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Research Article

EFFECT OF CURING TEMPERATURE ON COMPRESSIVE STRENGTH OF GEOPOLYMER CONCRETE

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ABSTRACT

The present study presents a comprehensive summary of the extensive studies conducted on fly ash based Geopolymer concrete. Test data are used to identify the effects of salient factors that influence the strength properties of the Geopolymer concrete. Geopolymer concrete can be manufactured by adopting the conventional techniques used in the manufacture of Portaland cement concrete. Low calcium fly ash is used as the source material instad of Portland cement to make concrete. Heat curing of low calcium fly ash based Geopolymer concrete is generally recommended. From the study it is clear that optimum curing temperature is 80^0C and as the concentration of sodium hydroxide increases, compressive strength of the Geopolymer concrete increases. Geopolymer concrete produced with NaOH in concentration of 8M cured at 80^0C yields a compressive strength of 18.44 MPa.

INTRODUCTION

The global use of concrete is second only to water. As the demand for concrete as construction material increases, so also the demand for Portland cement. It is estimated that the production of cement will increase from 1.5 billion tons in 1995 to 2.2 billion tons in 2010. On the other hand, climate change due to global warming has become a major concern. The global warming is caused by the emission of green house gases, such as carbon dioxide to the atmosphere by human activities. Among the green houses gases carbon dioxide contributes about 65% of global warming. The cement industries are held responsible for the same, since one ton of cement production causes one ton of carbon dioxide emission into the atmosphere.

Several efforts are in progress to reduce the use of Portland cement in concrete in order to address the global warming issue. These include the utilization of supplementary materials such as fly ash, silica fume, granulated blast furnace slag, rice husk ash and metakaolin and the development of alternative binders to Portland cement. In this respect, the Geopolymer technology proposed by Davidovits (1988) shows considerable promise for application in concrete industry as an alternative binders to Portland cement. In terms of global warming, the Geopolymer technology could significantly reduce carbon dioxide emission to the atmosphere caused by the cement industries as shown by the detailed analysis of Gartner (2004).

Geopolymer Concrete

Davidovits (1988:1994) proposed that an alkaline liquid could be used to react with the silicon (Si) and Aluminium (Al) in a source material of geological origin or in by-product materials such as fly ash and rice husk to produce binders. Because the chemical reaction that takes place in this case is a polymerization process, he coined the term "Geopolymer" to represent these binders.

Geopolymers are members of the family of inorganic polymers. The chemical composition of the Geopolymer material is similar to natural Zeolitic materials, but the microstructure is amorphous. The polymerization process involves a substatially fast chemical reaction under alkaline condition on Si-Al minerals, that results in three diemension polymeric chain and ring structure consisting of Si-OAl-O bonds.

The schematic formation of Geopolymer material can be shown as described by equations The last term in the above equation reveals that water is released during the chemical reaction that occur in the formation of Geopolymers.

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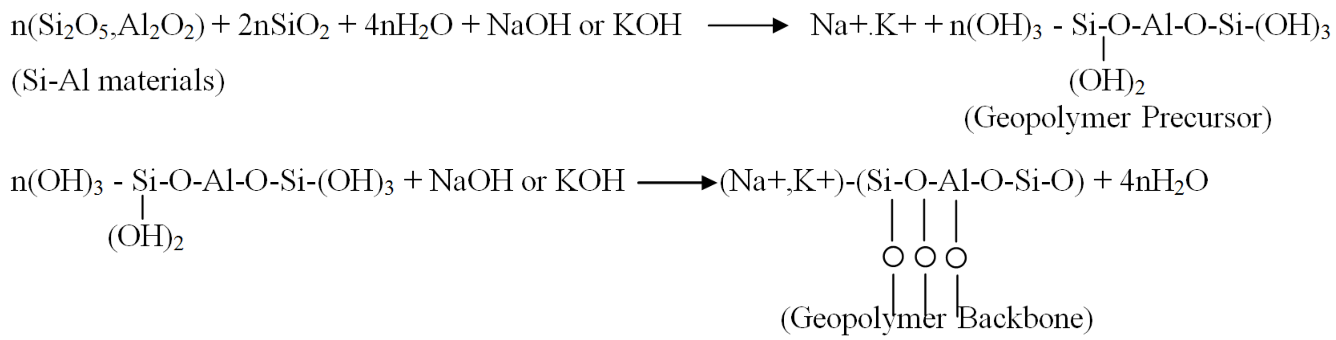

This water, expelled from the Geopolymer matrix during curing and further drying periods, leaves behind discontinues nano pores in the matrix, which provide benefit to the performance of Geopolymers. The water in the Geopolymer mixture, therefore plays no role in the chemical reaction that takes place, it mearly provides the workability to the mixture during handling. This is in contrast to the chemical reaction of water in a Portland cement concrete mixture during hydration process.

There are two main constituents of Geopolymers, namely the source of materials and the alkaline liquids. The source materials for Geopolymers based on alumina silicate should be rich in silicon and aluminium These could be minerals such as kaolinite, clays etc. Alternatively, by-product materials such as fly ash, silica fume, slag, rice husk ash, red mud, etc could be used as source materials. The choice of source materials. The choice of the source materials for making Geopolymers depend on factors such as availability, cost, type of application and specific demand of the end user.

The alkaline liquids are from soluble alkali metals that usually sodium or potassium based. The most common alkaline liquid used in Geopolymarization is a combination of sodium hydroxide or potassium hydroxide and sodium silicate or potassium silicate.

According to Devidovits (1994), Geopolymeric materials have a wide range of applications in the field of industries such as in automobile and aerospace, non-ferrous foundaries and metallurgy, civil engineering and plastic industries. The type of application of Geopolymeric materials is determined by the chemical structure in terms of atomic ratio Si: Al in polysialate. Devidovits (1994) classified the of application according to Si: Al ratio as shown in Table 1. A low ratio of Si: Al of 1,2 or 3 initiates a 3D network that is very rigid, while Si: Al ratio higher than 15 provides a polymeric character to Geopolymeric material.

Table 1 Applications of Geopolymer materials based on silica to alumina atomic ratio

Si : Al ratio	Applications
1	Bricks, Ceramics, Fire Protection.
2	Low CO_2 cement and concretes, Radioactive & toxic waste encapsulation.
3	Fire protection fibre glass composite, Foundry equipments, Tooling for aeronautics titanium process.
> 3	Sealants for industry (200^{0}C to 600^{0}C), Tooling for aeronautics SPF aluminium.
20 to 35	Fire resistance and heat resistance fibre composites.

For many applications in civil engineering field, a low Si: Al ratio is suitable. The present study is focuses on heat cured low calcium fly ash based Geopolymeric concrete. Low calcium (ASTM Class F) fly ash is preferred as a source material than high calcium (ASTM class C) fly ash. The presence of calcium in high amounts may interfere with polymerization process and alter the microstructure.

Objective of the Experimentation

Emission of CO_2 from cement production is increasing at a much more rapid rate than all other industrial sources put together. Few outside of the construction industry are aware that the manufacture of Portland cement based concrete, the material seen everywhere in buildings and pavements, emits green house gases, especially CO_2. As countries develop, they build infrastructure and housing that utilize abundant quantity of concrete. As global development increases, Portland cement manufactures can be expected to exert an increasingly greater influence on governmental policies regulating CO_2 emissions, a situation that needs to be corrected as soon as possible.

Manufacturing Geopolymer cement generates five times less CO_2 than does the manufacturing of Portland cement. Any country that converts to manufacture of Geopolymer cement/concrete would eliminate 80% of the emissions generated from the cement and aggregate industries. Newly developing countries that elect to utilize Geopolymer concrete could increase their construction rate five times without increasing present CO_2 emissions.

The thermal processing of naturally occurring compounds of aluminium and silica provides suitable raw materials for manufacturing Geopolymeric cements. A detailed survey of Geological resources in Europe and U.S. shows abundant amount of suitable natural resources and laboratory experimentation bears out the viability of making Geopolymer cements with these minerals. The resulting concrete has superior properties to Portland cement based concrete. While Portland concrete withstand thousands of years of harsh environmental conditions of all kinds. Geopolymer concrete is durable enough to afford permanent roads and bridges. Thus Geopolymer infrastructure will require very little maintenance, allowing a tremendous reduction in the amount of money that would otherwise have to be spent on the on-going repairs of crumbling roads, bridges, sewer systems and other elements of infrastructure.

The main objective of the experimentation is to find out the effect of curing temperature and effect of different concentration sodium hydroxide on the strength properties of Geopolymer concrete. The concentration of sodium hydroxide opted for study are 1M, 4M and 8M. Different curing temperature obtained for the study are 30^0C (room temperature), 60^0C, 70^0C, 80^0C, 90^0C and 100^0C.

RESULTS AND DISCUSSION

For the present study locally available sand and coarse aggregates were used. The specific gravity of sand was found to be 2.36 and was zone II sand. The specific gravity of coarse aggregate was found to be 2.91. The aggregates used were 12mm and down size. To affect the workability a super plasticizer is used.

The fly ash used in the experimentation was obtained from thermal power station, Gujarat. Sodium silicate solution and sodium hydroxide solution were used in the preparation of alkaline liquid. Sodium silicate solution is having Na2O - 16.45%, SiO2 - 34.35% and water - 49.20%.

Casting and Testing of Specimen

A combination of sodium silicate and sodium hydroxide solutions were used as the alkaline liquids. Alkaline liquid was prepared by mixing both sodium silicate solution and sodium hydroxide together hours prior to the use in the concentration of sodium hydroxide of 1M, 2M and 8M.

Table 2 Compressive strength of Geopolymer concrete cured at 30^0C.

Specimen No.	Concentration of NaOH (M)	Weight of Specimen (N)	Density (KN/m^3)	Avg. Density (KN/m^3)	Failure Load (KN)	Comp. Strength (MPa)	Avg. Comp. Strength (MPa)
A1		6.31	18.40		27	5.51	
A2	1	6.17	17.99	18.01	24	4.90	5.30
A3		6.05	17.64		27	5.51	
A4		6.33	18.45		34	6.94	
A5	4	6.45	18.80	18.96	32	6.53	6.53
A6		6.73	19.62		30	6.12	
A7		7.61	22.19		40	8.16	
A8	8	7.95	23.18	22.73	39	7.96	7.96
A9		7.83	22.83		38	7.76	

Table 3 Compressive strength of Geopolymer concrete cured at 60^0C.

Specimen No.	Concentration of NaOH (M)	Weight of Specimen (N)	Density (KN/m^3)	Avg. Density (KN/m^3)	Failure Load (KN)	Comp. Strength (MPa)	Avg. Comp. Strength (MPa)
A1		6.17	17.99		40	8.16	
A2	1	6.09	17.76	17.70	42	8.57	8.57
A3		5.95	17.35		44	8.98	
A4		6.73	19.62		51	10.41	
A5	4	6.41	18.69	18.94	52	10.61	10.41
A6		6.35	18.51		50	10.20	
A7		7.93	23.12		60	12.24	
A8	8	7.71	22.48	22.59	62	12.65	12.38
A9		7.61	22.19		60	12.24	

Table 4 Compressive strength of Geopolymer concrete cured at 70^0C.

Specimen No.	Concentration of NaOH (M)	Weight of Specimen (N)	Density (KN/m^3)	Avg. Density (KN/m^3)	Failure Load (KN)	Comp. Strength (MPa)	Avg. Comp. Strength (MPa)
A1		6.37	18.57		45	9.18	
A2	1	6.29	18.34	18.29	46	9.39	9.25
A3		6.16	17.96		45	9.18	
A4		6.43	18.75		62	12.65	
A5	4	6.35	18.51	18.93	63	12.86	12.59
A6		6.70	19.53		60	12.24	
A7		7.53	21.95		82	16.73	
A8	8	7.89	23.00	22.53	84	17.14	16.87
A9		7.76	22.62		82	16.73	

Table 5 Compressive strength of Geopolymer concrete cured at 80^0C.

Specimen No.	Concentration of NaOH (M)	Weight of Specimen (N)	Density (KN/m^3)	Avg. Density (KN/m^3)	Failure Load (KN)	Comp. Strength (MPa)	Avg. Comp. Strength (MPa)
A1		6.33	18.45		53	10.82	
A2	1	6.19	18.05	18.09	52	10.61	10.82
A3		6.09	17.76		54	11.02	
A4		6.56	19.13		68	13.88	
A5	4	6.77	19.74	19.59	70	14.29	14.15
A6		6.83	19.91		70	14.29	
A7		7.69	22.42		90	18.37	
A8	8	7.89	23.00	22.90	92	18.78	18.44
A9		7.98	23.27		89	18.16	

The fly ash, sand and aggregates were weighed according to mix proportion 1: 1.4: 3.17 and all ingredients were dry mixed properly. During this instant predetermined quantity of alkaline solution (alkaline liquid / fly ash = 0.35) is added and mixed thoroughly, also super plasticizer is added at 0.30% of mass of concrete.

The homogenous mixture of concrete was poured in to the mould which was kept on the vibrating table. After sufficient mechanical vibration and hand compaction, the specimen were finished smooth. These concrete specimen were de-molded after 10 hours of casting. Then they were transferred to electric oven where they were cured for 24 hours. The curing temperature adopted for the experimentation were 30^0C (room temperature), 60^0C, 70^0C, 80^0C, 90^0C and 100^0C.

For the compression test, specimens of size 70.6 x 70.6 x 70.6 mm were caste. They were tested on 2000 KN capacity CTM as per IS 516 - 1959. After 24 hours of heat curing, the specimen were weighed accurately and tested for compression test.

Following tables represent the test results of Geopolymer concrete produced with different concentrations of sodium hydroxide, cured at predetermined temperature.

Following observations were made with reference to the experimentation conducted for Geopolymer concrete:

- It is observed that Geopolymer concrete produced with Na_2SiO_3: NaOH in the proportion of 1: 2.5 with 1M concentration of sodium hydroxide yields better compressive strength when it is cured at 80^0C. The compressive strength of the Geopolymer concrete goes on increasing from 30^0C to 80^0C curing temperature, there after the compressive strength shows a declining trend. The percentage increase in the compressive strength for Geopolymer concrete cured at 80^0C is found to be 104.15% as compared to the Geopolymer concrete cured at room temperature.
- It is observed that Geopolymer concrete produced with Na_2SiO_3: NaOH in the proportion of 1: 2.5 with 4M concentration of sodium hydroxide yields better compressive strength when it is cured at 80^0C. The compressive strength of the Geopolymer concrete goes on increasing from 30^0C to 80^0C curing temperature, there after the compressive strength shows a declining trend. The percentage increase in the compressive strength for Geopolymer concrete cured at 80^0C is found to be 116.69% as compared to the Geopolymer concrete cured at room temperature.
- It is observed that Geopolymer concrete produced with Na_2SiO_3: NaOH in the proportion of 1: 2.5 with 8M concentration of sodium hydroxide yields better compressive strength when it is cured at 80^0C. The compressive strength of the Geopolymer concrete goes on increasing from 30^0C to 80^0C curing temperature, there after the compressive strength shows a declining trend. The percentage increase in the compressive strength for Geopolymer concrete cured at 80^0C is found to be 131.66% as compared to the Geopolymer concrete cured at room temperature.

Table 6 Compressive strength of Geopolymer concrete cured at 90^0C.

Specimen No.	Concentration of NaOH (M)	Weight of Specimen (N)	Density (KN/m^3)	Avg. Density (KN/m^3)	Failure Load (KN)	Comp. Strength (MPa)	Avg. Comp. Strength (MPa)
A1		6.07	17.70		48	9.80	
A2	1	6.12	17.84	17.92	48	9.80	9.66
A3		6.25	18.22		46	9.39	
A4		6.91	20.15		66	13.47	
A5	4	6.83	19.91	19.91	65	13.27	13.27
A6		6.75	19.68		64	13.06	
A7		7.72	22.51		85	17.35	
A8	8	7.53	21.95	22.56	86	17.55	17.35
A9		7.96	23.21		84	17.14	

Table 7 Compressive strength of Geopolymer concrete cured at 100^0C.

Specimen No.	Concentration of NaOH (M)	Weight of Specimen (N)	Density (KN/m^3)	Avg. Density (KN/m^3)	Failure Load (KN)	Comp. Strength (MPa)	Avg. Comp. Strength (MPa)
A1		6.30	18.37		44	8.98	
A2	1	6.24	18.19	18.56	45	9.18	9.05
A3		6.56	19.13		44	8.98	
A4		6.98	20.35		56	11.43	
A5	4	7.01	20.44	20.29	54	11.02	11.29
A6		6.89	20.09		56	11.43	
A7		7.63	22.24		65	13.06	
A8	8	7.22	21.05	22.05	62	12.65	13.06
A9		7.84	22.86		66	13.47	

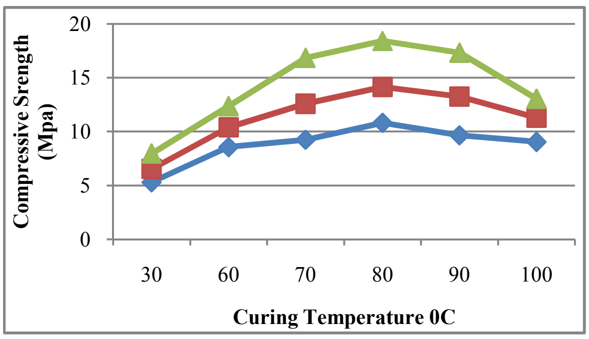

Figure 1 Variation of compressive strength w.r.t. temperature.

This may be due to the fact that a curing temperature of 80^0C may induce optimum polymerization into Geopolymer concrete, since the reaction is basically endothermic reaction.

CONCLUSION

From the present study it can be concluded that the optimum temperature for curing Geopolymer concrete is 80^0C. Geopolymer concrete produced with NaOH in concentration of 1M cured at 80^0C yields a compressive strength of 10.82 MPa. Similarly as the concentration of NaOH increases the compressive strength of the Geopolymer concrete increases. Sodium hydroxide with concentration 4M & 8M yields 14.15 MPa & 18.44 MPa respectively. Further works need to be carried to study the behavior of Geopolymer concrete with higher concentrations of sodium hydroxide.

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