

Research Article

Temperature Effect on Lime Powder-Added Geopolymer Concrete

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The need for concrete increases with rapid development in the field of infrastructure because of the increased use of cementing material of concrete. The production of concrete is unsafe to the earth. Consequently, there is a need to discover new binding material with cementing properties. Fly ash debris is wastage of thermal power plants and acquires hectares of land for the dumping reason. This paper concentrates on development of alternative binding material in the field of construction. The fly ash-based geopolymer concrete is a better option, but it needs heat curing for the polymerization. The use of lime powder in the geopolymer concrete gives better result without heat curing. The experiment depends on the characteristics of daylight curing and impact of temperature in controlled oven curing. The M30 grade geopolymer concrete plans with the addition of lime powder. The addition of lime powder is changed by 0%, 5%, 10%, 15%, 20%, and 25%. The compressive strength increases with addition of lime powder, but in the cases of 20% and 25%, the workability gets hamper. The study also deals with temperature variations when oven cured for 35°C, 40°C, 50°C, and 60°C hence assessed.

1. Introduction

Concrete, as a noteworthy development material, is being utilized at a regularly expanding rate all around the globe. The cement is right now used in ordinary Portland concrete, which brings about a gigantic worldwide bond industry. Consistently, the creation of OPC is expanding with the expanding interest of development. Hence, the carbon dioxide discharge rate increases step by step into the air. One ton of carbon dioxide is transmitted into the air with the generation of one ton of Portland cement. The ozone-depleting substance emanation from the creation of Portland concrete is around 1.35 billion tons yearly, which is around 7% of the aggregate ozone-depleting substance outflow [1] (Patankar 2013). On the other way, fly ash is the waste material of coal-based thermal power plants, available abundantly, but creates a disposal problem. Several hectares of agricultural land are acquired by the thermal power plant for the disposal of fly ash. As it is light in weight and flies easily, it creates health problems like asthma and bronchitis.

Now, the challenge amongst the researchers is to find an appropriate alternative for eliminating the environmental hazards caused by the production of cement. A very prominent research by Davidovits in 1978 was the invention of geopolymer concrete which was a cement-free concrete. This attracted a lot of attention where fly ash is replaced by cement for 100%. It had its own identity and left remarkable impressions in the research studies. Geopolymer exhibits similar properties to that of conventional concrete; the only difference is that it is being 100% cement free. But challenging human tendency of having blind faith for years over cement for its strength and durability is an uprising challenge. Building this faith and trust for the use of geopolymer concrete over conventional concrete is a huge task and requires testing of geopolymer concrete against conventional concrete. Not only can the elimination of CO₂ emission be avoided, but also there are lot many reasons for geopolymer concrete to be eco-friendly. The most prolific reason for use of fly ash is its dumping issue and its minimum use. Previous investigation made on geopolymer

concrete reveals that good strength is achieved when curing is done at elevated temperature limiting its application on site. With an addition and replacement of optimum percentage of lime and cement, respectively, an additional amount of heat will be produced; when mixed with water, the reaction being exothermic can be used as an alternative for the elevated curing temperatures, thereby achieving the desired strength at normal room temperature and by wet curing giving it a wide scope and various practical applications and uses.

2. Literature Review

Dutta and Ghosh [2] studied that the pore sizes get a reduction after addition of limestone dust into the geopolymer paste sample. This phenomenon influences water absorption and compressive strength. Incorporation of limestone dust up to 15% increases the compressive strength of paste specimens about 44%. The reduction in compressive strength due to lower curing temperature may be compensated by incorporation of calcium compound which can accelerate the rate of polymerization even at low temperature. Hake et al. [3] reported that the cement production generated carbon dioxide, which pollutes the atmosphere. The thermal industry produces a waste called fly ash which is simply dumped on the earth, which occupies larger areas. The waste water from the chemical industries is discharged into the ground which contaminates ground water. By producing geopolymer concrete, all the above-mentioned issues shall be solved by rearranging them. Waste fly ash from thermal industry + waste water from chemical refineries = geopolymer concrete. Further, the use of fly ash as a value-added material as in the case of geopolymer concrete reduces the consumption of cement. Reduction of cement usage will reduce the production of cement which in turn cut the CO₂ emissions. Many researchers have worked on the development of geopolymer cement and concrete for the past ten years. The present work deals with the result of the experimental investigation carried out on geopolymer concrete using processed and unprocessed fly ash with sodium silicate and sodium hydroxide. The study analyses the effect of processed and unprocessed fly ash on compressive strength and split tensile strength for different temperatures. To study the effect of different types of processed and unprocessed fly ash, we use processed fly ash such as P60, P80, and P100 from Dirk India Pvt. Ltd. and unprocessed fly ash from different cities such as Bhusawal, Nashik, and Beed. In this paper, the effect of the alkaline solution on different fly ash is investigated. Namagga and Atadero [4] investigated that the replacement of high-lime fly ash in concrete generally increases the ultimate strength of concrete. It is probable that even higher percentile replacements of cement would still be able to provide the same compressive strength as no fly ash concrete. Replacement of cement with high-lime fly ash reduces the rate of strength development/gain beyond the optimal limits obtained for 25–35% fly ash mixes. More air entrained admixture is required for increasing amounts of fly ash used. Vijaya Rangan [5] stated that the elastic properties of hardened geopolymer concrete and the behavior and strength of reinforced geopolymer concrete structural members are

TABLE 1: Chemical composition of materials.

Chemical composition	Fly ash (%)	Lime (%)
SiO ₂	57.30	3.92
Al ₂ O ₃	27.13	2.74
Fe ₂ O ₃	8.06	0.38
MgO	2.13	0.28
SO ₃	1.06	—
Na ₂ O	0.73	—
CaO	0.03	51.01
LOI	1.60	41.56
K ₂ O	—	0.04
TiO ₂	—	0.09

similar to those observed in the case of Portland cement concrete. Heat-cured low-calcium fly ash-based geopolymer concrete also shows excellent resistance to sulfate attack and fire, good acid resistance, low creep, and suffers very little drying shrinkage. Geopolymer concrete has several economic benefits. Bondar [6] investigated that geopolymer concrete can be produced with the same cost of OPC concrete and comparable properties. Geopolymer concrete develops moderate to high mechanical strength with a high modulus of elasticity and shrinkage much lower than that of OPC. Geopolymer concrete manufacture is liable to reduce CO₂ emission as compared to OPC production. Vora and Dave [7] investigated that the compressive strength of the geopolymer concrete increases with the increase of concentration in terms of molarity of sodium hydroxide. 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 workability of the geopolymer concrete in the fresh state increases with the increase of extra water added to the mix. The compressive strength of the geopolymer concrete decreases with the increase in the ratio of water to geopolymer solids by mass. The increase in the curing temperature in the range of 60°C–90°C also increases the compressive strength of the geopolymer concrete.

3. Materials Used

3.1. Fly Ash. Fly ash used in this study is low-calcium class F-processed fly ash from Dirk India Private Limited under the name of the product POZZOCONCRETE 60. The chemical compositions of the fly ash used along with the specifications are given in Table 1. The specific gravity of the fly ash used is 2.26. The residue of fly ash retained on 45 μm IS sieve was reported as 16.84%. The fineness of the fly ash by Blen's method is 360 m²/kg.

3.2. Alkaline Solution. 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 the local chemical supplier was used, and

sodium silicate solution ($\text{NaO} = 16.84\%$, $\text{SiO}_2 = 35.01\%$, and water = 46.37% by mass) was used as the alkaline liquid. Sodium hydroxide solution is prepared by dissolving the flakes in water. Tap water available in the laboratory was used to prepare NaOH solution. The activator solution was prepared at least one day prior to its use. Molarity of the solution was 16 M.

3.3. Aggregates. Locally available 12.5 mm and 20 mm crushed aggregates are used as coarse aggregates having specific gravity 2.65. Locally available river sand is used as fine aggregate in the concrete mixes having specific gravity 2.5 and of Zone-I conforming IS specifications.

3.4. Lime. The limestone dust is a solid composite having a specific gravity of 2.7 and a bulk density of 1425 kg/m^3 . It has an average particle size of 25 microns while particle size varies between 10μ and 70μ . Chemical compositions of the fly ash used along with the specifications are given in Table 1.

4. Experimental Work

The concrete cubes of size $150 \times 150 \times 150 \text{ mm}$ were cast for trial mixes M30 grade for checking the workability slump cone test performed. In the geopolymer concrete, the alkaline activators such as sodium hydroxide and sodium silicate were used. The proportionate ratio of the alkaline solution is taken as 2.5. The experimental work evaluation of the optimum percentage of lime addition has to be worked out. For the same, cubes are to be cast for 5%, 10%, 15%, 20%, and 25% of lime addition, whereas lime percentage is by weight to that of fly ash. Initially, temperature and testing age are kept constant, and curing hours are varied such as 06 hrs, 12 hrs, 18 hrs, and 24 hrs. In this case, the optimized curing hours were acquired; by using this, the degree of heating ranging from 40°C to 120°C at an interval of 10°C for oven curing was obtained. The concrete cubes were cast and cured at normal room temperature to know their characteristic strength as well. After evaluating the optimum curing hours, rest period and temperature beams and cylinders were cast for the evaluation of flexural and split tensile strength of lime-added fly ash-based geopolymer concrete.

4.1. Percentage of Lime Addition (M30). The specimens were cast of size $150 \text{ mm} \times 150 \text{ mm} \times 150 \text{ mm}$ of grade M30 having alkaline solution ratio as 2.5. The concrete cubes were cured at 90°C in an oven for 24 hrs with addition of varied lime percentages by weight of fly ash. After the completion of the defined curing time, the specimens were kept at normal room temperature with a rest period of 07 days. The specimens were tested for compression on a compression testing machine of capacity 2000 KN to know the optimum percentage of lime addition and to study its effect on the strength of geopolymer concrete.

Figure 1 represents the variation in the strength of geopolymer concrete of grade M30 with the addition of lime percentage cured for 24 hours at a temperature of 90°C .

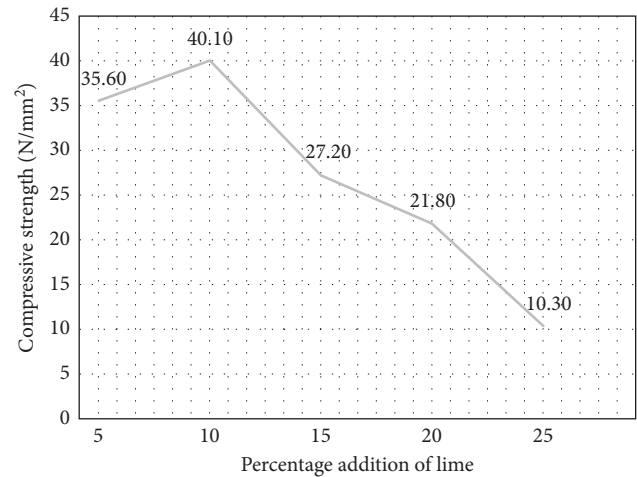


FIGURE 1: Percentage addition of lime powder in GPC oven cured at 90°C .

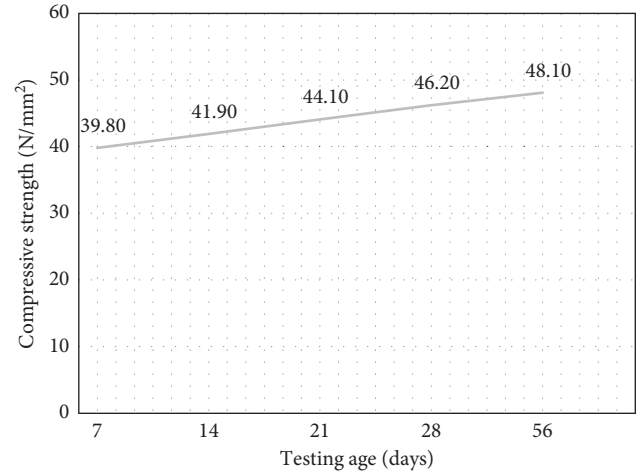


FIGURE 2: Effect of testing age on geopolymer concrete with oven curing.

The rest period for the cured specimens was 07 days. The maximum compressive strength was achieved with an addition of 10% of lime. Thus, the optimum percentage of lime addition observed here is 10%.

4.2. Effect of Rest Period. The specimens were cast of size $150 \text{ mm} \times 150 \text{ mm} \times 150 \text{ mm}$ of grade M30 having alkaline solution ratio as 2.5 and were cured at 90°C in an oven for 24 hrs with the addition of optimized lime percentages (10%). The lime percentages were calculated in accordance with the weight of fly ash. After the completion of the defined curing time, these specimens were kept at normal room temperature with a rest period or testing age of 07, 14, 21, 28, and 56 days. The specimens were tested after testing age to know the effect of the rest period on the strength of GPC with lime addition into geopolymer concrete.

Figure 2 represents the increase in the strength of geopolymer concrete of grade M30 with the increase in the rest period at a temperature of 90°C . The maximum compressive

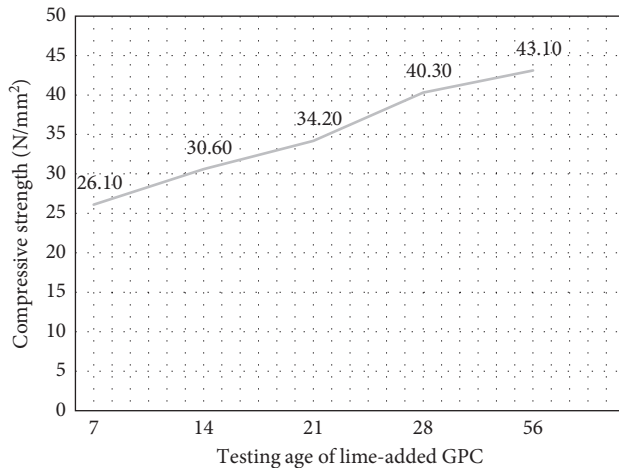


FIGURE 3: Cube cured at natural room temperature.

strength was achieved in 28 days. But, at 7th day, the strength achieved was more than the designed strength. Thus, the optimum rest period observed here is 7 days for the project work being time bound.

4.3. GPC (M30) with 10% Lime Addition Cured at Normal Room Temperature. The specimens were cast of size 150 mm × 150 mm × 150 mm of grade M30 having alkaline solution ratio as 2.5 and were cured at normal room temperature with an addition of 10% lime. These specimens were kept at normal room temperature for a rest period of 07, 14, 21, and 28 days after which the specimens were tested for compressive strength. The readings were recorded and listed, to know the effect on strength of GPC cured at normal room temperature.

Figure 3 represents the increase in the strength of geopolymer concrete of grade M30 + 10% with the increase in the rest period at normal room temperature. The normal room temperature on an average was recorded as 28°C (temperature in the morning was recorded as 27°C, and in the evening, it was recorded as 29°C). The strength observed during the rest period of 7 days was achieved more than 70%, unlike conventional cement concrete. The maximum compressive strength was achieved at 28th day which is more than the designed strength. Thus, geopolymer concrete of grade M30 with 10% lime addition by weight of fly ash does achieve strength more than desired at normal room temperature.

4.4. Effect of Varied Curing Temperature of GPC (M30) with 10% Lime Addition. The specimens were cast of size 150 mm × 150 mm × 150 mm of grade M30 with addition of 10% of lime. The concrete cubes were cured at different elevated temperatures of 40°C, 50°C, 60°C, 70°C, 80°C, 90°C, 100°C, 110°C, and 120°C in an oven for 24 hours. After the completion of the defined curing time, these specimens were kept at normal room temperature for a rest period of 07 days after which the specimens were tested for compression on a compression testing machine of capacity 2000 KN. The readings were recorded and listed to study the effect of

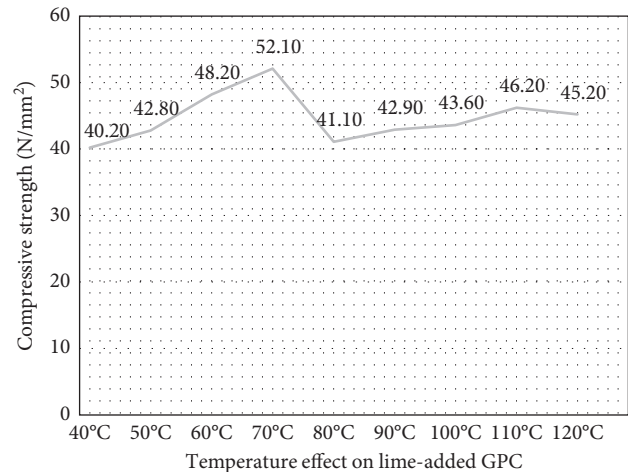


FIGURE 4: Effect of temperature on lime-based GPC.

varied curing temperature for geopolymer concrete with 10 percent of lime addition.

Figure 4 represents the variation in the strength of geopolymer concrete of grade M30 with the addition of 10% lime cured for 24 hours at varied temperatures. The rest period for the cured specimens was 07 days. The graph depicts the decrease in strength at higher temperatures. The maximum compressive strength was achieved with an addition of 10% of lime at 70°C. Thus, the optimum temperature with 10% lime addition observed here is 70°C.

5. Conclusion

- (1) The compressive strength of geopolymer concrete of grade M30 goes on increasing with the addition of 5% and 10% of lime, where maximum can be achieved by the addition of 10% of lime.
- (2) Addition of 15%, 20%, and 25% of lime in geopolymer concrete of grade M30 makes the concrete harsh which adversely affects its workability as well as its compressive strength.
- (3) The compressive strength goes on increasing for an M30 grade of geopolymer concrete with 10% lime addition, as the rest period increases, where the maximum strength is achieved at the completion of 28 days of the rest period.
- (4) The compressive strength of M30 grade of geopolymer concrete with the addition of 10% of lime goes on increasing with the increase in the curing temperature ranging from 40°C to 70°C, where maximum can be achieved at 70°C.
- (5) When 5% of fly ash was replaced by lime by weight, the mixture observed was deficient in the binder, that is, fly ash, thereby decreasing the compressive strength of the geopolymer concrete making it necessary to add lime rather than replacing lime in the preparation of geopolymer concrete.
- (6) compressive strength can also be achieved at higher curing temperatures ranging from 80°C to 120°C for

M30 grade of geopolymer concrete with the addition of 10% lime.

- (7) The compressive strength goes on increasing with the increase in the rest period of geopolymer concrete (M30) with the addition of 10% of lime when cured at normal room temperature, and the maximum compressive strength was achieved at the completion of 28 days of the rest period, thereby giving it a wide scope.
- (8) The compressive strength achieved by grade M30 of geopolymer concrete cured at normal room temperature in a rest period of 7 days is higher than the compressive strength achieved by ordinary concrete for a similar rest period.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

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