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TENSILE STRENGTH OF FLY ASH BASED GEOPOLYMER MORTAR

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ABSTRACT

Geopolymer is a promising binding material produced from alkali activated alumino silicate material and emerging as an eco-friendly sustainable construction material as an alternative to Ordinary Portland Cement. Geopolymer technology contributes to the reduction of greenhouse gas emissions and also reduces disposal costs of industrial waste by recycling. In the present study, effect of basic parameters such as activator to fly ash ratio and curing temperature on tensile strength development of geo-polymer mortar using low calcium fly ash is investigated. Samples of Geopolymer mortar specimens are made for varied alkaline activator to fly ash ratio with constant proportion of fly ash to sand. Laboratory tests are conducted on Geopolymer mortar specimens for compressive strength, direct tensile strength and flexural strength. The results reveal that higher mechanical strength can be obtained at higher alkaline activator to fly ash ratio and at higher curing temperature.

Keywords: geopolymer, low calcium fly ash, tensile strength, alkaline activator.

1. INTRODUCTION

Huge amount of carbon dioxide (CO_2) is liable to be produced during the manufacture of Ordinary Portland Cement (OPC) in turn the environment gets polluted at the rate of 1 ton per 1 ton production of cement [1]. In view of day to day increased demand of Portland cement in the construction field, installation of new cement plants are required, in other way needs to establish new thermal power plants, which result in piling up of huge coal ashes [2] and ultimately lead to increase in CO_2 emissions thereby polluting the atmosphere. It is the time to find an alternative solution in order to alleviate the growing environmental degradation caused by Portland cement. Application of Geopolymer technology is one among the other solutions for reduction of green house gas emissions in the construction industry.

The term geopolymer was first introduced by Davidovits in 1978 to represent the mineral polymers resulting from geochemistry. Geopolymers are the alkali aluminosilicate binders formed by the alkali silicate activation of aluminosilicate materials [3]. Davidovits. J [4, 5] carried the investigations in the field of alkali activation of aluminosilicate materials and named it as “Geopolymer”, since the chemical reaction that takes place in this case is a polymerisation process. Wallah S.E., and Rangan B.V. [6] reported that Geopolymers can be formed at elevated or ambient temperature and further reported that heat cured fly ash based geopolymers have excellent resistance to sulphate attack.

Fly ash is a by-product material produced from coal-fired thermal power plants, so far it is treated as waste material posing problems of its disposal (land filling) and environmental pollution. Usage of fly ash as partial replacement of OPC has resulted in better strength and durability. Increased application of fly ash in the construction field over two decades, it has emerged as resource material for cement industry. Thus, utilization of fly ash in construction industry helps not only to overcome disposal problem but also to conserve natural resources and lead to a number of environmental, technical and economical benefits. Much of the research work in this direction has been already under taken and established performance standards. Total replacement of cement in the concrete industry with the by-product materials such as fly ash reduces CO_2 footprints.

2. EXPERIMENTAL WORK

Experimental investigation is primarily focused on tensile strength and flexural strength response of fly ash based geopolymer mortar for varied alkaline activator to fly ash ratio under different curing temperature.

2.1. Materials

2.1.1. Fly ash

It is the aluminosilicate source material for the synthesis of geopolymeric binder. Low calcium fly ash (ASTM Class F) conforming to IS: 3812-1987 specifications, collected from Ramagundam Super Thermal Power Station, India is utilized in this study. Chemical composition of the fly ash obtained by X-Ray Fluorescence analysis is shown in Table-1.

Table-1. Chemical composition of fly ash.

Elements	SiO_2	Al_2O_3	Fe_2O_3	CaO	TiO_2	K_2O	MgO	P_2O_5	SO_3	Na_2O
Percentage by mass	59.61	27.93	4.24	2.76	1.82	1.61	0.96	0.32	0.20	0.15

The silicon and aluminium oxides constitute 87.54% of the fly ash and the Si to Al molar ratio is 2.13 satisfying the basic requirements suggested by Davidovits [4] for producing cement and concrete. 65% of fly ash particles are smaller than 45 micron possessing specific gravity of 2.06 and specific surface area of 440 m^2/kg (Blaine).

2.1.2. Fine aggregate

River sand (confirming to Zone-II of IS 383-1970) obtained from Pathankot, India is used in this investigation. The sand possesses bulk density of 1639kg/m^3, compacted density of 1824Kg/$m^3$and fineness modulus of 2.76. The sand is made saturated surface dry (SSD) before using in geopolymer mix to avoid water absorption from activator solution.

2.1.3. Alkaline activator

In general, either of Sodium Silicate or Potassium Silicate and Sodium Hydroxide or Potassium Hydroxide in liquid state are used as alkaline activator. In this investigation, Analytical Grade Sodium Hydroxide pellets with 98% purity and Sodium Silicate Solution (Na_2O = 8%, SiO_2 = 26.5%, and water = 65.5% by mass) are mixed in liquid state and used as an alkaline activator.

2.2. Experimentation

The mixture composition for different alkaline activator to fly ash ratio with constant fly ash to sand ratio of 1:1 is shown in Table-2.

Table-2. Details of mixture composition (kg/m^3).

Sample identity	NaOH Conc.	SS/SH ratio	Activator to fly ash ratio	Fly ash	Sand	Sodium silicate	Sodium hydroxide
M1	14M	2.0	0.30	1054	1054	211	105
M2	14M	2.0	0.35	1054	1054	246	123
M3	14M	2.0	0.40	1054	1054	281	141

2.2.1. Alkaline activator solution

Analytical Grade Sodium Hydroxide pellets in the required quantity are dissolved in the distilled water in order to obtain specific concentration of Sodium hydroxide solution. Then this solution is mixed and stirred with the Sodium silicate solution in the desired ratio to obtain the specified alkaline activator solution (AAS).

2.2.2. Compressive strength of geopolymer mortar

Fly ash based geopolymer mortar is prepared similar to Portland cement mortar by replacing the cement with fly ash and water with alkaline activator solution. Fly ash and fine aggregate in 1:1proportion is placed in the pan mixer and dry mixed for 5 minutes, then the alkaline activator solution of desired mixture of 14M of Sodium Hydroxide (NaOH) with Sodium silicate to Sodium hydroxide solution (SS/SH ratio) of 2.0 for varied alkaline activator to fly ash ratio of 0.30, 0.35 and 0.40 in required quantity is added and mixed for further 5 minutes. The geopolymer mortar specimens are cast with the prescribed cube moulds of size 70.6mm×70.6mm×70.6mm and prism moulds of size 70.6mm×70.6mm×141.2mm and placed in the hot air ovens under specified temperature of 30^{o}C and 60^{o}C, then allowed to cure for 24 hours. They are de-moulded after 24 hours and allowed to ambient curing at room temperature until testing. The Geopolymer mortar specimens are tested for compressive strength at the age of 28 days under the Compressive Testing Machine (CTM). The mean of three tested specimens is reported as the representative compressive strength of the corresponding mix.

2.2.3. Tensile strength of geopolymer mortar

Geopolymer mortars Specimens for direct tension are cast with the specially prepared moulds and the standard moulds of size 100mm×100mm×500mm are used for flexure. They are placed into the hot air ovens for curing at specified temperature of 30^{o}C and 60^{o}C and allowed to cure for 24 hours. They are de-moulded after 24 hours and allowed to ambient curing at room temperature until testing. The Geopolymer mortar specimens are tested for direct tensile strength and flexural strength at the age of 28 days under Electronic Universal Testing Machine. The mean of three tested specimens each for direct tension and flexure is reported as the representative strength of the corresponding mix.

3. RESULTS AND DISCUSSIONS

In this section, tensile strength of geo-polymer mortar specimens is discussed with reference to the variation in alkaline activator to fly ash ratio and curing temperature. Flexural and direct tensile strength of geopolymer mortar tested in this investigation is compared with Compressive strength of the corresponding geopolymer mortar. Experimental results are presented in Table-3.

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Table-3. Properties of Geopolymer mortar mix.

Mix	Curing temperature (°C)	Cube compressive strength (MPa)	Prism compressive strength (MPa)	Direct tensile strength (MPa)	Flexural strength (MPa)
M1	30°C	22.08	18.40	3.03	3.81
M2	30°C	25.61	21.34	3.24	4.50
M3	30°C	30.14	25.12	3.44	5.38
M1	60°C	29.28	24.40	3.15	5.07
M2	60°C	33.40	27.83	3.75	5.86
M3	60°C	35.36	29.47	4.91	6.58

3.1. Alkaline activator to fly ash ratio

The compressive strength (cube and prism) of the tested members varying alkaline activator to Fly ash ratio is presented in Figure-1 and Figure-2.

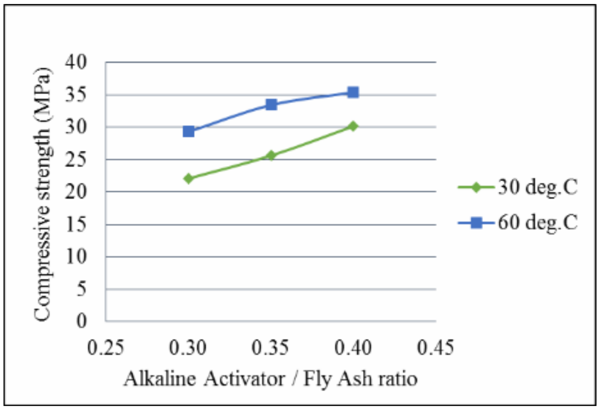

Figure-1. Variation compressive strength (Cube) with AA/FA ratio for varied curing temperature.

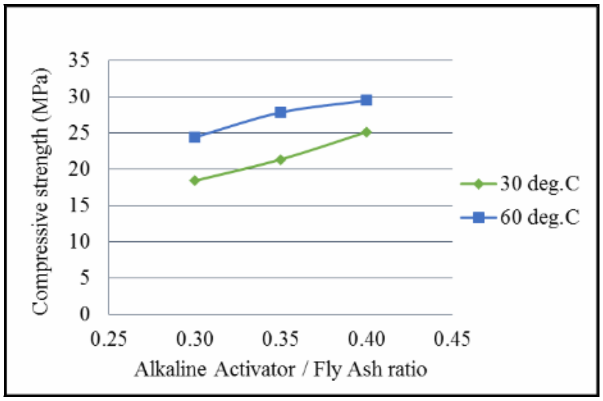

Figure-2. Variation of compressive strength (Prism) with AA/FA ratio for varied curing temperature.

From these variations it can be understood that increase in alkaline activator to fly ash ratio increases the compressive strength. Djwantoro Hardjito *et al*. [7] have reported that increase in alkaline activator to fly ash ratio increases the compressive strength of the geopolymer mortar. Similar trend is observed even for direct tensile strength and modulus of rupture of the mortar as indicated in Figure-3 and Figure-4.

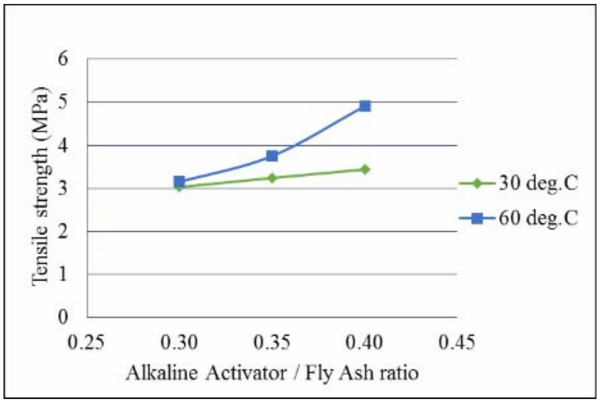

Figure-3. Variation of direct tensile strength with aa/fa ratio for different curing temperature.

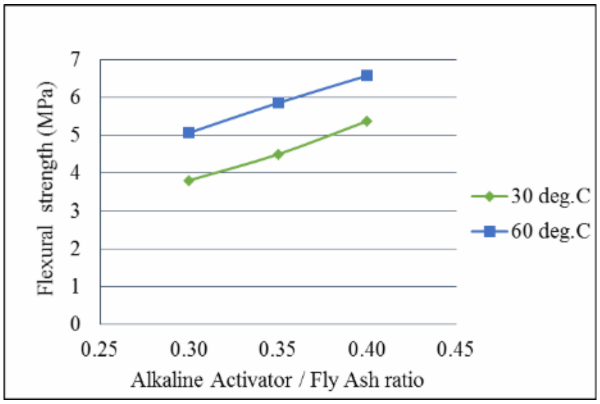

Figure-4. Variation of modulus of rupture with AA/FA ratio for different curing temperature.

The reason for this can be attributed to the fact that more the availability of alkaline activator in the mixture is more for better dissolution of fly ash.

3.2. Curing temperature

The variation of compressive strength for cubes and prisms of the Geopolymer mortar elements cured under different conditions is presented in Figure-1 and Figure-2 respectively. Increase in compressive strength is found to be increasing with curing temperature. In the research conducted by Hardjito D. *et al*. [8] reported that increase in curing temperature increases compressive strength up to 60°C. The reason for this increase in strength can be attributed to the fact that complete polymerization process takes place at an elevated temperature. Similar trend is observed for direct tensile strength and flexural strength of the mortar as indicated in Figure-3 and Figure-4.

3.3. Direct tensile strength

From the Figure-5 it is observed that the direct tensile strength under 30°C and 60°C curing temperature is found to be respectively 0.14 times and 0.11 times of the compressive strength at an activator liquid fly ash ratio of 0.30.

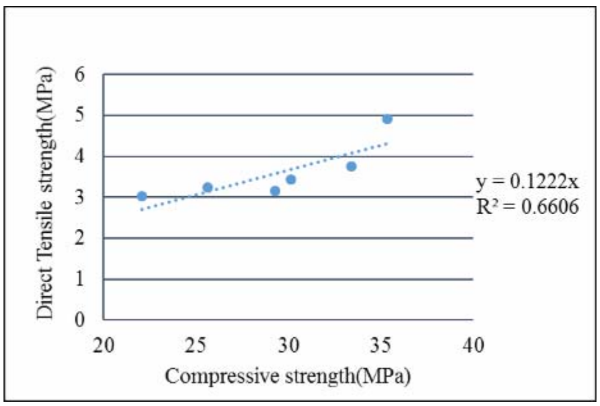

Figure-5. Variation of direct tensile strength with compressive strength of geopolymer mortar.

Similarly 0.13 times and 0.11 times at the activator liquid fly ash ratio of 0.35 and furthermore it is 0.11 times and 0.14 times at the activator liquid fly ash ratio of 0.40. This study indicates that the tensile strength is more at lower curing temperature and is less for higher curing temperature for lower activator fly ash ratio. The reason might be due to insufficient alkaline liquid for complete polymerization. On the other hand it is vice-versa for higher activator fly ash ratio because of availability of sufficient alkaline liquid to undergo complete polymerization.

3.4. Modulus of rupture

The variation of flexural strength on par with compressive strength is shown in Figure-6.

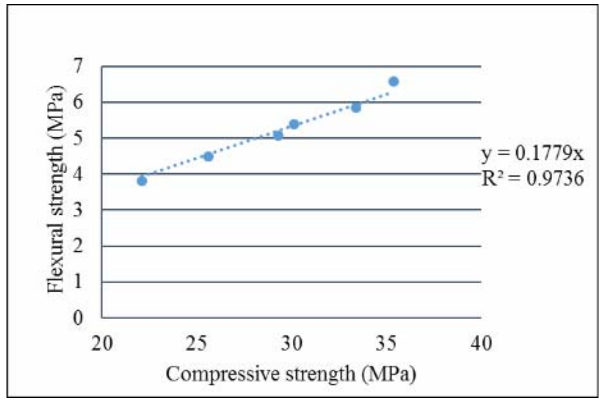

Figure-6. Variation of flexural strength with compressive strength of geopolymer mortar.

From the Figure-6 it is observed that the flexural strength of GPM specimens under 30°C and 60°C curing temperature is observed to be 0.17 times of the compressive strength at an activator liquid fly ash ratio of 0.30, and 0.18 times at an activator liquid fly ash ratio of 0.35, further more it is 0.19 times the compressive strength at the activator liquid to fly ash ratio of 0.40. This is because of the reason that the availability of sufficient alkaline liquid to take complete polymerization.

4. CONCLUSIONS

Increase in alkaline activator to fly ash ratio of Geopolymer mortar increases the tensile strength and modulus of rupture. Moreover increase in curing temperature also increases the tensile strength and modulus of rupture. Average direct tensile strength is found to be 0.12 times the compressive strength whereas the average flexural strength is found to be 0.18 times the compressive strength of Geopolymer mortar.

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