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Influence of aggregate content on the behavior of fly ash based geopolymer concrete

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KEYWORDS

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Concrete.

Abstract Concrete made using geopolymer technology is environmental friendly and could be considered as part of the sustainable development. Even though aggregate constitutes major volume in geopolymer concrete, only limited study related to this parameter has been reported. This paper presents the summary of study carried out to understand the influence of aggregate content on the engineering properties of geopolymer concrete. Influence of other parameters on engineering properties of geopolymer concrete such as curing temperature, period of curing, ratio of sodium silicate to sodium hydroxide, ratio of alkali to fly ash and molarity of sodium hydroxide are also discussed in this paper. Based on the study carried out, it could be concluded that a geopolymer concrete with proper proportioning of total aggregate content and ratio of fine aggregate to total aggregate, along with the optimum values of other parameters, can have better engineering properties than the corresponding properties of ordinary cement concrete.

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1. Introduction

Even though cement is a versatile construction material and is being used worldwide extensively, the green house gas (CO_2) produced during its manufacturing process causes environmental impact [1,2]. However concrete made out of geopolymer technology replaces cement completely in it and thereby reduces the said environmental deterioration.

Geopolymers are formed by alkaline activation of an aluminosilicate material like fly ash, metakaolin, rice husk ash, activated bentonite, clay, red mud etc. [3–8]. Effective use of fly ash in geopolymer concrete further reduces the environmental pollution otherwise caused by fly ash [9].

Even though the geopolymer technology was developed as early as 1950's [10], most of the early studies were limited to the area of geopolymer paste and mortar. Study of its application in concrete making has gained momentum only recently [4,11–18]. Even though studies have been carried out on the influence of certain parameters on geopolymer concrete such as alkali concentration, Si/Al ratio, Alkali/fly ash ratio, particle size and loss of ignition of fly ash etc. [15,19–27], little study has reported on the influence of aggregate content in geopolymer concrete. Aggregate content suggested by different investigators in geopolymer concrete varies widely and are primarily based on their own study [13,15,18]. Hardjito et al. [12] suggested certain guidelines for the selection of aggregate content in geopolymer concrete. However, a clear mixture design procedure for geopolymer concrete is yet to be established. Present study focuses, in addition to other parameters, the influence of aggregate content on engineering properties of geopolymer concrete.

2. Experimental program

The geopolymer concrete mixtures prepared were grouped into three, namely M1, M2 and M3. M1 group of mixtures were prepared to study the influence of aggregate content on various properties of geopolymer concrete. Having obtained an optimum proportion of aggregate content, the influence of other parameters were studied by making M2 and M3 group of mixtures.

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Table 1: Quantity of materials for 1 m^3 of geopolymer concrete — Group M1 mixes.

Sl. No.	Mix ID	Total aggregate (% by vol.)	Fine aggregate/total Agg. (by mass)	Coarse aggregate (kg)	Sand (kg)	Fly ash (kg)	Alkali content (kg)	Super plasticizer (kg)
1	M1A60R20	60	0.20	1273.07	318.27	420.57	231.31	8.41
2	M1A60R25	60	0.25	1195.69	394.58	420.57	231.31	8.41
3	M1A60R30	60	0.30	1112.14	476.66	420.57	231.31	8.41
4	M1A60R35	60	0.35	1031.99	555.73	420.57	231.31	8.41
5	M1A60R40	60	0.40	948.62	632.73	420.57	231.31	8.41
6	M1A65R20	65	0.20	1379.16	344.79	365.16	210.84	7.3
7	M1A65R25	65	0.25	1295.34	427.46	365.16	210.84	7.3
8	M1A65R30	65	0.30	1204.82	516.38	365.16	210.84	7.3
9	M1A65R35	65	0.35	1117.99	602.04	365.16	210.84	7.3
10	M1A65R40	65	0.40	1027.67	685.46	365.16	210.84	7.3
11	M1A70R20	70	0.2	1485.25	371.31	309.85	170.41	6.2
12	M1A70R25	70	0.25	1394.98	460.34	309.85	170.41	6.2
13	M1A70R30	70	0.30	1297.5	556.11	309.85	170.41	6.2
14	M1A70R35	70	0.35	1203.99	648.35	309.85	170.41	6.2
15	M1A70R40	70	0.40	1106.72	738.18	309.85	170.41	6.2
16	M1A75R20	75	0.20	1591.34	397.83	254.54	139.99	5.1
17	M1A75R25	75	0.25	1494.62	493.22	254.54	139.99	5.1
18	M1A75R30	75	0.30	1390.18	595.83	254.54	139.99	5.1
19	M1A75R35	75	0.35	1289.99	694.66	254.54	139.99	5.1
20	M1A75R40	75	0.40	1185.77	790.91	254.54	139.99	5.1

2.1. Mixture proportioning

Group M1 consist of 20 mixtures, wherein the total aggregate content was varied from 60% to 75% of the volume of concrete. Further, for each value of total aggregate content, the ratio of mass of fine aggregate to total aggregate was varied from 0.2 to 0.4.

The alkali-fly ash ratio selected by different investigators ranges from 0.25 to 0.75 and the ratio of Na_2SiO_3 to NaOH ranges from 0.17 to 3 [13,15,17]. A preliminary study conducted by authors revealed that the ratio of alkali to fly ash as 0.55, ratio of Na_2SiO_3/NaOH as 2.5, ratio of water to geopolymer solid as 0.25 and a curing temperature of 100 °C yields good strength properties in geopolymer concrete. Hence, for M1 group of mixtures, the above values were kept constant throughout. A total of 20 mixture was cast under M1 group and Table 1 presents the various quantities of materials required for one cubic meter of geopolymer concrete under group M1.

Having arrived at the optimum aggregate content, influence of the ratios of sodium silicate to sodium hydroxide and alkali to fly ash on strength properties of polymer concrete has been investigated in M2 group of mixtures. The total aggregate content (70%), ratio of the fine aggregate to total aggregate (0.35), ratio of water to geopolymer solid (0.25) and a curing temperature (100 °C) were kept constant in all 20 mixtures considered under M2 group. Table 2 presents the details of various mixtures considered under M2 group.

Third group of mixtures, M3, was prepared to study the influence of the ratios of water to geopolymer solid and Alkali to fly ash on the strength properties of geopolymer concrete. They were varied from 0.20 to 0.32 and 0.35 to 0.65, respectively. The parameters kept constant in this group include total aggregate content (70%), mass ratio of the fine aggregate to total aggregate (0.35), ratio of sodium silicate to sodium hydroxide (2.50) and curing temperature (100 °C). The quantity of materials used for making one cubic meter of concrete under this group is given in Table 3.

2.2. Materials

2.2.1. Fly ash

Geopolymeric material with a low Sl : Al ratio is suitable for general civil engineering applications [25]. The aluminosilicate source material used in the present study for making geopolymer binder was low calcium fly ash (ASTM Class F). The fly ash used had both Sl : Al ratio and specific gravity values as 1.9, and 90% of fly ash was passing through the 45 μm sieve. The chemical composition of the fly ash as determined by X-ray Fluorescence analysis is presented in Table 4.

2.2.2. Alkali

The alkali used consisted of a mixture of NaOH and Na_2SiO_3 solution. NaOH pellets of 98% purity were used to make NaOH solution of desired molarity. The Na_2SiO_3 solution had 34.64% SiO, 16.27% Na_2O, and 49.09% water. The specific gravity of alkali liquid solution with molarity 10 was 1.54 and it varies with the change in molarity.

2.2.3. Aggregates

Crushed granite rock and natural river sand were used as coarse and fine aggregates, respectively. The nominal sizes of coarse and fine aggregates were 20 and 4.5 mm. The specific gravity of coarse and fin aggregates were 2.72 and 2.64, respectively, and fine aggregate had a fineness modulus of 2.36.

2.3. Mixing, casting and curing

Adding of NaOH and Sodium Silicate solutions leads to the development of high temperature and different investigators propose the mixing of alkali solutions differently. While some investigators premix the alkali solutions and wait till it reaches the ambient temperature for adding into the dry mix [12,23,28,29], others [16,18] recommend adding the alkali solutions during dry mixing itself. For the present study, the alkali solution was first prepared by thoroughly mixing the NaOH and Na_2SiO_3 solutions. It was prepared 24 h prior to its use to bring down its temperature to the ambient temperature.

Coarse and fine aggregates in saturated surface dry condition were well mixed with fly ash in a pan mixture. Naphthalene based water reducing admixture (commercial name — CERAPLAST 300) has been used to improve the workability of the mixture. An admixture dosage of 2% by mass of fly ash, arrived based on trial mixes, has been found suitable in the

Table 2: Quantity of materials for 1 m^3 of geopolymer concrete — Group M2 mixes.

Sl. No	Mix ID	Alkali/Fly ash ratio (by mass)	Sodium silicate/NaOH (by mass)	Coarse aggregate (kg)	Sand (kg)	Fly ash (kg)	Alkali solution (kg)	Super plasticizer (kg)
1	M2AL35S1	0.35	1.5	1203.99	648.35	329.56	115.35	6.59
2	M2AL35S2	0.35	2.0	1203.99	648.35	327.33	114.56	6.55
3	M2AL35S3	0.35	2.5	1203.99	648.35	325.75	114.01	6.51
4	M2AL35S4	0.35	3.0	1203.99	648.35	324.7	113.65	6.49
5	M2AL35S5	0.35	3.5	1203.99	648.35	323.78	113.32	6.47
6	M2AL45S1	0.45	1.5	1203.99	648.35	322.28	145.03	6.45
7	M2AL45S2	0.45	2.0	1203.99	648.35	319.49	143.77	6.39
8	M2AL45S3	0.45	2.5	1203.99	648.35	317.67	142.95	6.35
9	M2AL45S4	0.45	3.0	1203.99	648.35	316.22	142.3	6.32
10	M2AL45S5	0.45	3.5	1203.99	648.35	315.13	141.81	6.30
11	M2AL55S1	0.55	1.5	1203.99	648.35	314.11	172.76	6.28
12	M2AL55S2	0.55	2.0	1203.99	648.35	312.1	171.65	6.24
13	M2AL55S3	0.55	2.5	1203.99	648.35	309.85	170.41	6.19
14	M2AL55S4	0.55	3.0	1203.99	648.35	308.17	169.49	6.16
15	M2AL55S5	0.55	3.5	1203.99	648.35	306.83	168.76	6.14
16	M2AL65S1	0.65	1.5	1203.99	648.35	292.67	190.23	5.85
17	M2AL65S2	0.65	2.0	1203.99	648.35	292.67	190.23	5.85
18	M2AL65S3	0.65	2.5	1203.99	648.35	292.67	190.23	5.85
19	M2AL65S4	0.65	3.0	1203.99	648.35	292.67	190.23	5.85
20	M2AL65S5	0.65	3.5	1203.99	648.35	292.67	190.23	5.85

Table 3: Quantity of materials for 1 m^3 of geopolymer concrete — Group M3 mixes.

Sl. No	Mix ID	Alkali/Fly ash Ratio (by mass)	Water/Geo solid ratio	Coarse aggregate (kg)	Sand (kg)	Fly ash (kg)	10 molar NaOH Solution (kg)	Sodium silicate (kg)	Super plasticizer (kg)
1	M3AL35W1	0.35	0.24	1203.99	648.35	329.56	32.99	82.5	6.60
2	M3AL35W2	0.35	0.26	1203.99	648.35	321.41	32.14	80.35	6.43
3	M3AL35W3	0.35	0.28	1203.99	648.35	313.53	31.28	78.22	6.27
4	M3AL35W4	0.35	0.30	1203.99	648.35	304.32	30.40	76.07	6.09
5	M3AL35W5	0.35	0.32	1203.99	648.35	297.75	29.77	74.44	5.95
6	M3AL45W1	0.45	0.24	1203.99	648.35	322.03	41.40	103.51	6.44
7	M3AL45W2	0.45	0.26	1203.99	648.35	313.56	40.31	100.79	6.27
8	M3AL45W3	0.45	0.28	1203.99	648.35	305.08	39.22	98.07	6.1
9	M3AL45W4	0.45	0.30	1203.99	648.35	296.6	38.13	95.34	5.93
10	M3AL45W5	0.45	0.32	1203.99	648.35	289.95	37.28	93.2	5.8
11	M3AL55W1	0.55	0.24	1203.99	648.35	314.11	49.36	123.4	6.28
12	M3AL55W2	0.55	0.26	1203.99	648.35	305.59	48.02	120.05	6.11
13	M3AL55W3	0.55	0.28	1203.99	648.35	297.62	46.77	116.92	5.95
14	M3AL55W4	0.55	0.30	1203.99	648.35	289.77	45.52	113.84	5.79
15	M3AL55W5	0.55	0.32	1203.99	648.35	282.48	44.39	110.97	5.65
16	M3AL65W1	0.65	0.24	1203.99	648.35	292.67	41.45	135.89	5.85
17	M3AL65W2	0.65	0.26	1203.99	648.35	292.67	49.03	135.89	5.85
18	M3AL65W3	0.65	0.28	1203.99	648.35	290.37	53.93	134.81	5.81
19	M3AL65W4	0.65	0.30	1203.99	648.35	282.48	52.46	131.14	5.65
20	M3AL65W5	0.65	0.32	1203.99	648.35	275.42	51.15	127.87	5.51

Table 4: Chemical composition of fly ash.

Sl. No	Parameter	Content (% by mass)
1	SiO_2	59.70
2	Al_2O_3	28.36
3	$Fe_2O_3 + Fe_2O_4$	4.57
4	CaO	2.10
5	Na_2O	0.04
6	MgO	0.83
7	Mn_2O_3	0.04
8	TiO_2	1.82
9	SO_3	0.40
10	Others	2.14
11	Loss of ignition	1.06

present study. The alkali liquid and the admixture were mixed together, and then, added to the dry mix, and the whole mixture was mixed together for 5 min.

Specimens such as cubes of size 150 mm, beams of size 100 mm × 100 mm × 500 mm (long) and cylinder of diameter 150 mm and height 300 mm were cast using standard steel moulds. Concrete specimens compacted with the help of a table vibrator. Top of the moulds were covered with steel plates and edges were sealed immediately after casting to avoid loss of water from the specimens.

The specimens, thus, prepared were kept at room temperature for 60 min, before they were temperature cured. The specimen, along with their moulds and cover plates were then subjected to temperature curing in an electric oven at different curing temperatures (60–120 °C) as well as curing periods (6–72 h). Specimens were taken out of the moulds at the end of the curing period and were kept in room temperature under laboratory conditions until they were tested.

3. Analysis of test result

Each value of the test results discussed or presented in tables and figures is the mean of 3 test results. Individual strength test results were well within the range of ±15% of the mean value.

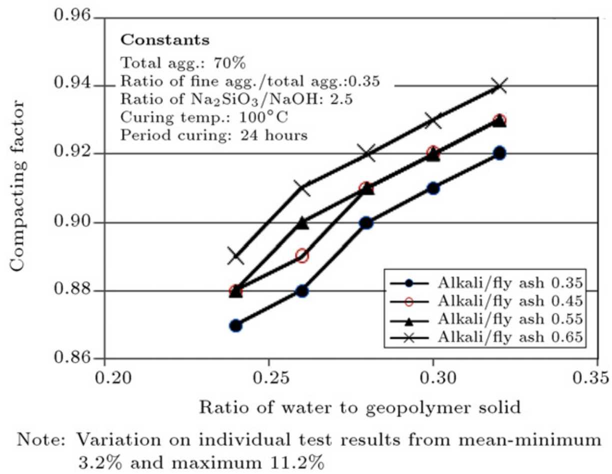


Figure 1: Variation of copacting factor with ratio of water to geopolymer solid.

Table 5: Cube compressive strength of geopolymer and OPC concrete.

Mix ID	Cube compressive strength (MPa)		
	3th day	7th day	28th day
M1A60R35*	42	43	45
M1A65R35*	45	46	47
M1A70R35*	52	54	56
M1A75R35*	45	48	49
OPC70R35	45	51	58

* Curing temperature: 100; curing period: 24 h; ratio of alkali to fly ash: 0.55; ratio of Na_2SiO_3 to NaOH: 2.5; and ratio of fine aggregate to total aggregate: 0.35.

3.1. Workability

Due to the high viscosity of geopolymer concrete, no appreciable slump value could be obtained. As a result, compacting factor [30] has been considered for comparing the workability of geopolymer concrete. A typical comparison of compacting factor with different ratio of water to geopolymer solid is shown in Figure 1. It could be seen from Figure 1 that the compacting factor increases almost linearly with the ratio of total water to geopolymer solid. Further, for a given ratio of total water to geopolymer solid, the compacting factor is higher for a higher ratio of alkali to fly ash.

3.2. Compressive strength

The strength of geopolymer concrete with age after the period of temperature curing is presented in Table 5 for geopolymer concrete with different total aggregate content. Comparing the ordinary concrete having approximately the same compressive strength as that of the geopolymer concrete M1A70R35 (with same aggregate content of M1A70R35), it can be seen from Table 5 that while ordinary concrete had a strength of 77.5% and 87.9% of the 28th day strength on 3rd and 7th days, respectively, geopolymer concrete had the corresponding values as 92.8% and 96.4%. So, unlike ordinary concrete, the rate of strength development of geopolymer concrete beyond 7th day is not significant.

The influence of aggregate content on the compressive strength of geopolymer concrete is presented in Figures 2 and 3. While Figure 2 shows the influence of total aggregate content on compressive strength, Figure 3 shows the variation of the

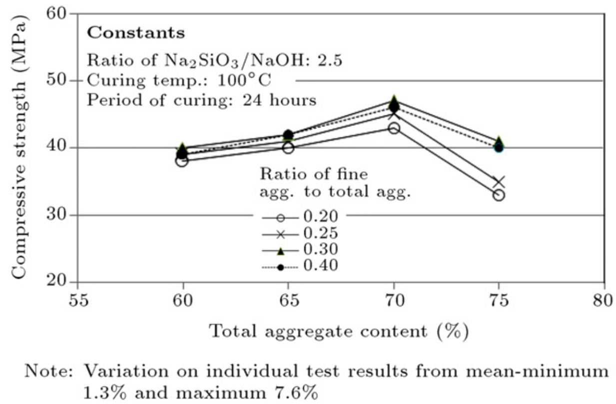


Figure 2: Variation of 7th day compressive strength with total aggregate content.

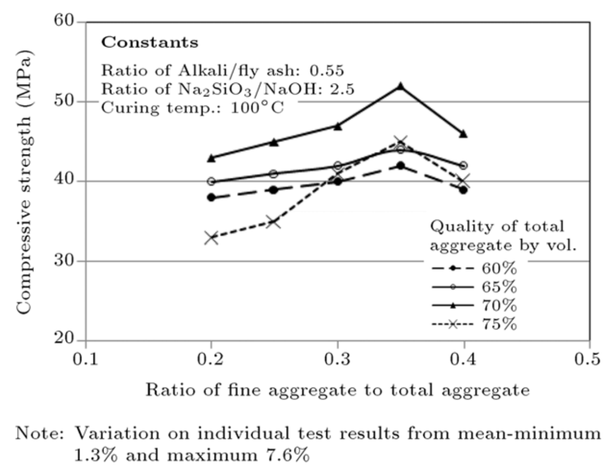


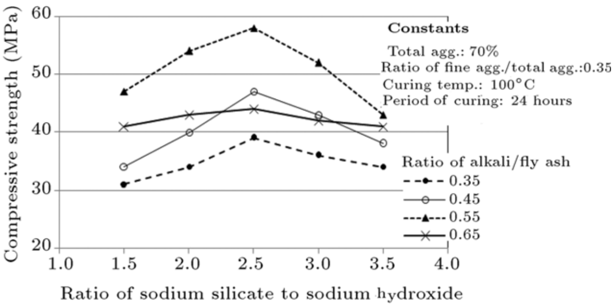
Figure 3: Variation of 7th day compressive strength with ratio of fine aggregate to total aggregate content.

ratio of fine aggregate to total aggregate on 7th day compressive strength of geopolymer concrete. It could be observed from Figure 2 that the compressive strength of geopolymer concrete increases with increase in total aggregate content upto a value of 70% and then it decreases. This phenomenon is true for all values of fine aggregate to total aggregate ratios considered (0.20–0.40). From Figure 3, it could be observed that the compressive strength of geopolymer concrete increases with an increase in the ratio of fine aggregate to total aggregate for a value upto 0.35 and then it decreases. This phenomenon is true for all the values of the total aggregate content in the mixture considered (60%–75% by volume).

So, it is evident that for a given type of fine and coarse aggregate, there is a definite proportion of total aggregate and fine aggregate that gives maximum compressive strength for geopolymer concrete. This behaviour is similar to that of conventional concrete and is due to the fact that the optimum proportion of fine aggregate and coarse aggregate yields efficient binding by geopolymer.

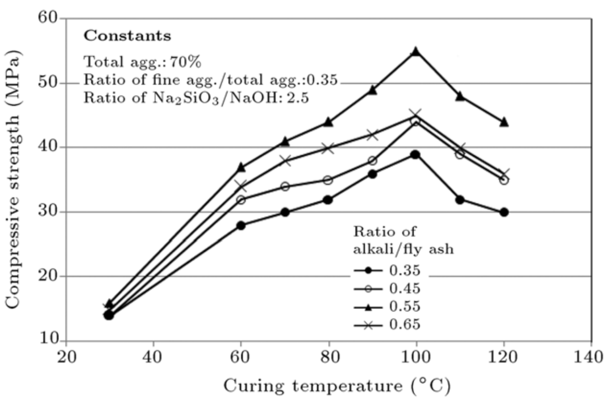
Figure 4 shows the variation of 7th day compressive strength of geopolymer concrete with the variation of the ratio of the sodium silicate to sodium hydroxide for different values of alkali to fly ash ratios. The total aggregate content and the ratio of fine aggregate to total aggregate in all these mixes were kept at a constant value of 70% and 0.35 respectively.

From Figure 4, it could be seen that the compressive strength of geopolymer concrete Increases with the ratio of sodium



Note: Variation on individual test results from mean-minimum 2.1% and maximum 9.7%

Figure 4: Variation of 7th day compressive strength with ratio of sodium silicate to sodium hydroxide.



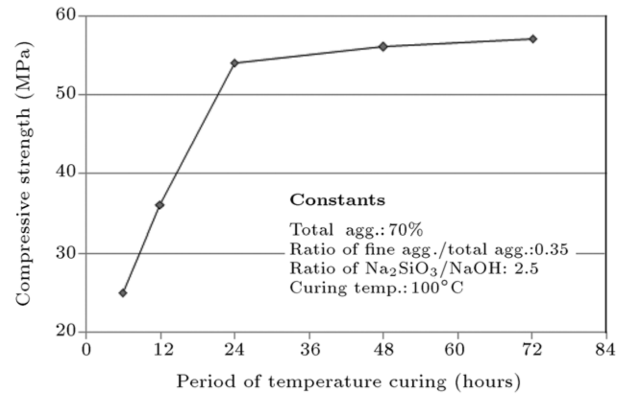
Note: Variation on individual test results from mean-minimum 1.2% and maximum 8.3%

Figure 5: Variation of 7th day compressive strength of geopolymer concrete with curing temperature.

silicate to sodium hydroxide upto a value of 2.5 and then it decreases. Further, upto a value of the ratio of alkali to fly ash 0.55, the compressive strength increases and beyond that it decreases. Increase in compressive strength is mainly due to the change in microstructure of geopolymer, which was influenced by the quantity of sodium silicate. On the other hand, the decrease in compressive strength is because at high ratios of Sodium silicate to sodium hydroxide, the quantity of sodium hydroxide is not sufficient for the completion of dissolution process during the formation of geopolymer [31,32].

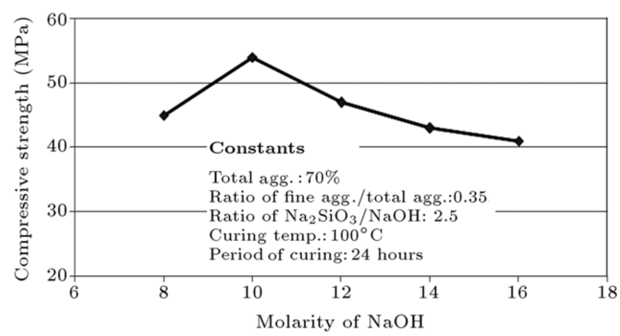
The variation of compressive strength with change in molarity of NaOH is depicted in Figure 5. It could be observed from Figure 5 that the compressive strength of geopolymer concrete increased with increase in molarity of NaOH upto a value of 10 and on further increase of molarity of NaOH, the compressive strength decreases. This behavior is mainly due to the fact that concentration of NaOH solution used for geopolymer synthesis has a positive influence on dissolution, hydrolysis and condensation reactions but excess alkali concentration hinders the condensation of the silicate species [31–33]. So, it could be observed that there is an optimum value for the ratio of sodium silicate to sodium hydroxide, ratio of alkali to fly ash and molarity of NaOH that yields maximum compressive strength for geopolymer concrete.

Figure 6 shows the effect of curing temperature on cube compressive strength of geopolymer concrete. The variation has been presented for different values of alkali/fly ash ratio.



Note: Variation on individual test results from mean-minimum 0.6% and maximum 8.0%

Figure 6: Variation of 7th day compressive strength of geopolymer concrete with period of temperature curing.



Note: Variation on individual test results from mean-minimum 0.6% and maximum 6.6%

Figure 7: Variation of 7th day compressive strength of geopolymer concrete with molarity of NaOH.

From Figure 6, it could be seen that the compressive strength increases with increase in curing temperature upto 100 °C, and then it decreases. Further, the maximum compressive strength has been observed for the mixture having the ratio of alkali to fly ash as 0.55. The behavior of increase in strength with increase in temperature is in line with the reported literature, although the curing temperature for maximum strength differs from 100 °C [15,34].

The loss of strength beyond the curing temperature of 100 °C is due to the loss of moisture from the specimen. Even if sealed properly, at temperatures above 100 °C, the specimen may dry out and lead to a reduced strength. Even though similar observations were reported by investigators earlier [34,35], study on the shrinkage, cracking and durability behaviour may yield a better understanding on the actual behaviour.

Figure 7 shows the influence of curing period on strength of geopolymer concrete for a curing temperature of 100 °C. From Figure 7, it could be observed that, upto a curing period of 24 h, the strength gain of geopolymer is proportional to the period of curing and no appreciable strength gain could be obtained beyond 24 h. This could be due to the reason that most of the polymerization would have been completed within 24 h.

Variation of the compressive strength of geopolymer concrete with the ratio of total water to geopolymer solid is presented in Figure 8. From Figure 8, it could be seen that the compressive strength of geopolymer concrete decreases as the total water to geopolymer solid ratio increases. The variation is almost linear for all values of alkali to fly ash ratios considered.

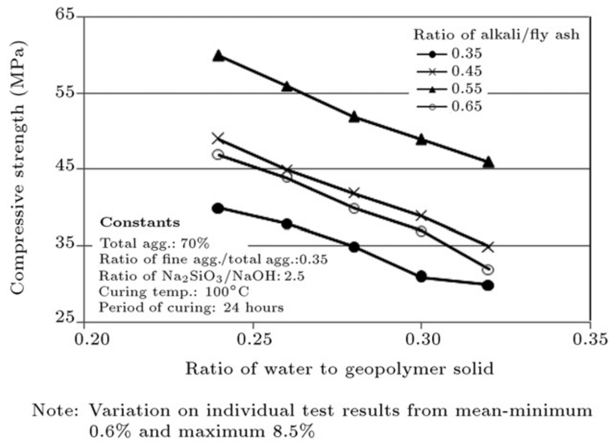


Figure 8: Variation of 7th day compressive strength of geopolymer concrete with ratio of water to geopolymer.

Table 6: Mechanical properties of Group M1 mix concrete.

S.l. No.	Mix ID	Tensile strength in (MPa)		Poisson's ratio	Young's modulus in (MPa)
		Split tensile	Flexural strength		
1	M1A60R35*	3.1	3.79	0.192	42 369
2	M1A65R35*	3.34	3.82	0.202	45 082
3	M1A70R35*	3.45	4.74	0.242	59 068
4	M1A75R35*	4.51	4.95	0.195	47 519
5	OPC70R35**	4.39	4.79	0.203	51 623

* Strength results on 28th day. Curing temperature: 100; curing period: 24 h; ratio of alkali to fly ash: 0.55; ratio of Na_2SiO_3 to NaOH: 2.5; and ratio of fine aggregate to total aggregate: 0.35.
** Strength results on 28th day.

3.3. Other mechanical properties

Various mechanical properties like split tensile strength, flexural strength, Poissons's ratio and Young's modulus of geopolymer concrete are presented in Table 6 for the typical mixtures in M1 group of Mixtures.

From the Table 6, it could be seen that the modulus of elasticity of geopolymer concrete varies with aggregate content and is highest for a total aggregate content of 70% with ratio of fine aggregate to total aggregate content as 0.35. In the present study, the above optimum proportion of aggregate content gave 14.4% higher value for the modulus of elasticity of geopolymer concrete compared to ordinary cement concrete. While many investigators reported a lower value for the modulus of elasticity for geopolymer concrete compared to ordinary cement concrete [12,13,17], only limited study reported a higher value [18]. It could be concluded that the modulus of elasticity of geopolymer concrete can be brought equal to or even higher than that of the corresponding ordinary cement concrete by appropriate selection of total aggregate content and ratio of fine aggregate to total aggregate.

From the values of Poisson's ratio presented in Table 6, it may be observed that suitable proportioning of aggregate content can have a geopolymer concrete with higher Poisson's ratio than ordinary cement concrete. Higher Poisson's ratio in concrete improves its elastic behavior. In the present study, by proper proportioning of aggregate contents, 19.2% enhancement in Poisson's ratio could be achieved in geopolymer concrete when compared to ordinary cement concrete.

From Table 6, it could be observed that the tensile strength of geopolymer concrete increases with the total aggregate content. Geopolymer concrete with 70% aggregate content gave a flexural strength higher by 37% than its corresponding split tensile strength. On the other hand, the corresponding ordinary concrete gave a flexural strength higher by only 9% than its split tensile strength. Further, geopolymer concrete with total aggregate content value other than 70% gave a flexural strength higher by 9%–22% than the corresponding split tensile strength.

4. Conclusions

Study on the engineering properties of geopolymer concrete made from alkali activated fly ash has been presented. Crushed granite aggregate of nominal size 20 mm and natural river sand were used in the study. The alkalis used were Sodium Silicate and Sodium Hydroxide. The curing temperature was varied from ambient (30 °C) to 120 °C. Major conclusions derived based on the present study could be summarized as follows:

1. The compressive strength of geopolymer concrete increases with increase in curing temperature upto a value of 100 °C and beyond which it decreases.
2. An early strength development in geopolymer concrete could be achieved by the proper selection of curing temperature and the period of curing. With 24 h of curing at 100 °C, 96.4 % of 28th day cube compressive strength could be achieved in 7 days time.
3. Modulus of elasticity as well as the Poisson's ratio of geopolymer concrete can be brought equal to or even higher than that of the corresponding ordinary cement concrete, by the proper selection of total aggregate content and ratio of fine aggregate to total aggregate content. In the present study, compared to ordinary cement concrete, 14.4% enhancement in modulus of elasticity and 19.2% enhancement in Poisson's ratio could be achieved in geopolymer concrete.
4. The tensile strength of geopolymer concrete increases with increase in the total aggregate content. In the present study, as the total aggregate content varied from 60% to 75% (with constant fine aggregate to total aggregate ratio of 0.35), the split and flexural tensile strength increased by 45.5% and 30.6%, respectively.
5. Based on the present study, a geopolymer concrete with total aggregate content of 70% by volume, ratio of fine aggregate to total aggregate of 0.35, NaOH molarity 10, Na_2SiO_3/NaOH ratio of 2.5 and alkali to fly ash ratio of 0.55 when cured for 24 h at 100 °C gave an average cube compressive strength of 52 MPa after temperature curing (56 MPa after 28th day). This geopolymer concrete gave a higher value of Poisons ratio and modulus of elasticity compared to ordinary cement concrete having almost same cube compressive strength as that of geopolymer concrete.

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