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Parametric Studies on Compressive Strength of Geopolymer Concrete

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Abstract

The demand of concrete is increasing day by day for satisfying the need of development of infrastructure facilities. It is well established fact that the production of OPC not only consumes significant amount of natural resources and energy but also releases substantial quantity of carbon dioxide to the atmosphere. Therefore, it is essential to find alternatives to make the concrete environment friendly. Geopolymer is an inorganic alumino-silicate compound, synthesized from fly ash. The fly ash, one of the source materials for geopolymer binders, is available abundantly in India, but to date its utilization is limited. Hence it is essential to make the efforts to utilize this by-product in concrete manufacturing in order to make the concrete more environmental friendly. This paper describes the experimental work conducted by casting 20 geopolymer concrete mixes to evaluate the effect of various parameters affecting its the compressive strength in order to enhance its overall performance. Various parameters i.e. ratio of alkaline liquid to fly ash, concentration of sodium hydroxide, ratio of sodium silicate to sodium hydroxide, curing time, curing temperature, dosage of superplasticiser, rest period and additional water content in the mix have been investigated. The test results show that compressive strength increases with increase in the curing time, curing temperature, rest period, concentration of sodium hydroxide solution and decreases with increase in the ratio of water to geopolymer solids by mass & admixture dosage, respectively. The addition of naphthalene based superplasticiser improves the workability of fresh geopolymer concrete. It was further observed that the water content in the geopolymer concrete mix plays significant role in achieving the desired compressive strength.

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Keywords: Geopolymer, Concrete, Fly ash, Compressive strength, Parametric study

1. Introduction

Concrete is one of the widely used materials all over the world. Ordinary Portland cement (OPC) is used as the primary binder to produce the concrete. The demand of concrete is increasing day by day for the need of development of infrastructure facilities [1]. However, it is well known that the production of OPC not only consumes significant amount of natural resources and energy but also releases substantial quantity of carbon dioxide to the atmosphere [2]. The global cement industry contributes around 2.8 billion tons of the greenhouse gas emissions annually, or about 7% of the total man-

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made greenhouse gas emissions to the earth's atmosphere. It is essential to find alternatives to make environment friendly concrete [1].

One of the alternatives to produce more environmentally friendly concrete is to replace the amount of Portland cement in concrete with by-product materials such as fly ash. An important investigation in this regard is the development of high volume fly ash concrete that utilizes up to 60 percent of fly ash, and yet possesses excellent mechanical properties with enhanced durability performance [3].

Another alternative to make environmentally friendly concrete is the development of inorganic alumina-silicate polymer, called Geopolymer, synthesized from materials of geological origin or by-product materials such as fly ash that is rich in silicon and aluminum [4]. Fly ash, one of the source materials for geopolymer binders, is available abundantly worldwide, but to date its utilization is limited. Currently, 90 million tones of fly ash is being generated annually in India. By exploring use of the fly ash based geopolymer concrete two environment related issues are tackled simultaneously i.e. the high amount of CO_2 released to the atmosphere during production of OPC and Utilization of this fly ash.

The production of geopolymer concrete is carried out using the conventional concrete technology methods. The fly ash based geopolymer concrete consists 75% to 80% by mass of aggregate, which is bound by a geopolymer paste formed by the reaction of the silicon and aluminum within the fly ash and the alkaline liquid made up of sodium hydroxide and sodium silicate solution with addition of superplasticiser. In this paper, various factors which influencing the strength of concrete are studied and results are discussed by various graphs corresponding to the strength of the test cubes.

It can be observed from the above discussion that the geopolymer concrete has not been studied much in detail in India. India also is facing the problem of depletion on natural resources such as limestone which is the most important ingredient to produce cement and in turn the concrete in India. In this situation, detailed study of geopolymer concrete which is the concrete with zero cement in concrete naturally becomes very important. Therefore, an attempt has been made in the present investigation by casting 20 geopolymer concrete mixes with 100% replacement of OPC with processed fly ash in each concrete mix [5]. Indian standards have always emphasized on the importance of compressive strength amongst various mechanical properties of concrete. Hence, the effect of various parameters affecting the compressive strength i.e. ratio of alkaline liquid to fly ash, concentration of sodium hydroxide, ratio of sodium silicate to sodium hydroxide, curing time, curing temperature, dosage of superplasticiser, rest period and additional water content in the Geopolymer concrete mixes has been investigated in order to enhance its overall performance.

2. Experimental Programme

2.1. Materials

Fly ash used in this study was low calcium class F processed fly ash from Dirk India private limited under the name of the product POZZOCRETE 60. Chemical compositions of the fly ash used along with the specifications are given in Table 1.

Table 1. Composition of class F fly ash (POZZOCRETE)

SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	Na_2O	CaO	LOI
57.30 %	27.13 %	8.06 %	2.13 %	1.06 %	0.73 %	0.03 %	1.60 %

The alkaline liquid used was a combination of sodium hydroxide and sodium silicate solution. Sodium hydroxide (NaOH) in flakes form with 98% purity purchased from local chemical supplier was used and Sodium silicate solution (Na_2O = 16.84%, SiO_2 = 35.01% and water = 46.37% by mass) was used as alkaline liquid. Sodium hydroxide solution is prepared by dissolving the flakes in water. Tap water available in laboratory was used to prepare NaOH solution. The activator solution was prepared at least one day prior to its use. Locally available 10 mm and 20 mm crushed aggregates have been used as coarse aggregates. Locally available river sand is used as fine aggregate in the concrete mixes. To improve the workability of the fresh geopolymer concrete, naphthalene sulphonate based superplasticiser was used in all of the geopolymer mixes.

2.2. Casting of concrete mixes

The mixing procedure used for geopolymer concrete is similar to that of conventional OPC concrete. Mixing of all the materials have been done in the laboratory at room temperature. The fly ash and the aggregate were mixed together in concrete pan mixture. The mixing is allowed to continue for about 3 to 4 minutes. The alkaline solution which was prepared one day before is added with additional water in the mix. The liquid component and superplasticiser was added to the dry material and mixing is continued for another 3 to 4 minutes.

The fresh concrete is cast into the moulds immediately after mixing in two layers for prismatic specimens. For compaction of the concrete specimens, each layer was given 25 to 35 manual strokes using 20 mm rod. Concrete specimens were 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.

The details of mix design for geopolymer concrete Mix-1 to Mix-6 is given in Table 2. The coarse and fine aggregate proportions used in different geopolymer concrete mixes are about 75-77 % percent by mass of the concrete.

Table 2. Ingredients for geopolymer concrete Mix-1 to Mix-6

Ingredient	Unit	Mix-1	Mix-2	Mix-3	Mix-4A	Mix-4B	Mix-5A	Mix-5B	Mix-5C	Mix-6A	Mix-6B
Fly ash	kg/m^3	428	444	428	428	428	428	428	428	428	428
C.A	kg/m^3	1170	1170	1170	1170	1170	1170	1170	1170	1170	1170
F.A	kg/m^3	630	630	630	630	630	630	630	630	630	630
Na_2SiO_3	kg/m^3	122	111	114	122	122	122	122	122	122	122
NaOH	kg/m^3	49	44	57	49	49	49	49	49	49	49
Extra water	kg/m^3	43	43	43	43	43	43	43	43	43	43
Molarity		14	14	14	14	14	14	14	14	14	14
Superplasticiser	kg/m^3	8.5	9	8.5	8.5	8.5	8.5	13	17	8.5	8.5
Curing temp	^0C	75	75	75	75	75	75	75	75	75	75
Curing period	Hours	24	24	24	24	48	48	48	48	48	48
Rest period	Days	1	1	1	0	0	0	0	0	0	1
No. of cube		3	3	3	3	3	3	3	3	3	3

2.3. Curing of concrete specimen

The concrete specimens were heat cured in oven at required temperature up to the completion of curing time. After the curing period, the test specimens left in the moulds for at least 4-6 hours in order to avoid a major change in the environmental conditions. After demoulding, the concrete specimens are allowed to become air-dry in the laboratory until the day of the testing.

3. Results and discussion

3.1. Ratio of alkaline liquid to fly ash

Two concrete mixes Mix-1 and Mix-2 with the alkaline liquid to fly ash ratio 0.35 and 0.4 have been cast using the ingredients as given in Table 2. The effect of alkaline liquid to fly ash ratio by mass on compressive strength of concrete at age 3 days has been evaluated by comparing results of both mixes. The results are presented in Fig. 1. It has been observed that the ratio of alkaline liquid to fly ash, by mass, is not much effective in varying the compressive strength of the geopolymer concrete.

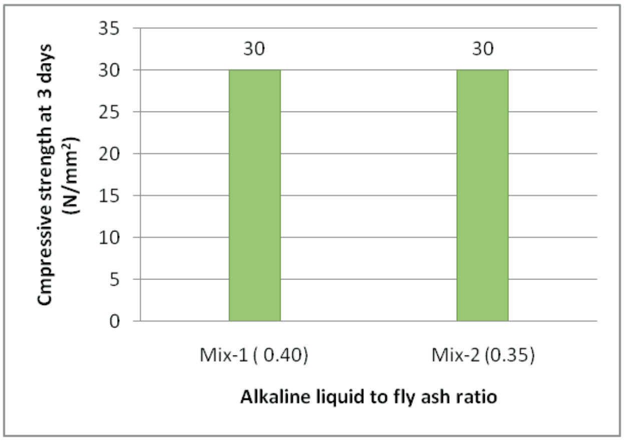

Fig. 1. Effect of alkaline liquid to fly ash ratio on compressive strength

3.2. Ratio of sodium silicate solution to sodium hydroxide solution

The effect of sodium silicate solution to sodium hydroxide solution by mass on compressive strength of concrete has been observed by comparing results of Mix-1 and Mix-3 having ingredients as given in Table 2. The results are presented in Fig. 2. Higher Compressive strength has been observed in concrete Mix-3 as compared to that of concrete Mix-1.

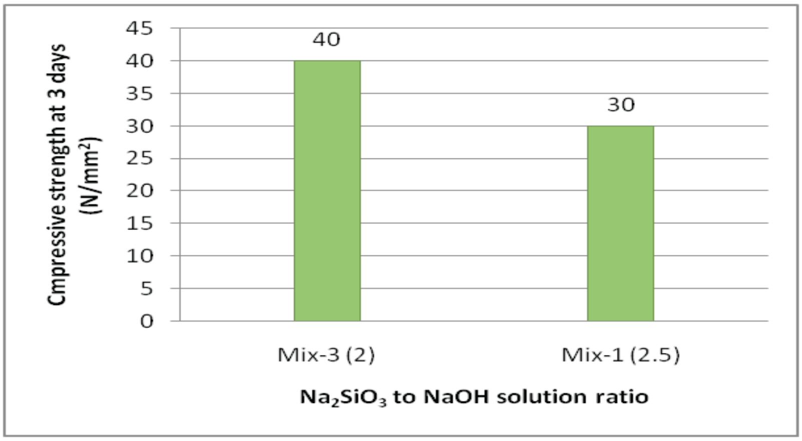

Fig. 2. Effect of sodium silicate solution to sodium hydroxide solution ratio on compressive strength

3.3. Curing time

In order to investigate the effect of curing time, test specimens have been cured for curing periods of 24 hours and 48 hours, respectively. Concrete Mix-4 with ingredients used as per Table 2 has been cast for investigating of the influence of curing time on the compressive strength.

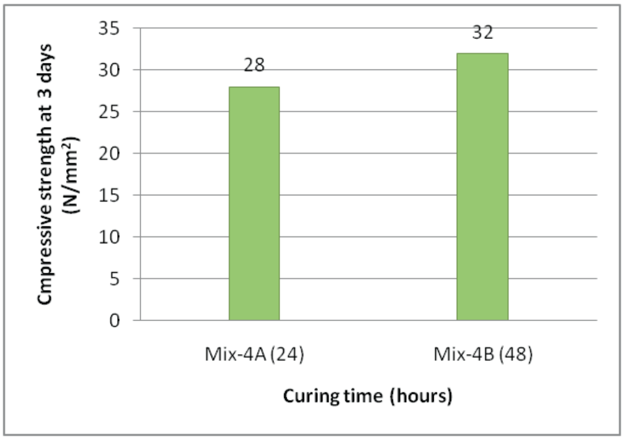

Fig. 3. Effect of curing time on compressive strength

Fig. 3 shows that Longer curing time has improved the polymerisation process resulting in development of higher compressive strength. Rapid rate of increase in the strength has been observed up to the curing time of 24 hours.

3.4. Additional of superplasticiser

Geopolymer concrete has a stiff consistency in the fresh state. Although adequate compaction was achievable, an improvement in the workability was considered as desirable [6]. Superplasticiser has been added in proportion to the fly ash in the concrete mix by mass as given in Table 2. Tests have been performed to study the effect of adding conventional commercially available Naphthalene Sulphonate based super plasticiser.

The test specimens have been cured for 48 hours at 75^0C in an oven. The effect of addition of superplasticiser on compressive strength of concrete has been observed by comparing results of Mix-5 as presented in Table 2. Concrete mixes 5 have been cast using 2%, 3% and 4% dosage of admixture, respectively.

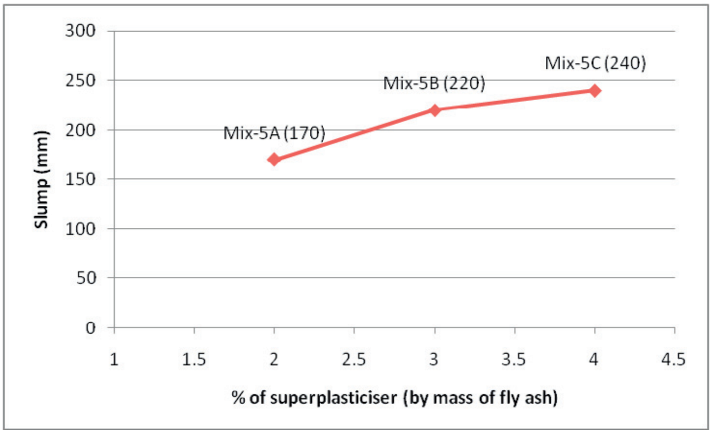

Fig. 4. Effect of addition of superplasticiser on workability

It has been observed that the addition of superplasticiser improved the workability of the fresh concrete as shown in Fig. 4. Increase in dosage of the superplasticiser also resulted in improved workability for the geopolymer concrete.

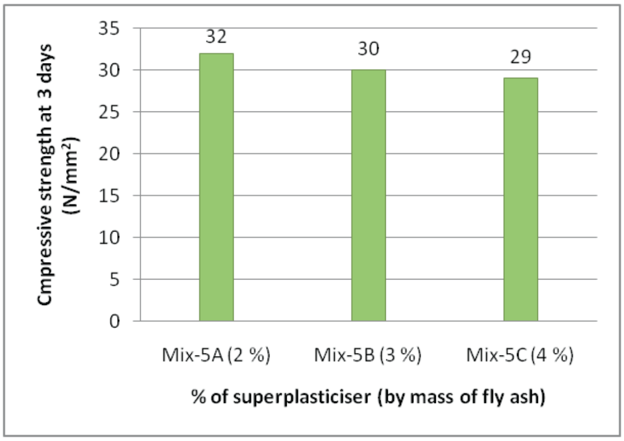

Fig. 5. Effect of addition of superplasticer on compressive strength

Concrete mix with 2% dosage of superplasticiser has archived higher compressive strength as compared to the 3% and 4% dosage of the superplasticiser. Thus, the addition of naphthalene based superplasticiser has been able to improve the workability of fresh geopolymer concrete. On the other hand, higher dosage of the admixture up to 4% has resulted into reduction of the compressive strength of the geopolymer concrete.

3.5. Rest period

The term 'Rest Period' is defined by the time taken from the completion of casting of concrete specimens to the start of curing at an elevated temperature. This is very important in context to many practical applications. For instance, when the fly ash based geopolymer concrete is used in precast concrete industry, there must be sufficient time available between casting of products and sending them to the curing chamber [7].

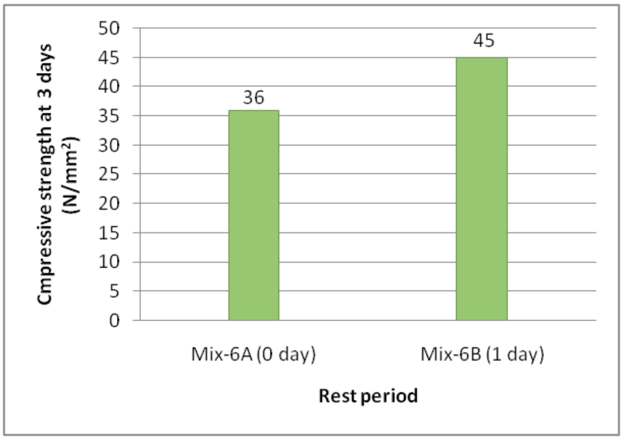

Fig. 6. Effect of rest period on compressive strength

For studying the effect of rest period concrete mixes 6 using ingredients as given in Table 2 has been cast. The test results for 0 day and 1 day rest period are presented as shown in Fig. 6. It has been observed that one day rest period has resulted into higher gain in compressive strength as compared to that for 0 day rest period.

Amount of concreting ingredients used for casting the geopolymer concrete Mix-7 to Mix-9 is given in Table 3.

Table 3. Ingredients for geopolymer concrete Mix-7 to Mix-9

Ingredient	Unit	Mix-7A	Mix-7B	Mix-7C	Mix-8A	Mix-8B	Mix-8C	Mix-8D	Mix-9A	Mix-9B	Mix-9C
Fly ash	kg/m^3	428	428	428	428	428	428	428	428	428	428
C.A	kg/m^3	1170	1170	1170	1170	1170	1170	1170	1170	1170	1170
F.A	kg/m^3	630	630	630	630	630	630	630	630	630	630
Na_2SiO_3	kg/m^3	114	114	114	114	114	114	114	114	114	114
NaOH	kg/m^3	57	57	57	57	57	57	57	57	57	57
Extra water	kg/m^3	43	64	86	43	43	43	43	43	43	43
Molarity		14	14	14	8	10	12	14	14	14	14
Superplasticiser	kg/m^3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3
Curing temp	^0C	75	75	75	75	75	75	75	60	75	90
Curing period	Hours	24	24	24	24	24	24	24	24	24	24
Rest period	Days	1	1	1	1	1	1	1	1	1	1
No. of cube		3	3	3	3	3	3	3	3	3	3

3.6. Water content of mix

The geopolymer concrete mix does not take any part in the chemical reaction. In ordinary Portland cement (OPC) concrete, water in the mix chemically reacts with the cement to produce a paste that binds the aggregates. The chemical reaction that occurs in geopolymers produces water that is eventually expelled from the binder. It has been observed that additional water content in the geopolymer concrete mix affected the properties of concrete in the fresh state as well as in the hardened state [7].

Water to geopolymer solids ratio by mass is very important in the design of geopolymer concrete mix. The total mass of water is the sum of the mass of water contained in the sodium silicate solution, the mass of water used in the making sodium hydroxide solution, and the mass of extra water, if any, present in the mix. The mass of geopolymer solids is the sum of the mass of fly ash, the mass of solids in the sodium silicate solution i.e. the mass of Na_2O and SiO_2.

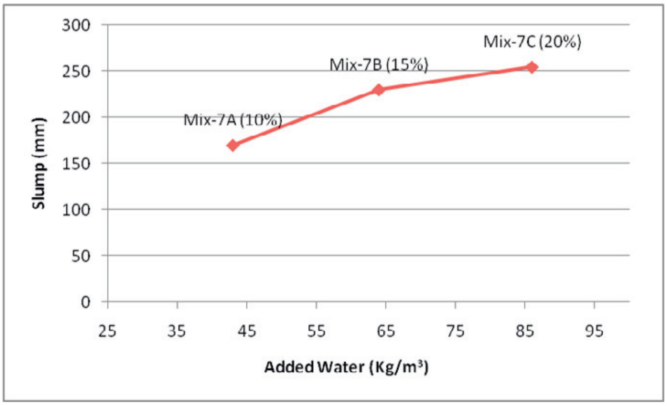

Fig. 7. Effect of water to geopolymer solids ratio on workability

The effect of water content of mix on compressive strength of geopolymer concrete can be observed by comparing results of Mixes 7. The concrete Mixes 7 have been cast using additional water of 10%, 15% and 20% by mass of fly ash as given in Table 3. Fig. 7 shows that increase in water to geopolymer solids ratio results into increase of the workability of mixes.

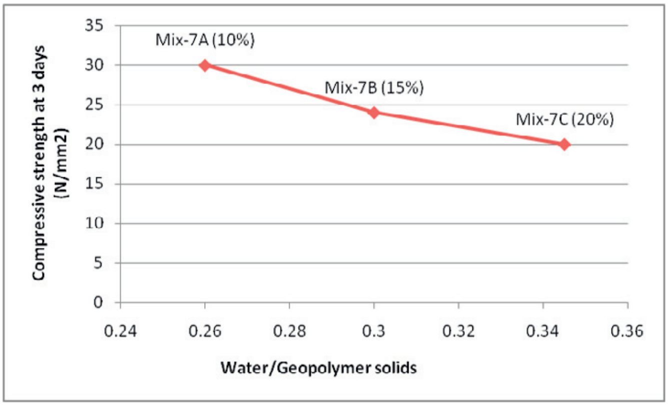

Fig. 8. Effect of water to geopolymer solids ratio on compressive strength

Fig. 8 shows the reduction in compressive strength of 33% for concrete Mix-7C as compared to that of concrete Mix-7A. Compressive strength of geopolymer concrete reduces with increase in the ratio of water to geopolymer solids. This test results are similar to the effect of water to cement ratio on the compressive strength of Portland cement concrete.

3.7. Concentration of sodium hydroxide solution

Mixes 8 have been cast using ingredients as shown in Table 3 to study the effect of concentration of sodium hydroxide solution on the compressive strength of geopolymer concrete. The measured compressive strength of test specimens after 7 days is given in Fig. 9.

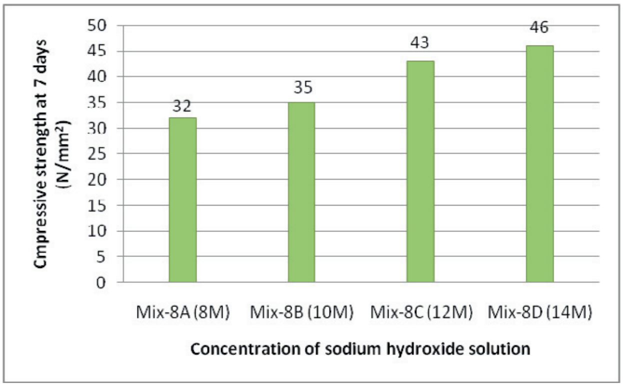

Fig. 9. Effect of concentration of sodium hydroxide solution on compressive strength

The difference between cases of Mixes 8 in terms of variation in compressive strength is the molar concentration of sodium hydroxide solution. Mix-8D with 14 M concentration of sodium hydroxide solution has been able to gain much higher compressive strength as compared to other cases. It has been observed that, higher concentration of sodium hydroxide solution gives better results in terms of compressive strength of geopolymer concrete.

3.8. Curing temperature

The effect of curing temperature on compressive strength of concrete has been observed by comparing results of concrete Mixes 9. Details of the mixes are given in Table 3. Specimens of all mixes have been cured after heat curing the test specimens in an oven for 24 hours. The measured compressive strength of test specimens after 7 days is given in Fig. 10.

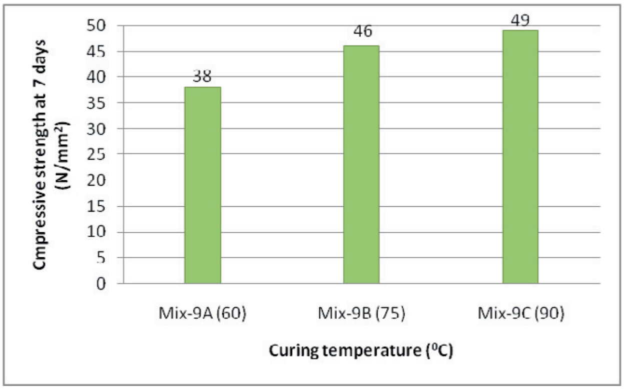

Fig. 10. Effect of curing temperature on compressive strength

The curing temperature has resulted in achieving higher compressive strength for geopolymer concrete. Increase in curing temperature beyond 75^0C has yielded into minor increment in the compressive strength for the concrete.

4. Conclusions

Following concluding remarks have been made on basis of the work conducted:

- The ratio of alkaline liquid to fly ash, by mass does not affect the compressive strength of the geopolymer concrete.
- The sodium silicate to sodium hydroxide ratio by mass equal to 2 has resulted into the higher compressive strength as compared to the ratio of 2.5 for the geopolymer concrete.
- The compressive strength of the geopolymer concrete increases with increase of concentration in terms of molarities of sodium hydroxide.
- The compressive strength of the geopolymer concrete increases with increase in the curing time. However, the increase in strength beyond 24 hours is not much significant.
- Workability of the geopolymer concrete mix increases with the addition of superplasticiser up to 4% of fly ash by mass. Minor reduction of compressive strength of the geopolymer concrete is observed when the superplasticiser dosage used is greater than 2%.
- 1 day rest period increases the compressive strength of the geopolymer concrete as compared to that for the concrete without the rest period.
- Compressive strength of the geopolymer concrete decreases with increase in the ratio of water to geopolymer solids by mass.
- The workability of the geopolymer concrete in fresh state increases with the increase of extra water added to the mix.
- With increase in the curing temperature in the range of 60^0C to 90^0C, the compressive strength of the geopolymer concrete also increases.

It has been observed from the above discussion that wide variety of parameters affect the compressive strength of the geopolymer concrete. Therefore, parametric study of various factors affecting the compressive strength of the geopolymer concrete is strongly recommended first before conducting any further investigations related to mechanical properties and durability of the geopolymer concrete in order to get the desirable benefits from the further investigations.

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