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Strength Evolution of Eco-friendly Geopolymer Mortar Under Ambient Temperature

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Abstract

Green materials which gives high performance and saves the environment by developing sustainable technology in terms of usage of waste materials targeted to landfills which can cause environmental pollution. Recent technologies have developed a new binder as Geopolymer which builds a polymeric structure using oxides and alkalis to mitigate carbon footprint in construction industry. This paper presents a geopolymer mortar matrix using Class F Fly ash and crushed stone dust as precursors with Sodium based activators. Mix design is developed for binder content of 1200 Kg/m^3 with a fluid binder ratio of 0.5, Compressive strength as destructive test method and Dynamic modulu's of elasticity as non-destructive test method for the designed mortar matrix are computed. Results made an observation that, flow of 225mm is achieved which represents as high workable and hardened

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density ranges from 2150 Kg/m^3 to 2350Kg/m^3. Compressive strength at 28 days is obtained as 37.6 MPa and 43.4 MPa as maximum at ambient curing temperature of 35±2^{0}C, Maximum Dynamic modulus of elasticity at ambient temperature is obtained as 28.74 MPa at velocity of 3.8 m/s. Hence practical observations leads to conclusion that the geopolymer mortar made of cent percent Class F flyash can be used as sustainable material for mortar structural applications.

Keywords: Fly ash, Compressive strength, Dynamic elastic modulus, Geopolymer, Ambient curing

1 Introduction

In Construction industry, concrete or mortar is extensively used material which is produced by using the Portland Cement of ordinary or pozzolana based. In traditional concrete, the binder occupies approximately 10% to 15% by mass. Since the manufacture of Portland binder releases the greenhouse gas which effects the environment, a sustainable binder as Geopolymer is emerging out which is not only an alternative to portland cement but also possesses sustainable characteristics in terms of usage of waste materials and reduction in greenhouse gases.

2 Literature Study

Residential building walls are made of masonry either by clay bricks or concrete blocks with mortar rendering on both sides. Performance of mortar plays an important role in structure since its makes up 7% of the total volume of the masonry wall as far as seals the building against air penetration and moisture by bonding the individual unit of masonry wall [1]. The essential ingredients in mortar are binder and filler, the most used construction binding material to produce mortars and concretes is cement. Recent studies have revealed that the cement is accountable for global warming because of its carbon di oxide emission during manufacturing [2].

Davidovits a French researcher proposed a new elective binder as geopolymer in 1978, process of which involves the chemical reaction between silica alumina rich precursors (source materials) and sodium or potassium based activators(alkaline liquids), precursors should be derived from the industrial by product such as Iron ore tailings, Flyash, Rice husk ash etc. or natural materials like clay or kaolinite etc., the alkaline liquid should be sodium or potassium based, most commonly used alkali activators are sodium based hydroxide and Silicate (NaOH and Na_2SiO_3) [3].

From earlier investigations it was found that using high concentration of NaOH results in a great resistance to compression in fly ash geopolymer mortars[4,5].Several variables like curing temperature, curing time affect the geopolymer mechanical properties [6] and also the choice of source materials such as cost, availability, application type etc. [7]. Fly ash geopolymer mortars has ability to cure at the ambient temperature leading to the advantages of repair and rehabilitation works [8] and also performs better in high water vapour permeability, higher resistance to salt crystallization etc. contrasted to cement mortars with different binding ratios[9].

Hence to implement the sustainable technology in the production of geopolymer mortar, the present investigation deals with the study of geopolymer mortar composite in controlled ambient room temperature with Destructive and Non-Destructive strength test methods by utilizing flyash as total replacement for binder and crushed stone dust as filler with the sodium based alkalis ratio of 1:2.5.

3 Material Requirements

The procured materials for geopolymer mortar are flyash(FA), alkali activators(NaOH and Na_2SiO_3), Crushed stone dust(CSD) and Portland pozzolana cement(PPC) is used as conventional binder to prepare cement mortar.

3.1 Fly Ash

This research consists of commercially available alumino silicate material called Fly ash which is used as a binder with a median particle size of 10µm collected from RTPS, Shaktinagar, Raichur, Karnataka, India. Fly ash contains calcium oxide(CaO) of 2.804% which is less than 10% and considered as siliceous fly ash (Class F) as per Bureau of Indian Standards (BIS) 3812-Part II [13]. Characteristics of fly ash is represented in Table 1, morphology using Scanning Electron microscope manufactured by HITACHI is shown in figure 1, which indicates the spherical nature representing the presence of quartz.

Table 1 Physico-chemical Class F Fly Ash properties

Elemental Oxides(Percent by mass)	**Fly Ash (FA)**
Silica (SiO_2)	63.72
Alumina (Al_2O_3)	24.92
Iron (Fe_2O_3)	5.19
Magnesium (MgO)	1.61
Sulphur (SO_3)	0.75
Calcium (CaO)	2.804
Sodium (Na_2O)	1.20
Potassium (K_2O)	0.28
Loss on Ignition (30 minutes)	1.06
Fineness by Blaine's apparatus (m^2/kg)	488
Specific Gravity	2.08
Residue on 45 µ	1.3%

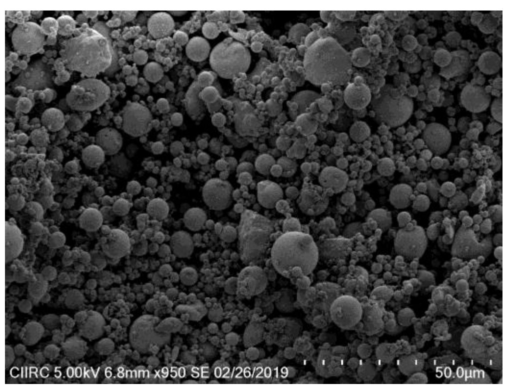

Fig 1 Microstructure of Flyash

3.2 Alkali Activators

Sodium based alkali activators procured from Bangalore scientific chemical and industrial supplies, Bangalore. Basically, silicate of sodium is represents as water gel or liquid gel due to the presence of silicon di oxide. In this investigation sodium silicate of commercial grade is utilized with a modulu's ratio[SiO_2/Na_2O] of 2.07 (SiO_2=34.92%, Na_2O= 16.80%, H_2O=48.28%)and specific gravity of 1.52,Sodium hydroxide exist in pellets or flakes with 99% purity which is mixed with distilled water to obtained sodium hydroxide solution of required molarity. Since the reaction is exothermic the solution should be prepared 24h prior before use. Sodium hydroxide solution prepared for constant molarity of 12 M which means 480g of flakes are added in 1 litre of Distilled water having pH of 6.95, the chemical composition of sodium based activators are shown in table 2 and figure 2 illustrates the chemical used in this study.

Table 2 Chemical constituents of Alkali activators

Constituents	**Na_2Sio_3**	**NaOH**
Silicon di oxide (SiO_2), % by mass	34.92	-
Water content , % by mass	29.52	-
pH Value	12.51	-
Density, g/ml	1.60	1.696
Sodium Oxide (Na_2O)	16.80	-
Potassium Oxide (K_2O)	2.86	-
Specific gravity	1.52	2.1
[OH^-], mol/l	7.62	-
Purity	-	99.97 %

Fig 2: Sodium hydroxide and sodium silicate

3.3 Crushed Stone Dust

Crushed stone dust (CSD) a non-voluble product after extraction and processing of rocks is acquired from local stone crusher, Ramnagaram, Karnataka, India. Crushed rock dust used as a fine aggregate with three grades representing grade 1(2.36mm- 1.18mm), grade 2 (1.18mm – 600 µ) and grade 3 (600µ-90µ) to impart workability, homogeneity and uniformity when mixed with other ingredients of geopolymer mortar. CSD taken in saturated surface dry condition with a nominal size of 1.18mm and fineness modulus of 2.64 for preparing the mortar samples. Table 3 represents the physical properties of CSD.

Table 3: Physical composition of CSD

Constituents	Crushed Stone Dust (CSD)
Specific Gravity(G_s)	2.56
Water Absorption(WA) in %	1.95
Loose Density, Kg/l	1.70
Rodded Density, Kg/l	1.88
Moisture Content	3.08
Particles less than 75 µ	14.84%
Zone Grade	II

3.4 Portland Pozzolana Cement

Portland pozzolana cement (PPC), RAMCO based incubated with 15% to 21% of fly ash in it as per Indian standard specification BIS 1489 [14], is used as a conventional binder to interpret the geopolymeric binder. Due to pozzolanic activity of flyash the time of Initial Setting (IST) is more and Final Setting (FST) is less, the composition of PPC is shown in table 4.

Table 4: Physico-chemical composition of PPC

Constituents (Percent by mass)	Portland pozzolana cement (PPC)
SiO_2	29.69
Al_2O_3	8.68
Fe_2O_3	3.81
MgO	1.86
SO_3	2.20
CaO	40.93
Na_2O	0.29
K_2O	0.82
Loss on Ignition (30 minutes)	2.39
Fineness by Blaine's apparatus (m^2/kg)	371
Specific Gravity	3.06
Consistency in %	30
IST (min)	185
FST (min)	245

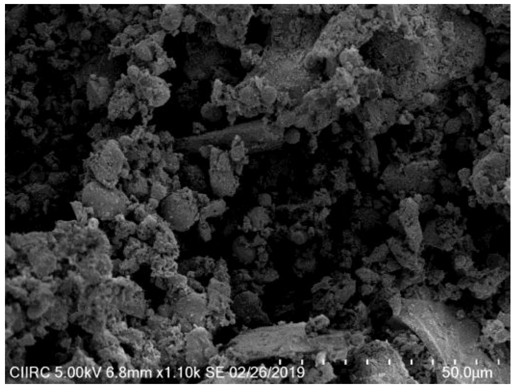

Fig 3: Microstructure of PPC

Figure 3 shows the morphology of PPC, in which the flyash (Quartz) is combined with lime (Calcium) which reduces some part of greenhouse effect, but since the lime content is more in cement(approximately 70-80%) which tends to the release of CO_2 during manufacturing process.

4 Experimental Methodology

Methodology describes the destructive and non-destructive methods of geopolymer mortar matrix used for structural applications. The objective of the study is segregated as follows.

4.1 Mix Design and Mixing of Ingredients

Mix design was developed using the previous literatures illustrative methods [10,11], the geopolymer mix designed for 100% FA with constant ratio of Sand to binder (S/B) as 3, Binder to alkali activator (B/AA) as 2 or ratio of fluid-binder as 0.5 and sodium based silicate to hydroxide (Na2Sio3/ NaoH) as 2.5[12], conversely conventional mix design was made with PPC considering same sand to binder ratio and water content of 189 l/m3. A 10 litre planetary mortar mixer manufactured by HEICO Engineering Instruments Private ltd. As shown in figure 4,it was used to mix proportioned ingredients of mortar mixture. The dry ingredients were mixed for first 3-4 minutes, then the alkali activators which was combined 30 minutes ahead, is included to dry ingredients and mixed for another 5 minutes as per BIS 10890 [15] The total mixing is done approximately for 8 minutes by ensuring no dry materials should be present at the bottom of mixing pan.

Fig 4: Planetary Mortar Mixer

4.2 Casting and Curing Regime

The mix was poured into two layers in 50 mm3 rubber wood moulds and 40mm X 40mm X 160mm prisms moulds respectively. After casting the moulds were kept on vibrating table for 30s to remove air voids. After compaction samples were maintained at controlled temperature of 35±20 C for initial curing using humidity chamber. After 36hours of curing, the specimens were kept for self-curing at ambient temperature by covering polypropylene bags to prevent evaporation of moisture till the testing age of required days. Similarly, the PPC mortar (PPCM) specimens are made and kept for water curing of required age and results are compared with GM specimens. The vibrating table is shown in figure 5 and humidity chamber in figure 6.

Fig 5: Compaction of mortar using vibrating table

Fig 6: Humidity chamber

4.3 Tests Methods

Test methods define the procedures of fresh and hardened properties of mortar. The procedures are as follows,

4.3.1 Flow Table Test

In accordance to BIS 5512[16], the determination of workability using flow table method was adopted, in which the cone with bottom diameter of 100mm, top diameter of 70mm and height of 50mm is placed eccentrically on the flow table as shown in figure 7. The fresh geopolymer mortar is filled in two layers by tamping each layer 20times using tamping rod, after filling the mould. The top surface wiped and leveled to remove excess quantity of mortar, then instantly lifted vertically. Flow table is dropped 25 times in 15s to get maximum flowability of mix. Based on the flow diameter of the mix, the workability of geopolymer mix is classified as stiff, moderate, and high.

Fig 7: Flow table with mould

4.3.2 Destructive Strength Test

Destructive compressive strength is computed as per BIS 516 specification [17], the cube specimens after specified age of curing i,e 3, 7 and 28 days were tested using digital compression testing machine(CTM) of capacity 500kN manufactured by AIMIL Ltd. As shown in figure 8. At a load capacity of 0.58 kN/s, Three Cubes were tested at a time and results are represented in graphs as three cubes average strength. The compressive strength is also calculated for prisms based on density at the same age.

Fig 8: CTM of capacity 500Kn

4.3.3 Non-Destructive Strength Test

Non-destructive test is computed by dynamic modulus of elasticity (D_E) for geopolymer mortar composite according to BIS 13311[18], in which specimens with dimension 40mm X 40mm X 160mm were weighed to obtained the hardened density (ρ), then two side surfaces 40mm X 40mm of the specimens covered with a thin layer of grease and exposed to direct test using Ultrasonic Pulse Velocity (UPV) tester manufactured by PROCEQ. The tester gave the velocity (V) pulse value, using which the elastic modulu's is found by following equation with the unit as MPa or N/mm^2.

$$\mathbf{D_E} = \frac{\rho\ (1+\gamma)(1-2\gamma)}{(1-\gamma)}\ \mathbf{V^2}$$

The dynamic poisson's ratio (γ) varies from 0.2 to 0.35, the opted value is 0.24 as per the standard mentioned above. Figure 9 shows ultra-sonic pulse velocity apparatus.

Fig 9: Ultrasonic pulse velocity

5 Results and Discussions

In the present investigation, the effect of FA as geopolymer binder is studied as the complete with various properties such as S/B=3, Na_2Sio_3/NaOH= 2.5 and B/AA =2 or F/B of 0.5. Workability of geopolymer mortar results the flow diameter of 225mm and represents as high workable due to the fineness of FA .Fresh density is measured by 50mm^3 mould with weight balance of 0.001g accuracy which gives the value of 2240 Kg/m^3. The prepared geopolymer mortar cubes (GMC) and geopolymer mortar prisms (GMP) are allowed to self-curing under ambient temperature and compressive strength is computed with hardened density at 3, 7 and 28 days. PPC mortar cubes of 50mm are also tested for same age and results are interpreted. The hardened density ranges from 2150 Kg/m^3 to 2350 Kg/m^3 for all the tested samples.

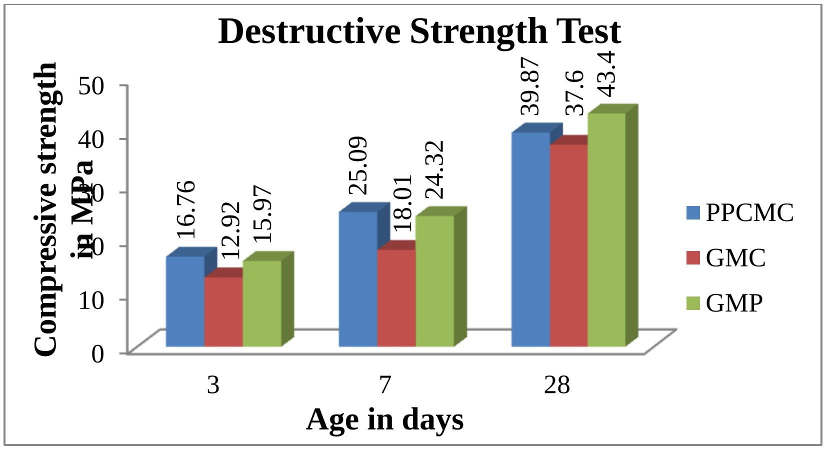

Fig 10: Destructive compression strength of GMC and GMP.

Destructive strength results are shown in figure 10, with which it can be deduce that geopolymer strength increases with increase in curing time, from the observations it can be seen that Geopolymer cubes and prisms value is less at initial stage (3 days and 7days) contrast to conventional cement cubes, later the results were comparable or slightly more at the age of 28 days compared to desired strength.

Figure 11 represents the non-destructive strength results for geopolymer mortar prisms at the age of 28 days, it has been observed that the dynamic modulus of elasticity increases with increase in velocity and vice versa. The maximum hardened density of GMP with velocity 3.831 is 2308.2 Kg/m^3.

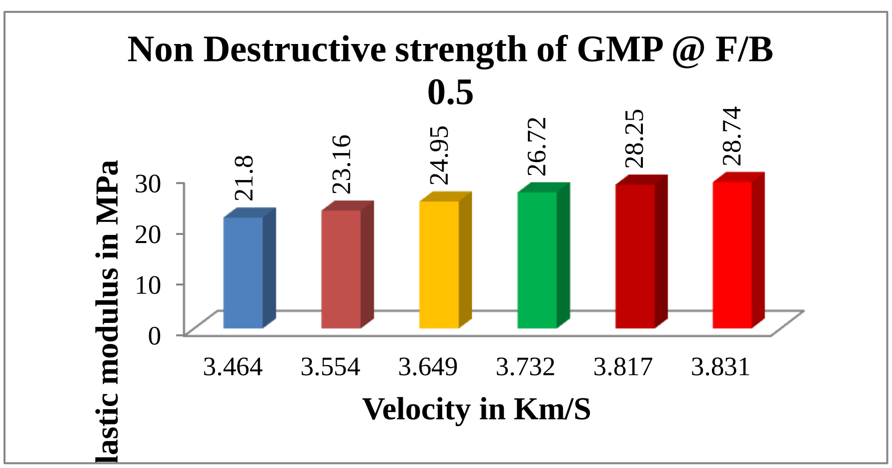

Fig 11: Elastic modulus values of geopolymer mortar prisms with velocity.

6 Conclusions

The following observations are predicted from the above parameters;

• Curing temperature should be maintained properly else it will leads to efflorescence by the reaction of NaOH with CO2.

• Flowability of geopolymer mortar for 100% Class F fly ash and F/B of 0.5 is 225mm representing as high workable.

• Utilizing 100% Class F flyash gives maximum compression destructive strength of 37.6 MPa and 43.4 MPa for GMC and GMP at 28 days respectively.

• Maximum dynamic modulus of elasticity is obtained as 28.74 Mpa for velocity of 3.8 m/s at 28 days. Hence geopolymer mortar can be suitable for structural applications like restoration of cracks caused by tensile or shear stresses.

• Further investigations can be focused on higher temperatures and durability which leads to the sustainable construction.

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