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RESEARCH ARTICLE

PARAMETRIC STUDIES ON VARIOUS FACTORS AFFECTING COMPRESSIVE STRENGTH OF GEOPOLYMER CONCRETE

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Abstract

Concrete is becoming more and more in demand as infrastructure facilities are being developed. It's good. It is a known fact that the manufacture of OPC uses a big amount of energy and natural resources and also emits a significant amount of carbon dioxide into the atmosphere. Therefore, it's crucial to come up with alternatives to environmentally friendly concrete. Fly ash is used to create the inorganic aluminosilicate substance known as geopolymer. India has a large supply of fly ash, one of the raw materials used to make geopolymer binders, although it has only just begun to be used. Therefore, in order to produce concrete that is more environmentally friendly, it is imperative to make the effort to use this by-product. In order to improve its overall performance, this research details the experimental work carried out by casting 20 different geopolymer concrete mixtures to assess the impact of different parameters impacting its compressive strength. There have been studies on a number of parameters, including the ratio of alkaline liquid to fly ash, sodium hydroxide concentration, sodium silicate to sodium hydroxide ratio, curing time, curing temperature, dose of superplasticizer, rest period, and additional water content in the mix. According to the test results, compressive strength improves with increased curing time, temperature, rest time, and sodium hydroxide solution concentration while decreasing with increased water to geopolymer solids by mass and admixture dose. The workability of new geopolymer concrete is enhanced by the use of a naphthalene-based superplasticizer. It was further discovered that a key factor in reaching the optimum compressive strength of the geopolymer concrete mix is the water content.

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Introduction:-

One of the most frequently used materials in the world is concrete. The main binder for making concrete is ordinary Portland cement (OPC). The necessity to build infrastructure facilities is driving the demand for concrete on a daily basis. However, it is generally known that the manufacture of OPC uses a sizable amount of energy and natural resources and also emits a sizable amount of carbon dioxide into the atmosphere. Around 2.8 billion tonnes

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of greenhouse gas emissions, or roughly 7% of all man-made greenhouse gas emissions, are contributed to the atmosphere each year by the global cement industry. Finding solutions to manufacture environmentally friendly concrete is crucial.

The use of byproduct materials like fly ash in place of Portland cement is one way to manufacture concrete that is more environmentally friendly. The development of high volume fly ash concrete, which uses up to 60% fly ash yet still has outstanding mechanical qualities and improved durability performance, is an important study in this area.

The creation of an inorganic alumina-silicate polymer, known as Geopolymer, made from byproducts like silicon- and aluminum-rich fly ash or components with a geological origin is another option for producing concrete that is environmentally benign. Although fly ash, one of the raw materials used to make geopolymer binders, is widely accessible, its use has not yet reached its full potential. Currently, India produces 90 million tonnes of fly ash each year. By investigating the usage of geopolymer concrete based on fly ash, two environmental issues are simultaneously addressed: the significant amount of CO₂ released into the atmosphere during the production of OPC and the utilisation of this fly ash.

The traditional concrete technology processes are used to create geopolymer concrete. The fly ash-based geopolymer concrete contains between 75 and 80 percent aggregate by mass. The aggregate is held together by a geopolymer paste that is created when the silicon and aluminium in the fly ash react with an alkaline liquid made of sodium hydroxide and sodium silicate solution, along with the addition of superplasticizer. Various elements that affect concrete's strength are examined in this study, and the findings are described using various graphs that correspond to the strength of the test cubes.

From the discussion above, it is clear that India has not done a lot of in-depth research on geopolymer concrete.

Limestone, which is the primary component used to make cement and ultimately concrete in India, is one of the natural resources that is being depleted. A thorough examination of geopolymer concrete, which is concrete that contains no cement, becomes crucial in this case. In the current experiment, an attempt has been made by casting 20 geopolymer concrete mixes with 100% of the OPC replaced by processed fly ash in each concrete mix. The relevance of compressive strength among the many mechanical qualities of concrete has always been emphasised by Indian standards. Thus, in order to improve the overall performance of Geopolymer concrete mixes, the effect of various parameters affecting the compressive strength, such as the ratio of alkaline liquid to fly ash, concentration of sodium hydroxide, ratio of sodium silicate to sodium hydroxide, curing time, curing temperature, dosage of superplasticizer, rest period, and additional water content, has been studied.

Experimental Work

Materials:-

The product POZZOCRETE 60, a low calcium class F processed fly ash from Dirki India private limited, was used in this study.

Sodium hydroxide and sodium silicate solution were combined to create the alkaline solution. To create the alkaline liquid, sodium silicate solution (Na₂O = 16.84%, SiO₂ = 35.01%, and water = 46.37% by mass) and sodium hydroxide (NaOH) in flakes with a 98% purity were both employed. You make sodium hydroxide solution by combining the flakes with water. To make the NaOH solution, tap water from the lab was utilised. At least a day was spent preparing the activator solution. As coarse materials, 10 mm and 20 mm crushed aggregates that are readily available locally have been utilised. In the concrete mixes, locally accessible river sand is employed as a fine aggregate. All of the geopolymer mixes contained a naphthalene sulphonate-based superplasticiser to increase the fresh geopolymer concrete's workability.

Casting of concrete mixes

Similar to traditional OPC concrete, geopolymer concrete is mixed in a similar way. All of the components were combined in a laboratory setting at room temperature. The concrete pan mixture included both the fly ash and the aggregate. For around 3 to 4 minutes, the mixing is allowed to continue. A day earlier, the alkaline solution was made, and it is mixed with more water. After adding the liquid component and superplasticizer, the dry material was mixed for an additional three to four minutes.

For prismatic examples, the freshly mixed concrete is instantly cast into the moulds after being divided into two layers. Each layer of the concrete sample received 25 to 35 manual strokes with a 20 mm rod to compact it. For

an additional 10 to 15 seconds, concrete specimens were vibrated using a vibration table. The concrete specimen was held at room temperature after casting in accordance with the predetermined resting period.

Table 1 lists the specific of the mix design for Mix-1 through Mix-6 of geopolymer concrete. In various geopolymer concrete mixtures, coarse and fine aggregate proportions range from 75-77% of the total mass of the concrete.

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

Ingredients	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
N ₂ SiO 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
Superplasticizer	Kg/m ³	8.5	9	8.5	8.5	8.5	8.5	13	17	8.5	8.5
Curing Temp.		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 Cubes		3	3	3	3	3	3	3	3	3	3

Curing of concrete specimen

For the course of the curing process, the concrete samples were baked in an oven to the required temperature. The test specimens were retained in the moulds for at least 4-6 hours after the curing period to avoid a major change in the ambient conditions. After being demolded, the concrete samples are allowed to air-dry in the lab until the day of the test.

Results and Discussion:-

Ratio of alkaline liquid to fly ash

Two concrete blends Mix-1 and Mix-2, having an alkaline liquid to fly ash ratio of 0.35 and 0.4, respectively, have been cast using the elements specified in Table 1. The effect of the alkaline liquid to fly ash ratio by mass on the compressive strength of concrete at age 3 days has been evaluated by comparing the results of the two mixes. The results are displayed in Fig. 1. It has been discovered that changing the mass ratio of alkaline liquid to fly ash has no effect on how strong the geopolymer concrete is in its compressive state.

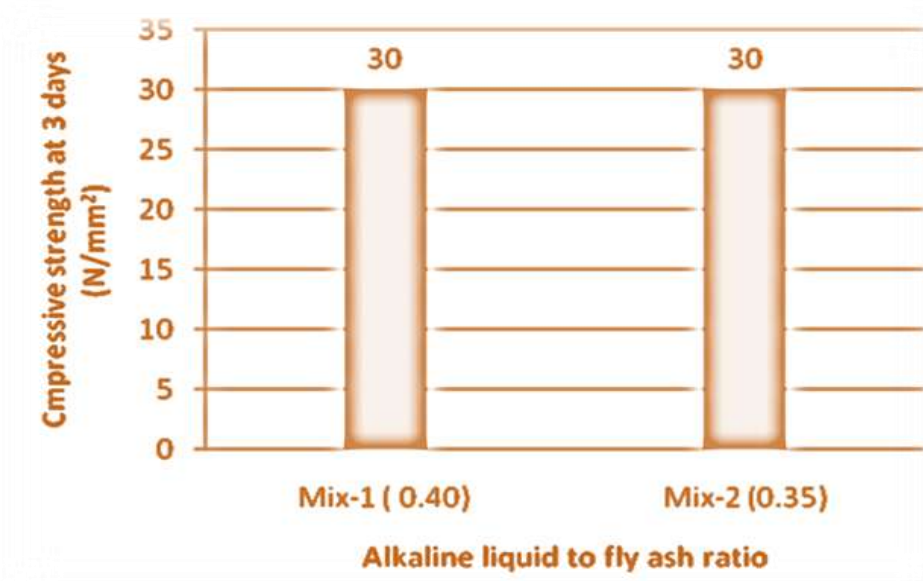


Fig.1:- Effect of alkaline liquid to fly ash ratio on compressive strength.

Ratio of sodium silicate solution to sodium hydroxide solution

By contrasting the findings of Mix-1 and Mix-3, which contained the elements listed in Table 1, it was possible to see the influence of sodium silicate solution to sodium hydroxide solution by mass on the compressive strength of concrete. The outcomes are shown in Fig. 2. Concrete Mix-3 has been found to have greater compressive strength than concrete Mix-1.

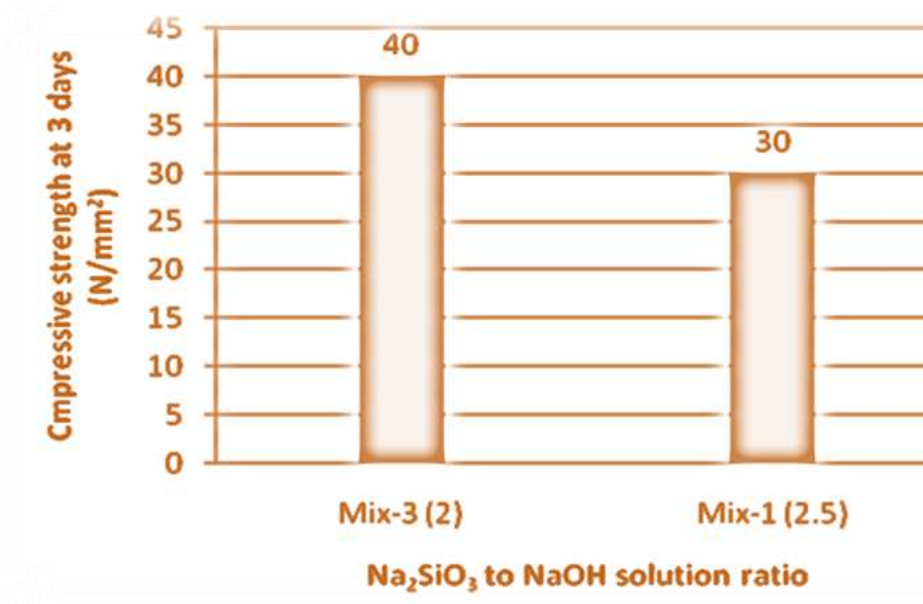


Fig2:- Effect of sodium silicate solution to sodium hydroxide solution on compressive strength.

Curing time

Test specimens have been cured for curing periods of 24 hours and 48 hours, respectively, to evaluate the impact of curing time. For the purpose of examining how curing time affects compressive strength, Concrete Mix-4 with the ingredients listed in Table 1 has been cast.

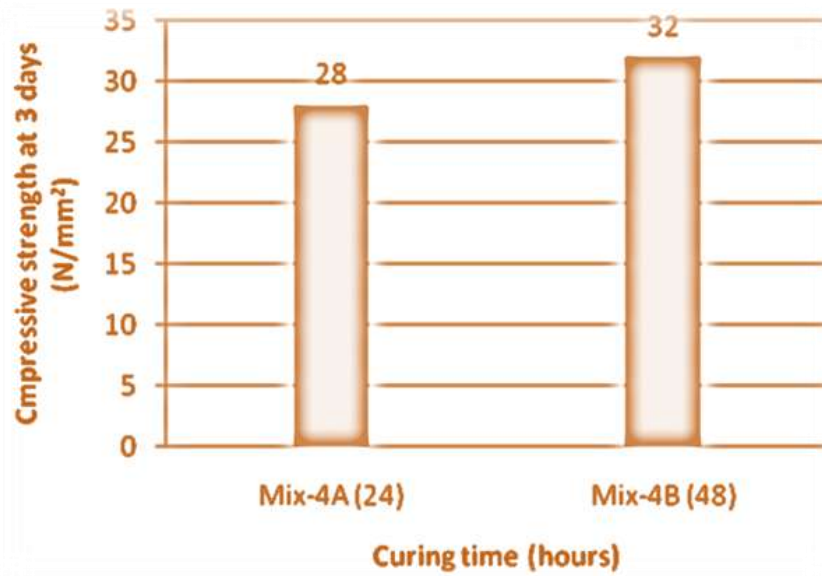


Fig.3:- Effect of curing time on compressive strength.

Longer curing times have improved the polymerization process, which has led to the production of higher compressive strength, as seen in Fig. 3. Up until a 24-hour cure time, a rapid rate of strength rise was noted.

Additional of superplasticiser

In its initial form, geopolymer concrete has a rigid consistency. Although sufficient compaction could be achieved, an increase in workability was thought to be desired. Superplasticizer has been added to the concrete mix by mass in Table 1's proportion to the fly ash. Tests have been conducted to determine the impact of adding a conventional, commercially available super plasticizer with a Naphthalene Sulphonate base.

The test specimens were cured in an oven for 48 hours at 750 C. By contrasting the outcomes of Mix-5, which are shown in Table 2, it has been possible to observe the impact of the addition of superplasticizer on the compressive strength of concrete. The dosages of additive used for Concrete Mix 5 were 2%, 3%, and 4%, respectively.

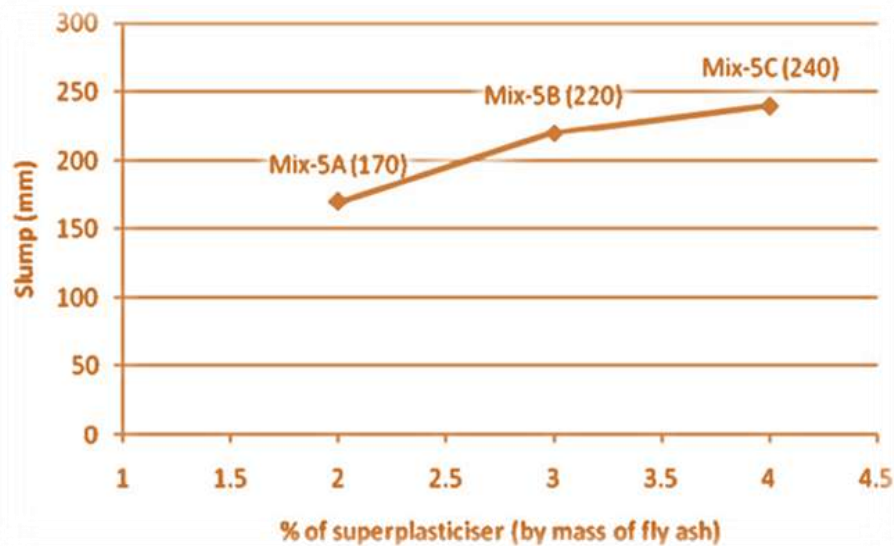


Fig.4:- Effect of addition of superplasticiser on workability.

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.

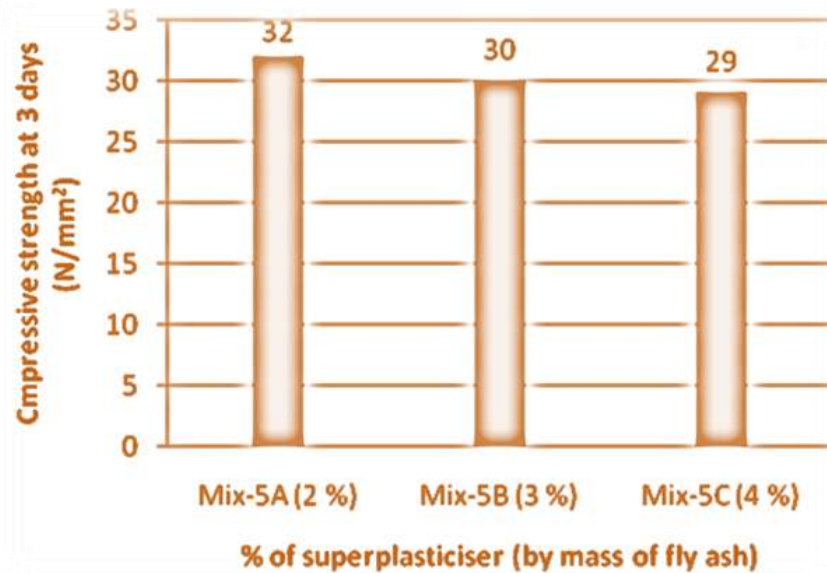


Fig.5:-Effect of addition of superplasticiser on compressive strength.

Concrete mix with 2% dosage of superplasticiser has achieved 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.

Rest period

When it comes to many practical applications, the term "Rest Period" refers to the period of time between the end of the concrete specimen casting process and the beginning of the high-temperature curing process. For instance, when fly ash-based geopolymer concrete is used in the precast concrete industry, there must be enough time between the product's casting and sending it to the curing chamber.

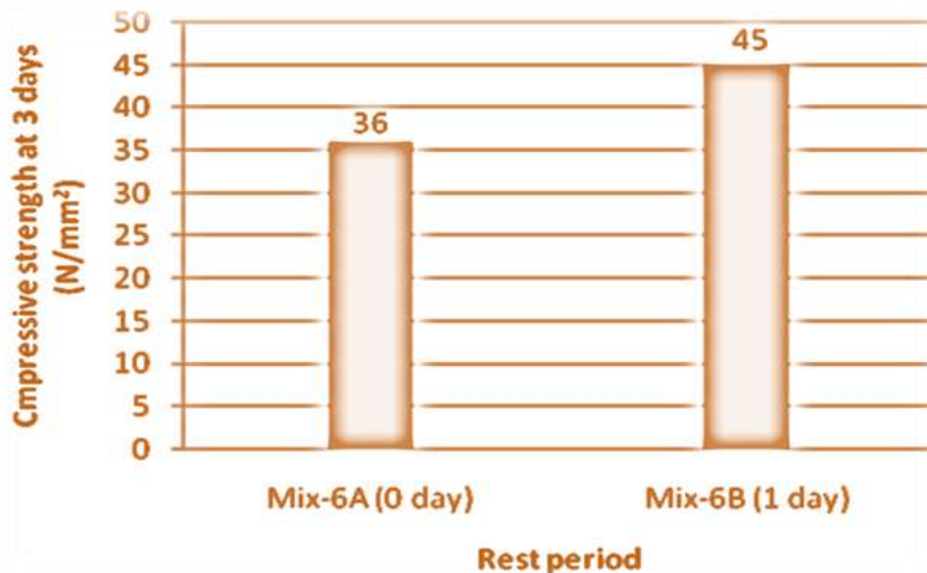


Fig.6:-Effect of rest period on compressive strength.

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 concrete ingredients used for casting the geopolymer concrete Mix-7 to Mix-9 is given in Table 2.

Ingredients	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
N ₂ SiO 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
Superplasticizer	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.		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 Cubes		3	3	3	3	3	3	3	3	3	3

Table 2:-Ingredients for geopolymer concrete Mix-7 to Mix-9

Water content of mix

The chemical process does not include the geopolymer concrete mixture in any way. Water in the mixture chemically reacts with the cement in ordinary Portland cement (OPC) concrete to create a paste that binds the aggregates. Geopolymers undergo chemical reactions that result in the production of water, which is finally ejected from the binder. It has been noted that adding more water to the geopolymer concrete mixture had an impact on the qualities of the concrete, both while it was still fresh and when it had hardened.

When creating a geopolymer concrete mix, the mass ratio of water to geopolymer solids is crucial. The total mass of water is the sum of the masses of the sodium silicate solution, the sodium hydroxide solution, and any additional water that may have been added to the mixture. The mass of geopolymer solids is made up of the combined masses of fly ash, sodium silicate solution solids (Na₂O and SiO₂), and fly ash.

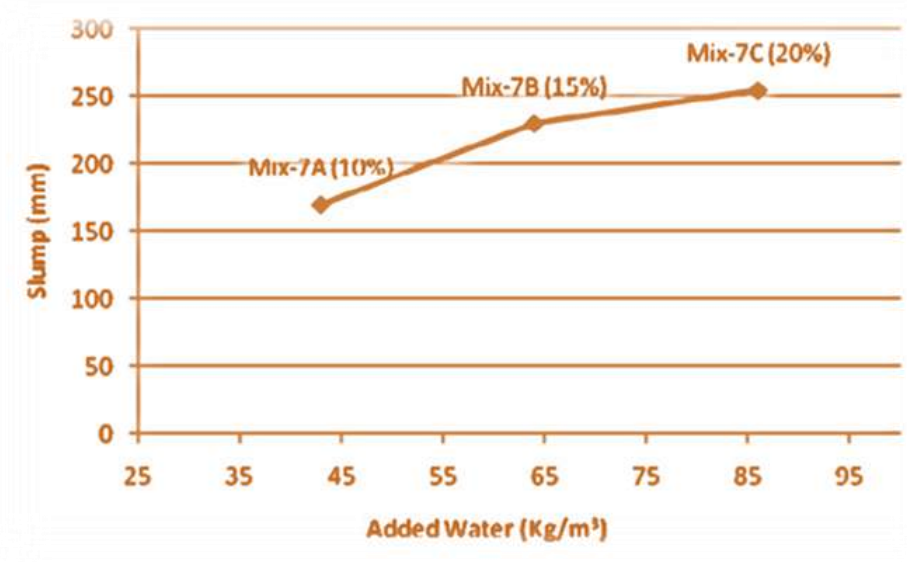


Fig.7:-Effect of water to geopolymer solids ratio on workability.

By contrasting the outcomes of Mixes 7 and 8, it is possible to observe how the water content of the mix affects the compressive strength of geopolymer concrete. According to Table 2, additional water containing 10%, 15%, and 20% by mass of fly ash was used to cast Concrete Mixes 7. According to Fig. 7, a higher water to geopolymer solids ratio makes mixtures easier to work with.

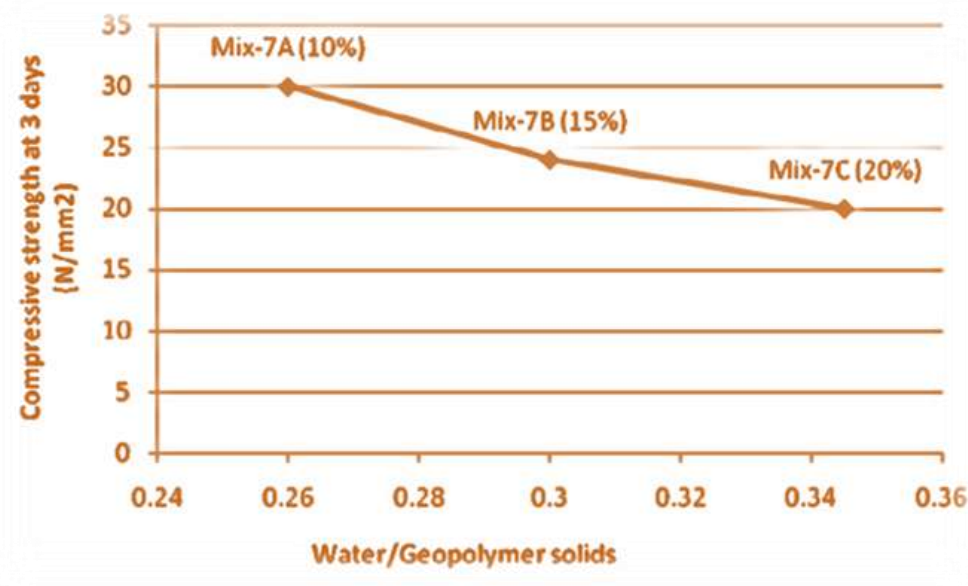


Fig.8:-Effect of water to geopolymer solids ratio on compressive strength.

According to Fig. 8, the compressive strength of concrete Mix-7C is 33% lower than that of concrete Mix-7A.

As the proportion of water to geopolymer solids increases, geopolymer concrete's compressive strength decreases. The effects of water to cement ratio on the compressive strength of Portland cement concrete are comparable to the test results.

Concentration of sodium hydroxide solution

For the purpose of examining how the concentration of sodium hydroxide solution affects the compressive strength of geopolymer concrete, Mixes 8 were cast using the components listed in Table 2. Figure 9 displays the test specimens' estimated compressive strength after 7 days.

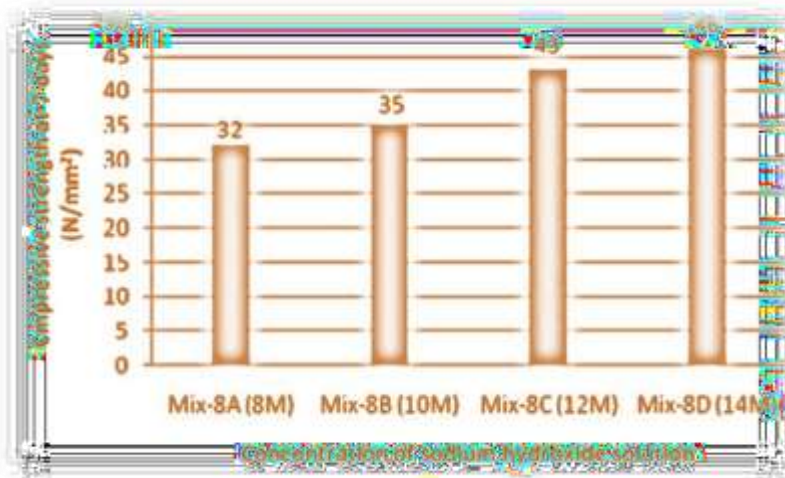


Fig.9:-Effectofconcentrationofsodium hydroxidesolutiononcompressivestrength.

The molar content of sodium hydroxide solution distinguishes one case of Mixes 8 from another in terms of variance in compressive strength. In comparison to other situations, Mix-8D with a 14 M concentration of sodium hydroxide solution has been able to achieve a significantly better compressive strength. Higher sodium hydroxide solution concentration has been found to produce superior outcomes in terms of compressive strength of geopolymer concrete.

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 2. 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.

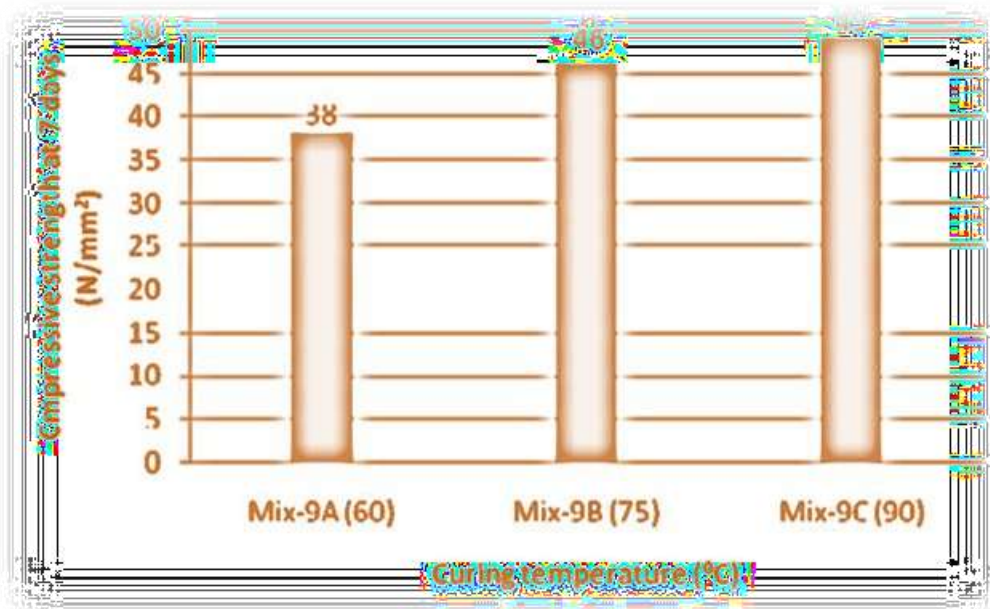


Fig.10:-Effectofcuringtemperature oncompressive strength.

Higher compressive strength has been attained for geopolymer concrete as a result of the curing temperature. Beyond 750 C, the curing temperature has resulted in a small increase in the concrete's compressive strength.

Conclusions:-

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

1. The compressive strength of the geopolymer concrete is not affected by the proportion of alkali liquid to fly ash, measured in mass.
2. In comparison to the ratio of 2.5 for geopolymer concrete, the sodium silicate to sodium hydroxide mass ratio of 2 has led to a better compressive strength.
3. With an increase in sodium hydroxide concentration in terms of molarities, geopolymer concrete's compressive strength rises.
4. With an increase in curing time, geopolymer concrete's compressive strength rises. Beyond 24 hours, the strength does not significantly increase.
5. With the addition of superplasticizer up to 4% of fly ash by mass, the workability of the geopolymer concrete mix improves. When the amount of superplasticizer employed is larger than 2%, there is a slight drop in the compressive strength of the geopolymer concrete.
6. When compared to concrete without a rest period, the compressive strength of geopolymer concrete has a 1-day rest interval.
7. Compressive strength of the geopolymer concrete decreases with increase in the ratio of water to geopolymer solids by mass.
8. With each additional amount of water added to the mix, the geopolymer concrete's workability rises in its fresh form.
9. The compressive strength of the geopolymer concrete likewise increases as the curing temperature rises between 60 and 90.

From the explanation above, it can be seen that a wide range of factors influence the compressive strength of geopolymer concrete. In order to obtain the desired results from the further investigations, parametric analysis of various factors affecting the compressive strength of the geopolymer concrete is strongly advised before conducting any other investigations related to its mechanical properties and durability.

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