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Strength Characteristics of Geopolymer Concrete Floor Tiles on Various Mix Proportions

Sivapriya Sekhar, Annie Thomas
B. Tech Scholars
Dept. of Civil Engineering
Adi Shankara Institute of Engineering and Technology
Kochi, Kerala, India

Clydin P A
Assistant Professor
Dept. of Civil Engineering
Adi Shankara Institute of Engineering and Technology
Kochi, Kerala, India

***Abstract*— Traditional ceramic tiles are produced at very high temperatures of 1100-1200°C, which also increases the production costs upto 30%. These processes also involve the evolution of large amount of greenhouse gases like CO_2 (around 0.2 kg per final product) to the atmosphere and contributes to global warming. To overcome these problems, geopolymers are recommended as the potential alternative as they could be synthesized by curing at ambient temperature or slightly higher temperature (25-150°C). Geopolymer is a material which is formed as a result of the reaction between alumino-silicate containing materials (like fly ash, GGBS, metakaolin, etc.) and alkali activators (like NaOH and sodium silicate). In this paper, geopolymer concrete floor tiles are manufactured with different mix proportions containing fly ash, cement, fine aggregates and coarse aggregate with ratio of alkaline solution to fly ash taken as 0.4 and by varying the percentage replacement of cement by fly ash as 60%, 70% 80% and 90%. Sodium hydroxide and sodium silicate are used as alkali- activator solution which is designed at 12M and prepared one day prior to the casting of the specimens to avoid a fast setting of paste and the binder ratio is fixed as 1:2.5. Metallic moulds of size 150mm x 150mm x 10mm are used to cast the specimens. The water to fly ash ratio is reduced to 0.15 by adding 2% super plasticizer. The casted tile specimens are cured by placing it in hot air oven at 60°C for 24 hours. The cured GPC floor tile specimens are tested for water absorption, compressive strength, flexural strength and abrasion resistance as per IS 1237:2012, at the end of 7 days and 28 days. The geopolymer concrete floor tile specimens with 80% fly ash and 20% cement shows the most desirable properties after 28 days, including high compressive strength of 34.81 MPa, high flexural strength of 63 MPa at 6.3 kN, permissible water absorption of about 4.35% and better abrasion resistance. The tile specimens at this mix proportion also possess high resistance to wear and tear and is also highly stiff.**

Keywords—Geopolymer concrete, fly ash, mix proportions, alkali activators

I. INTRODUCTION

The tile industry, which is one of the important branches of ceramic industry sector, involves high energy consuming processes during the manufacture of traditional ceramic tiles. These processes are also responsible for the emission of greenhouse gases into the atmosphere, mainly CO_2, which contributes to the global warming. The process is also highly costly. Also, infrastructure developments are very essential for a developing country like India and highly promotes the development of building materials like bricks, tiles, etc. building materials like tile has its advantages of aesthetic view and performance-based utilization. But cost plays a major role in the manufacturing processes. Thus, geopolymers are seen as potential alternative to overcome all these disadvantages in tile industry. Researchers conducted various studies to produce the best fly ash based geopolymer tiles with different mix proportions to achieve much better concrete performance and to satisfy the common conditions. Fly ash characteristics also influences the performance of the geopolymer products produced. Geopolymer concrete floor tiles made with partial replacement or complete replacement level of cement may control the cost of the production and may also improve the durability properties. It also encourages the utilization of waste materials like fly ash for the manufacture of building materials like tiles [1].

Geopolymer, introduced by Davidovits, is an inorganic alumino-silicate polymer synthesized from predominantly silicon (Si) and aluminium (Al) materials of geological origin or by product materials like fly ash, metakaolin, Granulated Blast Furnace Slag (GGBS), etc. the geopolymerization process involves a substantially fast chemical reaction under alkali condition on aluminosilicate minerals that result in a three-dimensional polymeric chain and ring structure consisting of Si-O-Al-O bonds. The geopolymerization process involves the following steps:

1. Dissolution of Si and Al atoms form the aluminosilicate containing source materials through the action of hydroxide ions.
2. Formation of precursor ions into monomers by condensation.
3. Polycondensation or setting or polymerisation of monomers into polymeric structures.

Demand for concrete as construction material is also on the increase and so is the production of cement but it has been reported that the durability of ordinary Portland cement concrete is questionable, as many concrete structures especially those built-in corrosive environments start to deteriorate after 20 to 30 years, even though they have been designed for more than 50 years of service life. But since the use of portland cement is unavoidable, finding an alternative to this is a necessity. Also, the abundant availability of fly ash worldwide could be utilized as a substitute for OPC to manufacture concrete. When fly ash is used as a partial replacement of OPC, it reacts with the calcium hydroxide present in the cement, during the hydration process to form calcium hydrate silicate (C-S-H) gel which is responsible for its increased properties. Pozzolans such as GGBS, fly ash, etc might be activated under alkaline condition to form a binder, thus completely replacing cement in concrete preparation.

The main binder produced here is a C-S-H gel during the hydration process. Thus, compared with tiles made with ordinary portland cement concrete, geopolymers concrete floor tiles possess many advantages. Low-calcium fly ash-based geopolymer concrete floor tiles may show excellent compressive strength, suffers very little drying shrinkage and low creep, excellent resistance to sulphate attack, and good acid resistance. It also reduces the cost of production compared to the material costs for the production of ordinary portland cement. Also, the production of one ton of cement emits one ton of CO_2 to the atmosphere, which is also reduced by replacing cement with fly ash [24].

In this paper, variation of the amount of fly ash in the geopolymer concrete mix as 60%, 70%, 80% and 90% is carried out and theses mixes were used to prepare GPC floor tiles and they were tested for various properties like water absorption, compressive strength, flexural strength and abrasion resistance.

II. MATERIAL AND METHODS

A. *Materials used*

OPC 33, class F fly ash, M sand, coarse aggregate of 6mm size and alkali-activator solutions of sodium silicate and sodium hydroxide designed at 12M and prepared one day prior to casting of geopolymer concrete tile specimens is used to produce the geopolymer concrete [1][2].

B. *Preparation of alkali-activator solution*

Sodium hydroxide (NaOH) in pellets form with 98% purity purchased from a local chemical supplier and Sodium silicate solution (containing 16.84% Na_2O, 35.01% SiO_2 and 46.37% water by mass) are used. Tap water available in laboratory is used to prepare NaOH solution. In previous works, sodium hydroxide (NaOH) solution was prepared by dissolving pellets in 1 litre of water to obtain sodium hydroxide solution. In order to avoid evolution of excessive heat due to exothermic reaction during the alkali solution preparation, it should be prepared one day prior to use. Sodium silicate solution is mixed with the sodium hydroxide solution at the time of casting [8]. Sodium hydroxide and sodium silicate solution is prepared for 12M value [1][23].

C. *Mix proportion of concrete*

The mix proportions for geopolymer are calculated and the proportion of geopolymer is analyzed [9]. The ratio between Sodium hydroxide to sodium silicate and fly ash to alkali activator is fixed as 1:2.5[1][23].

Table 1: Mix proportioning of geopolymer concrete tiles

Fly ash: Cement	Sodium Hydroxide	Sodium silicate	Water	Cement	Fly ash	M Sand
90:10	1	2.5	0.17	0.43	3.90	6.25
80:20	1	2.5	0.17	0.87	3.47	6.25
70:30	1	2.5	0.17	1.30	3.03	6.25
60:40	1	2.5	0.17	1.73	2.60	6.25

D. *Geopolymer tile formation*

The coarse aggregates, M sand and fly ash are dry mixed for about 3 minutes and then mixed thoroughly with the alkali activator solution and water until a homogenous slurry is obtained [2]. By adding 2% of a suitable naphthalene-based superplasticizer like Conplast SP 430 (with specific gravity 1.2), the water to fly ash ratio can be reduced to 0.15. This fresh paste is then rapidly poured and casted into a moulds of size 150mm × 150mm × 10 mm. The geopolymer concrete tile samples are cured at 60°C in oven for 24 hours [26]. The cured samples are kept at room temperature for 7 and 28 days in order to analyze their properties.

Figure 1: Mould of size 150mm x 150mm x 10 mm prepared for casting of geopolymer concrete tile specimens

E. *Casting of specimens*

The tiles with 150mm x 150mm x 10mm size are casted with geopolymer concrete. Generally, the tile having minimum thickness does not need compaction and the surface has been smoothened by travel only. Geopolymer concrete specimen should be casted immediately to avoid porosity formation [1].

F. *Curing*

The casted geopolymer concrete tile specimens are hot air oven cured at 60°C for 24 hours. Hot air curing helps in equal distribution of the heat which helps to attain maximum strength to the geopolymer concrete tiles [26].

III. RESULT AND DISCUSSION

A. *Compressive strength*

The results of compressive strength are taken as the average of three tile specimens for each mixture at 7 and 28 days as shown in Figure 2. The compressive strength values are found to be increased at all ages with the increase in cement replacement by fly ash up to 80% and beyond that, the strength decreased. The maximum strength value of 34.81 MPa is obtained for the tile specimens with 80% fly ash at 28 days. With the inclusion of fly ash up to 80%, the increase in strength is due to the reaction of calcium hydroxide present in cement with the alkalis present in the mixture. CASH (Ca-Al-Si) and CSH (calcium silicate) gel may be obtained as an additional product after the hydration reaction which co-existed with NASH as additional phases. Also, since the process is exothermic in nature, the extra heat produced increased the effective curing temperature for polymerization reaction and further increased the formation of NASH (Na-Al-Si bonds). The additional calcium content present in cement is also expected to accelerate hardening and dissolution by increasing extra nucleation sites. Also, the

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increase in compressive strength values after 7 days is not significant for all the mixtures. For instance, for the mixtures with 80% fly ash after 7 days, the increase in strength values for 28 days is only 19.2%. This is unlike conventional concrete where an increase of about 20– 30% can be expected. The high compressive strength may be mainly due to the geopolymer mechanism which involves polymerization reaction between aluminosilicates, liberated from fly ash with the alkali-activator solution, which is initiated by high-temperature curing. Polymerization products obtained are strong Na-Al-Si (NASH) bonds, which yielded high strength values. After the formation of geopolymer products, with the development of age, the homogeneity is maintained in the matrix with slight modifications.

Table 2: Table showing the compressive strength values of fly ash based geopolymer concrete floor tiles with fly ash inclusion as cement replacement at 7 and 28 days

Proportion of fly ash and cement	7 days	28 days
60% fly ash+40% cement	28.32	34.21
70% fly ash+30% cement	28.63	34.52
80% fly ash+20% cement	29.2	34.81
90% fly ash+10% cement	27.91	33.19

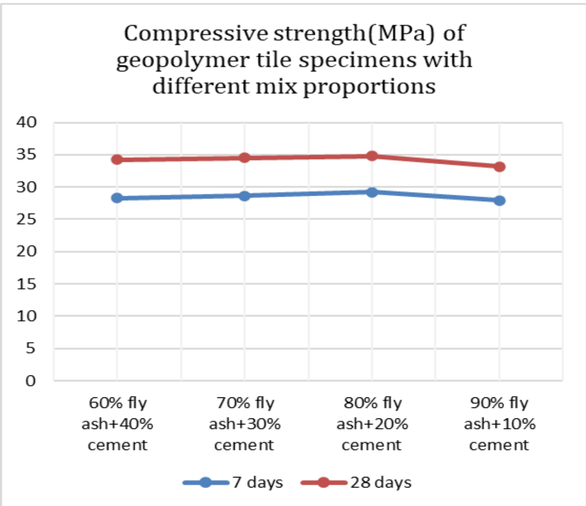

Figure 2: Compressive strength of fly ash based geopolymer concrete floor tiles with fly ash inclusion as cement replacement at 7 and 28 days.

However, with the inclusion of fly ash beyond 80%, the calcium content increased with the reduction of silica and alumina (as OPC contains high calcium and low silica and alumina in comparison to fly ash). Therefore, at higher cement content, silica and alumina content is less for the polymerization reaction and resulted in the formation of less NASH bond as polymerization product. Also, higher calcium requirement increased the water demand for hydration reaction which is liberated from water filled pores and resulted in extra void spaces. Also, the heat evolved due to exothermic reaction of hydration enhanced the effective heat inside the geopolymer system which further evaporated the available moisture present in the geopolymer concrete mixture and resulted in micro-cracking and voids. Therefore, it can be concluded to the optimum fly ash content of 80% to obtain maximum compressive strength. Similar reduction in strength after certain calcium content are also observed in previous studies.

B. Water absorption

In general, porosity and water absorption are directly related to the compressive strength as an increase in compressive strength reduces porosity as well as water absorption and vice versa. From the results as shown in Table 1, a decrease in water absorption is observed with the increase in fly ash content up to 80%, however, it is slightly increased for 70% fly ash containing specimens. Similar improvement is observed at 7 days and 28 days as well with the best results obtained for the specimens with 80% fly ash content. These results are likely to indicate lesser cracks, lesser void spaces and denser matrix for the specimens with increasing calcium content. This is due to the additional hydration products, CASH and NASH, with the addition of OPC which co-existed with geo-polymeric products which is responsible for not only increase in its compressive strength but also reduced the porosity as well as water absorption by filling and covering the pore spaces significantly. Also, for these specimens, with the passage of time, the porosity and water absorption values decreased further which indicate improvement in the microstructure. However, the improvement is not so significant as the geopolymer mechanism involves polymerization reactions which took place at the time of temperature curing and thereafter slight modification is observed.

Table 3: Water absorption results for geopolymer concrete floor tile specimens with different % of fly ash inclusion.

Geopolymer concrete mixtures with fly ash content (%)	Water absorption (%) after 7 days= {(Saturated weight of the tile-Dry weight of the tile)/Dry weight of the tile}x 100	Water absorption (%) after 28 days= {(Saturated weight of the tile-Dry weight of the tile)/Dry weight of the tile}x 100
60	3.85	3.94
70	4.07	4.21
80	4.12	4.35
90	3.05	3.19

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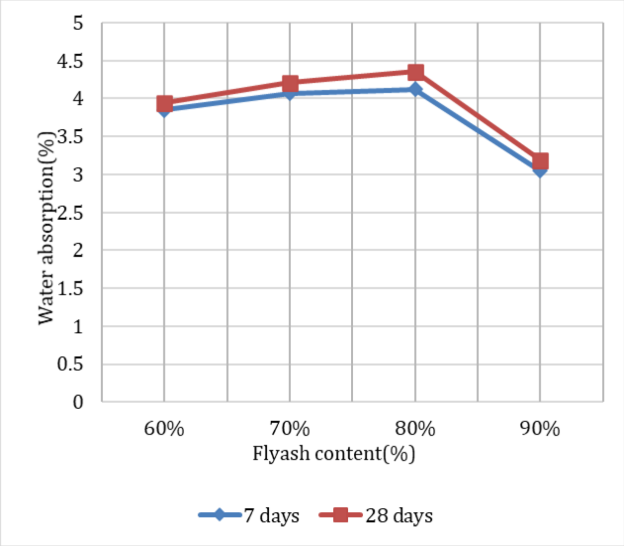

Figure 3: Water absorption results of fly ash based geopolymer concrete floor tiles with fly ash inclusion as cement replacement at 7 and 28 days

As per ISO 10545 – 3, the water absorption of floor tile should be within 3%-6% which has been satisfied by all the geopolymer tile specimens except for tiles with 90% replacement of cement with fly ash.

C. Flexural strength

Flexural strength of geopolymer concrete tile at 80% fly ash content at 28 days is obtained as 63 N/mm^2 at 6.3 kN load, which shows the improved quality in stiffness and the strength can be further improved by changing the alkali activator molarity and replacement level of cement.

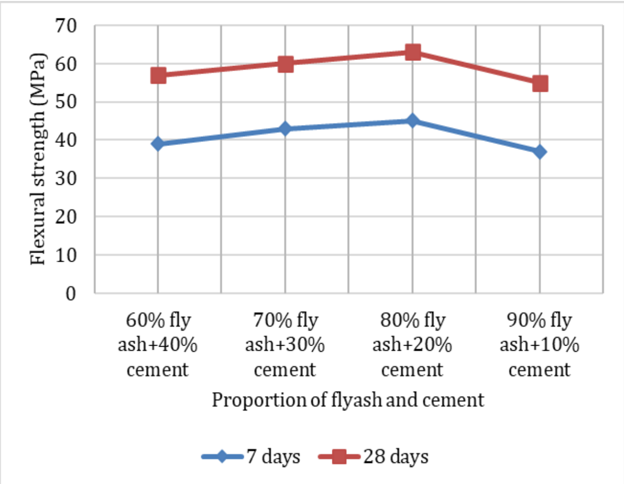

Figure 4: Flexural strength of fly ash based geopolymer concrete floor tiles with fly ash inclusion as cement replacement at 7 and 28 days.

Table 4: Flexural strength results for geopolymer concrete floor tile specimens with different % of fly ash inclusion.

Different % content of fly ash in the tile specimens	Flexural strength (MPa)	
	7 days	28 days
60% fly ash+40% cement	39	57
70% fly ash+30% cement	43	60
80% fly ash+20% cement	45	63
90% fly ash+10% cement	37	55

D. ABRASION TEST

In abrasion test, geopolymer concrete floor tiles at 80% fly ash content showed more abrasion resistance than the other specimens. The value of abrasion loss of 80% fly ash containing GPC tiles is obtained as 0.01mm which is much less compared to OPC tiles which losses 0.9mm while wearing.

Table 5: Abrasion test results for geopolymer concrete floor tile specimens with different % of fly ash inclusion.

Different % content of fly ash in the tile specimens	Abrasion loss (mm)	
	7 days	28 days
60% fly ash+40% cement	0.016	0.015
70% fly ash+30% cement	0.0135	0.011
80% fly ash+20% cement	0.012	0.01
90% fly ash+10% cement	0.01	0.009

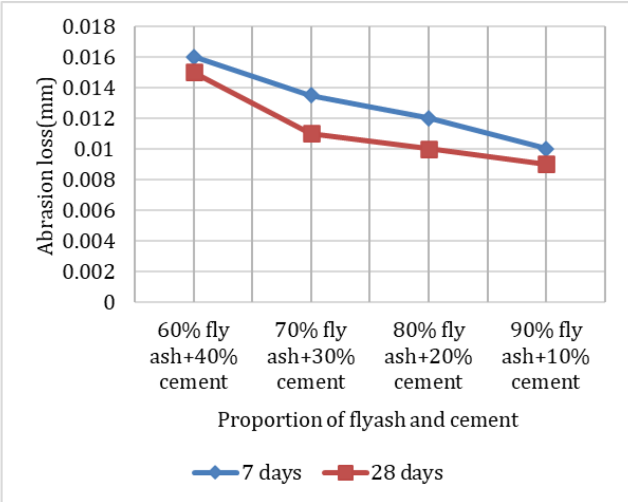

Figure 5: Abrasion test result of fly ash based geopolymer concrete floor tiles with fly ash inclusion as cement replacement at 7 and 28 days.

IV. CONCLUSION

The compressive strength of low-calcium fly ash based geopolymer concrete increased with the inclusion of fly ash as cement replacement up to 80% at all ages. The increase in strength is mainly due to the additional calcium-based hydration products like CASH and NASH, which is formed by the hydration mechanism which coexisted with the alumina-silicate polymeric products. Compressive strength of geopolymer concrete tiles at 28 days for 80% fly ash content is 34.81 N/mm^2. This may be due to the cement replacement and curing temperature and period. The polymeric bonding which is taking place in early age with minimum water content in hot air oven influences the strength parameter. The inclusion of fly ash up to 80% as cement replacement reduced the permeation properties such as sorptivity, porosity, and water absorption. Also, geopolymer tiles are very easy to manufacture and easy to install & replace in industries for flooring. Water absorption of geopolymer concrete tiles at 28 days for 80% fly ash content is 4.35 % which is within the permissible range as per IS 10545 – 3, which states that the water absorption of floor tile should be within 3%-6%. Flexural strength of geopolymer concrete tile at 28 days for 80% fly ash content is 63 N/mm^2 at 6.3 kN load, which shows the improved quality in stiffness. Also, the abrasion loss of 80% fly ash containing specimens which is obtained as 0.01mm indicates that geopolymer concrete floor tiles have much resistance to abrasion and cause only very little abrasion loss. Thus, the optimum mix proportion of geopolymer concrete floor tile with maximum strength consists of 80% fly ash and 20% cement along with other constituents. Also, geopolymer concrete floor tiles offer environmental protection as it utilizes one of the abundant industrial waste products, fly ash. M-sand is used instead of river sand, so the scarcity of river sand can be reduced. Moreover, geopolymer floor tile is eco-friendly as it reduces the emission of CO_2 up to 78 kg/ton of geopolymer production, whereas, for the manufacture of normal concrete tiles, 900 kg/ton of cement production takes place.

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