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Abstract - *The goal of this study focuses on the influence of gum Arabic as a biopolymer admixture on setting time, Workability, and mechanical properties of concrete mixed with calcined kaolin. Concrete was mixed with calcined kaolin (CK) in the proportion of 0%-30% by cement weight and cured under laboratory conditions for 28 days. Later gum Arabic was added to the concrete at the following ratios 0%-1% after obtaining the optimum percentage of calcined kaolin. The addition of gum Arabic in concrete delayed the initial and final time, improved the Workability, and increased the mechanical properties of concrete. Furthermore, an SEM test was performed on cement, calcined kaolin, and gum Arabic in powder form to study their surface morphology. Gum Arabic was added to the cement mixture and calcined kaolin in powder form and was subjected to X-ray fluorescence to analyse its chemical compositions. Finally, the study concluded that 20%CK was the optimum since the compressive strength was above the minimum value required at 28 days due to the silicon content in CK that could react with lime in cement compared to 25% and 30%. Also, 0.8%GAB was the percentage whereby concrete reached its high compressive strength.*

Keywords — Compressive strength, X-ray fluorescence, Workability, Setting time.

I. INTRODUCTION

The use of admixtures is generally classified according to their function and how they act on concrete. According to the standard American C-494, there are several types of admixture. We have class D admixtures that play the role of water reducing and set retarding in the formulation of concrete [1,20]. These so-called admixtures can improve and increase the properties of concrete, such as strength and Workability, while allowing the reduction of the water-cement ratio. Several works carried out by researchers have shown that gum Arabic can be classified as a viscosity-modifying agent. In [2], respectively, has ranked gum Arabic as a viscosity-modifying agent. The viscosity modifying agents are polysaccharides that increase the stability and cohesion of cement. Surveys by [3,4] reported that the existence of Gum Arabic and Acacia Karroo in concrete improved the compressive strength. In their study, Elah et al. [5] worked on GAB with a recommended dosage of 0.2% and 0.6% by cement weight, and they found an increase in the shrinkage and setting time but a reduction in water requirement. Their findings reported decreased compressive strengths with a slight improvement in Durability when used in an acidic medium. Gum Arabic was confirmed in their results and other related works to improve the cement paste and concrete characteristics [6,7]. In [8] respectively, the study was focused on the impact of added GAB on the setting time, Durability of ordinary concrete, and Workability. They also worked on X-ray fluorescence tests on cement GAB mix powder to assess its chemical structure for estimating carbonation depth in GAB concrete samples for Durability. The results recorded the initial setting time, and the fluidity of the GAB mortar increased with the increase of GAB content up to 0.9%. On the contrary, the increase in the dosage proportions of GAB was due to the slight decrease in density.

This research aims to investigate the influence of Gum Arabic as a biopolymer admixture on the setting time, Workability, and strength of concrete mixed with calcined kaolin. There is a need for using a natural admixture in concrete mixed with calcined kaolin due to the particle size of calcined kaolin that requires a more considerable water demand to improve the rheological properties of concrete.

II. EXPERIMENTAL STUDY

A. Materials

The following materials were used calcined kaolin (CK) as a partial replacement for cement, Portland cement type I 42.5 N (PC). Local vendors in Kenya supplied the kaolin, and the kaolin was burnt to a calcination temperature of 650 °C for 1.5 h to obtain calcined kaolin (CK). Natural river sand was used for the mixtures with a specific gravity of 2.62, water absorption 0.503%, bulk density 1151 kg/m3, silt content 1.87%, moisture content 3.414%, and fineness modulus 2.79. The gradation curve of fine aggregate and calcined kaolin was obtained, illustrated as shown in Figure 1. The maximum size of coarse aggregate was 20 mm with a specific gravity of 2.46, bulk density 1315 kg/m3, aggregate crushing value (ACV) 16.74%, aggregate impact value (AIV) 6.26%. The chemical composition, physical and mechanical properties of cement, calcined kaolin are summarised in Table I. So that the Workability, setting time, and mechanical properties of concrete improved, gum Arabic biopolymer (GAB) was used in all mixtures as a natural admixture after obtaining the optimum percentage of calcined kaolin. To examine the surface morphology of the cement samples, calcined kaolin, and gum Arabic, scanning electron microscope (SEM) images were taken to investigate the microstructure of samples. Figure 2 illustrates the SEM image.

The chemical composition of gum Arabic biopolymer may differ from one region to another due to the climatic conditions, processing conditions, and tree age. Gum Arabic is an organic material consisting of polysaccharides and glycoproteins. Some investigations have been carried out to discover the molecular structure of gum Arabic biopolymer and relate it to its rheological and emulsifying properties. Tables I and II show the chemical composition of gum Arabic and gum Arabic mixed with cement and calcined kaolin.

B. Testing procedure

The determination of consistency test was measured under the BS 4550 [19] method. The water-cement ratio was found to be 0.34, and it was kept constant to analyse the influence of calcined kaolin and gum Arabic in setting time. This test consisted of defining the amount of water used in cement to penetrate the Vicat plunger apparatus to reach 5-7 mm from the bottom of the Vicat mould.

The initial and final setting time determination was done according to the BS 4550 [19] standard. The test was carried out in the JKUAT Lab under a temperature ranging between 23 ± 2 ºC. Vicat apparatus was used to conduct the test, four grams of Portland cement type I (PC) was mixed with calcined kaolin at 0%, 5%, 10%, 15%, 20%, 25%, and 30% by weight of cement. Another scenario was done by mixing 20% of calcined kaolin (optimum dosage based on the compressive strength of concrete) with gum Arabic at 0.2%, 0.4%, 0.6%, 0.8%, and 1% by the weight of cement.

The water absorption, compressive, flexural, and splitting tensile tests were carried out in this work using a Mix design ratio of 1: 1.75: 2.52 and a water-cement ratio of 0.55. The water-cement ratio was kept constant in all mixings to study the behaviour of calcined kaolin and gum Arabic in concrete. The materials content were 381.82 kg of cement, fine aggregate 669.6 kg, coarse aggregate 963.58 kg, water 210kg, and the concrete grade was 30. Firstly, dosages of 0%, 5%, 10%, 15%, 20%, 25%, and 30% by weight of cement were prepared to determine the optimum percentage of calcined kaolin. Secondly and lastly, five dosages of 20% of calcined kaolin mixed with gum Arabic at 0.2%, 0.4%, 0.6%, 0.8%, and 1% were prepared to improve the Workability, setting time, and mechanical properties of concrete. Samples were tested at ages 7, 14, and 28 days; the average of three specimens per test was recorded.

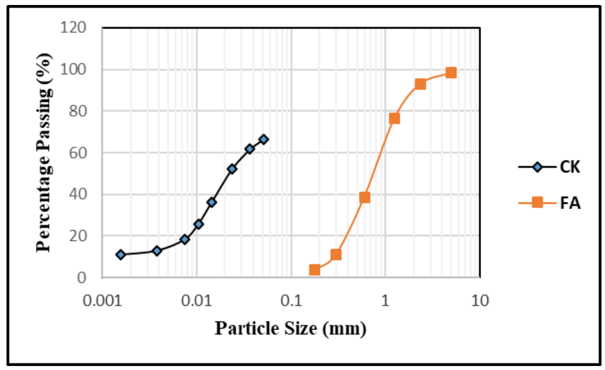
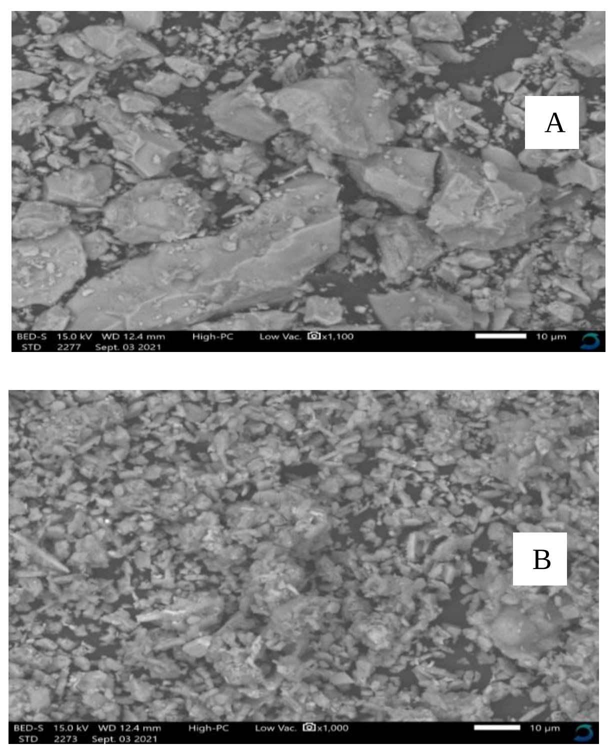


Fig. 1 Calcined Kaolin and fine aggrate distribution curve



II. TABLE I
CHEMICAL COMPOSITION, PHYSICAL AND MECHANICAL PROPERTIES OF OPC, CK AND GAB ADDED TO OPC AND CK MIXTURE

Elements	OPC 42.5 N (%)	CK (%)	OPC-CK-GAB (%)
Al_2O_3	5.454	14.043	3.582
SiO_2	24.619	71.781	19.596
Fe_2O_3	2.741	5.404	4.186
P_2O_5	0.439	0.212	0.947
SO_3	2.964	-	2.717
K_2O	0.607	4.583	0.910
CaO	62.741	0.461	67.398
TiO_2	0.193	0.33	0.329
CuO	-	-	0.022
S. gravity	3.10	2.54	-
Consistency (%)	34	44	-
Loss on ignition (%)	4.48	0.72	-
Compressive strength 14 days	46.031	-	-

II. TABLE II
CHEMICAL COMPOSITION AND PHYSICAL PROPERTIES OF GAB

Elements	GAB (%)
Sr	0.12
Zr	0.12
Fe_2O_3	0.453
MgO	24.414
SO_3	2.35
K_2O	15.251
CaO	56.935
TiO_2	0.334
CuO	0.003
S. gravity	1.55

III. RESULTS AND DISCUSSION

A. Setting time and consistency

The influence of calcined kaolin on standard consistency required a more significant amount of water due to the high surface area and small particle size. The setting time prepared with cement paste was higher than that of cement mixed with calcined kaolin at 5%, 10%, 15%, 20%, 25%, and 30%. It was observed that the initial and setting time decreased with the increase of calcined kaolin content, as is illustrated in figure 3. Results revealed the diminution of the initial and final time of 45 min and 95 min, respectively, with the addition of 20% of calcined kaolin compared with the reference cement. The cause that explains this significant diminution refers to the size and reactivity of calcined kaolin particles that require a more considerable amount of water and participate significantly in accelerating the hydration process and increasing the pozzolanic reaction [10,11]. At 1% of gum Arabic biopolymer, the initial and final time was delayed up to 100 min and 120 min compared to the reference cement, and 130 min and 200 min compared to the reference 20% calcined kaolin as shown in figure 4. Results showed that the initial and final time remained above the references in all dosages of gum Arabic biopolymer; as the percentage of GAB increased, the initial and final time increased. The delay in setting time is helpful in hot weather for early setting time. So gum Arabic can be used as a set retarder admixture in concrete mixes. In [12], this remark of retardation is due to tricalcium aluminate (C_3A) in cement. The effect of retardation can also occur when the calcium sulfate in cement reacts with C_3A in the presence of water [12]. As for gum Arabic in water, its presence will activate the reaction of the tricalcium aluminate with the calcium sulfate that increases the setting time. This statement agrees with the previous findings where some hydration products, together with C_3A, adsorb the gum, which existed in the solution before the tricalcium aluminate reacted with calcium sulfate [13,14]. The increase in setting time could be attributed to the SiO_2 decrease by 25.63% to the reference cement and 266.3% to the calcined kaolin, as shown in Table I. This reason agrees with the previous findings in [15], the SiO_2 fraction relative decrease by 3% is among the factors contributing to the prolongation of setting time.

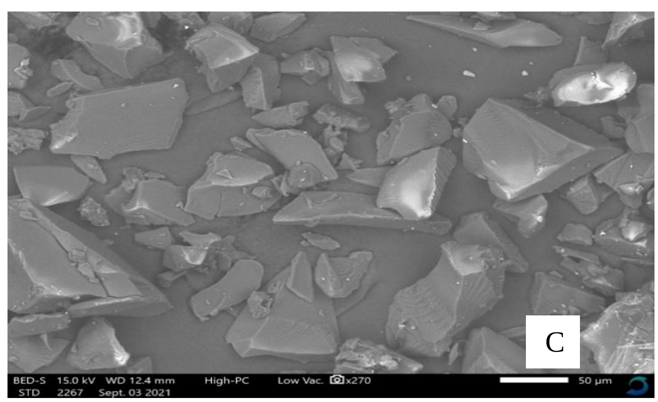


Fig. 2 SEM Analysis (A) cement, (B) calcined kaolin, (C) gum Arabic

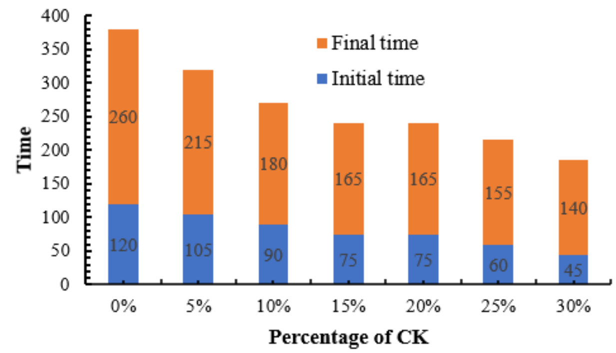


Fig. 3 Initial and final time with CK content

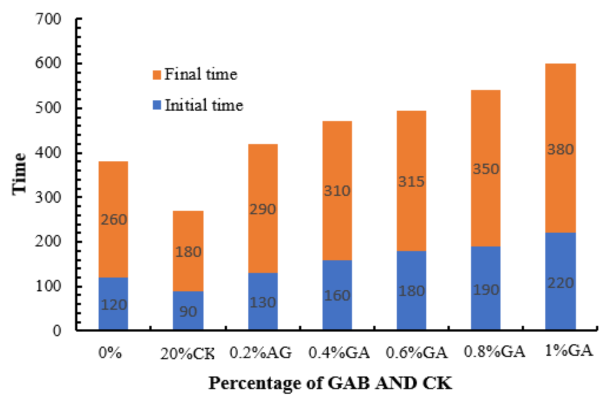


Fig. 4 Initial and final time with GAB and CK content

B. Water absorption and Workability

The results of the water absorption as a function of calcined kaolin are graphically presented in figure 5. This test was done as per BS 1881-122 [24]. Results revealed the reduction of the water absorption from 2.076 % to 1.719 % with the increase of calcined kaolin. The higher surface area of calcined kaolin required a more significant water demand to improve the rheology of concrete. This quantity of water is consumed by calcined kaolin, which explains the decrease in water absorption. This diminution of water absorption is also due to the water-cement ratio, which was kept constant in all dosage mixes to investigate the influence of calcined kaolin on Workability. Calcined kaolin can thus play the role of a filler in concrete, thanks to its particle size. The addition of gum Arabic at all dosages in concrete increased the percentage of water absorption ranging from 0% to 4.1%, as shown in figure 6. This cause could be the presence of the palygorskite and Modernite minerals, which are present in gum Arabic and have a porous structure with high water absorption and high surface area. This argument agrees with previous findings in research [7].

The results of the slump test are presented in figure 7. As calcined kaolin content increased, the figure showed the decrease of a slump. The presence of calcined kaolin at 30% reduced sharply the recession up to 20 mm and 27 mm at 20%. This could be attributed to the high surface area of calcined kaolin pozzolana due to the small particles size increased the water demand for concrete. So for the same water-cement ratio and materials content, the Workability reduced. In figure 8, results showed that as the Arabic gum content increased, the slump increased. At 0.2% of gum Arabic, there was a slight increase in the recession, and from 0.4% up to 1%, the slump significantly increased compared to the references 0% and 20%CK. The improvement of the slump is due to the relative reduction of Al_2O_3 by 292.04 % to the reference calcined kaolin and by 52.261% to the reference cement, as shown in Table I. In [7], it was reported that the relative reduction of Al_2O_3 and TiO_2 fractions by 5% could improve the Workability of fresh concrete. The nana particles of Al_2O_3 and TiO_2, respectively, are favourable to the Workability of new concrete [16]. It was noticed that at 0.8% and 1% of gum, Arabic concrete showed bleeding and necessitated more than 24 hours to be removed from the mould. In [25], the same trend was observed in workability.

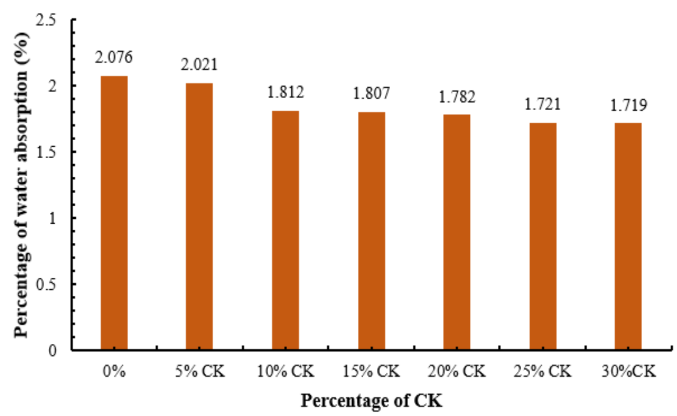


Fig. 5 Water absorption with CK content

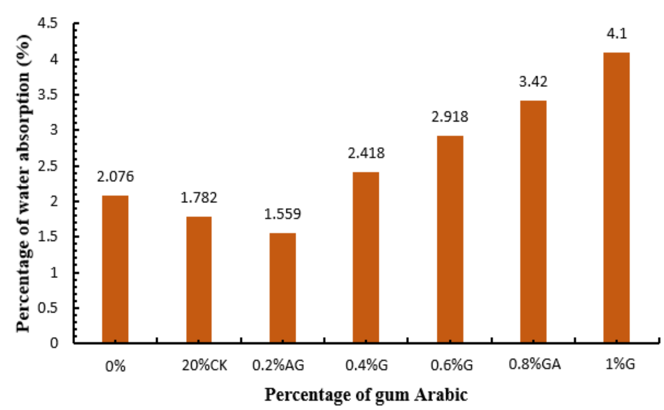


Fig. 6 Water absorption with CK and GA content

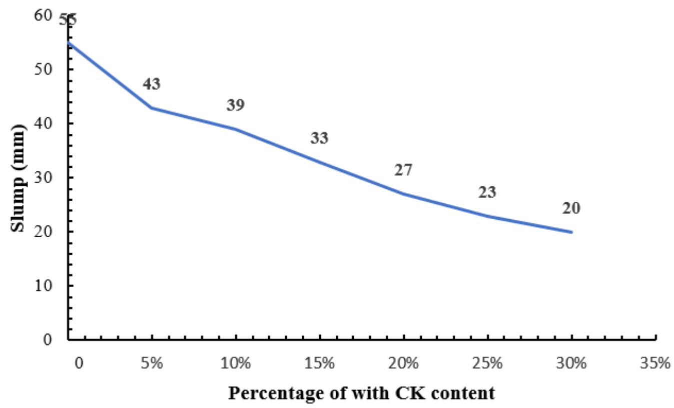


Fig. 7 Slump with CK content

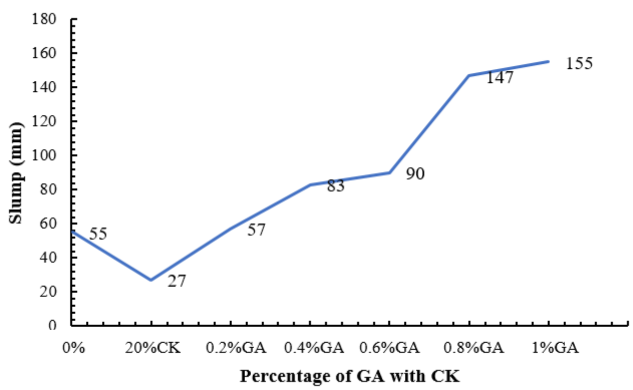


Fig. 8 Slump with CK and GAB content

C. Compressive strength

The compressive strength was done by applying the axial load to the specimen of 100 mm x 100 mm x 100 mm through the compressive testing machine following the BS 1881-116 [21]. It was observed that the compressive strength decreased with the increasing substitution of the calcined kaolin pozzolana at 7, 14 and 28 days. At 10% C.K., the compressive strength at 28 days was above all other dosages containing calcined kaolin and remained below the control by 3.097%. At 20% C.K., the compressive strength was 30.671 MPA, above the minimum required strength at 28 days for concrete grade 30, and was lower than the control by 22.66%. Based on the results, 20% CK was able to react with free lime in cement at an early age than 25% and 30%, which strength was below 30 MPa; this brought us to choose 20% as an optimum for this study. The decrease in strength is illustrated in figure 9. The reason for the diminution of the compressive strength for all dosages of calcined kaolin could be the reaction of calcined kaolin pozzolana liberated with lime generated from cement paste to form stable compounds possessing cementitious properties leading to increased strength at an early age. The inclusion of gum Arabic at ratios of 0.2%, 0.4%, 0.6%, 0.8% and 1% in concrete increased the compressive strength as shown in figure 10. As the Arabic gum content increased, the strength also increased, but at 1%, the strength decreased and remained above the control and other dosages except for 0.8%. The increase in strength is due to the relative increase of CaO and CuO content in the chemical composition of added gum Arabic to cement with calcined kaolin, as shown in table 1. CaO was increased by 6.91% to the reference cement and CuO 100%. In [7,18], it was reported that the addition of burnt pure CaO would increase the shear bond and compressive strength in a specific condition up to 200 °C. In [17], it was reported that up to a 4% weight fraction of CuO nanoparticles in cement could improve the mechanical and physical properties of concrete by reducing its porosity.

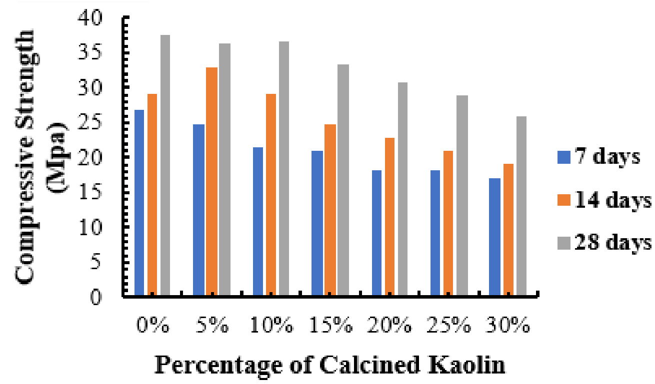


Fig. 9 Compressive strength with CK content

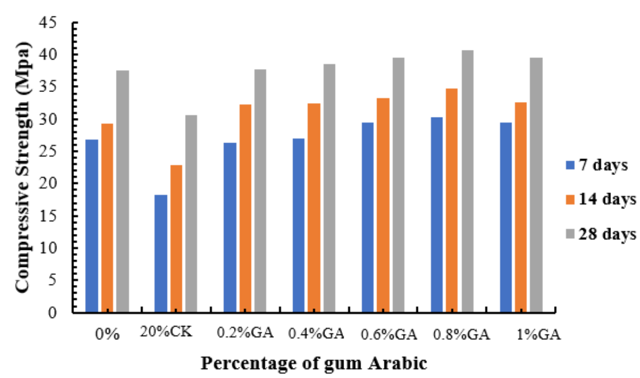
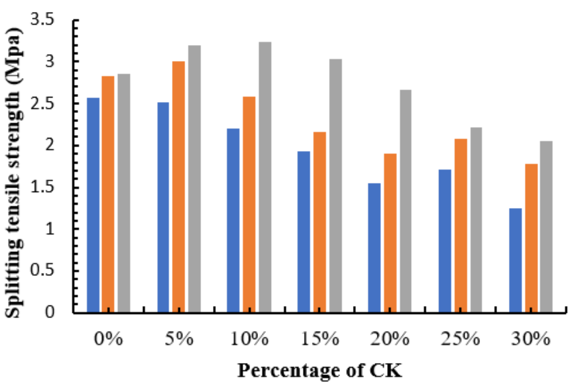


Fig. 10 Compressive strength with CK and GAB content

D. Splitting tensile test

The splitting tensile test was carried out according to the BS 1881-117 [22]. Results also showed the same behaviour in tensile strength as the percentage of calcined kaolin increased the strength decreased, as shown in figure 11. But it was observed that at 14 days, 5% CK had higher power than the control by 5.85% and remained above all dosages containing calcined kaolin. At 28 days, the situation was different with 10% CK which the strength was higher than the control by 11.94% and remained higher than all other dosages of calcined kaolin. Also, at 28 days, 5% CK showed higher tensile strength with an increase of 10.59% above the control. The same trend for 15% CK at 28 days had higher tensile strength by 5.81% than the control. From 20% CK up to 30% CK, the tensile strength was below the control at all days. Clay pozzolana exhibited relatively higher tensile strength, making it better for unreinforced structures like dams under earthquakes. The addition of gum Arabic in concrete increased the tensile strength as the percentage increased, but the increase was insignificant compared to the reference calcined kaolin at 5% and 10%. This could be because of the decrease of SO_3 by 9% to the reference cement, as shown in Table 1. The variations of strength are



illustrated in figure 12.

Fig.11 Splitting tensile with CK content

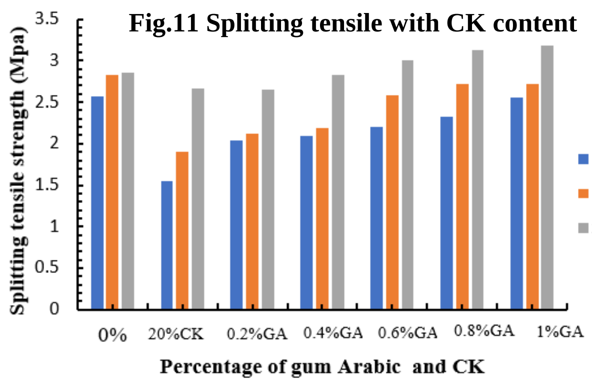


Fig. 12 Splitting tensile with GAB and CK content

E. Flexural strength

The flexural test was carried out as per ASTM C 78 [23]. Similarly, as the percentage of calcined kaolin increased, the flexural strength decreased, as shown in figure 13. But, It was observed that 5% CK at 7, 14, and 28 days the flexural strength was higher than the control by 1.53%, 5.393%, and 5.075%. The same trend for 10% at 14 and 28 days was higher than the control by 3.638% and 0.995%. From 15% to 30% of calcined kaolin, the flexural strength was lower than the control except for 15% at 14 days which strength was higher than the control by 0.2%, but at 28 days, the results were above 4 MPA, which is not bad for concrete. The increase of flexural strength at 5% and 10% could be the high percentage of silicon dioxide content in calcined kaolin. The more the SiO_2 rate is high, the more the dispersion of calcined kaolin is believed to be responsible for the increase of flexural strength. In [18], it was found that when the nano-SiO_2 content was 3%, the nano-modified provided the highest flexural strength at 3, 7, 28, and 90 days. The addition of gum Arabic at 1% for 20% of calcined kaolin at 28 days by 1.258% has improved the flexural strength compared to the references control. As the Arabic gum content increased, the flexural strength increased, as is illustrated in figure 14.

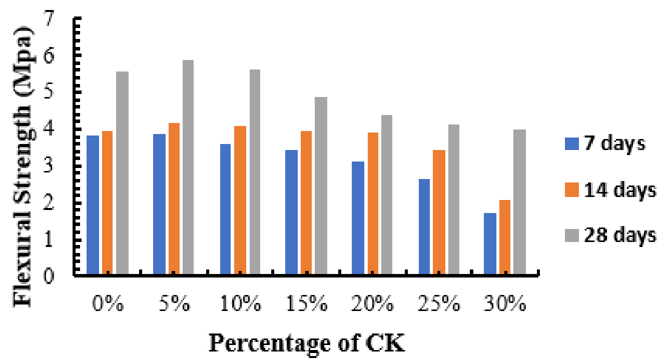


Fig. 13 Flexural strength with CK content

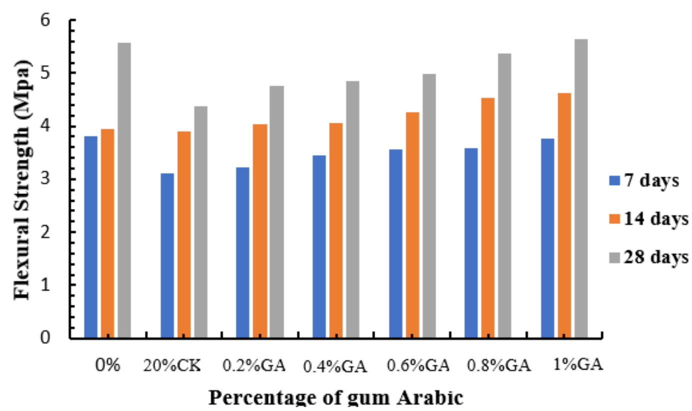


Fig. 14 Flexural strength with GAB and CK content

F. SEM analysis

The SEM test was performed using the magnification of 10 µm and 50 µm to understand the surface morphology of materials. From images 2A and 2B, it can be noticed that the particle size of cement is more significant than that one of calcined kaolin. The presence of calcined kaolin in concrete will occupy more surface area due to its ultra-fineness, which will require more water demand to achieve the requirements of concrete. Image 2C shows that how gum Arabic is constituted of sugars that make it react as an admixture.

IV. CONCLUSION

The influence of adding gum Arabic into concrete mixed with calcined kaolin has been studied. The following are the findings: The chemical composition of gum Arabic mixed with cement and calcined kaolin increased the percentage of lime (CaO) which improved the mechanical properties of concrete. 0.8% AGB is the percentage whereby the high compressive strength was recorded. 0.8% and 1% of gum Arabic are the better percentages to use in concrete as a water-reducing admixture and set retarding. The addition of gum Arabic at 0.8% and 1% concrete showed the bleeding and necessitated more than 24 hours before removing the mould. The addition of gum Arabic increased water absorption due to the presence of the palygorskite and Modernite minerals, which are present in gum Arabic and have a porous structure with high water absorption and high surface area.

For future study, I wish to recommend a survey of the microscopic behaviour of concrete mixed with calcined kaolin in adding gum Arabic.

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