, followed by the mechanical property tests. The following findings were made: 669.6 kilograms fine aggregate, 963.58 kilograms coarse aggregate, 210 kilograms water, 381.12 kilograms cement, 30 MPa concrete grade, and a water-cement ratio of 0.55. Second, the optimal percentage of calcined kaolin was established by partially substituting 5%, 10%, 15%, 20%, 25%, and 30% calcined kaolin by the weight of cement. Concrete was being cast in metallic cubic and cylindrical moulds, as depicted in Figure 4. The cubic moulds were 100 × 100 × 100 mm in size, while the cylindrical moulds were 100 × 200 mm in size. Due to the quantity of silicon in calcined kaolin and lime in conventional Portland cement that can react and form stable compounds in the strength of concrete, it was found that 20% was the maximum proportion that could be used to provide satisfactory mechanical properties results. Gum Arabic was coupled with 20% calcined kaolin at concentrations of 0.2%, 0.4%, 0.6%, 0.8%, and 1% to test its effect on concrete. Compressive strength and splitting tensile tests were performed in accordance with British Standards 1881-116 and 4550-3 [12, 13]. The strength and mass loss of concrete were determined after exposure to a 5% solution of sulphuric acid. Finally, the density test on hardened concrete was conducted after 56 days to compare the weight of the specimens.

Figure 4. Concrete casting using cubic and cylindrical moulds

3. Results

3.1. Compression

Compressive strength testing was performed in two stages per British Standard BS1881-116. Foremost and first, specimens were tested at 7, 14, 28, and 56 days containing calcined kaolin at inclusion rates of 0%, 5%, 10%, 15%, 20%, 25%, and 30% by the weight of cement, respectively, as illustrated in Figure 5. After determining the ideal percentage of calcined kaolin, it was blended with gum Arabic in proportions ranging from 0% to 1%, as shown in Figure 6. The strength of concrete without calcined kaolin rose linearly with curing time, increasing from 26.85 MPa after 7 days to 32.76 MPa after 14 days; from 37.62 MPa after 28 days to 42.667 MPa after 56 days. The presence of calcined kaolin in concrete decreased its strength from 17.135 MPa after 7 days to 29.767 MPa after 56 days when 30% of calcined kaolin was used; from 18.124 MPa after 7 days to 31.46 MPa after 56 days when 25% of calcined kaolin was used; from 18.175 MPa after 7 days to 36.287 MPa after 56 days when 20% of calcined kaolin was used; and from 21.133 MPa after 7 days to 39.982 MPa after 56 days when 15% of calcined kaolin was used. The trend differed when 10% and 5% of calcined kaolin were used at 56 days. At 56 days, compressive strength rose by 0.743 % and 1.162 % at inclusion rates of 5% and 10%, respectively, compared to the control. When 10% calcined kaolin was used, the strength increased from 21.504 MPa after 7 days to 43.163 MPa after 56 days and from 24.781 MPa after 7 days to 42.984 MPa after 56 days when 5% was used. Second, the addition of GA as an admixture has positively modified the characteristics of concrete, as illustrated in Figure 6. Evidently, compressive strength rose exponentially from 26.335 MPa after 7 days to 42.762 MPa after 56 days when 0.2% of gum Arabic was used; from 27.072 MPa after 7 days to 43.862 MPa after 56 days when 0.4% of gum Arabic was used; from 29.448 MPa after 7 days to 43.96 MPa after 56 days when 0.6% of gum Arabic was used; from 30.363 MPa after 7 days to 46.864 MPa after 56 days when 0.8% of gum Arabic was used; from 29.393 MPA after 7 days to 44.86 MPa after 56 days when 1% of gum Arabic was used.

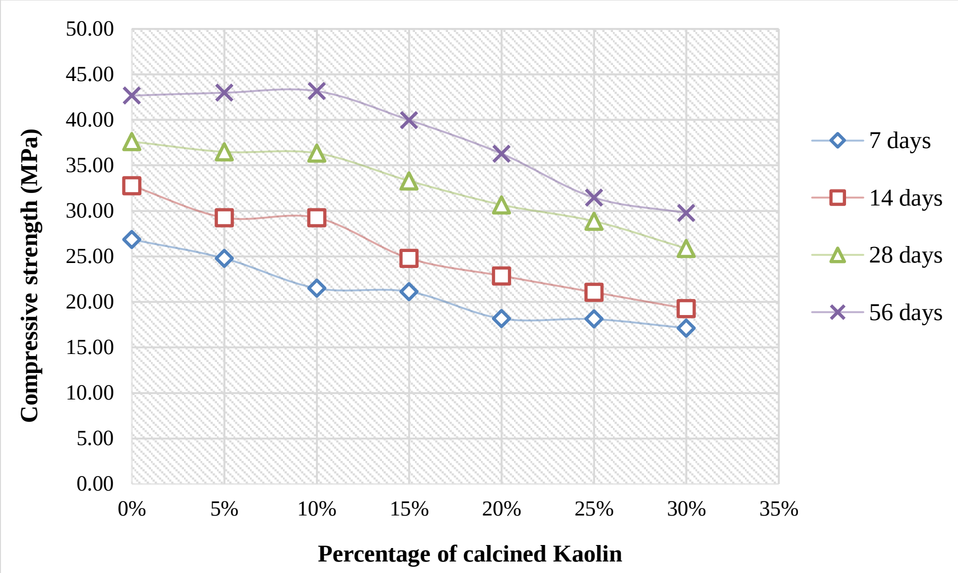


Figure 5. Compressive strength with calcined kaolin

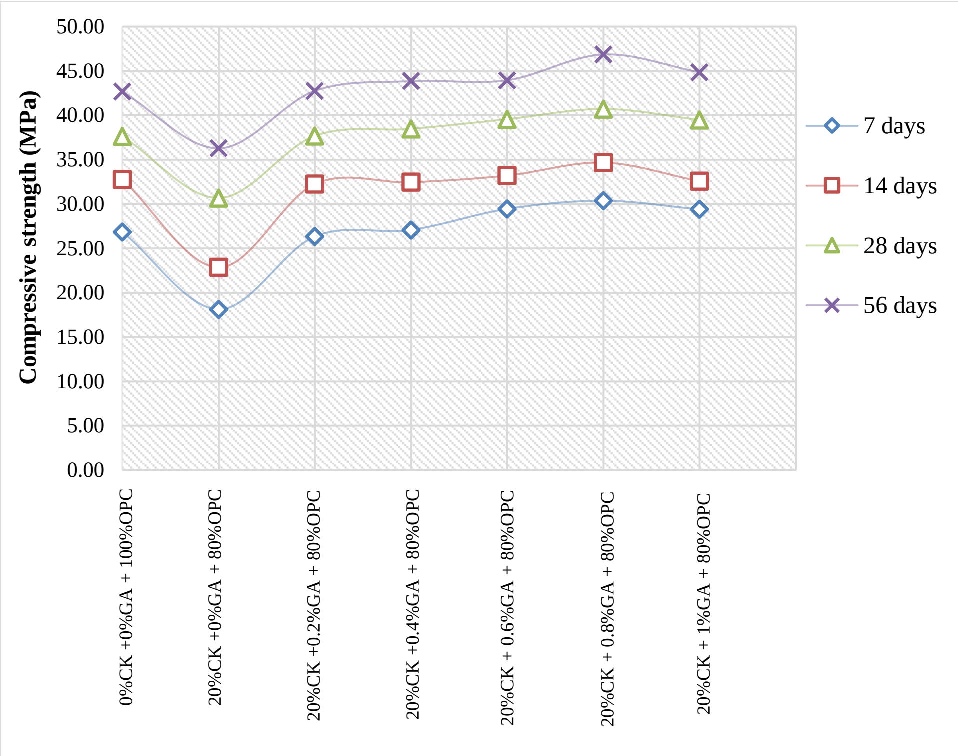


Figure 6. Compressive strength with gum Arabic and calcined kaolin

3.2. Splitting Tensile Strength

This experiment testing was performed in two stages as per BS1881-117. Foremost and first, specimens were tested at 7, 14, 28, and 56 days by partially replacing 0%, 5%, 10%, 15%, 20%, 25%, and 30% calcined kaolin by the weight of cement, respectively, as shown in Figure 7. After determining the ideal percentage of calcined kaolin, it was blended with gum Arabic in proportions ranging from 0% to 1%, as shown in Figure 8. The strength of conventional concrete rose linearly with the curing period, increasing from 2.57 MPa after 7 days to 2.972 MPa after 56 days. The presence of calcined kaolin to concrete increased the strength from 2.511 MPa after 7 days to 3.232 MPa after 56 days when 5%CK was used; from 2.199 MPa after 7 days to 3.267 MPa after 56 days when 10%CK was used; from 1.935 MPa after 7 days to 3.188 MPa after 56 days when 15%CK was used; and from 1.707 MPa after 7 days to 3.093 MPa after 56 days when 20%CK was used. The trend differed when 25%CK and 30%CK were used at 56 days. After 56 days, strength decreased by 3.398% and 8.647 % for 25% and 30%, respectively, compared to the control. When 25%CK was used, the strength decreased to 2.871 MPa after 56 days and 2.715 MPa after 56 days when 30%CK was used. Second, the addition of GA as an admixture biopolymer has positively modified the characteristics of concrete, as illustrated in

Figure 8. The strength rose exponentially from 2.037 MPa after 7 days to 2.995 MPa after 56 days when 0.2%GA was used; from 2.087 MPa after 7 days to 3.073 MPa after 56 days when 0.4%GA was used; from 2.196 MPa after 7 days to 3.273 MPa after 56 days when 0.6%GA was used; from 2.33 MPa after 7 days to 3.285 MPa after 56 days when 0.8%GA was used; from 2.552 MPa after 7 days to 3.373 MPa after 56 days when 1%GA was used. The increased percentage was 13.493% when 1%GA was used compared to the reference.

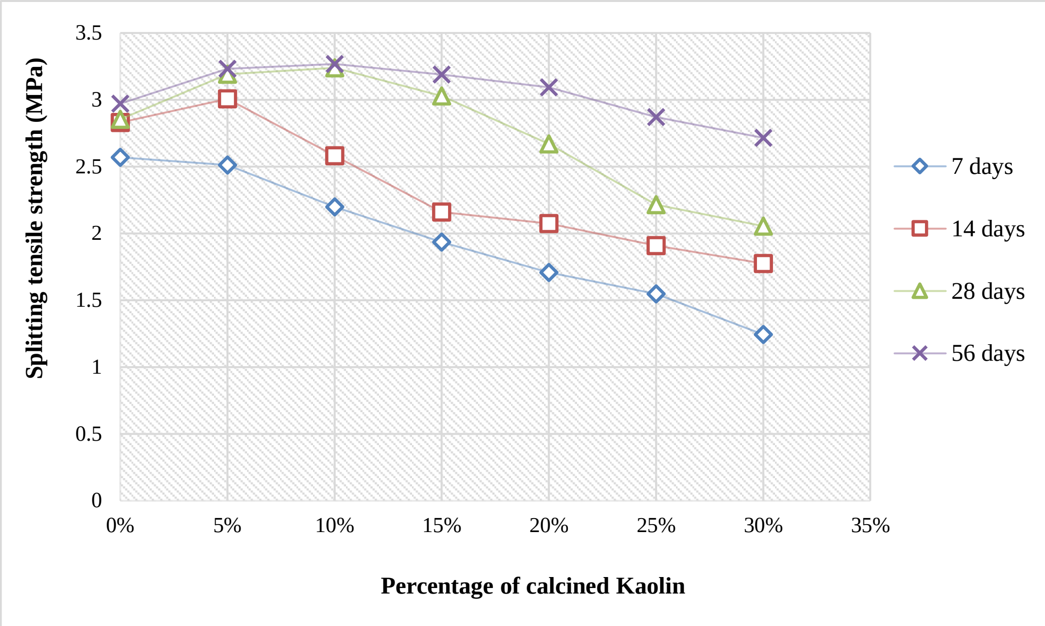


Figure 7. Splitting tensile strength with calcined kaolin

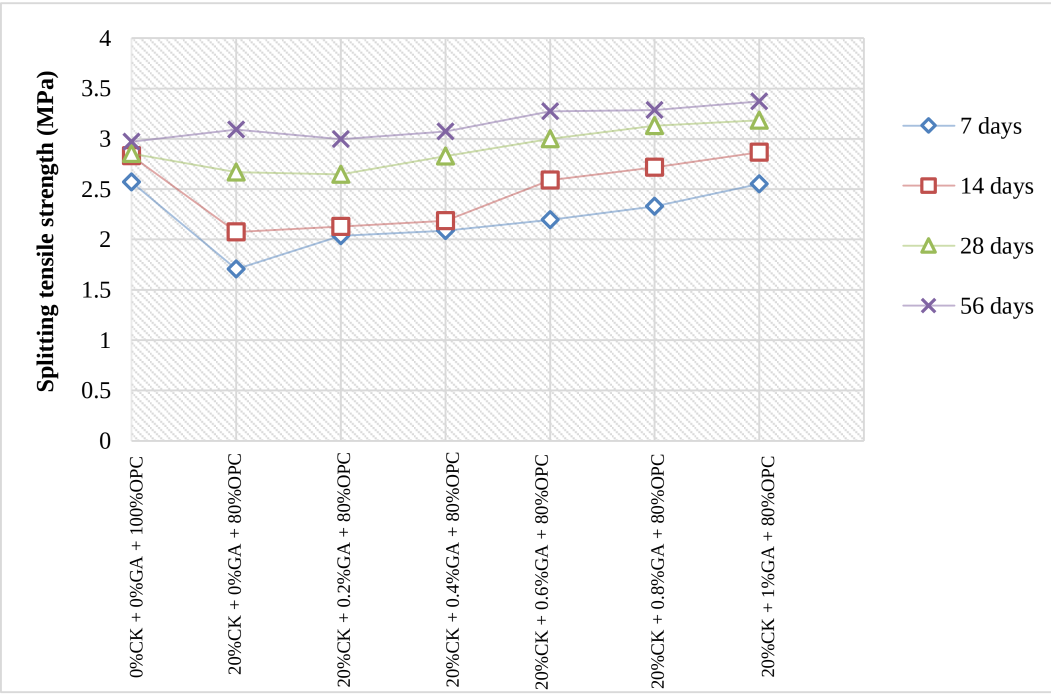


Figure 8. Splitting tensile strength with calcined kaolin and gum Arabic

3.3. Density

The density test was performed by calculating the mass of the sample divided by its volume; geometrically shaped cylindrical specimens measuring 100 mm × 200 mm was used to calculate the density. First, the density of concrete mixed with CK was established at 5%, 10%, 15%, 20%, 25%, and 30%. The density of concrete mixed with gum Arabic at inclusion rates of 0.2%, 0.4%, 0.6%, 0.8%, and 1%, with 20% the optimum percentage of calcined kaolin was then determined. The results indicated that specimens containing calcined kaolin had a lower density, as illustrated in Figure 9. However, when gum Arabic was added to concrete, its density rose, as shown in Figure 10.

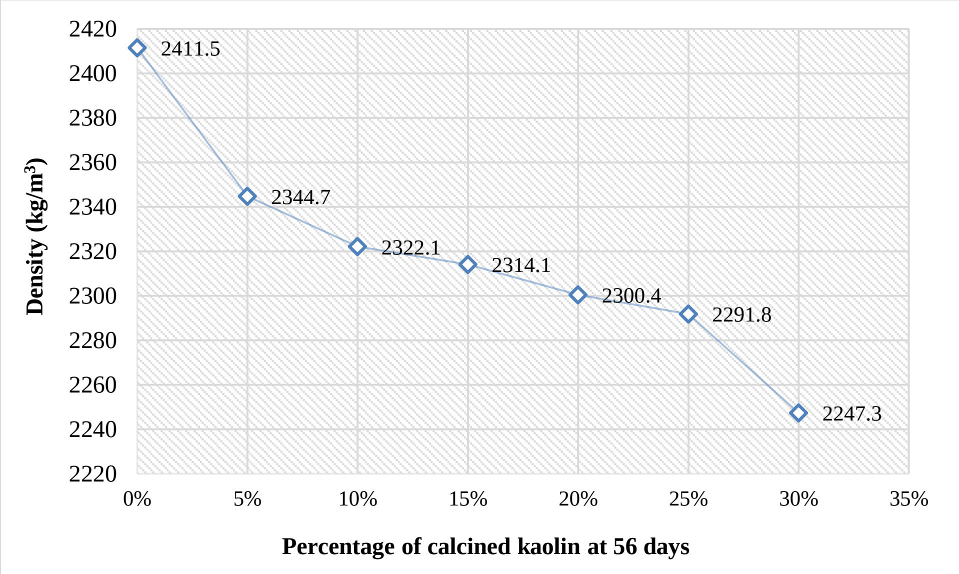


Figure 9. Density of concrete with calcined kaolin at 56 days

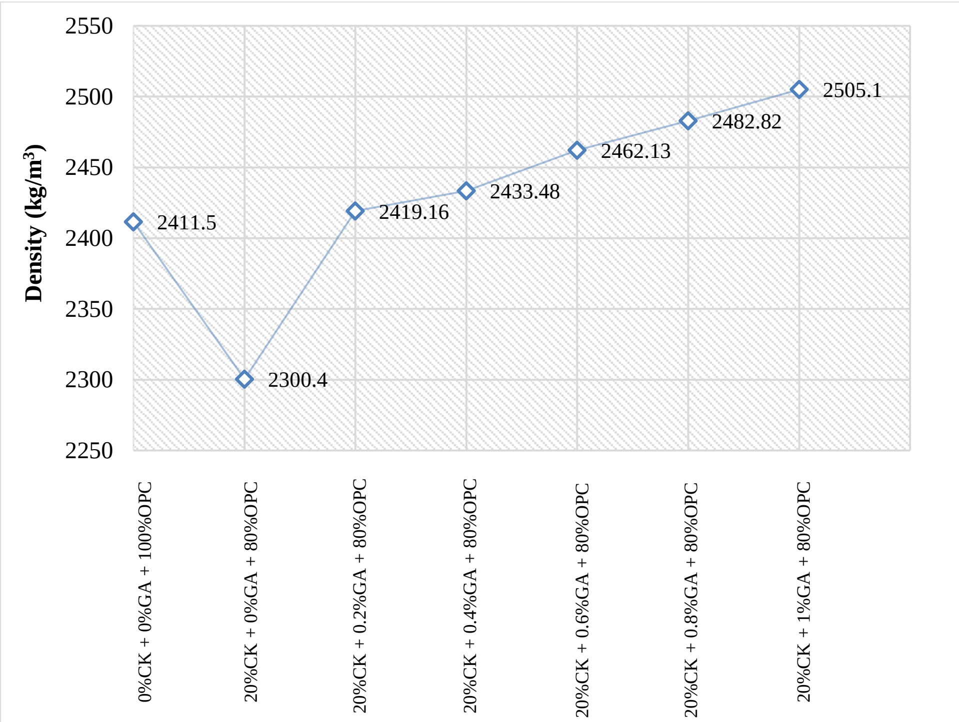


Figure 10. Density of concrete with calcined kaolin and gum Arabic at 56 days

3.4. Durability Test

ASTM C-267 was used to conduct the durability test [14]. Weighed specimens were submerged in a 5% sulphuric acid solution (H_2SO_4) for 56 days. After the acid solution immersion phase, the samples were removed, thoroughly rinsed in water, and air-dried for 48 hours under laboratory conditions. Each sample was reweighed following the drying period to determine each sample's weight and strength loss. The samples immersed in sulphuric acid were concrete mixed with (0%CK + 0%GA + 100% OPC), which is the control, (20%CK + 0%GA + 80% OPC) the optimum of calcined kaolin, and (20%CK + 80% OPC with the following percentage of GA at inclusion rates of 0.2%, 0.4%, 0.6%, 0.8%, and 1%). The effect of H_2SO_4 on concrete showed a severe compressive strength failure on concrete mixed with (20%CK + 0%GA + 80% OPC) than the control. Concrete mixed with gum Arabic had lower strength than the control except for 0.6%GA, which the value was 23.011 MPa compared to the control 22.99 MPa, as illustrated in Figure 11. Results revealed that the 0.6%GA had the highest compressive strength than the control by 0.1%. Results also showed that the strength increased as GA increased to 0.6%GA, then decreased. The scenario was not the same for the mass loss; results indicated that the weight decreased as the percentage of gum Arabic increased. The weight loss of all specimens containing gum Arabic was below the control, which the value was 2423.5 kg, as shown in Figure 12.

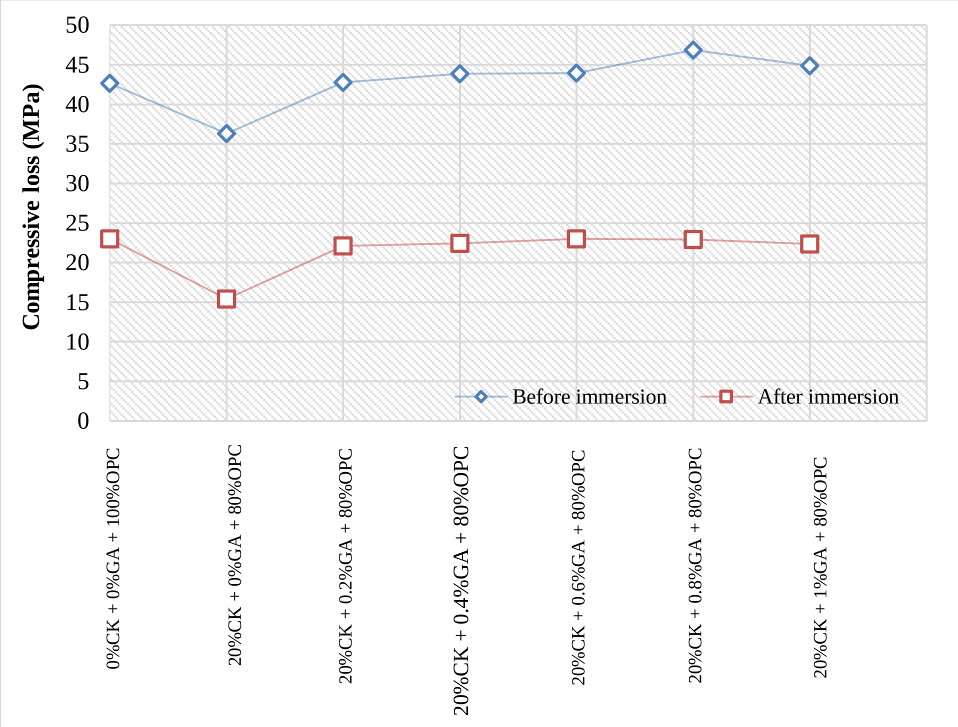


Figure 11. Strength loss at 56 days with calcined kaolin and gum Arabic

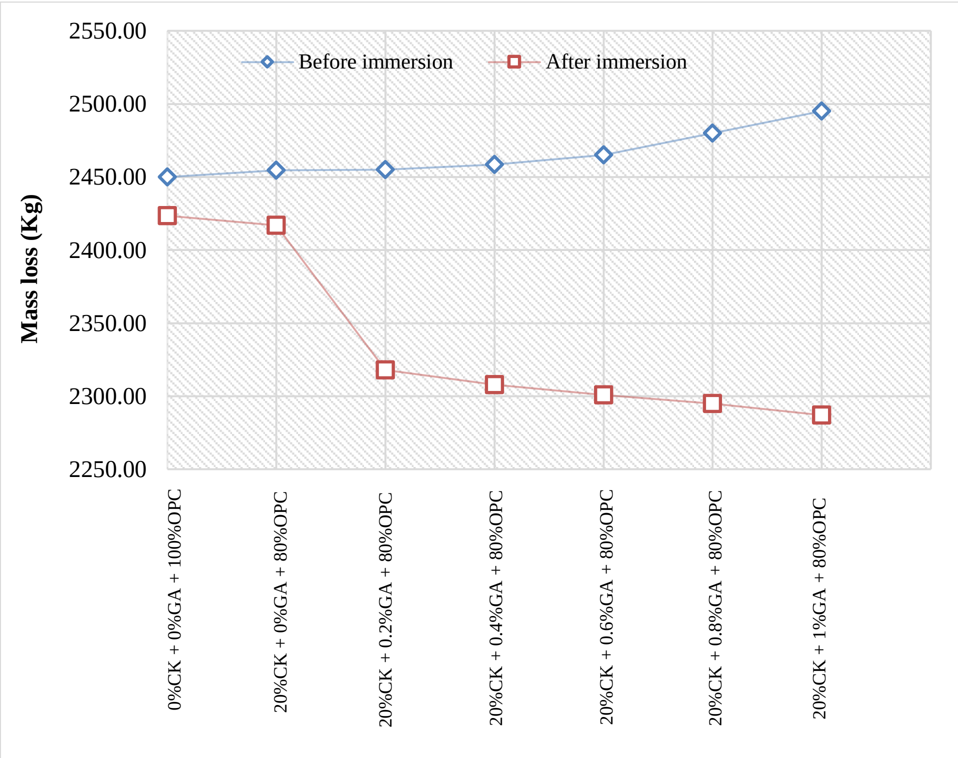


Figure 12. Mass loss at 56 days with calcined kaolin and gum Arabic

4. Discussion

4.1. Compressive Strength

Compressive strength decreased as calcined kaolin pozzolana was substituted, as shown in Figure 5. At inclusion rates of 5% and 10% CK, Compressive strength was significantly greater than all other dosages containing calcined kaolin and the control after 56 days, by 0.72% and 1.14%, respectively. Compressive strength at an inclusion rate of 20% CK was 30.671 MPa, greater than the minimum required strength at 28 days for concrete grade 30 but lower by 18.47% than the control. At inclusion rates of 25% CK and 30% CK, the compressive strength was below 30 MPa after

28 days. This decrease in compressive strength is explained by the no effective interaction of $Ca(OH)_2$ in cement and SiO_2 in calcined kaolin resulting in the formation of calcium silicate hydrate (C-S-H) gel, one of the key compounds contributing to concrete's strength which enhances the pore structure of concrete and prevents capillary pores from forming. The compressive strength values obtained in this study followed the same trend as those obtained by Karatas et al. [8], who investigated the effects of kaolin and calcined kaolin on the durability and mechanical properties of self-compacting mortars exposed to elevated temperatures. Their findings reported that as the rate of calcined kaolin inclusion increased, the compressive strength decreased slightly. The findings for this current research revealed that the compressive strength increased as gum Arabic inclusion rates increased, as shown in Figure 6. At 56 days, it was observed that 1% GA had a slight compressive strength reduction of 4.86 % compared to 0.8% GA. And it remained higher than the control by 4.88 %. The slight decrease in compressive strength at 1% GA is explained by concrete bleeding during demolding. Compressive strength improvement is a result of gum Arabic's rheological properties, such as chemical properties, as shown in Table 9. Also, the presence of a high calcium oxide (CaO) content in the chemical composition of the combined materials such as gum Arabic, calcined kaolin, and cement is one of the reasons for the increase in strength. This assertion is consistent with the findings of Enliwa et al. [15] who investigated the X-ray diffraction and microstructure of gum Arabic-cement concrete. This present study concluded that the combination of (20% CK + 80% CK + 0.8% GA) increased the compressive strength by 8.94% compared to the reference (0% CK + 0% GA + 100% OPC), after 56 days. According to the findings, 0.8%GA is the suitable percentage for use as a water reducer in concrete mixed with calcined kaolin.

Table 9. Chemical composition for CK, OPC and GA combined

Component	Percentage (%)
Al_2O_3	3.582
S_iO_2	19.596
Fe_2O_3	4.186
K_2O	0.910
CaO	67.398
TiO_2	0.329

4.2. Splitting Tensile Strength

The results of the splitting tensile strength have shown promising results with calcined kaolin before introducing gum Arabic into concrete, as shown in Figure 7. At inclusion rates of 5%CK, 10%CK, 15%, and 20%CK, the splitting tensile strength increased and remained higher than the control by 8.04%, 9.03%, 6.78%, and 3.91%. Between 25% and 30% CK, the results indicated a slight decrease in splitting tensile strength of 3.4 % and 8.65 %, respectively, compared to the control. Concerning the increase in tensile strength, it is evident that calcined kaolin has more branching, which means that its intermolecular forces are more vital with increased tensile strength; whenever it is dispersed in a matrix of raw or calcined kaolin, the molecules being diluted experience comparatively stronger intermolecular forces. Thus, tensile strength increases linearly with filler content until it reaches a certain weight or percentage of calcined kaolin, which begins to deteriorate. Also, the strength improvement can be explained because of the gained silicon percentage content in calcined kaolin. The higher the SiO_2 rate, the more silicon can contribute to the improvement of the concrete tension. This statement agrees with Rong et al. [16], who studied NanoSiO_2 particles affecting the mechanical and microstructural properties of ultra-high performance cementitious composites. Also, the gain in strength explains the particularity of clay over other pozzolanic materials. Clay exhibits good stability in pressure that renders it suitable for construction such as dams and bridges. Additionally, gum Arabic to concrete improved the splitting tensile strength. This is due to the rheological properties of the chemical composition of the combined materials such as gum Arabic, calcined Kaolin, and cement, which is one of the reasons for the increase in strength. For instance, calcium oxide may contribute to strength gain.

4.3. Density

The density of concrete mixed with calcined kaolin decreased as the percentage of calcined kaolin increased, as illustrated in Figure 9. At 30%CK, the density decreased by 6.8% compared to the control after 56 days. The reason for the decrease in density is due to the constant water-cement ratio used in all mixes. The more the amount of calcined kaolin increased, the amount of water became little to fill the microstructure of specimens that contributed to the weight reduction. Moisture in concrete produces paste between cement and other materials to improve the pore structure of concrete, rendering it dense. The findings of this research revealed that the addition of gum Arabic to concrete increased the density of concrete. The rise in density is because of the degree of viscosity of gum Arabic, which is qualified as a viscosity modifying agent. The findings of this work are in line with those conducted by Elinwa et al. [15] who studied X-ray diffraction and microstructure studies of gum Arabic-cement concrete. Their findings reported that the increase in density is attributed to the transformation phase of gum Arabic, arising from the interactions of gum Arabic and the cement in the hydration process. The product of this reaction is the production of palgorskite and mordenite minerals.

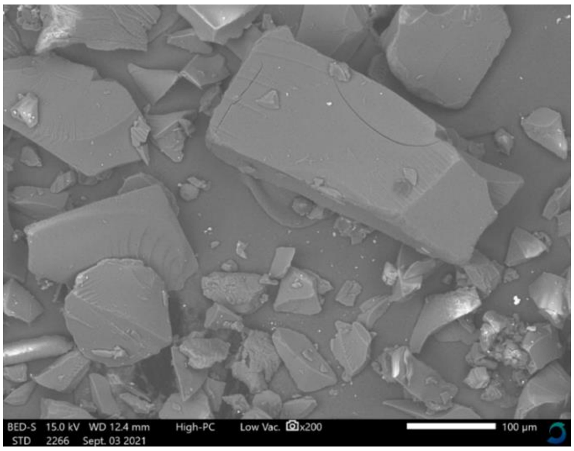
These two minerals are present in all the dosages. Palygorskite and mordenite have been identified as filler materials. Gum Arabic is a viscosity modifying agent. The viscosity modifying agents are composed of sugars known as polysaccharides; they can increase the stability and cohesiveness of concrete.

4.4. Durability Test

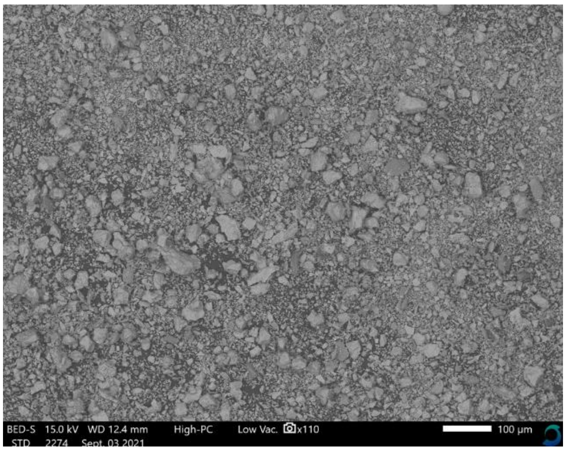
The durability test was handled to see the effect of gum Arabic as an admixture biopolymer on concrete after exposure to sulphuric acid. The compressive strength and weight loss were all performed to validate the structural performance of concrete. Before exposure of specimens to sulphuric acid, the compressive strength increased as the percentage of gum Arabic increased, as shown in Figure 11. After exposure of samples to sulphuric acid, it was observed that the strength loss increased linearly at inclusion rates of 0.2%GA, 0.4%GA, and 0.6%GA then there was a strength reduction. At an inclusion rate of 0.6%GA, the compressive strength was higher by 0.1% compared to the control. The reason for gained strength could be related to the density of the microstructure of concrete mixed with gum Arabic. According to the recent research carried out by Ariffin et al. [17], gum Arabic in concrete can density the matrix of specimens by reducing the percentage of voids and contributes to the acidic attack resistance in preventing any dangerous agent in concrete. The weight loss increased as the percentage of gum Arabic increased, as illustrated in Figure 11. The increase in weight is because of the degree of viscosity of gum Arabic in concrete, which can fill the pore structure of concrete and render it denser. After exposure of specimens to sulphuric acid, a reduction in the weight of samples was observed, as illustrated in Figure 12. The decrease in weight could be the loss of the volume of specimens due to the acid attack gum Arabic is also a viscous material that makes it dissolve faulty in the presence of water.

4.5. SEM Analysis

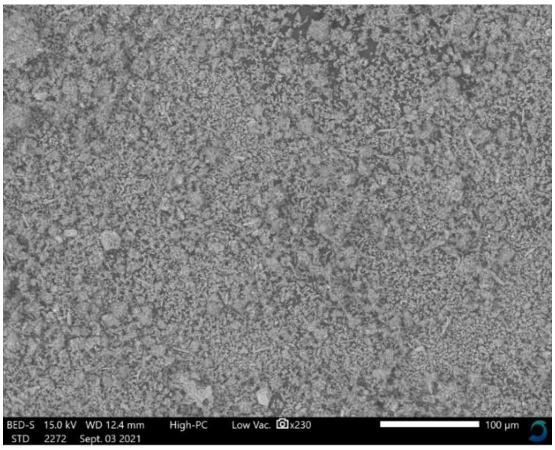
Cement paste microstructure and morphology can be tracked via SEM analysis of changes in the C–S–H phase of hydration [18-20]. Also, SEM analysis can be used to characterize the pore structures in porous materials by calculating the total porosity and pore size distributions. As shown in Figures 13-c and 13-c, the SEM analysis was performed at a scale of 100 µm to analyse the morphology of the materials. The results indicated that the cement particles are significantly larger than those of calcined kaolin. This size difference explains why calcined kaolin requires a considerable amount of water to improve the rheological qualities of concrete. Figure 13-a shows how gum Arabic is composed of polysaccharides. Polysaccharides are large particles that are minerals consisted of sugars.



a) Gum Arabic



b) OPC



c) Calcined kaolin

Figure 13. Scanning Electron Microscope for OPC, gum Arabic and calcined kaolin

5. Conclusions

Incorporating gum Arabic into concrete containing calcined kaolin has been investigated. This study aimed to determine the advantages (engineering properties and durability) of employing gum Arabic and calcined kaolin as a partial cement replacement in the building sector. The findings are as follows:

- According to the standards, the material properties of coarse aggregates, fine aggregates, cement, calcined kaolin, and gum Arabic were characterized. The findings indicated that all materials complied with applicable standards and could be used in the experimental work for this investigation;
- At 56 days, the results showed that the compressive strength was 8.94% higher with 20% CK, 80% CK, and 0.8% GA than with the reference mix of 0% CK, 0% GA, and 100% OPC;
- The results from the compressive strength showed that 20% CK + 0.8% GA + 80% OPC had the highest compressive strength compared to 20% CK + 1% GA + 80% OPC. According to the findings, this research concluded that concrete with 20% CK + 80% OPC + 0.8% GA is more effective in terms of compressive strength than the reference (0% CK + 0% GA + 100% OPC);
- About 0.8% GA is the percentage whereby the high compressive strength was recorded. 0.8% of gum Arabic is the better percentage to be used in concrete as a water-reducing admixture and set retarding.
- The addition of gum Arabic at 1% to concrete showed bleeding and necessitated more than 24 hours before removing the mould.
- The maximum percentage of calcined kaolin that can be used as a cementitious material is 20%; above this percentage, the interaction between the lime in the cement and the silicon content in the calcined kaolin to form C-S-H, which contributes to the strength of concrete, takes longer to take effect.
- About 0.6% GA is a percentage that has demonstrated high durability stability.

Finally, the experiments on X-ray diffraction and microstructure to determine the behavior of the materials were not covered in this study. In addition, durability tests at a later age should be performed to better understand the behavior of the materials. As a result, I strongly advise further research in these areas.

6. Declarations

6.1. Author Contributions

Conceptualization, G.F.M.M.; S.O.A.; and J.N.T.; methodology, G.F.M.M.; validation, S.O.A. and J.N.T.; investigation, G.F.M.M.; data curation, G.F.M.M.; S.O.A.; and J.N.T.; writing—original draft preparation, G.F.M.M.; writing—review and editing, S.O.A., and J.N.T. The published version of the manuscript has been read and approved by all authors.

6.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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6.4. Acknowledgements

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6.5. Conflicts of Interest

The authors declare no conflict of interest.

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