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Effect of Potassium Hydroxide and Sodium silicate as an alkaline Activator on the Properties of GPC

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ملخص البحث:

الخرسانه الجيوبوليمريه هى التطور الجديد فى مجال الانشاءات التى من خلالها يتم عمل احلال كامل للاسمنت بماده بوزولانيه مثل الرماد المتطاير التى يتم تنشيطه باستخدام منشط قلوى . هذا البحث يدرس دراسه معمليه تاثير تركيزات مختلفه من هيدروكسيد البوتاسيوم ونسب مختلفه بين هيدروكسيد البوتاسيوم وسيليكات الصوديوم ونسب منشط قلوى الى الرماد المتطاير على مقاومه الضغط وكذلك التشغيليه.الخرسانه الجيوبوليميريه عباره عن خليط من الركام الكبير والصغير والرماد المتطاير والماء والمنشط القلوى الذى هو عباره عن خليط من هيدروكسيد البوتاسيوم وسيليكات الصوديوم . تم استخدام معالجه حراريه ف درجه حراره 70 درجه مئويه لمده 48 ساعه وتم قياس مقاومه الضغط والكثافه والتشغيليه . اظهرت النتائج ان بزياده تركيز هيدروكسيد الصوديوم تزداد المقاومه حتى نسبه 16 تركيز مولارى , نسبه هيدروكسد بوتاسيوم الى سيليكات الصوديوم 2 اعطى اعلى مقاومه ضغط 75.6 ميجا بسكال ونسبه المنشط الى الرماد المتطاير المثاليه 40% , عناصرالمنشط القلوى تؤثر على التشغيليه ولا تؤثر تاثير ملحوظ على الكثافه .

Abstract

Geopolymer concrete (GPC) is the new development in the field of building constructions in which cement is totally replaced by pozzolanic material like fly ash and activated by alkaline solution. The current paper research experimental investigation on influence of different concentration of potassium hydroxide solution (10M, 12M, 14M, 16Mand 18M) and activator ratio between potassium hydroxide and sodium silicate (.5,2,2.5,3) and different activator/fly ash ratios which were (.35,.4,.45) on compressive strength as well as workability of GPC The GPC is the mixture of coarse aggregate, sand, fly ash, extra water and alkaline solution which is combination of Potassium hydroxide(KH) and sodium silicate (N).. The temperature of oven curing was maintained at 70∘C for heating period of 48 hours and tested for compressive strength at the ages of 3 and 28 days as test period after specified degree of heating. Test results show that Compressive strength of GP increases with increase in molarity of potassium hydroxide (KOH) solution until 16 M, the sodium silicate to potassium hydroxide ratio by mass equal to 2 has resulted in the higher compressive strength (75.6 Mpa) and the ideal ratio of alkaline liquid to fly ash ratio was 40% when we use a combination of sodium silicate/potassium hydroxide as alkaline activator, which gave compressive strength 71.9 Mpa. The alkaline activator is an influencing factor in the workability of GP. The GP density does not change much when one of the component variables of the alkaline activator changes.

1-Introduction

Since the era when Portland cement was invented the cement manufacturing industries are contributing in large emission of greenhouse gas in atmosphere and energy intensive issues [1]. About 2.80T of raw materials along with fuel and other materials are required to produce 1.0T of Portland cement [2]and as a consequence, decarbonation of lime releases about 1.30 billion tons of greenhouse gas [3, 4]. From past 3-4 decades, remarkable evolution has been accomplished in concrete technology to partially or completely eradicate the various ill effects on environment from the aftermath of Portland cement production, one such advancement is GPC (GPC) which is complete replacement of Portland cement by waste products of industries [5].

In GPC high alumina and silica source materials like fly ash and GGBS are widely used along with strong alkali solutions like combination of sodium hydroxide or potassium hydroxide and sodium silicate or potassium silicate. These aluminosilicate materials are converted into eco-friendly binder by undergoing geopolymerization forming 3D network of amorphous aluminosilicate with better physical and chemical properties [6]. The crucial aspect in alkali activation is selection of high alkali activators, their ratios and concentrations

Geopolymerization is divided into 3 phases; in first phase alumina and silica liquefy under high alkaline environment, in second phase the emplacement of liquefied oxides proceeded by gel formation and in third phase silico – aluminate structures are formed in 3D network due to polycondensation [7]. Depending on type of chemical bond, the 3D network of aluminosilicate structures are divided into 3 different structures (a) poly (sialate) (Si-O-Al-O), (b) poly (sialate - siloxo) (-Si-O-Al-O-Si-O), (c) poly (sialate - disiloxo) (Si-O-Al-O-Si-O-Si-O) [8].

Around 440-450 million tons of fly ash and 310 to 370 million tons of GGBS is produced worldwide annually. Only 5-7% of the by-products are used in cement and concrete sectors, this is mainly because fly ash and GGBS idiosyncrasy are not constant [9].

Subhash V. Patankar studied the effect of concentration of sodium hydroxide on compressive strength of fly ash-based geopolymer mortar. Sodium silicate solution containing Na2O of 16.45%, SiO2 of 34.35%, and H2O of 49.20% and sodium hydroxide solution of 2.91, 5.60,8.10, 11.01,13.11, and 15.08. Moles concentrations were used as alkaline activators. Geopolymer mortar mixes were prepared by considering solution-to-fly ash ratio of 0.35, 0.40, and 0.45. Test results show that the workability and compressive strength both increase with increase in concentration of sodium hydroxide solution for all solution-to-fly ash ratios[10]

Sharayu Satpute [11]presented the experimental investigation were total nine different trial combination of alkaline activators are used having concrete grade M30 with 8M molarity at 80 oven curing. From those, three combinations are selected for further studies as KOH + Na2SiO3, NaOH+K2SiO3 and KOH + Ca2SiO3for different molarity for temperature 90. The compressive strength of GPC were carried out during this study and it was observed that, how different alkaline activators effect the strength of GPC. Also it is found that KOH+Na2SiO3combination having maximum strength than other two combinations. Also it is found that KOH + Na2SiO3 and KOH + Na2SiO3is suitable for concrete work.

The effect of the alkaline medium on the strength of alkali-activated natural pozzolans has been investigated and characterized. the effect of the type and form of the alkaline activator, the dosage of alkali and the SiO2/Na2O ratio (silica modulus, Ms) when using water–glass solutions and different curing conditions on the geopolymerisation of natural pozzolans have been studied. The optimum range for each factor is suggested based on the different effects they have on compressive strength. The concentration of dissolving silicon, aluminum and calcium in alkaline solution, the formation of gel phase and the factors affecting this have been studied by using leaching tests, ICP–AES, and FTIR.[12]

Different molarities of sodium hydroxide solution i.e. 8M, 10M and 12M are taken to prepare different mixes and the compressive strength is calculated for each of the mix. The results show that there is increase in comp. strength of GPC with increase in molarity of Sodium Hydroxide Solution[13]

This paper presents an evaluation on compressive strength of fly ash–based geopolymer by using different activator (KOH and NaOH) with respect to different curing conditions (time and temperature) in the absence of sodium silicate It can be observed that the highest compressive strength up65.28 MPa was obtained using NaOH. Meanwhile, synthesis using KOH only recorded 28.73 MPa. The compressive strength was better when cured at elevated temperature (60oC) than room temperature (25oC). Further analysis on the microstructure of the highest compressive strength geopolymer samples for both activators was carried out using Field Emission Scanning Microscopy(FESEM) and Raman spectroscopy.[14]

The current study focuses on effect of different concentrations of potassium hydroxide solution (10M, 12M, 14M, 16Mand 18M), different activator ratios between potassium hydroxide and sodium silicate (.5,2,2.5,3) and different activator/fly ash ratios which were (.35,.4,.45) on workability and compressive strength through a parametric investigation using different lab analysis.

2. Experimental program.

2.1 Materials used

2.1.1 Source Materials

-Class (F) FA complies with the chemical of [ASTM C618] and relevant international quality standards for FA with specific gravity 2.25. The chemical composition of the fly ash, as determined by X-Ray Fluorescence (XRF) analysis, is given in Table 1.

Table (1) Composition of fly ash as determined by XRF (mass %)[15]

Oxides	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	TiO_2	P_2O_5	LOI	Total
(%)	60.25	28.57	4.99	1.19	0.24	0.04	0.01	1.08	2.31	0.52	0.55	99.74

2.1.2. FINE AGGREGATES.

The fine aggregate used in the experimental program was natural siliceous medium well graded sand. Its characteristics satisfy the requirements of [ECP 203/2007-part3]. It was clean and free from impurities, passing through sieve size 4.75 mm with a specific gravity of 2.65 and a fineness modulus of 2.73. The physical properties of the used sand are shown in table (2). The grading of the used sand as well as the limits of [ECP 203/2007] are given in table (3).

Table (2): The physical properties of the used siliceous sand.

Property	Test results	Limits*
Specific weight	2.65	-
Bulk density (t/m3)	1.52	-
Fineness modulus	2.73	-
Material finer than No 200 sieve %	2.6	Less than 3%

Table (3) Grading of used sand.

Sieve size, mm	9.75	4.76	2.36	1.18	.6	.3	.15
Passing %	100	100	96.3	83.25	34.3	11.5	1.62
% Passing ECP [203/2007]	100	89-100	60-100	30-100	15-100	5-70	0-15

2.1.3. COARSE AGGREGATE.

The coarse aggregate used was crushed lime stone, which satisfies the requirements of [ECP 203/2007]. The specific gravity was 2.6. The delivered crushed lime stone had a maximum nominal size of 10 mm. The physical and mechanical properties of the crushed dolomite are shown in the Table (4). On the other hand, the grading as well as the limits of [ECP 203/2007] for the used coarse aggregate are presented in Table (5).

Table (5) Physical and mechanical properties of coarse aggregate.

Property	Test results	Limits*
Specific weight	2.60	-
Bulk density (t/m3)	1.36	-
Coefficient of abrasion (Loss Angloss) %	20	Less than 30
Coefficient of impact %	18	Less than 30
Crushing value %	29	Less than 30
Absorption %	1.8	Less than 2.5
Clay and fine dust content %	1	Less than 3.0

Table (6): Grading of used coarse aggregate.

Sieve size, mm	14	10	5	2.36
Passing %	100	95	7	0
% Passing ECP [203/2007]	90-100	50-85	0-10	0

2.1.4 THE ALKALINE LIQUID

A combination of sodium silicate (Na_2O = 14.7%, SiO_2 = 29.4% and water = 55.9% by mass) [16]and potassium Hydroxide The sodium hydroxide (NaOH) and potassium Hydroxide (KOH) solids were a commercial grade in form of pellets with 96% purity. KOH solutions was prepared one day before the casting of GPC during which it pass by some exothermic procedure thus results in the reduction of heat. [17].

The mass of KOH solids in a solution varied depending on the concentration of the solution expressed in terms of molar, M as shown in table (7). in this experimental work, KOH solution with a concentration of 10M consisted of 10x56.11 = 561.1 grams of KOH solids (in pellet form) per liter of the solution, where 56.11 is the molecular weight of KOH[11].

Table (7) properties of alkaline activator.

Alkaline activator type	molecular weight	Chemical formula
potassium Hydroxide	56.1056 g/mol[18]	1 KOH

4.1.5. WATER.

Faucet water free from impurities was used for preparing alkaline solution and Mixing according to the requirement of the [ECP 203/2007].

4.2. PREPARATION OF THE SOLUTION.

A combination of sodium silicate solution and potassium hydroxide solution was chosen as the alkaline liquid. The potassium Hydroxide (KOH) solids were a commercial grade in form of pellets with 96% purity. The potassium hydroxide (KOH) solution was prepared by dissolving either the flakes or the pellets in water.

4.3. CASTING OF CONCRETE MIXES.

The blending method utilized for GPC is like that of customary OPC concrete. Blending of the considerable number of materials is done in the laboratory at room temperature. The fly ash and the aggregate is mixed together in concrete pan mixture. The blending is permitted to proceed for around 3 to 4 minutes. The alkaline solution which was prepared one day before is added with additional water in the mix. The liquid component is added to the dry material and mixing is continued for another 3 to 4 minutes. The fresh concrete is casted into the molds immediately after mixing in two layers for prismatic specimens. For compaction of the concrete specimens, each layer is given 25 to 35 manual strokes using 20 mm rod. Concrete specimens are vibrated using vibration table for another 10 to 15 seconds. After the casting, the concrete specimen was kept at room temperature as per the decided rest period.

4.4. CURING OF CONCRETE SPECIMEN.

The concrete specimens were warmth restored in stove at 80°C up to the finishing of curing time. After the curing period, the test examples left in the molds for in any event 4-6 hours so as to stay away from a major change in the natural conditions. In the wake of demolding, the concrete specimens are permitted to progress toward becoming air-dry in the laboratory until the day of the testing.

4.5. Testing methods.

4.5.1Workability

Workability is the ease of working with a freshly mixed concrete in the stages of handling, placing, compacting and finishing. Slump test is used as a common test for measuring the workability of concrete. The workability of fresh GPC was determined immediately after mixing of the concrete by the standard slump test in accordance with the ASTM: C 143 -12[19].

4.5.2 Compressive strength.

Compressive strength is the most common property used to describe a concrete. Since other properties of concrete often correlate well with the compressive strength. it is used as an indicator of the other mechanical properties.[20],a universal testing machine was used to test the compressive strength of GPC concrete at 7and 28, where the constant rate of loading was set as 6 kN/s.

5-Experimental plan.

Table (8) Ingredients for geopolymer mixes

Group. No.	**Ingredient ID**	**Fly ash, kg/m3**	**CA kg/m3**	**FA kg/m3**	**KH (kg/m3)**	**KH M**	**NS kg/m3**	**KH/NS**	**W kg/m3**
G1	KF10	428	1200	500	55	10	138	2.5	22
	KF12	428	1200	500	55	12	138	2.5	22
	KF14	428	1200	500	55	14	138	2.5	22
	KF16	428	1200	500	55	16	138	2.5	22
	KF18	428	1200	500	55	18	138	2.5	22
G2	KF2	428	1200	500	64	14	128	2	22
	KF2.5	428	1200	500	55	14	138	2.5	22
G3	NF35	494	1200	500	49.4	14	123.5	2.5	22
	KF40	460	1200	500	52.5	14	131.5	2.5	22
	KF45	428	1200	500	55	14	138	2.5	22

The table (8) consists of three groups each group has been allocated to study the impact of one variable on the compressive strength in the early age after 3 days and late age after 28 days.

Table (9): Test results of concrete.

Ingredient ID	Density (t/m3)	Slump (cm)	Compressive strength (MPa)	
			7-days	28-days
KF10	2.32	190	30.1	32.95
KF12	2.33	170	31.2	36.7
KF14	2.38	150	44.4	48.2
KF16	2.41	140	54.9	62.1
KF18	2.46	120	41	45.2
KF2	2.45	130	64.8	75.6
KF2.5	2.38	150	44.4	48.2
NF35	2.39	100	61.6	70.8
KF40	2.37	120	63.1	71.9
KF45	2.38	150	44.4	48..2

Mixes in group 1 have been cast to study the effect of concentration of potassium hydroxide solution on the properties of GPC. The contrast between Mixes as far as variety in Concentration of sodium hydroxide solution starting at a concentration of 10M with a constant increase rate of 2M.

Mixes in group 2 have been cast to study the effect of Ratio of sodium silicate solution to potassium hydroxide solution on the properties of GPC. The contrast between Mixes as far as variety in Ratio of sodium silicate solution to potassium hydroxide solution.

Mixes in group 3 have been cast to study the effect of Ratio of alkaline liquid to fly ash on the properties of GPC. Mixes as far as variety in Ratio of alkaline liquid to fly ash starting at ratio .35 with a constant increase rate .05.

6-RESULTS AND DISCUSSION.

6.1. Workability.

There are several factors that can be affect the slump value of fresh geopolymer which are moisture content of aggregates, variation of ambient temperature, mixing time and degree of condensation reaction between binder and alkaline solution [21].

6.1.1Effect of molarity of potassium hydroxide.

From figure1, it can be found that the workability of GP decreased with the increase of KH molarity This is mainly because that the increase of KH molarity increased the viscosity of the solution**.** This is similar to the effect of sodium hydroxide on GP slump values As mentioned by F.A. Memon [22]

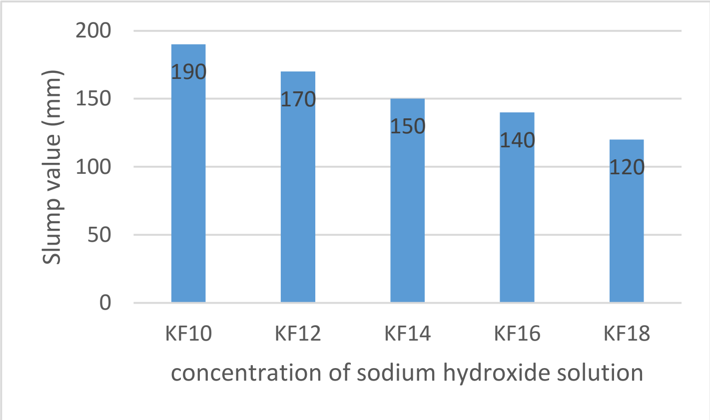

Figure 1: Effect of concentration of potassium hydroxide on flow of GPC for solution-to-fly ash ratio 45.

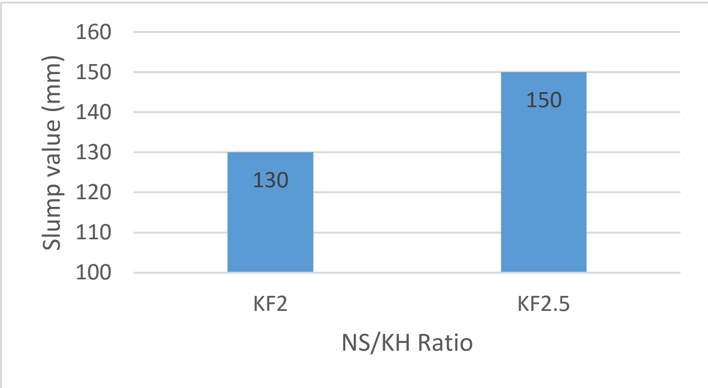

Fig. 2: Effect of alkaline ratio on workability (slump value) of GPC

6.1.2 Effect of alkaline ratio .

It is observed that the workability increases with increase in solution-to-fly ash ratio as shown in fig.2. As sodium silicate–to-potassium hydroxide ratio increases, the mix was more and more viscous which reduces the rate of gain of workability.

6.1.3. Effect of alkaline liquid to fly ash ratio.

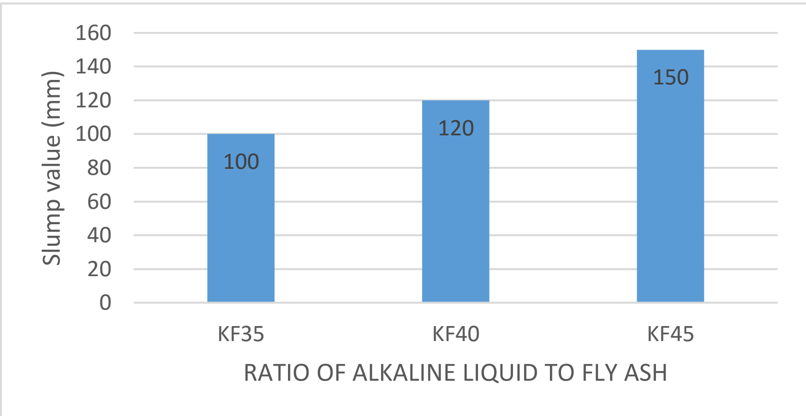

Figure 3: Effect of alkaline liquid to fly ash ratio on workability of GPC.

Figure 3 show slump values increase with the increase in the rate of alkaline activator. When comparing the results of mix KF40 with mix KF35, we notice an increase of 20%, and also when increasing the rate of alkali activator to 45% of the fly ash, we find that the value of the slump increased by 25%.

6.2. DENSITY.

The density of concrete primarily depends on the unit mass of aggregates used in the mixture. Because the type of aggregates in all the mixtures did not vary, the density of the low-calcium fly ash-based GPC varied only marginally between 2330 to 2430 kg/m3[23].

6.1.1. Effect of molarity of sodium hydroxide solution.

Figure 4 shows a slight increasing trend density of GPC parallel to the increasing in molarity of potassium hydroxide solution Whereas when comparing the density of the mix (KF10) with the density of the mix(KF18), we find an increase in density of only 6%.

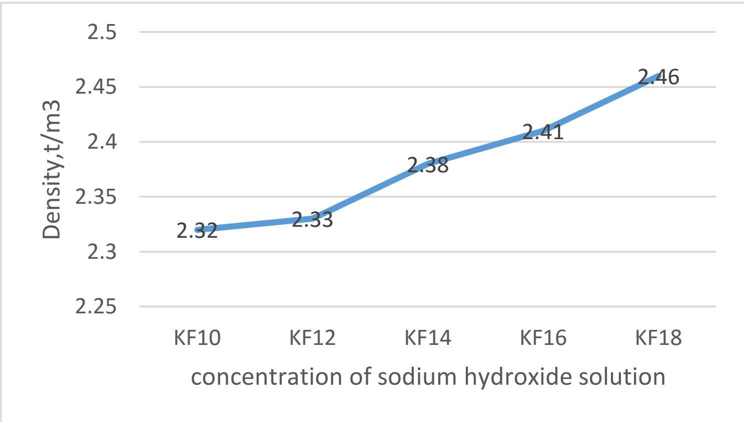

Figure 4: Effect of concentration of potassium hydroxide on density of GPC for solution-to-fly ash ratio 45.

6.2.2 Effect of alkaline ratio.

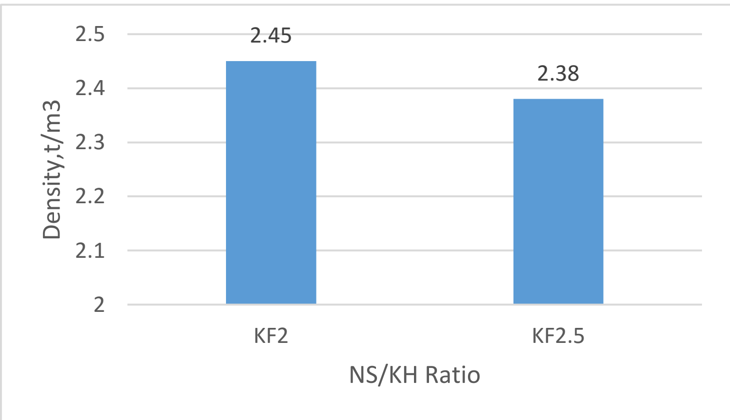

Fig. 5: Effect of alkaline ratio density of GPC

Figure.5 shows that by comparing the first mixture with the second, we find a slight decrease in the density of concrete by only 3%, and therefore we find that by increasing the ratio of silicates to hydroxide the density decreases by almost negligible value.

6.2.3. Effect of alkaline liquid to fly ash ratio.

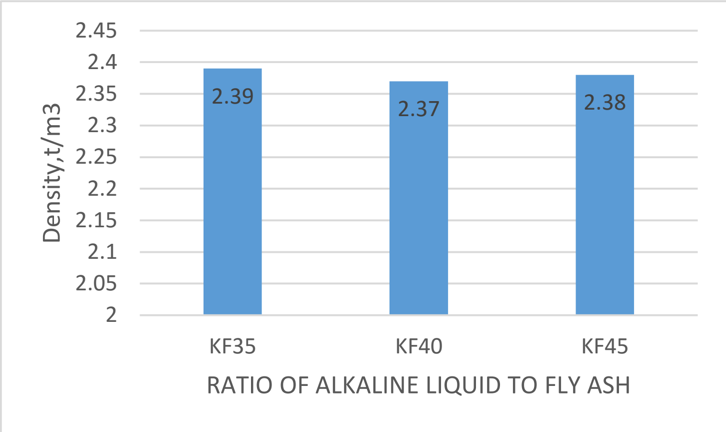

Figure 6: Effect of alkaline liquid to fly ash ratio on workability of GPC.

figure.6 shows that the ratio of alkaline activator to fly ash does not affect the density of concrete significantly.

6.3. Compressive strength.

Compressive strength is one of the most important mechanical properties of concrete. According to ACI 318 M-05 [24], the 28-d compressive strength of concrete need to achieve at least 28 MPa for the basic engineering application.

6.3.1 Effect of molarity of potassium hydroxide solution.

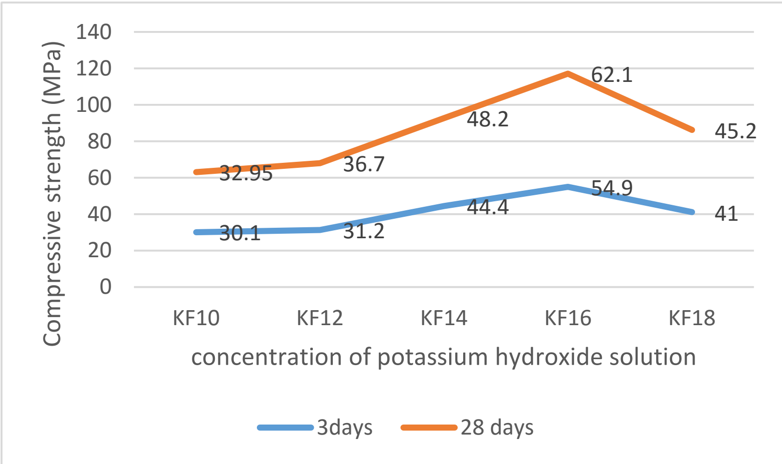

Figure 7: Compressive strength of concrete with different molarity of potassium hydroxide solution.

Fig. 7 shows the effect of molarity of KH on compressive strength of GP. It can be noted that compressive strength increased slightly by 11% when we increased molarity from 10M to 12M, then it increased significantly by 70% when we increased molarity from 12M to 16M, then It is greatly reduced by 37% When we continue to increase molar concentration until 18M. The rate of compressive strength growth from the age of 7 days to 28 days is high in concentrations 10M and 12M, and then decreases by increasing the molar concentration. which can be explained by the reaction of the internal Si, Al and Ca components caused by the increased breakage of the T-O-T bonds (T: Si or Al) in FA provoked by the high alkalinity resulting from the increasing molarity of SH [11].

6.3.2Effect of sodium silicate/potassium hydroxide solution ratio.

Fig. 8 shows the compressive strength of GP with different SS/KH ratios of 2 (KF2) and 2.5 (KF2.5), increasing NS/KH ratio showed a decrease of the compressive strength. The highest compressive strength was recorded at NS/NH= 2 as 75.6MPa.

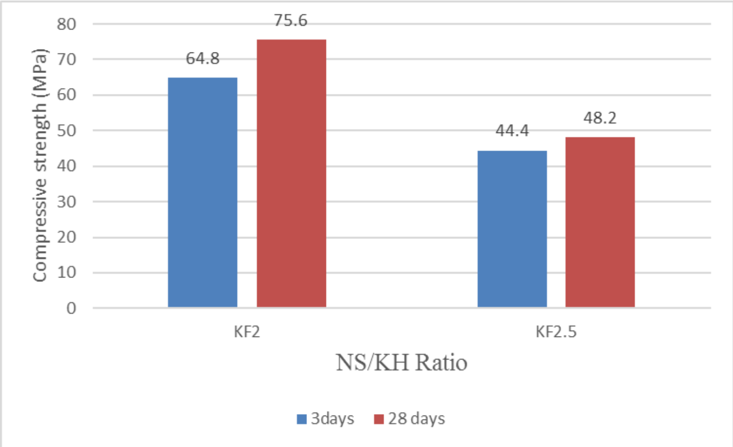

Fig. 8: Effect of sodium silicate solution to potassium hydroxide solution ratio on compressive strength.

6.3.3. Effect of alkaline liquid to fly ash ratio.

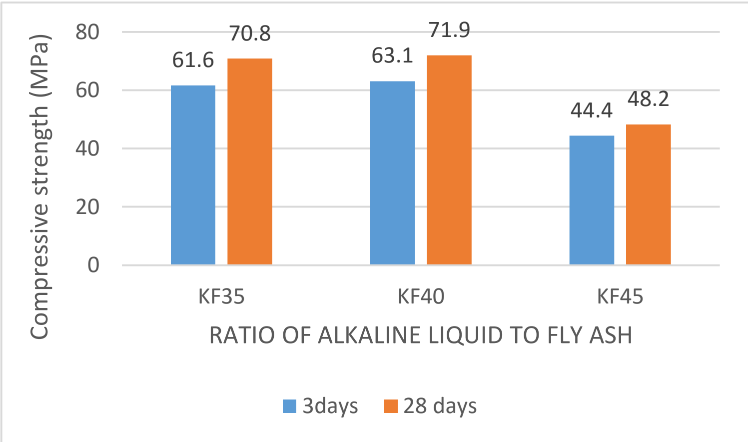

Figure 9: Effect of alkaline liquid to fly ash ratio on compressive strength.

The Figure.9 shows that the value of compressive strength between mix(KF35) and mix(KF40) did not change much, only 2%, while it decreased when the alkaline liquid to fly ash ratio increased to 45% by 42%. so, the ideal ratio of alkaline liquid to fly ash ratio was 40% when we use a combination of sodium silicate/potassium hydroxide as alkaline activator, which gave pressure resistance 71.9 Mpa.

7-CONCLUSIONS

Based on the experimental work in this paper the following conclusions can be driven:

1-The alkaline activator is an influencing factor in the workability of GP, as it decreases with increasing molar concentration of potassium hydroxide and increases with an increase in the sodium silicate/potassium hydroxide solution ratio and an increase in the alkaline liquid to fly ash ratio.

2- The GP density does not change much when one of the component variables of the alkaline activator changes, whether its concentration, its ratio, or its ratio to fly ash, where the value of the difference between the lowest and highest value is 6%, which is negligible.

3- Compressive strength of GP increases with increase in molarity of potassium hydroxide (KOH) solution until 16 M concentration so Mix (16) give the best compressive strength which is equal to 62.1 Mpa, this was due to progressive gel formation and geopolymerization which results in denser pore structure making it more homogenous by filling up the void fractions.

4- The sodium silicate to potassium hydroxide ratio by mass equal to 2 has resulted in the higher compressive strength (75.6 Mpa) as compared to the ratio of 2.5 by increase 40%.

5- The ideal ratio of alkaline liquid to fly ash ratio was 40% when we use a combination of sodium silicate/potassium hydroxide as alkaline activator, which gave compressive strength 71.9 Mpa.

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