Compressive Strength and Split Tensile Styrength of Geopolymer Mortar with Binary and Quinary Blends

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Abstract— *Today, the world is on the verge of witnessing a sustained growth in infrastructure build up. The demand in the construction industry has increased the necessity of high strength concrete. In all construction work, concrete plays a vital part and it increases the total cost of the project. There is also concern on the production and usage of concrete due to its impact on environment. Concrete can be generally be produced of locally available constituents, However, environmental concerns, stemming from the high energy expenses and CO_2 emission associated with cement manufacture have brought about pressures to reduce cement consumption through the use of supplementary materials. It reduces the cost, makes concrete more durable and it is eco-friendly. As part of the research efforts to develop cement less alkali-activated mortar using fly ash and other supplementary materials as a binder.*

Keywords— Fly ash, volcanic ash, Metakaolin, Zeolite, Rice Husk ash, Nano silica, Alkaline Activator

I. INTRODUCTION

The use of alkali materials and aluminosilicates to form a cement is broadly referred to as 'Geopolymer' technology, coined by French researcher Davidovits, but is also known as alkali-activated cement and inorganic polymer concrete in various parts of the world. Geopolymer technology provides comparable performance to traditional cementitious binders, but with the added advantage of significantly reduced Greenhouse emissions, increased fire and chemical resistance and waste utilization. The use of Geopolymer in modern industrial applications is a recent development, becoming increasingly popular due to its intrinsic environmental and technical benefits.

In general, inorganic Geopolymer can be synthesized by the alkali activation of materials that are rich in SiO2 and Al2O3. Although the entire process has yet to be fully described, there is evidence that the geopolymerisation mechanisms include the dissolution of Al and Si in the alkali medium, transportation (orientation) of the dissolved species, and polycondensation, which forms a 3D network of silicon-aluminatestructures. Geopolymer binders generally consist of reactive solid components that contain SiO2 and Al2O3 and an alkaline activator solution. When these two components, i.e., reactive solids and an alkaline activation solution react, an aluminosilicate network, ranging from amorphous aluminosilicate to partially crystalline aluminosilicate, forms, creating a hardened product that is resistant to water..

The properties of Geopolymer cement, when used to make concrete, have been repeatedly and independently shown to be equivalent to other cements in terms of the structural qualities of the resulting concrete. This presents a review of recent research on low calcium fly ash-based geopolymer paste with different additives included. These approaches will be used to predict the utilization of various supplementary materials in geopolymer mortar.

Geopolymerization Process: Dissolution of the solid alumino silicates source by alkaline hydrolysis (Consuming water) produces a Complex mixture of aluminate, Silicate aluminosilicateSpecies. If dissolution of amorphous aluminosilicate is rapid, and this quickly creates a supersaturated aluminosilicate Solution. In Concentrated solution this results in the formation of gel, as the oligomers in the aqueous phase form large networks by Condensation. After gelation the system continues to rearrange and reorganize as the connectivity of the gel network increases. And this will result in the three dimensional aluminosilicate network commonly attributed to Geopolymer.

New state-of-the-art materials designed with the help of polymerization reactions are opening up new applications and procedures and transforming ideas that have been taken for granted in inorganic chemistry. J.Davidovits(1997),Arts et métiers magazine(1993)deals with the structure of geopolymer and reaction process and also the overall view about geopolymer. Geopolymer binders have been successfully introduced in the industry. They yield synthetic mineral products with such properties as hard surfaces (4-7 on the MohsScale), thermal stability, and high surface smoothness and precise mouldability.Such products are useful for tooling, for moulding art objets, ceramics,and the like, and as building materials. Xiao Yao.et al.,(2009),A.M. Mustafa Al Bakri(2011)said about that the geopolymerization process. Metakaolinite under alkali activation condition can be reasonably supposed into three stages: destruction, polymerization and stabilization.The appropriate elevation in concentration of alkalisolution could speed up the reaction during stage II and improve thegeopolymerization extent of raw materials. The period of geopolymerizationcould be shortened by increasing the alkali content, namely decreasing the modulus when alkali silicate solution was used

II. MATERIALS AND METHODS:

Class - F Fly ash, Volcanic ash, Zeolite, metakaolin, Rice husk ash and Nano silica were used in the present study for producing geopolymer mixtures and were obtained from the nearby local source. A sodium hydroxide at 8M and Sodium Silicate based alkali was used for initiating geopolymerisation and the detailed mixture proportions are given in Tables I and II.The Compressive strength test and Split tensile strength test studies of geopolymer mixtures were tested at oven curing at 100oC. Test was conducted for Class - F Fly ash replaced with Volcanic ash , Zeolite, metakaolin at 10%, 20% and 30% and Rice Husk ash upto 15% and Nano silica upto 3%for constant 8M of sodium hydroxide and Sodium Silicate cured at 100°C hot air oven. The properties were also compared with the mixture containing Class - F Fly ash replaced with quinary components and cured at 100°C of hot air oven. The mortar cubes were casted for the different mixtures as given in Table I and II and the compressive strength of mortar cubes were tested as per IS 1727-1967 for different curing days 7 and 28 days.Mortar specimens were casted in a standard cube mould of size 50 mm x 50 mm x 50 mm.The specimens were tested after sufficient curing in oven.

III. MIX DESIGN:

Geopolymer mortar is a mixture of any supplementary materials as binder, sand and fluid(sodium hydroxide, sodium silicate and water). Flyash, Metakaolin, Volcanic ash, zeolite, Rice Husk ash in its original form cannot function as binder rather it can be used just as filler material in cement mortar as a replacement of cement. Hence to activate above binders a strong alkali solution of sodium hydroxide and sodium silicate is used. The activated above said binders which is rich in silica and aluminium can function as a binder like OPC. In this investigation geopolymer mortar with constant alkaline liquid to binder ratio of 0.35 was used and flyash: sand ratio as 1:1. The molar concentration of NaOH is 8M. Ratio of NaOH: Na2SiO3 is taken as 2.5. The mix proportions and details of mix are given in Table I and table II respectively.

3.1 Step 1: Unit weight of mortar= 2400kg/m^3(approximately). Take cement: Sand ratio as 1:1. Then mass of the sand = 1200 kg/m^3. The mass of low-calcium fly ash and the alkaline liquid = 2400 – 1200 = 1200 kg/m^3.

Take the alkaline liquid-to-fly ash ratio by mass as 0.35

- The mass of fly ash = 1200/ (1+0.35) = 888.89 kg/m3
- The mass of alkaline liquid = 1200 – 888.89 = 311.11 kg/m3.

Take the ratio of sodium silicate solution-to-sodium hydroxide solution by mass as 2.5

- The mass of sodium hydroxide solution = 311.11 / (1+2.5) = 88.89 kg/m3
- The mass of sodium silicate solution = 311.11 – 88.89 =222.22 kg/m3.

Therefore, the trial mixture proportion is as follow:

- Mass of sand= 1200 kg/m^3, low-calcium fly ash = 888.89 kg/m3
- Sodium silicate solution = 222.22 kg /m3, sodium hydroxide solution = 88.89 kg/m3.

3.2 Step 2: For the trial mixture, water-to-geopolymer solids ratio by mass is calculated as follows:

In sodium silicate solution,water = 0.559x222.22 = 124.22 kg solids = 222.22 – 124.22 = 98 kg. In sodium hydroxide solution(10M), solids = 0.31x88.89 = 27.56 kg ,water = 88.89 – 27.56 = 61.33 kg. Therefore, total mass of water = 124.22 +61.33 = 185.55 kgThe mass of geopolymer solids = 888.89 (i.e. mass of fly ash) +98 +61.33 = 1014.45 kg. Hence the water-to-geopolymer solids ratio by mass = 185.55/1014.45 = 0.18.

IV. METHOD OF EXPERIMENT:

The sodium hydroxide (NaOH) solids were dissolved in distilled water to make the solution. The mass of NaOH solids in a solution varied depending on the concentration of the solution expressed in terms of molar, M. For instance, NaOH solution with a concentration of 8M consisted of 8x40 = 320 grams of NaOH solids (in flake or pellet form) per litre of the solution, where 40 is the molecular weight of NaOH. The mass of NaOH solids was measured as 26% NaOH solids and 74% waterfor

8M concentration. The sodium hydroxide solution prepared at least one day prior to use. On the day of casting of the specimens, sodium silicate solution and alkaline liquid was mixed together with the super plasticizer and the extra water (if any) to prepare the liquid component of the mixture.

4.1 Preparation Of Mortar: The binder and the fine sand were first mixed together in for about 3 minutes. The liquid component of the mixture was then added to the dry material sand the mixing continued for further about 4 minutes to manufacture the fresh mortar. The fresh mortar was cast into the cube size of 50x50x50mm and cylinder size of 50x100mm immediately after mixing and compacted by vibrating the moulds for 20 seconds on a vibrating table cubes and cylinders were casted for study of compressive strength and split tensile strength respectively.

TABLE 1
DETAILS OF MIX PROPORTION WITH BINARY BLENDS (KG/M3)

Mix ID	Fly ash	Volcanic	Zeolite	RHA	Metakaolin	Nano Silica	Sand	NaOH	Na_2SiO_3
M1	888.89	-	-	-	-	-	1200	88.89	222.22
M2	755.56	133.33	-	-	-	-	1200	88.89	222.22
M3	622.22	266.67	-	-	-	-	1200	88.89	222.22
M4	755.56	-	133.33	-	-	-	1200	88.89	222.22
M5	622.22	-	266.67	-	-	-	1200	88.89	222.22
M6	844.45	-	-	44.44	-	-	1200	88.89	222.22
M7	800	-	-	88.89	-	-	1200	88.89	222.22
M8	844.45	-	-	-	44.44	-	1200	88.89	222.22
M9	800	-	-	-	88.89	-	1200	88.89	222.22
M10	755.56	-	-	-	133.33	-	1200	88.89	222.22
M11	871.11	-	-	-	-	17.78	1200	88.89	222.22
M12	862.22	-	-	-	-	26.67	1200	88.89	222.22

TABLE 2
DETAILS OF MIX PROPORTION WITH QUINARY BLENDS (KG/M3)

Mix	Fly ash	Volcanic	Zeolite	RHA	Metakaolin	Nano	Sand	NaOH	Na_2SiO_3
M13	648.9	44.44	88.89	44.44	44.44	17.78	1200	88.89	222.22
M14	604.45	44.44	88.89	44.44	88.89	17.78	1200	88.89	222.22
M15	560.01	44.44	88.89	44.44	133.33	17.78	1200	88.89	222.22
M16	604.46	44.44	133.33	44.44	44.44	17.78	1200	88.89	222.22
M17	560.01	44.44	133.33	44.44	88.89	17.78	1200	88.89	222.22
M18	515.57	44.44	133.33	44.44	133.33	17.78	1200	88.89	222.22
M19	604.45	88.89	88.89	44.44	44.44	17.78	1200	88.89	222.22
M20	560	88.89	88.89	44.44	88.89	17.78	1200	88.89	222.22
M21	515.56	88.89	88.89	44.44	133.33	17.78	1200	88.89	222.22
M22	560.01	88.89	133.33	44.44	44.44	17.78	1200	88.89	222.22
M23	515.56	88.89	133.33	44.44	88.89	17.78	1200	88.89	222.22
M24	471.12	88.89	133.33	44.44	133.33	17.78	1200	88.89	222.22

V. EXPERIMENTAL TEST RESULTS AND DISCUSSIONS:

5.1 Compressive strength of Geopolymer mortar: The compressive loading tests on mortar cubes were carried out on a compression testing machine of capacity 2000 kN. The test piece, usually in the form of a cube and cylinder, is compressed between the platens of a compression-testing machine by a gradually applied load. For the compressive strength test, a loading rate of 2.5 kN/s was applied as per IS: 516-1959. The specimen used was 50 mm cube. The test was performed at 7 & 28 days. The relative strength properties of mortar cubes cured at hot air oven at 100°C are given in Tables III and IV. It can be noted from the test results that, the maximum compressive strength (31.67 MPa) was recorded in the binary blends containing Fly ash and Nano Silica at 2% (M11) with alkali activator. Similarly more or less same Compressive Strength obtained with Metakaolin upto 15% and at the same time with Rice Husk ash at 10%. In the case of Quinary blends containing (M24) a highest compressive strength (19.78 MPa) of the mortar was recorded. It can be summarized from the compressive strength results that among the binary blends, the maximum addition of metakaolin up to 15% and Volcanic ash 10% had shown consistent increase in the compressive strength. It can be noted that all the binary and ternary mixtures attained 65% of the ultimate strength within 7 days of curing. In general, compared to binary blends, Quinary blends containing Metakaolin upto 15% showed higher strength gain of all the mixtures. The compressive strength results clearly shows that without the addition of cementing material, the addition of Quinary mixtures in the presence of alkali activator (NaOH and Na2Sio3) can provide a strong cementing material as a result of geopolymerization.

TABLE 3
COMPRESSIVE STRENGTH RESULTS FOR BINARY BLENDS CURED AT 100^{o}C

Mix ID	Fly ash	Volcanic ash	Zeolite	RHA	Metakaolin	Nano Silica	Compressive Strength	
							7 days(MPa)	28days(MPa)
M1	888.89	-	-	-	-	-	15.95	24.51
M2	755.56	133.33	-	-	-	-	8.34	10.23
M3	622.22	266.67	-	-	-	-	5.52	6.53
M4	755.56	-	133.33	-	-	-	8.21	9.43
M5	622.22	-	266.67	-	-	-	5.57	5.89
M6	844.45	-	-	44.44	-	-	18.99	20.45
M7	800	-	-	88.89	-	-	19.38	23.89
M8	844.45	-	-	-	44.44	-	23.85	26.89
M9	800	-	-	-	88.89	-	24.50	28.76
M10	755.56	-	-	-	133.33	-	24.55	29.98
M11	871.11	-	-	-	-	17.78	28.03	31.67
M12	862.22	-	-	-	-	26.67	26.92	29.34

TABLE 4
COMPRESSIVE STRENGTH RESULTS FOR QUINARY BLENDS CURED AT 100^{o}C

Mix ID	Fly ash	Volcanic ash	Zeolite	RHA	Metakaolin	Nano Silica	Compressive Strength	
							7 days(MPa)	28 days(MPa)
M13	648.9	44.44	88.89	44.44	44.44	17.78	7.17	7.81
M14	604.45	44.44	88.89	44.44	88.89	17.78	8.36	9.45
M15	560.01	44.44	88.89	44.44	133.33	17.78	8.29	10.12
M16	604.46	44.44	133.33	44.44	44.44	17.78	10.07	11.83
M17	560.01	44.44	133.33	44.44	88.89	17.78	12.03	13.56
M18	515.57	44.44	133.33	44.44	133.33	17.78	12.71	14.56
M19	604.45	88.89	88.89	44.44	44.44	17.78	10.19	10.78
M20	560	88.89	88.89	44.44	88.89	17.78	11.01	12.56
M21	515.56	88.89	88.89	44.44	133.33	17.78	11.98	13.76
M22	560.01	88.89	133.33	44.44	44.44	17.78	13.16	15.12
M23	515.56	88.89	133.33	44.44	88.89	17.78	15.13	17.89
M24	471.12	88.89	133.33	44.44	133.33	17.78	16.99	19.78

5.2 Split Tensile Strength: A direct measurement of ensuring tensile strength of mortar is difficult. One of the indirect tension test methods is split tension test. The split tensile strength test was carried out on the compression testing machine. The casting and testing of the specimens were done as per IS 5816: 1999. Table V and VI demonstrates the split tensile strength of morta for different mixes.

TABLE 5
SPLIT TENSILE STRENGTHOF BINARY BLENDS OF SIZE 50 X 100 MM

Mix ID	Fly ash	Volcanic ash	Zeolite	RHA	Metakaolin	Nano Silica	Split Tensile Strength	
							7 days(MPa)	28days(MPa)
M1	888.89	-	-	-	-	-	1.35	1.509
M2	755.56	133.33	-	-	-	-	0.51	0.65
M3	622.22	266.67	-	-	-	-	0.68	0.87
M4	755.56	-	133.33	-	-	-	0.42	0.57
M5	622.22	-	266.67	-	-	-	0.91	1.109
M6	844.45	-	-	44.44	-	-	1.342	1.527
M7	800	-	-	88.89	-	-	1.398	1.569
M8	844.45	-	-	-	44.44	-	1.254	1.401
M9	800	-	-	-	88.89	-	1.31	1.456
M10	755.56	-	-	-	133.33	-	1.41	1.569
M11	871.11	-	-	-	-	17.78	1.366	1.568
M12	862.22	-	-	-	-	26.67	1.445	1.493

TABLE 6
SPLIT TENSILE STRENGTH OF QUINARY BLENDS OF SIZE 50 X 100 MM

Mix ID	Fly ash	Volcanic ash	Zeolite	RHA	Metakaolin	Nano Silica	Split tensile Strength	
							7 days(MPa)	28 days(MPa)
M13	648.9	44.44	88.89	44.44	44.44	17.78	1.361	1.436
M14	604.45	44.44	88.89	44.44	88.89	17.78	1.41	1.445
M15	560.01	44.44	88.89	44.44	133.33	17.78	1.404	1.452
M16	604.46	44.44	133.33	44.44	44.44	17.78	1.319	1.411
M17	560.01	44.44	133.33	44.44	88.89	17.78	1.329	1.456
M18	515.57	44.44	133.33	44.44	133.33	17.78	1.339	1.501
M19	604.45	88.89	88.89	44.44	44.44	17.78	1.368	1.445
M20	560	88.89	88.89	44.44	88.89	17.78	1.398	1.479
M21	515.56	88.89	88.89	44.44	133.33	17.78	1.401	1.498
M22	560.01	88.89	133.33	44.44	44.44	17.78	1.421	1.511
M23	515.56	88.89	133.33	44.44	88.89	17.78	1.433	1.531
M24	471.12	88.89	133.33	44.44	133.33	17.78	1.451	1.561

VI. CONCLUSION

The comprehensive experimental test results and analysis of various geopolymer mixtures in this study can be summarized below:

- The addition of alkali activator (NaOH and Na2Sio3) was not effective in the initiation of geopolymerisation reaction at ordinary room temperature and showed a marked improved setting when cured in hot air oven at 100oC.
- In this investigation geopolymer mortar with constant alkaline liquid to binder ratio of 0.35 was used and flyash: sand ratio as 1:1. The molar concentration of NaOH is 8M. Ratio of NaOH: Na2SiO3 is taken as 2.5. It can be summarized from the compressive strength results that among the binary blends, the maximum addition of metakaolin up to 15% and Nano Silica upto 10% had shown consistent increase in the compressive strength.
- Compressive Strength decreased (5.89MPa) while adding binary Blends containing Volcanic ash and Zeolite alone. But while adding Quinary components compressive strength increased upto 19.78MPa
- Fly ash is actually a solid waste. So, it is priceless. If it can be used for any purpose then it will be good for both environment and economy. Hence it is a safe and environmentally consistent method of disposal.
- Uses of these materials in concrete can save the metal industry disposal costs and produce a ‘greener’ concrete for construction. An innovative supplementary Construction Material is formed through this study.
- It is found to be finally concluded that replacement level should be varied, to gain higher strength at early stages instead of using various synthesized process.

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