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Experimental Investigation in Effect of Low-Calcium FlyashGeopolymer Concrete

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Abstract: Geopolymer concrete results from the reaction of a source material that is richin silica and alumina with alkaline liquid. A summary of the extensive studies conducted on fly ash-based geopolymer concrete is presented. Geopolymerconcrete utilizes an alternate material including fly ash as binding material inplace of cement. This fly ash reacts with alkaline solution (e.g. NaOH) andSodium Silicatec(Na2SiO3) to form a gel which binds the fine and coarse aggregates. One kinds of system were considered in this study using 100% replacement of cement by ASTM class F flyash. It was analyzed from the testresult that the Indian standard mix itself can be used for the geopolymerconcrete with some modification.

Keywords: Geopolymer – Flyash – Polymerization – Sodium hydroxide – Sodium silicate – Hot curing - Ambient temperature – Super plasticizer.

1. INTRODUTION

1.1 GENERAL

Concrete usage around the world is second only to water. Ordinary Portland cement(OPC) is conventionally used as the primary binder to produce concrete. The environmental issues associated with the production of OPC are well known. The amount of carbon dioxide released during the manufacture of OPC due to the calcination of limestone and combustion of fossil fuel is in the order of one ton for every ton of OPC produced. In addition, the extent of energy required to produce OPC is only next to steel and aluminium. On the other hand, the abundant availability of flyash worldwide creates opportunityto utilise this by-product of burning coal, as a substitute for OPC to manufacture concrete. When used as a partial replacement of OPC, in the presence of water and in ambient temperature, fly ash reacts with the calcium hydroxide during the hydration process of OPC to form the calcium silicate hydrate (C-S-H) gel. The development and application of high volume fly ash concrete, which enabled the replacement of OPC up to 60% by mass. Geopolymers may be seen as man-made rocks. They can be produced by reacting solid alumino silicates with a highly concentrated aqueous alkali hydroxide or silicate solution. Hardened cementitious paste made from flyash and alkaline solution combines waste products into useful product. Setting mechanism depends on polymerization. Curing temperature is between 60-90 degree Celsius.

1.2 LOW-CALCIUM FLY ASH-BASED GEOPOLYMER CONCRETE

In this work, low-calcium (ASTM Class F) fly ash-based geopolymer is used as the binder, instead of Portland or other hydraulic cement paste, to produce concrete. The fly ash-based geopolymer paste binds the loose coarse aggregates, fine aggregates and other un-reacted materials together to form the geopolymer concrete, with or without the presence of admixtures. The manufacture of geopolymer concrete is carried out using the usual concrete technology methods.As in the case of OPC concrete, the aggregates occupy about 75-80 % by mass, ingeopolymer concrete. The silicon and the aluminium in the low-calcium (ASTMClass F) fly ash react with an alkaline liquid that is a combination of sodium silicateand sodium hydroxide solutions to form the geopolymer paste that binds the aggregates and other un-reacted materials.

2. METHODOLOGY

1. To develop a mixture proportioning process to manufacture low-calcium fly ash based geopolymer concrete.
2. To identify and study the effect of salient parameters that affects the properties of low-calcium fly ash-based geopolymer concrete.
3. To study the short-term engineering properties of fresh and hardened low calcium fly ash-based geopolymer concrete.

2.1 MATERIALS USED

Sodium hydroxide

Generally sodium hydroxide is available in solid state by means of pellets and flakes. The cost of the sodium hydroxide is mainly varied according to the purity of the substance. Since our geopolymer concrete is homogenous material and its main process to activate the sodium silicate, so it is recommended to use the lowest cost i.e. up to 94% to 96% purity. In this investigation the sodium hydroxide pellets were used.

Fig 2.1 Sodium hydroxide

Sodium silicate

Sodium silicate is also known as water glass, available in liquid (gel) form. Inpresent investigation sodium silicate 2.0 (ratio between Na2O to SiO2) is used. As per the manufacture, silicates were supplied to the detergent company and textile industry as bonding agent. Same sodium silicate is used for the making of geopolymer concrete.

Fig 2.2 Sodium Silicate

Alkaline liquid

Generally alkaline liquids are prepared by mixing of the sodium hydroxide solution and sodium silicate at the room temperature. When the solutions were mixed together, both solution starts to react i.e. (polymerization takes place) it liberate large amount of heat so it is recommended to leave it for about 24 hours thus the alkaline liquid is get ready as binding agent.

Fig 2.3 Alkaline solution

Fly-ash

Fly ash, also known as flue-ash, is one of the residues generated in combustion, and comprises the fine particles that rise with the flue gases. In an industrial context, fly ash usually refers to ash produced during combustion of coal.In the past, fly ash was generally released into the atmosphere, but pollution control equipment mandated in recent decades now require that it be captured prior to release. In the US, fly ash is generally stored at coal power plants or placed in landfills.Two type of flyash is there: ASTM Class C (high calcium flyash) and ASTM Class F (low calcium flyash).In this project, we are using ASTM Class F (low calcium flyash).

Aggregate

The coarse aggregate should be free from salt, mica and impurities.The specific gravity of aggregate is not less than 2.5. The compressive strength of coarse aggregate is 14.5N/mm$^{2.}$For most work, 20mm aggregate is suitable.Crushing strength of good stone should be greater than 100N/mm^2

Hot Curing Chamber

Hot Curing Chamber is used in precast concrete units which are kept under warm and damp atmosphere. This chamber is used for the curing of geopolymer concrete. It consists of coils and it is surrounded by clay rods. The curing temperature for geopolymer concrete is 60^{o}c.

Fig 2.4 Hot Curing Chamber

Fig 2.5 Curing temperature at 60^{0}c

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3. SCOPE OF WORK

The research utilized low-calcium (ASTM Class F) fly ash as the base material for making geopolymer concrete. The fly ash was obtained from only one source. As far as possible, the technology and the equipment currently used to manufacture OPC concrete were used to make the geopolymer concrete. The concrete properties studied included the compressive and indirect tensile strengths, the elastic constants, the stress-strain relationship in compression, and the workability of fresh concrete

3.1 Trial Mix

Density of the plain concrete =2400kg/m^3

Aggregates are major component of concrete; it normally occupies 70% to 80% of the volume of concrete.

Therefore, combined aggregate =75%
=75/100 x2400
=1800kg/m^3

Coarse aggregate =70%
=70/100 x1800
=1260kg/m^3

Fine aggregate =30%
=30/100 x1800
= 540kg/m^3

Combined alkaline solution and flyash
=25/100 x2400
(Remaining 25%) = 600kg/m^3

Standard ratio of flyash to alkaline solution is 0.2 to 0.6
=0.4

Mass of flyash =600/1+0.4
= 428.57kg/m^3

Mass of combined alkaline solution (NaOH&Na_2SiO_3)
=600-428.57
=171.42kg/m^3

Standard ratio of NaOH to Na_2SiO_3 solution=2 to 3
We take 2.5

Mass of NaOH solution =171.42/1+2.5
= 48.97kg/m^3

Mass of Na_2SiO_3 =171.42-48.97
=122.44kg/m^3

Trial mix ratio is 1:1.2:2.94

Flyash**:** fine aggregate**:** coarse aggregate
Flyash (class F) =428.57kg/m^3
Fine aggregate =540kg/m^3
Coarse aggregate =1260kg/m^3
Sodium silicate solution = 122.4kg/m^3
Sodium hydroxide = 48.9kg/m^3

4.RESULTSANDDISCUSSIONS

Table 4.1Required Quantities

Specimen	Mould	Number of specimen	Fly-ash (kg)	Coarse aggregate (kg)	Fine aggregate (kg)	Super plasticizers (kg)
8 Molarity	Cube	12	17.36	51.03	21.87	0.3472
	Cylinder	12	27.43	80.64	34.56	0.5486
	Prism	12	25.72	75.6	32.4	0.5144
10 Molarity	Cube	12	17.36	51.03	21.87	0.3472
	Cylinder	12	27.43	80.64	34.56	0.5486
	Prism	12	25.72	75.6	32.4	0.5144
12 Molarity	Cube	12	17.36	51.03	21.87	0.3472
	Cylinder	12	27.43	80.64	34.56	0.5486
	Prism	12	25.72	75.6	32.4	0.5144

Table 4.2Quantity Arrival

Materials	Weight	Unit	Phase 1	Phase 2	Phase 3
Coarse aggregate	1260	Kg/m^3	1260	1260	1260
Fine aggregate	540	Kg/m^3	540	540	540
Fly-ash	428.6	Kg/m^3	428.6	428.6	428.6
Liquid/fly-ash			0.4	0.4	0.4
Na_2Sio_3/NaOH			2.5	2.5	2.5
Super plasticizers (2%)			8.57	8.57	8.57
Coarse aggregate	1260	Kg/m^3	1260	1260	1260

Table 4.3Properties of fine aggregate

Property	River sand
Specific gravity	2.47
Density	1605.26 Kg/m^3
Sieve analysis	6.35
Water absorption	15.1

Table 4.4 Properties of Coarse Aggregate

Property	Coarse aggregate (20mm)
Specific gravity	2.84
Density	1355.68 Kg/m^3
Impact value	9.1%
Water absorption	9.88%

Table 4.5 Properties of fly-ash

Property	Fly-ash
Specific gravity	2.3
Density	1029.7 Kg/m^3
Sieve analysis	-

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Table 4.6 Test Resultfor8 Molarity

Specimen	7 Days				
	Weight (kg)	Cracking load	Ultimate load	Compressive/split tensile/flexural strength (N/mm^2)	Average
Cube	7.538	195	205	9.11	
	8.125	255	270	12	
	8.205	260	275	12.22	11.11
Cylinder	12.134	75	85	1.2	
	12.100	70	80	1.13	
	12.540	75	90	1.27	1.2
Prism	12.516	6	8	4	
	12.780	10	12	6	5
	12.655	8	10	5	

Table 4.7 Test Resultfor8 Molarity

Specimen	14 Days				
	Weight (kg)	Cracking load	Ultimate load	Compressive/split tensile/flexural strength (N/mm^2)	Average
Cube	8.251	300	455	20.22	
	8.078	255	355	15.78	
	8.427	385	405	18	18
Cylinder	11.994	60	110	1.56	
	12.585	70	140	1.98	
	12.110	55	135	1.91	1.82
Prism	11.386	7	13.2	66	
	11.550	8	14	7	
	11.958	7.5	13.5	6.75	6.78

Table 4.8 Test Result for8 Molarity

Specimen	28 Days				
	Weight (kg)	Cracking load	Ultimate load	Compressive/split tensile/flexural strength(N/mm^2)	Average
Cube	7.760	360	515	22.89	
	7.749	300	410	18.22	
	8.201	330	475	21.11	20.78
Cylinder	12.812	120	180	2.55	
	12.55	155	220	3.11	
	12.62	125	195	2.76	2.81
Prism	12.232	12	15.6	7.8	
	11.210	12.4	16.8	8.4	
	11.892	11.6	15.2	7.6	7.93

Table 4.9Test Resultfor10 Molarity

Specimen	7 Days				
	Weight (kg)	Cracking load	Ultimate load	Compressive/split tensile/flexural strength (N/mm^2)	Average
Cube	8.990	220	400	17.78	
	9.02	250	380	16.89	17.11
	8.90	195	375	16.67	
Cylinder	13.02	120	190	2.69	2.62
	12.82	105	160	2.26	
	13.25	125	205	2.9	
Prism	12.95	6.2	10.4	5.2	5.77
	13.35	6.8	11.6	5.8	
	13.40	7.2	12.6	6.3	

Table 4.10Test Resultfor 10 Molarity

Specimen	14 Days				
	Weight (kg)	Cracking load	Ultimate load	Compressive/split tensile/flexural strength(N/mm^2)	Average
Cube	9.050	200	385	17.11	
	9.250	230	420	18.67	17.70
	9.110	190	390	17.33	
Cylinder	13.35	140	205	2.9	
	13.45	110	180	2.55	
	13.10	150	225	3.18	2.88
Prism	12.88	7.6	12.5	6.25	
	13.55	6.6	12.0	6.0	
	13.82	6.2	11.6	5.8	6.02

Table 4.11Test Resultfor 10 Molarity

Specimen	28 Days				
	Weight (kg)	Cracking load	Ultimate load	Compressive/split tensile/flexural strength(N/mm^2)	Average
Cube	8.55	225	485	21.56	
	8.95	320	500	22.22	
	9.025	280	490	21.78	21.85
Cylinder	13.100	130	250	3.54	
	12.50	140	220	3.11	
	13.58	160	210	2.97	3.21
Prism	12.75	7.8	13.6	6.8	
	13.35	8.6	14.0	7.0	6.7
	13.88	7.6	12.6	6.3	

Table 4.12Test Resultfor 12 Molarity

Specimen	7 Days				
	Weight (kg)	Cracking load	Ultimate load	Compressive/split tensile/flexural strength (N/mm^2)	Average
Cube	9.150	260	380	16.8	
	8.95	280	350	15.5	
	9.00	180	320	14.22	15.5
Cylinder	14.10	90	150	2.12	
	13.80	80	120	1.69	
	12.99	110	180	2.55	2.12
Prism	12.85	6.4	9.4	4.7	
	13.15	6.2	8.2	4.1	
	12.90	6.8	9.2	4.6	4.47

Table 4.13Test Resultfor 12 Molarity

Specimen	14 Days				
	Weight (kg)	Cracking load	Ultimate load	Compressive/split tensile/flexural strength (N/mm^2)	Average
Cube	8.55	280	400	17.8	
	8.90	310	360	16	
	9.05	265	350	15.5	16.43
Cylinder	13.55	120	190	2.68	
	14.15	110	180	2.54	
	13.85	120	165	2.33	2.51
Prism	12.95	6.5	11.5	5.75	
	12.85	5.8	10.5	5.3	
	13.10	6.2	9.8	4.9	5.32

Table 4.14Test Resultfor 12 Molarity

Specimen	28 Days				
	Weight (kg)	Cracking load	Ultimate load	Compressive/split tensile/flexural strength (N/mm^2)	Average
Cube	9.005	280	410	18.2	
	9.010	260	420	18.67	
	8.85	310	435	19.3	18.72
Cylinder	12.5	120	210	2.97	
	13.45	140	190	2.68	
	12.95	120	200	2.82	2.82
Prism	11.95	6.5	12.5	6.25	
	12.35	7.5	13.5	6.75	
	12.05	6.2	10.8	5.4	6.13

GRAPHICAL REPRESENTATIONS

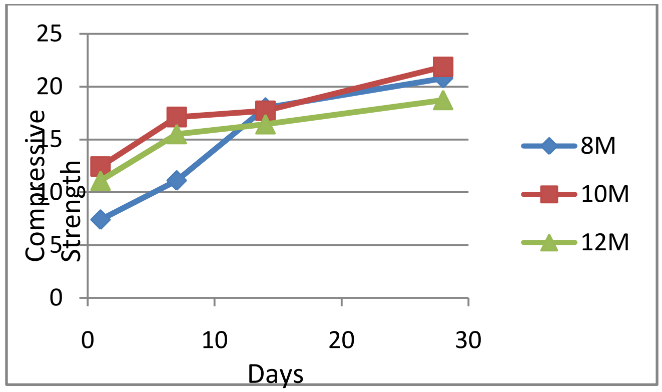

Fig 4.1Compressive strength Vs days for Cube

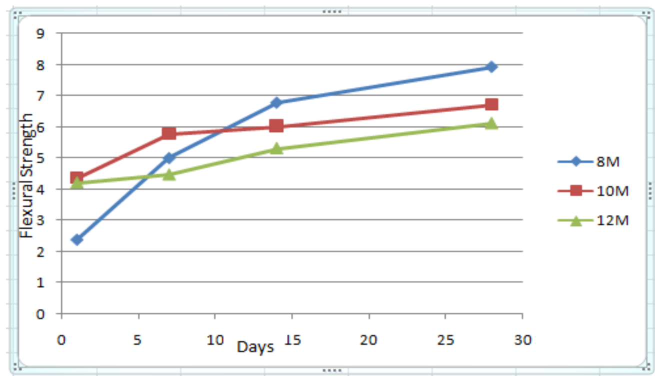

Fig 4.2 Flexural strength Vs days for Prism

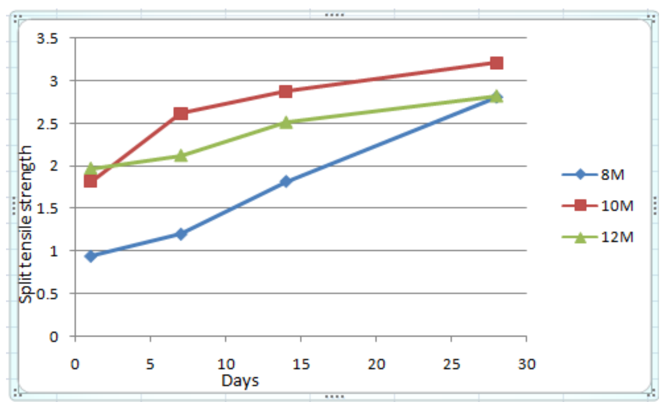

Fig 4.3 Split tensile strength Vs days for cylinder

5.CONCLUSION

Low-calcium fly ash-based geopolymer concrete is cheaper than Portland cement concrete. Geopolymer concrete is an excellent alternative solution to the CO_2 producing port land cement concrete. The price of fly ash-based geopolymerconcrete is estimated to be about 10 to 30 percent cheaper than that of Portland cement concrete.Theexcellent resistance to sulphate attack, and the good acid resistance offered by the low-calcium fly ash-based geopolymer concrete provides additional economic benefits when used in infrastructure applications. Based on the experimental work reported in this study, the following conclusions are drawn:Compared to 8M,10M and 12M, 10M of NAOH solution gives higher compressive strength of fly-ash based geopolymerconcrete.Higher concentration (in terms of molar) of sodium hydroxide solution results in higher compressive strength of fly ash-based geopolymer concrete. Higher the ratio of sodium silicate to sodium hydroxide ratio by mass, higher is the compressive strength of low calcium fly ash-based geopolymer concrete. As the curing temperature in the range of 30^{o}C to 90^{o}C increases, the compressive strength of fly ash-based geopolymer concrete also increases longer curing time, in the range of 4 to 96 hours (4 days), produces higher compressive strength of fly ash-based geopolymer concrete.

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