Engineering and Technology Journal
Journal homepage: https://etj.uotechnology.edu.iq

A Proposed New Mix Proportioning Method for Fly Ash-Based Geopolymer Concrete

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HIGHLIGHTS

- A new mix proportion design for fly ash geopolymer concrete is proposed.
- The method allows the use of any sodium silicate solution, with the addition of flakes or pellets of sodium hydroxide.
- There is no need to prepare sodium hydroxide at a specific molarity; it simplifies the process.
- Compressive strength can be predicted accurately using the proposed Equation.

ARTICLE INFO

Handling editor: Wasan I. Khalil

Keywords:
Geopolymer Concrete
New Mix proportion design
Fly Ash
Sodium Silicate
Sodium Hydroxide

ABSTRACT

Global warming on planet Earth results from the high emission of greenhouse gases, especially CO_2. The Portland cement industry releases high amounts of CO_2 and is responsible for about 5-8% of total emissions. Efforts have been made to look for alternative cementless binders to mitigate the impact on the environment. Geopolymers are one of the highlighted alternatives and can be obtained from the reaction of any aluminosilicate material with an alkaline solution. Aluminosilicate materials are found in byproduct materials such as fly ash. Geopolymer concrete is a promising environmentally friendly option. However, previous conventional mix proportioning methods for fly ash-based Geopolymer concrete have been limited. Most of these methods focused on a single weight ratio of SiO_2/Na_2O, which was 2. However, the sodium silicate solution is produced industrially with various concentrations depending on the weight ratio of SiO_2/Na_2O. Adding sodium hydroxide to the sodium silicate solution increases the alkalinity of the resulting activation liquid. This work proposes a new mix proportioning procedure named the "Ratio of the Resulting Sodium Silicate Method for Geopolymer Binder." The method has been successfully verified to achieve the desired compressive strength on the 7th and 28th days. We also tested different control specimens from previous studies using this new proposal to study the effect of different parameters on compressive strength predictions.

1. Introduction

Developments of Infrastructure had been increased rapidly in the last two decades. Consequently, the demand for concrete has increased wildly. About 17.2 billion tons were estimated to be the annual consumption of concrete worldwide [1]. Conventionally, cement is the main binder to produce concrete. It has been reported that cement production has reached about 4.2 billion tons since 2014 [1]. The cement industry releases carbon dioxide, CO_2 into the atmosphere. Each ton of cement production will cause to release about one ton of CO_2 [2,3]. Carbon dioxide is one of the greenhouse gases, GHG, that are mostly responsible for global warming. It is found that 65% of global atmosphere warming is caused by carbon dioxide [3]. Therefore, the cement industry circumstantially contributed to some of the global warming.

Many efforts have been made to minimize the increase of global warming by producing environmentally friendly concrete. One of these efforts was partially replacing cement with supplementary materials like Fly Ash, Silica Fume, Metakaolin, Rice Husk Ash, and Granulated Blast furnace Slag to produce concrete. Other efforts were to find alternative binders instead of cement to produce concrete.

Geopolymer is one of the highlighted alternative binders to produce cement-less concrete [4]. It was reported that Geopolymer can significantly decrease CO_2 emission by up to 80% [2]. On the other hand, many types of research had been found that the mechanical properties of Geopolymer concrete, GPC, are superior to Portland cement concrete, PCC, such as better fireproofing, lower permeability, a higher resistance in both acid and salt environments and providing a viable use for 'waste' materials which are often disposed of in landfill [5].

http://doi.org/10.30684/etj.2023.139354.1427
Received 28 March 2023; Received in revised form 23 June 2023; Accepted 26 June 2023; Available online 20 September 2023
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Generally, a Geopolymer binder is obtained from the reaction of any aluminosilicate material with an alkaline solution. The binder is the main difference between PCC and GPC. The aggregate similarly occupies 60-80% of the mass of the concrete [5]. The consideration and the influence of the combination of coarse and fine aggregates take the same role used for PCC. The GPC is formed due to the binding of aggregate particles and other unreacted material together by the Geopolymer paste. Up to date, none of the previous studies on the mix design of fly ash Geopolymer concrete are concerned with the type of sodium silicate solution, i.e., the molar ratio of SiO_2:Na_2O. Hardjito and Rangan [5], depending on one specific type of sodium silicate solution, proposed simplified guidelines after a series of experiments of trials of mixes considering the compressive strength and workability as performance criteria. They use type A53 sodium silicate, which has a weight ratio of SiO_2:Na_2O of 2:1; other commercial sodium silicate types with different weight ratios of SiO_2:Na_2O were not included in their work. Jarvis [6] studied the mix design process of fly ash Geopolymer concrete by gathering data from numerous test results and putting them in a graph to outline the mix design, he claimed that a full mix design process has not been investigated yet and all previous studies/results publish results for limited mixture proportion examples. Nevertheless, he used one type of sodium silicate because the molar ratio of SiO_2:Na_2O of the sodium silicate solution is pre-mixed and cannot be varied. According to this, the recommendations concluded by Jarvis [6] do not apply to a wide range of activation liquids. Ferdous and Khennane [7] proposed a mix design based on the volume of the constituents of material of fly ash Geopolymer concrete by dividing each material on its specific gravity and including the air volume, and adjusting the volume when a superplasticizer is used. However, they also used one type of sodium silicate and a fixed ratio of sodium silicate solution to sodium hydroxide solution.

Commercially, many types of sodium silicate solutions are produced. The type or the kind of silicate solution in the industry is decided by the weight ratio WR SiO_2: Na_2O Davidovits [8]. Moreover, Chemically, adding sodium hydroxide solution to sodium silicate solution of a specified molar or weight ratio of SiO_2:Na_2O will produce a sodium silicate solution. Still, with a different molar or weight ratio of SiO_2:Na_2O, i.e., the molar ratio of SiO_2:Na_2O of sodium silicate solution can be changed or specifically decreased by the addition of sodium hydroxide solution due to the extra added moles of Na_2O. The NaOH solids comprise Na_2O and Water Davidovits [8], as shown in Equation 1:

$$2NaOH \Leftrightarrow Na_2O + H_2O \quad (1)$$

Therefore, according to the above, manufacturing geopolymer concrete is a limited practice depending on one type of sodium silicate solution. The main significance of this research is to develop a new mix proportion design for manufacturing fly ash Geopolymer concrete using any commercial type of sodium silicate solution.

2. Materials and Experimental Work

2.1 Fly Ash

A hard coal class F fly ash from the power station of Iskenderun- Turkey was used as source material for GPC. The X-Ray Fluorescence, XRF, results are shown in Table 1, and the particle size distribution is shown in Figure 1.

Table 1: Fly Ash Chemical Composition Analysis

Component	SiO_2	Fe_2O_3	Al_2O_3	CaO	MgO	SO_3	L O I	Na_2O	K_2O
Mass %	65.65	5.98	17.69	0.98	0.72	0.19	3.1	1.35	2.99

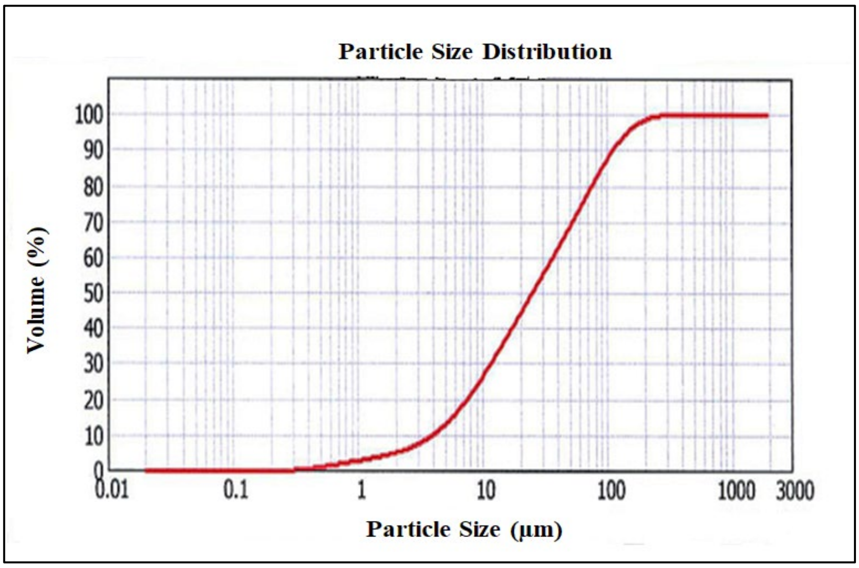

Figure 1: Fly ash particle size distribution

2.2 Combined Alkaline Liquid

The alkaline liquid is obtained by blending sodium silicate and sodium hydroxide solutions. Two types of sodium silicate solutions of two different weight ratios of SiO_2:Na_2O were adopted. The weight ratios are 2:1 and 2.4:1 [8]. The concentrations were; SiO_2=29.5%, Na_2O =14.75% and H_2O=55.75% for the first type (Z) and SiO_2 =32.4%, Na_2O =13.5%, and H_2O =55.75% for the second type (U). The local market provided a commercial type of NaOH pellets or flakes with 97% purity. The sodium hydroxide solution was simply prepared by dissolving the NaOH flakes in tap water with different concentrations as required.

2.3 Aggregate

Crushed gravel, coarse aggregate, and natural sand, fine aggregate, were employed to produce the GPC mixes. Table 2 lists the all-in grading and its compliance with BS882:1992.

Table 2: Coarse and fine aggregate sieve analysis and combination

Sieve size (mm)	Crushed Coarse Aggregate, (10 mm)	Natural Fine Aggregate	Combination Aggregate 65% CCA+35%NFA	BS882:1992
14	99.84	100.00	99.90	100
10	92.22	100.00	94.94	95-100
4.75	12.23	94.51	41.03	30-65
2.36	0	78.52	27.79	20-50
1.18	0	62.24	21.91	15-40
0.6	0	48.65	17.15	10-30
0.3	0	22.28	7.91	5-15
0.15	0	3.90	1.46	0-18

2.4 High-Range Water Reducer

High-range water reducer based on modified sulfonated naphthalene formaldehyde condensate was used to enhance the workability of fly ash-based GPC. It was named commercially as KUT PLAST SP 400.

3. Proposed Proportioning Method

Two types of sodium silicate can differ in the molar or weight ratio of SiO_2:Na_2O but have the same specific gravity [9]. The addition of sodium hydroxide solution can decrease the molar ratio of SiO2:Na2O of sodium silicate solution due to the extra added moles of Na_2O.

The exact calculations for (the US patent) invented by Silverstrim et al. [10] were done in the current study, as detailed in Appendix A. These calculations were confirmed correct by Davidovits in [11]. Based on these calculations, a new procedure for mix proportioning was proposed in the following four steps:

1- Specifying the Ratio of SiO2:Na2O by mass of the alkaline liquid (Ratio of alkalinity), namely (R_a)

$$R_a = \frac{\text{weight of } SiO_2 \text{ in the alkaline liquid}}{\text{weight of } Na_2O \text{ in the alkaline liquid}} = \frac{Si_S \times S}{C \times H \times \frac{mwNa_2O}{2 \times mw\ NaOH} + Na_S \times S} \quad (2)$$

where Si_s=weight ratio of SiO_2 in the sodium silicate solution, S=weight of sodium silicate solution, C=weight concentration of sodium hydroxide solution, H=weight of sodium hydroxide solution, mw=molecular weight, Na_2O=62, NaOH=40, 62/(2x40) =0.775, and Na_s=weight ratio of Na_2O in the sodium silicate solution.

Equation 2 can be simplified as follows:

$$S(R_a \times Na_s - Si_s) + H(R_a \times 0.775 \times C) = 0$$

2- Specifying the water ratio in the alkaline liquid (R_w)

$$R_w = \frac{\text{weight of water in the alkaline liquid}}{\text{weight of alkaline liquid and extra water}} = \frac{w_S \times S + (1-C) \times H + C \times H \frac{mwH_2O}{2 \times mwNaOH} + W}{S+H+W} \quad (3)$$

where w_s= weight ratio of water in the sodium silicate solution, mwH_2O=18, 18/(2x40) =0.225, and W= the weight of extra water.

Equation 3 can be written as:

$$S(Rw - ws) + H(Rw + 0.775C - 1) + W(Rw - 1) = 0$$

3- Specifying the ratio of the weight of alkaline liquid to the weight of Fly Ash or Binder Ratio (R_b)

$$R_b = \frac{\text{weight of alkaline liquid}}{\text{weight of fly ash}} = \frac{S+H+W}{Fl} \tag{4}$$

4- Calculating the weight of binder components (Bw) as shown in Eqution 5.

$$S+H+W+Fl=Bw \tag{5}$$

where Bw=weight of binder components, where Bw depends on the unit weight of fly ash-based GPC. The unit weight of fly ash-based GPC has been experimented according to the previous studies. It was found that it ranged between 2330 kg/m^3 to about 2430 kg/m^3. Hardjito and Rangan [5]. Similarly to Portland cement concrete, they assumed that the aggregate comprises 75-80% of the weight of the mixture. Hence the binder comprises 20-25% of fly ash-based GPC.

The four Equations 2, 3, 4, and 5 can be finally arranged as follows:

$$S.a1 + H.b1 + W.c1 + Fl.d1 = 0 \tag{6}$$

$$S.a2 + H.b2 + W.c2 + Fl.d2 = 0 \tag{7}$$

$$S.a3 + H.b3 + W.c3 + Fl.d3 = 0 \tag{8}$$

$$S.a4 + H.b3 + W.c4 + Fl.d4 = Bw \tag{9}$$

where $a_1=(R_a \times Na_s - Si_s)$, $b_1=(R_a \times 0.775 \times C)$, $c_1=0$, $d_1=0$, $a_2=(R_w - w_s)$, $b_2=(R_w+0.775C-1)$, $c_2=(R_w-1)$, $d_2=0$, $a_3=1$, $b_3=1$, $c_3=1$, $d_3=-R_b$, $a_4=1$, $b_4=1$, $c_4=1$, and $d_4=1$

The above four Equations 6, 7, 8, and 9 can be written in matrix forms as follows:

$$\begin{bmatrix} a_1 & b_1 & 0 & 0 \\ a_2 & b_2 & c_2 & 0 \\ 1 & 1 & 1 & d_3 \\ 1 & 1 & 1 & 1 \end{bmatrix}^{-1} \times \begin{bmatrix} 0 \\ 0 \\ 0 \\ Bw \end{bmatrix} = \begin{bmatrix} S \\ H \\ W \\ Fl \end{bmatrix} \tag{10}$$

It is worth noting that if the weight concentration of NaOH solution C is substituted by 1 instead of the weight concentration of NaOH solution, the H value will be the weight of the NaOH solids or flakes and W will be the weight of total water (the weight of water needed for dissolving NaOH solids + extra water if any), i.e. not to be concerned about concentration or molarity of the NaOH solution, simply substituting C=1, and the method will compute the required NaOH flakes or pellets and the required total water for the mixture. This method can calculate the mix proportions of fly ash-based GPC binder using any type of sodium silicate at any concentration of sodium silicate solid and any weight ratio SiO_2:Na_2O.

4. Results and Discussion

To verify the applicability of the proposed method, two types of sodium silicate were used for manufacturing two mixtures of fly ash-based GPC having the same ratios of Ra, Rw, Rb, and Bw. The compressive strength was approximately equal for the two mixtures at the selected ages as shown in Table 3. This is due to the weight ratio of SiO_2:Na_2O of the resulting sodium silicate in each mixture being equal which is R_a. In addition, the water ratio R_w is also equal in the two-resulted sodium silicate. While the slump is significantly different due to the difference in viscosity, the higher viscosity of sodium silicate solution gives lower workability. Lower WR SiO_2:Na_2O of sodium silicate solution consumes lower NaOH pellets. Distinctly, the weight concentration or molarity of NaOH was not used in the calculation of the two mixtures; the pellets or flakes of NaOH in mixture Z was dissolved directly in sodium silicate solution, whereas in mixture U the NaOH flakes dissolved in water. The New mix design method can compute mix proportions even for low-concentration sodium silicate solutions.

Table 3: Comparison between two types of sodium silicate mixtures

Design ratio R_a= 1.25, R_w=0.6885, R_b= 0.511, B_w=529 kg, C=1											
Mixture Z sodium silicate solution						**Mixture U sodium silicate solution**					
Na_2O= 14.75%, SiO_2 =29.5% →WR=2 Water=55.75% viscosity =310cp						Na_2O=13.5%, SiO_2=32.4% →WR=2.4 Water=54.1% viscosity =1800cp					
Material kg						**Material kg**					
S	**H**	**W**	**Fl**	**C.agg**	**f.agg**	**S**	**H**	**W**	**Fl**	**C.agg**	**f.agg**
162.95	11.98	3.97	350	1200	650	95.56	15.31	68.03	350	1200	650
Slump=160mm 3-day compressive strength= 19.8 MPa 7-day compressive strength=23.2 MPa 28-day compressive strength=24.5 MPa						Slump=85mm 3-day compressive strength= 18.9 MPa 7-day compressive strength=22.8 MPa 28-day compressive strength=23.9 MPa					

The newly proposed method was also verified with mixtures from the literature [5]. Using one type of sodium silicate solution showed that the compressive strength increased when the mass ratio of sodium silicate solution to sodium hydroxide solution increased from 0.4 to 2.5. When this ratio is fixed and increasing the concentration of NaOH solution, the compressive strength also increases. The four mixtures used for this part are shown in Table 4.

Table 4: RRSSMGB analyses of Hardjito and Rangan, [5] mixtures

Mix No.	S kg	H solution kg	W kg	Fl kg	7day Compressive Strength Dry cured At 60°C for 24 hours MPa	R_a	R_w	Total Water In mixture kg	R_b
1	48 Water=26.8 Solids=21.2	120 (8M) C=0.2623 Flakes=31.5 Water=88.5 Ex. w=7*	0	476	17	0.449	0.729	122.3	0.353
2	120 Water=67.1 Solids=52.9	48 (8M) C=0.2623 Flakes=12.6 Water=35.4 Ex.water=2.8*	0	476	57	1.288	0.627	105.3	0.353
3	48 Water=26.8 Solids=21.2	120 (14M) C=0.4043 Flakes=48.5 Water=71.5 Ex.water=10.9*	0	476	48	0.361	0.65	109.2	0.353
4	120 Water=67.1 Solids=52.9	48 (14M) C=0.4043 Flakes=19.4 Water=28.6 Ex.water=4.3*	0	476	67	1.08	0.595	100	0.353
Sodium silicate solution 14.7% Na2O, 29.4%, 55.9%, WR=2 Total combined aggregate 1848 kg									

*22.5% of NaOH solids are water released when dissolving see Equation 3

The relation between compressive strength and NaOH molarity from Hardjito and Rangan, [5] is shown in Figure 2, and the relation between compressive strength and mass ratio of sodium silicate solution to NaOH solution Hardjito and Rangan, [5] is shown in Figure 3.

Figures 2 and 3 show no real defined relation between compressive strength and NaOH molarity or S/H. In Table 5, for the same quantity of NaOH solution, increasing the Molarity of NaOH, i.e., increasing the concentration, means more NaOH flakes and less water for mixtures 1 and 3, the same thing in mixtures 2 and 4. When the mass ratio of the sodium silicate solution was increased to NaOH, the water also decreased for mixtures 1 and 2 or 3 and 4.

Obviously, the increase in compressive strength was due to the reduction of total water in mixtures; mixture 1 has the highest amount of water and the lowest compressive strength. When the rate of reduction of water is high, the rate of increment of compressive strength is also high, as in between mixtures 1 and 2, and when the rate of reduction of water is low, the rate of increment is low, as in between mixture 2 and 4 or 2 and 3 or 3 and 4. Actually, the relation between the total water in the mixture and compressive strength is linear, and the RRSSMGB shows that simply by the Ratio of water $R_{w,}$ as shown in Figures 4 and 5.

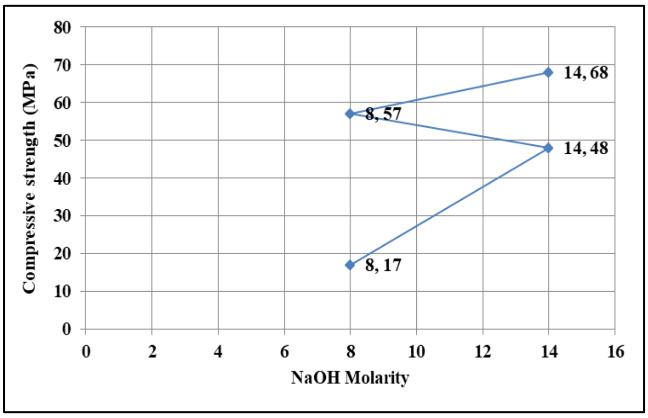

Figure 2: Compressive strength with NaOH Molarity

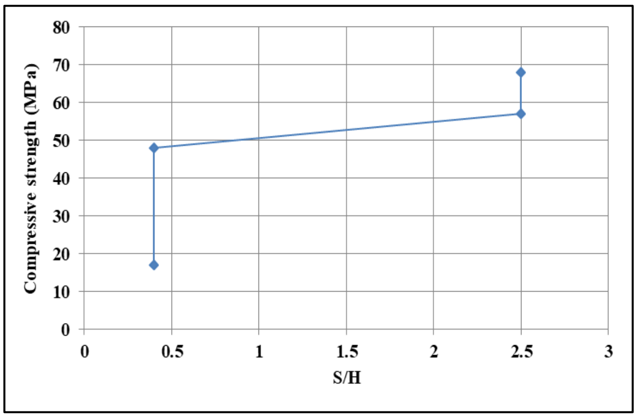

Figure 3: Compressive strength with S/H

Table 5: Calculated 7th-day compressive strength using equation 6 for Mixtures of other studies

Material	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 12	Mix 13	Mix 14	Mix 15	Mix 16	Mix 17	Mix 18	Mix 19	Mix 20
S	48	120	48	120	103	103	103	103	103	103	103	103	103	103
H	120	48	120	48	51.5	41	41	41	41	41	41	41	41	41
W	0	0	0	0	16.5	0	0	10.7	21.3	0	7.5	14.4	20.7	26.5
FL	467	467	467	467	408	408	408	408	408	408	408	408	408	408
size of aggregate mm	20	20	20	20	7	10	20	20	20	10	10	10	10	10
S.P	na	na	na	na	na	6.1	8.2	8.2	8.2	6.1	6.1	6.1	6.1	6.1
Molarity	8	8	14	14	14	8	14	14	14	8	10	12	14	16
$\sigma_{7th\ day}$	17	57	48	68	42**	63	59	60*	44	55	53	51	45	47
C	0.2623	0.2623	0.4043	0.4043	0.4043	0.2623	0.4043	0.4043	0.4043	0.2623	0.3137	0.3609	0.4043	0.4444
Ra	0.4487	1.2877	0.3160	1.0795	0.9682	1.2899	1.0819	1.0819	1.0819	1.2899	1.2060	1.1380	1.0819	1.0348
Rw	0.7288	0.6269	0.6501	0.5954	0.6400	0.6266	0.5953	0.6233	0.6474	0.6266	0.6343	0.6408	0.6462	0.6507
Rb	0.3597	0.3597	0.3597	0.3597	0.419	0.3529	0.3529	0.3791	0.4051	0.3529	0.3713	0.3882	0.4036	0.4178
$\sigma_{calculated}$	17.290	56.517	47.556	68.623	51.480	56.608	68.672	57.896	48.596	56.608	53.643	51.156	49.090	47.334
Slump mm	na	na	na	na	39	60	na	na	na	32	113	162	214	240

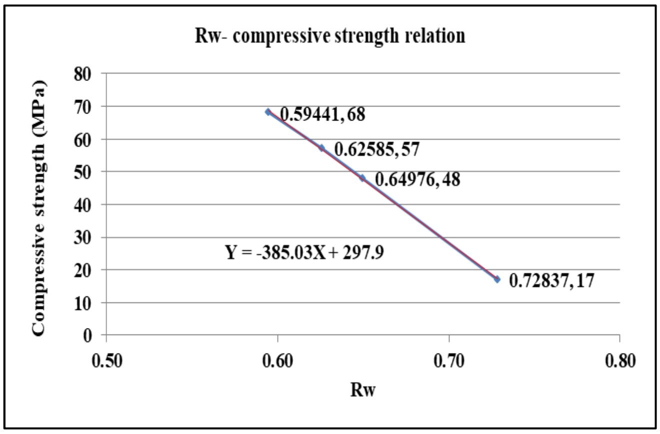

Figure 4: Relation between compressive strength and Rw hardjito and Rangan, [5]

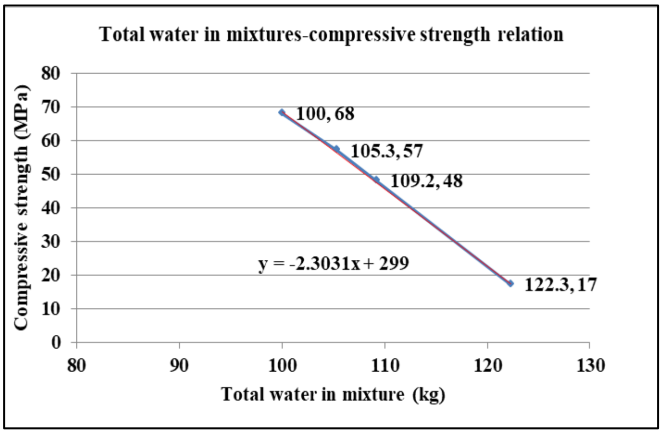

Figure 5: Relation between compressive strength and total water in mixtures Hardjito and Rangan, [5]

As R_w decreased, the compressive strength increased linearly. Therefore, the molarity of NaOH solution does not much affect the compressive strength. Because R_a in for mixture 3 is the lowest value, i.e., the highest alkalinity (very extremely corrosive), and it did not achieve the highest compressive strength. While R_a for mixture 2 was the highest, namely the lowest alkalinity, it achieved considerable compressive strength.

The following linear equation between compressive strength and R_w indicated in Figure 4 is:

$$\sigma_{7th} = 297.9 - 385.03 \times R_w \tag{11}$$

For, 100x200mm cylinder in a dry oven heat cured at 60°C for 24 hours, without a rest period, up to 4 minutes wet mixing time, and no more than 1.5% superplasticizer.

To confirm the validity of Equation (11), nine more mixtures of the Hardjito and Rangan [5] study were picked up according to dry oven heat curing at 60°C for 24 hours. The calculated compressive strength is listed in Table 5.

The aggregate size does not matter much because the fly as a Geopolymer paste is stronger than the aggregate [12].

The calculated compressive strength values matched the tested values except for mixtures 13, 14, and 15. The tested values were slightly lower than the calculated values of 7th day compressive strength due to extra water in a higher superplasticizer dosage of 8.2 liter, which is 2.1 liter than other mixtures. The extra water should be included in the calculation of R_w. Mixture 12 gives a 7th-day compressive strength a little higher than the calculated value; this mixture was prepared for rest period tests, but the rest period was zero-day. Moreover, mixture 12 has the same mix proportion as mixture 16, which has a matching value. Equation 5 can be used for steam-cured fly ash Geopolymer concrete with a 15% reduction for the calculated values. Increasing wet mixing time by up to 16 minutes will increase the compressive strength by 30% [5].

Moreover, the R_w used in equation 6 can also give a very good approach to the self-compacted Geopolymer concrete. Table 6 contains four mixtures of self-compacted Geopolymer concrete from the Fareed et al. study [13]. 100x100mm cube specimens with no rest period were dry oven heat cured at 70°C for 24 hours and tested one day after curing finished. The 100x200mm cube compressive strength is about 80% lesser than in the case of 100x200mm cylinder specimens. The 2^{nd} day compressive of fly ash Geopolymer concrete is about 95% of the 7^{th}-day compressive strength, according to the same research in a different part of the study for mix 2. However, the 7^{th}-day cylindrical compressive strength will be 85% of the 7^{th}-day cubic compressive strength.

The workability of reinforced fly ash Geopolymer concrete is one of the important issues in facilitating the casting process. Moderate workability gives about 40 MPa compressive strength of fly ash Geopolymer concrete; beyond 40MPa, the workability becomes stiff for 50MPa, which will be very stiff for 60 MPa compressive strength. The viscosity of sodium silicate plays a role in the workability of fly ash Geopolymer concrete, As shown in Table 4. From Table 5, mix 5 R_b gives the same practiced workability of water-to-cement ratio for normal Portland cement concrete. R_b More apparently in Table 6 has higher values than of water-to-cement ratio of self-consolidating conditions in Portland cement concrete.

Table 6: Calculated 7th-day compressive strength for self-compact fly ash Geopolymer concrete using equation 5 for Mixtures of other studies

material	mix1	mix2	mix3	mix4
S	143	143	143	143
H	57	57	57	57
W	40	48	60	80
FL	400	400	400	400
size of aggregate mm	10	10	10	10
S.P	28	28	28	28
M	12	12	12	12
2-day σ_{cube} test	53.46	45.01	37.31	22.58
C	0.4410	0.4410	0.4410	0.4410
R_a	1.05547	1.05547	1.05547	1.05547
R_w	0.65851	0.66952	0.68478	0.70729
R_b	0.60000	0.62000	0.65000	0.70000
σ calculated	44.3543	40.1129	34.2402	25.5709
0.85 σ_{cube}	45.44100	38.25850	31.71350	19.19300
Slump flow	630	710	770	820

5. Conclusions

Based on the experimental and analytical investigations for this study, the following conclusion remarks are made:

1) According to the results of this study, a new mix proportions design coined Ratios of Resulting Sodium Silicate Method for Geopolymer Binder (RRSSGB) is proposed and approved.
2) A higher concentration of sodium hydroxide at any term is not responsible for higher compressive strength.
3) Using high amounts of NaOH (high concentration), the resulting alkaline solution will be corrosive and unsafe to work with.
4) The mass ratio of the total water to the total liquids (Rw) is the main factor that influences compressive strength.
5) As Rw increased, the compressive strength decreased and vice versa (Equation 11).
6) Equation (11) can predict the target compressive strength.
7) As Rw increased, the workability increased and vice versa.
8) As the viscosity of sodium silicate increases, the workability decreases and vice versa.
9) The setting time of Fly Ash Geopolymer concrete decreased significantly at a hot climate of more than 40°C, affecting handling time (experienced).
10) The Fly Ash Geopolymer concrete has an adhesive nature with steel, especially after gardening, that coheres with the internal face of steel molds and malformed the finishing face of concrete; covering the internal steel of molds with adhesive-backed plastic sheets will solve the problem.

Appendix

A Sample of calculation of the resulting combined alkaline solution

1-Total weight of alkaline liquid T = S+H --- (3-B)

where T= Total weight of alkaline liquid, S= sodium silicate solution weight, H= sodium hydroxide solution weight

Then T=702+741=1443 g

2-mass ratio of SiO_2 in T = $\times\, Si_s\,.\,T$ --- (3-C)

where Si_s=*weight ratio of SiO_2 in the sodium silicate solution.*

Then mass ratio of SiO_2 in T = $702 \times 28.7\%.\,1443 = 13.96\%$

ofn T = $Na_s \times S + H \times C \times (mw\ of\ Na_2O.(2 \times mw\ of\ NaOH)).\,T$ --- (3-D)

where Na_s=*weight ratio of Na_2O in the sodium silicate solution.*

C=weight concentration of sodium hydroxide solution

Then

mass ratio of Na_2O in T = $702 \times 8.9\% + 741 \times 50\% \times \frac{62}{(2\times40)}.1443 = 24.23\%$

4-mass ratio of H_2O in T = $S \times w_s + H \times (1-C) + H \times C \times \frac{mw\ of\ H2O}{(2\times mw\ of\ NaOH)}.T$ ---(3-E)

where w_s= *weight ratio of water in the sodium silicate solution*

Then

mass ratio of H_2O in T =$702 \times 62.4\% + 741 \times (1-50\%) + 741 \times 50\% \times \frac{18}{(2\times40)}.1443 = 61.81\%$

In a second example, the same sodium silicate solution and the same sodium hydroxide solution were used, but with an equal amount of 358 grams for each of them and there was extra water added of 32 grams. The resulting sodium silicate liquid has 22.96% Na_2O, 13.74% SiO_2, 63.3% H_2O, and a SiO_2:Na_2O ratio of 0.6:1.

Similarly, the calculations were as follows:

1-Total weight of liquid (T) =S+H+W --- (3-F)

where, *W= the weight of extra water*

Then T=358+358+32= 748 g

2- the mass ratio of SiO_2 in T = $358 \times 28.7\% \backslash 748 = 13.74\%$

3- the mass ratio of Na_2O in T = $358 \times 8.9\% + 358 \times 50\% \times \frac{62}{80}.748 = 22.8\%$

4- the mass ratio of H_2O in T = $32 + 358 \times 62.4\% + 358 \times 50\% + 358 \times \frac{18}{80}.748 = 63.46\%$

The extra water amount was included in the resulting sodium silicate solution.

Author contributions

Conceptualization, Mazin. Alhifadhi, T. Al-Attar, Q. Hasan, methodology, M. Alhifadhi, validation, T. Al-attar and M.. Alhifadhi, investigation, M. Alhifadhi, resources, M. Alhifadhi, writing-original draft preparation, M. Alhifadhi, writing-review and editing, T. al-Attar, visualization, T. al-Attar, supervision, T. al-Attar, and Q. Hasan. All authors have read and agreed to the published version of the manuscript.

Funding

This research received no specific grant from any funding agency in the public, commercial, or not-for-profit sectors.

Data availability statement

The data supporting this study's findings are available on request from the corresponding author.

Conflicts of interest

The authors declare that there is no conflict of interest

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