ISSN 2320-5407 International Journal of Advanced Research (2016), Volume 4, Issue 4, 657-663

ISSN NO. 2320-5407

Journal homepage: http://www.journalijar.com
Journal DOI: 10.21474/IJAR01

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH

RESEARCH ARTICLE

Compressive Strength of Ceramic Waste Based Geopolymeric Binder.

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Manuscript Info

Manuscript History:

Received: 14 February 2016
Final Accepted: 19 March 2016
Published Online: April 2016

Key words:
Geopolymer mortar, Fly ash, GGBS, Ceramic waste powder, Binder, Alkaline liquid, Strength.

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Abstract

In this paper, the compressive strength of geopolymeric binder prepared using the source materials such as fly ash, ground granulated blast furnace slag (GGBS) and ceramic waste powder without using any conventional cement has been investigated. The compressive strength was determined as per relevant Indian Standard. The different parameters considered in this study are the proportion of binder components such as ratio of Na_2SiO_3/NaOH solutions and alkaline liquid to binder ratio. The various combinations of fly ash, GGBS and ceramic waste powder considered are 80%, 10% &10%; 60%, 20% & 20% and 40%, 30% & 30% respectively. The ratio of binder to sand and Na_2SiO_3/NaOH solutions is taken as 1:2 & 1:3 and 2 & 2.5. The alkaline liquid to binder ratio is 0.45. The compressive strength of mortar cubes are determined at 7 and 28 days. It can be concluded that, as the percentage of the Ceramic waste powder increases, the compressive strength of the geopolymeric binder decreases when compared to conventional binder.

Introduction:-

The manufacture of ordinary Portland cement (OPC) releases large amount of carbon dioxide (CO_2) to the atmosphere that significantly contributes to greenhouse gas emissions. It is estimated that one ton CO_2 is released into the atmosphere for every ton of OPC produced. In view of this, there is need to develop sustainable alternatives to conventional cement utilizing the cementitious properties of industrial by-products such as Fly ash, Ground Granulated Blast Furnace Slag (GGBS) and Ceramic tile waste powder. The ceramic industry inevitably generates wastes, irrespective of the improvements introduced in manufacturing processes. In the ceramic industry, about 15%-30% production goes as waste. These wastes pose a problem in present-day society, requiring a suitable form of management in order to achieve sustainable development.

In 1978, Davidovits developed a binder called ‘geopolymer’ to describe an alternative cementitious material which has ceramic-like properties. Geopolymers are environmental friendly materials that do not emit greenhouse gases during polymerization process. Geopolymer can be produced by combining a pozzolanic compound or aluminosilicate source material with highly alkaline solutions. Fly ash, GGBS and Ceramic waste powder reacts with alkaline solutions to form a cementitious material which does not emit carbon dioxide into the atmosphere.

Experimental Materials:-

Materials:-

Fly ash is the aluminosilicate source materials used for the synthesis of geopolymeric binder. In this study, low calcium fly ash (ASTM Class-F) obtained from the Tuticorin thermal power plant and GGBS obtained from Mangalore were utilized as the source materials. Fine aggregate is sieved using 2.36 mm sieve to remove all the pebbles. Specific gravity of fine aggregate is 2.64 and its fineness modulus is 2.59. It confirms zone II of IS 383-1970 requirements. In this investigation, a combination of sodium hydroxide solution and sodium silicate solution was used as alkaline activators for geopolymerisation. Sodium hydroxide is available commercially in flakes or pellets form. Table 1 shows the physical properties of these binders. Similarly Table 2 shows the chemical properties of these binders.

Table 1 Physical properties of binders

S.No.	Property	Fly ash	GGBS
1	Specific gravity	2.39	2.84
2	Fineness modulus	2.83	3.43

Table 2 Chemical properties of binders (%)

Binders	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Na_2O	LOI
Fly ash	54.54	28.41	7.26	2.82	0.81	0.35	5.14
GGBS	32.78	22.4	1.1	34.86	0.08	-	0.62
Ceramic powder	63.29	18.29	4.32	4.46	0.72	0.75	1.61

Ceramic waste powder:-

The principal waste coming from the ceramic industry is the ceramic powder, specifically in the powder form. Ceramic wastes are generated as a waste during the process of dressing and polishing. It is estimated that 15 to 30% wastes are produced of total raw material used and although a portion of this waste may be utilized on-site such as for excavation pit refill. Ceramic waste can be used in concrete to improve the strength and other durability factors. Specific gravity of ceramic waste powder is 2.30.

Design Mix:-

Mix Proportion:-

The density of mortar is 2100 kg/m^3. The ratio of binder to fine aggregate is taken as 1:2 & 1:3. The alkaline liquid to binder ratio as 0.45 and by knowing the density of mortar the amount of binder, fine aggregate and quantity of alkaline liquids was determined. The molarity of sodium hydroxide concentration is kept as 8M. The different parameters considered in this study are proportion of binder components, ratio of Na_2SiO_3/NaOH solutions and alkaline liquid to binder ratio. The proportion of binder components (i.e.) the various percentages of fly ash, GGBS and ceramic waste powder is taken as 80%, 10% & 10%; 60%, 20% & 20% and 40%, 30% & 30%. The ratio of Na_2SiO_3/NaOH solutions is taken as 2 and 2.5 & alkaline liquid to binder ratio as 0.45. Extra water was added 15% by weight of cementitious material to get desirable workability for all the mixes. Table 3 shows the mix proportion for alkaline liquid to binder ratio 0.45.

Table 3 Mix Proportions

Mix ID	Proportion of binders	Fly ash (kg/m^3)	GGBS (kg/m^3)	Ceramic powder (kg/m^3)	Sand (kg/m^3)	NaOH (kg/m^3)	Na_2SiO_3 (kg/m^3)	Alkaline liquid (kg/m^3)
Mix Proportion - 1:2; Na_2SiO_3 / NaOH = 2.0								
CM_1	$F_{90}G_{10}C_0$	547.83	60.87	-----	1217.40	91.31	182.61	273.92
CB_1	$F_{80}G_{10}C_{10}$	486.96	60.87	60.87	1217.40	91.31	182.61	273.92
CB_2	$F_{60}G_{20}C_{20}$	365.22	121.74	121.74	1217.40	91.31	182.61	273.92
CB_3	$F_{40}G_{30}C_{30}$	243.48	182.61	182.61	1217.40	91.31	182.61	273.92
Mix Proportion - 1:2; Na_2SiO_3 / NaOH = 2.5								
CM_2	$F_{90}G_{10}C_0$	547.83	60.87	-----	1217.40	78.26	195.66	273.92
CB_4	$F_{80}G_{10}C_{10}$	486.96	60.87	60.87	1217.40	78.26	195.66	273.92
CB_5	$F_{60}G_{20}C_{20}$	365.22	121.74	121.74	1217.40	78.26	195.66	273.92
CB_6	$F_{40}G_{30}C_{30}$	243.48	182.61	182.61	1217.40	78.26	195.66	273.92
Mix Proportion - 1:3; Na_2SiO_3 / NaOH = 2.0								
CM_3	$F_{90}G_{10}C_0$	424.72	47.19	-----	1415.73	70.78	141.57	213.36
CB_7	$F_{80}G_{10}C_{10}$	377.53	47.19	47.19	1415.73	70.78	141.57	213.36
CB_8	$F_{60}G_{20}C_{20}$	288.15	94.38	94.38	1415.73	70.78	141.57	213.36
CB_9	$F_{40}G_{30}C_{30}$	188.76	141.57	141.57	1415.73	70.78	141.57	213.36
Mix Proportion - 1:3; Na_2SiO_3 / NaOH = 2.5								
CM_4	$F_{90}G_{10}C_0$	424.72	47.19	-----	1415.73	60.67	151.69	213.36
CB_{10}	$F_{80}G_{10}C_{10}$	377.53	47.19	47.19	1415.73	60.67	151.69	213.36
CB_{11}	$F_{60}G_{20}C_{20}$	288.15	94.38	94.38	1415.73	60.67	151.69	213.36
CB_{12}	$F_{40}G_{30}C_{30}$	188.76	141.57	141.57	1415.73	60.67	151.69	213.36

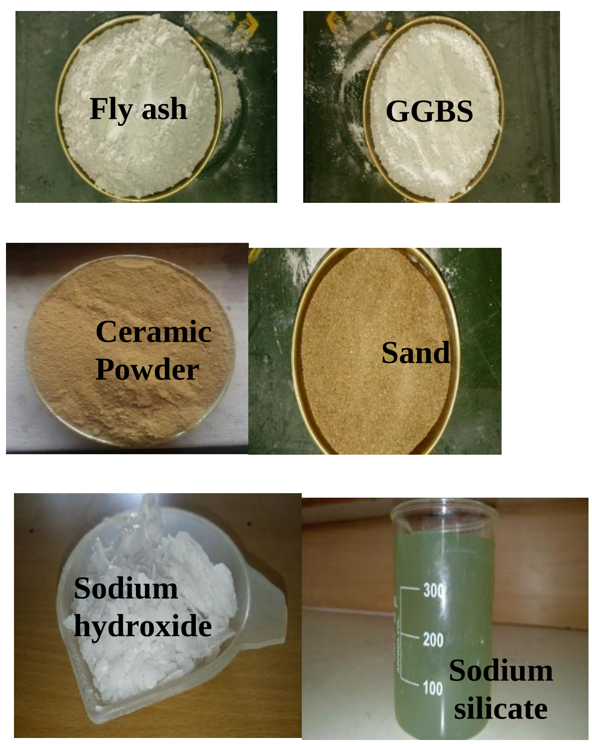

Fig.1. Ingredients of geopolymer mortar

Mixing:-

To prepare the 8 molarity concentration of sodium hydroxide solution, 320 grams (molarity x molecular weight) of sodium hydroxide flakes was dissolved in distilled water and makeup was done to one litre. The sodium hydroxide solution thus prepared is mixed with sodium silicate solution one day before mixing the mortar to get the desired alkaline solution. Distilled water is used to dissolve the sodium hydroxide flakes to avoid the effect of contaminants in the mixing water. The fly ash, GGBS, ceramic powder and fine aggregate was dry mixed before adding the alkaline solution. Sodium hydroxide is available commercially in flakes or pellets form. For this present study, sodium hydroxide flakes with 98% purity were used for the preparation of alkaline solution. Sodium silicate is available commercially in solution form and hence it can be used. Sodium silicate with Na_2O = 14.7%, SiO_2 = 29.4% and water = 55.9% by mass was used in this research. Sodium hydroxide solution was used as alkaline activator because it is widely available and is less expensive than potassium hydroxide solution.

Preparation of Test Specimens:-

Compressive strength was found out using mortar cubes of standard size 70.7 mm x 70.7 mm x 70.7 mm. Totally 96 mortar cubes were cast with 6 cubes for each mix ratio. Out of 96 mortar cubes were used to find the compressive strength. After casting process, the specimens were kept for 24 hours and then demoulded. They were self-cured at room temperature for 7 days and 28 days. Fig.2. shows the mortar cubes made with different mix proportion.

Fig.2. Mortar cubes made with different mix proportion

Experimental program:-

Compressive Strength Test:-

The compressive strength is the ratio of the maximum load to the surface area of the mortar cube. Three cubes were tested for each mix ratio and the average of three specimens is taken as the compressive strength it was tested by compression testing machine of capacity 2000 kN. The geopolymer mortars were tested for compressive strength at the age of 7 day and 28 day. The specimens were subjected to a compressive force at the rate of 132kN per minute. Fig.3. and Fig.4. Shows the mortar cube under test and the mortar cube specimens, after testing respectively.

Fig.3. Mortar cube under test


Fig.4. Mortar cube specimens after test

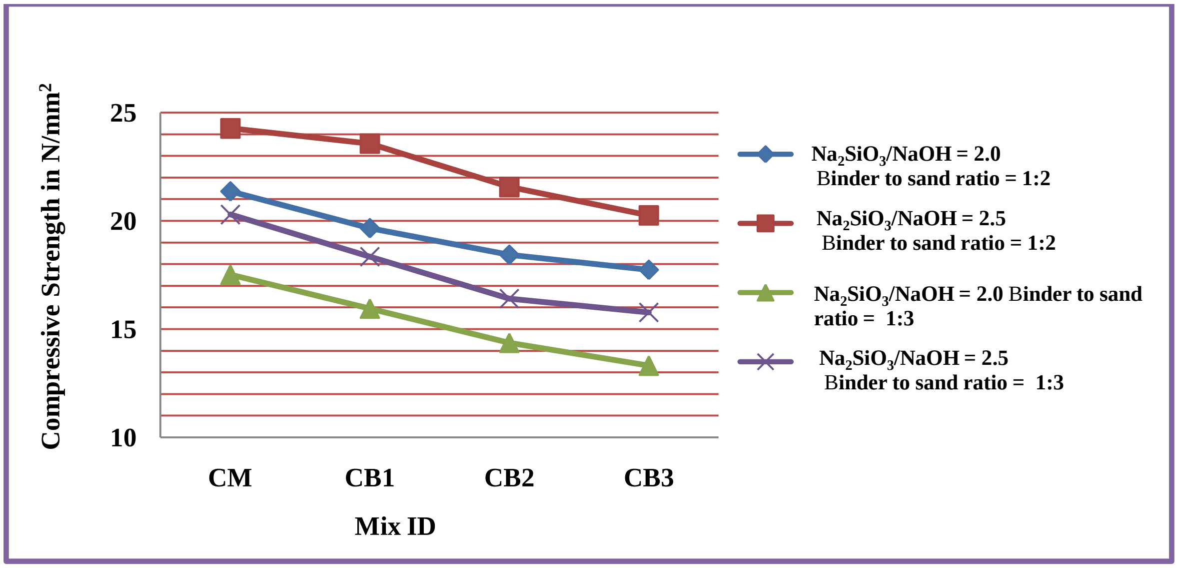

Fig.5. 7 Days compressive strength of mortar specimens

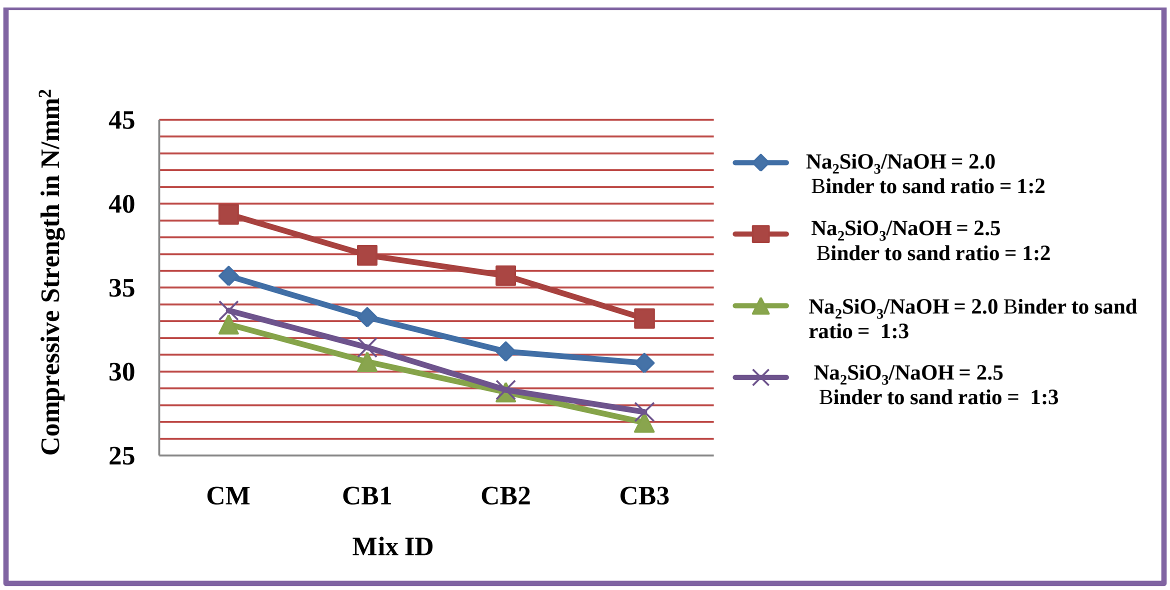

Fig.6. 28 Days compressive strength of mortar specimens

The test results of compressive strength of mortar cubes at 7 day and 28 days are shown in Fig.5. & Fig.6. As the age of mortar increases, compressive strength of mortar also increases for all the mixes. Also compressive strength decreases with an increase in quantity of Ceramic powder.Compressive strength of ambient cured geopolymer mortar at 28 days ranges from 39.36 – 26.96 MPa. The maximum compressive strength of 39.36 MPa is obtained for the mix CM_1 and minimum compressive strength of 26.96 MPa is obtained for the mix CB_3. The compressive strength values are higher for Na_2SiO_3/NaOH solutions ratio of 2.5 as compared with a ratio 2.0. The reduction in compressive strength with respect to control specimens without ceramic powder is about 7%, 12% & 14% and 6%, 9% & 15% for Na_2SiO_3/NaOH solutions ratio of 2.0 & 2.5 and binder to sand ratio 1:2. Similarly the reduction of compressive strength with respect to control specimens without ceramic powder is about 7%, 13% &18% and 7%, 14% & 18%for Na_2SiO_3/NaOH solutions ratio of 2.0 & 2.5 and binder to sand ratio 1:3.

Conclusion:-

1. The compressive strength of geopolymer mortar decreases with increases in quantity of ceramic powder.

2. The mortar specimens with a ratio of Na_2SiO_3/NaOH solution as 2.5 resulted in higher compressive strength as compared to a ratio of 2.0.
3. The geopolymer mortar specimens made of binder to sand ratio 1:2 produces the higher compressive strength as compared to the binder to sand ratio of 1:3.
4. Utilization of ceramic waste as a replacement material for cement is a possible alternative solution for the safe disposal of ceramic waste.

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