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MECHANICAL PROPERTIES OF CERAMIC WASTE BASED GEOPOLYMER CONCRETE

Rajeswaran P[1], Thahira Banu[1], Gopinath M R[2], Ms.Mallika B[1]
1- Assistant Professor, Department of Civil Engineering, Sethu Institute of Technology, Kariapatti, Virudhunagar
2- PG Scholar, Structural Engineering, Sethu Institute of Technology, Kariapatti, Virudhunagar

ABSTRACT

In this paper, the compressive strength of geopolymer concrete prepared using the source materials such as fly ash, ground granulated blast furnace slag (GGBS) and ceramic waste fine aggregate without using any conventional cement has been investigated. The compressive, split tensile and flexural strengths were determined as per relevant Indian Standard. The combinations of fly ash and GGBS are kept constant proportion as 80% & 20%. The various combinations of fine aggregate and ceramic waste fine aggregate considered are 100% & 0%; 90% & 10%; 80% & 20%; 70% & 30% and 60% & 40%; 50% & 50% respectively. The ratio of Na_2SiO_3/NaOH solutions is taken as 2.5. The alkaline liquid to binder ratio is 0.4. The compressive strength of cubes are determined at 7 and 28 days. As a result, the compressive strength achieved up to 40% replacing fine aggregate with ceramic waste fine aggregate. This research work is concerned with the experimental investigation on strength of geopolymer concrete and optimum percentage of the partial replacement by replacing fine aggregate via 0%, 10%, 20%, 30%, 40% and 50% of ceramic waste fine aggregate. Keeping all this view, the aim of the investigation is to study the behavior of concrete while replacing the ceramic waste with different proportions in geopolymer concrete.

1.0 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 natural sand utilizing the Ceramic waste as fine aggregate. 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, Fine aggregate, Ceramic waste fine aggregate and

Coarse aggregate reacts with alkaline solutions to form a concrete material which does not emit carbon dioxide into the atmosphere.

2.0 Literature Review

"Geopolymer Concrete an Eco-Friendly Construction Material" by L.Krishnan, S.Karthikeyan, S.Nathiya, K.Suganya in International Journal of Research in Engineering And Technology (Issn: 2319-1163 | pg no.164 to 167)

This research work was to produce a carbon dioxide emission free cementious material. The geopolymer concrete is such a vital and promising one. In this present study the main limitations of fly ash based geopolymer concrete are slow setting of concrete at ambient temperature and the necessity of heat curing are eliminated by addition of Ground Granulated Blast Furnace Slag (GGBS) powder which shows considerable gain in strength. The Alkaline liquids used in this study for the polymerization process are the solutions of sodium hydroxide (NaoH) and sodium silicate (Na_2Sio_3)

The following conclusions can also be derived from the study, the geopolymer concrete gained strength within 24 hours at ambient temperature without water curing. The necessity of heat curing of concrete was eliminated by incorporating GGBS and fly ash in a concrete mix. The strength of geopolymer concrete was increased with increase in percentage of GGBS in a mix. The compressive strength also increases with the increase in the alkaline liquid content.

"**Geopolymer Concrete- A Review**" by M. I. Abdul Aleem, P. D. Arumairaj in International Journal of Engineering Sciences & Emerging Technologies, Feb 2012 (Volume 1, Issue 2, pp: 118-122).

Concrete is the world's most versatile, durable and reliable construction material, So that large amount energy was also consumed for the cement production. Hence, it is inevitable to find an alternative material to the existing most expensive, most resource consuming Portland cement. Geopolymer concrete is an innovative construction material which shall be produced by the chemical action of inorganic molecules.

Fly Ash, a by- product of coal obtained from the thermal power plant is plenty available worldwide. Fly ash is rich in silica and alumina reacted with alkaline solution produced aluminosilicate gel that acted as the binding material for the concrete. It is an excellent alternative construction material to the existing plain cement concrete. Geopolymer concrete shall be produced without using any amount of ordinary Portland cement.

Due to the high early strength Geopolymer Concrete shall be effectively used in the precast industries, so that huge production is possible in short duration and the breakage during transportation shall also be minimized. The Geopolymer Concrete shall be effectively used for the beam column junction of a reinforced concrete structure. Geopolymer Concrete shall also be used in the Infrastructure works. In addition to that the Fly ash shall be effectively used and hence no landfills are required to dump the fly ash. The government can make necessary steps to extract sodium hydroxide and sodium silicate solution from the waste materials of chemical industries, so that the cost of alkaline solutions required for the geopolymer concrete shall be reduced.

“Compressive strength of ceramic waste based geopolymeric binder” by P.Rajeswaran, Dr.R.Kumutha, Dr.K.Vijai in International Journal of Advanced Research. (2016) volume 4 issue 4,657-663).

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 geopolymer mortar decreases with increases in quantity of ceramic powder. 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.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.Utilization of ceramic waste as a replacement material for cement is a possible alternative solution for the safe disposal of ceramic waste.

“Geo-polymer Concrete–Green Concrete for the Future” byA Review by Sourav Kr. Das1, Amarendra Kr. Mohapatra and A.K. Rath in International Journal of Civil Engineering Research.ISSN 2278-3652 Volume 5, Number 1 (2014), pp. 21-28.

Cements which are used for construction work are generally OPC/PSC or PPC and the production of this kind of cement not only consumes huge amount of the natural resources i.e. limestone and fossils fuel but also produces almost 0.9t of CO2 for 1t cement clinker production. Also world cement production generates 2.8 billion ton man-made greenhouse gas annually. Geo-polymer concrete is totally different in materials and chemistry which is synthesized from waste material like fly-ash(Class F or C), rice husk along with binding solution which is free of cement.

Till date it was seen that the strength of geo-polymer concrete mostly depends on the molarities of the alkaline liquid (NaOH or KOH) and ratios of SiO2and Na2O, H2O and Na2O, Si and Al, water to geopolymer solids by mass in the total alkaline solution. It was seen that geo-polymer concrete made of fully Fly-ash or partial replacement by GGBS results with 80% reduction in CO2 emission compared to OPC, although the alkaline solution to some extent pollutes the environment.Exhaustive studies in various processes and parameters show that geopolymer concrete is superior to cement concrete, which is a very good andidate material for future.

Higher the fineness of fly ash gives a higher compressive strength because of more surface area with more Si-Al bond for polymerization. With a higher Na_2O/SiO_2 gives a higher strength, generally with a ratio of 2.5. Generally heat cured geopolymer concrete gives higher strength but it can be obtained at ambient temperature by replacing fly ash content by GBBS.

Geopolymer concrete has excellent properties as discussed earlier so it can be very useful for rehabilitation and retrofitting works. It can also be used in road works because of its very early attainment of strength. The economic benefits and contribution of geopolymer concrete to sustainable development have also been outlined.

3.0 Experimental Materials

Materials

Fly ash is the aluminosilicate source materials used for the synthesis of geopolymer concrete. 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 4.75mm 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. Specific gravity of coarse aggregate is 2.73. In this investigation, a combination of sodium hydroxide 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 ingredients. Similarly Table.2. shows the chemical properties of these ingredients.

Table.1.Physical properties of Ingredients

S.No.	Property	Fly ash	Fine Aggregate	CWFA	GGBS
1	Specific gravity	2.39	2.64	2.57	2.84
2	Fineness Modulus	2.83	2.59	2.95	3.43

Table2.Chemical properties of Ingredients (%)

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	34.6	0.08	-	0.62
Ceramic Waste FA	63.29	18.29	4.32	4.46	0.72	0.75	1.61

Ceramic waste Fine Aggregate

The principal waste coming from the ceramic industry is the ceramic waste. 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 (F.A) is 2.3 and its fineness modulus is 2.95

4.0 Experimental Program

Mix Proportion:

The density of geopolymer concrete is 2400 kg/m^3.The alkaline liquid to binder ratio as 0.4 and by knowing the density of concrete the amount of binders, and coarse aggregate and quantity of alkaline liquids was determined. The morality of sodium hydroxide concentration is kept as 8M. The ratio of Na_2SiO_3/NaOH solutions and alkaline liquid to binder ratio is kept constant. The proportion of fine aggregate components (i.e.) the various percentages of fine aggregate and ceramic waste fine aggregate is taken as 100% & 0%; 90% & 10%; 80% & 20%; 70% & 30%; 60% & 40%; 50% & 50% The ratio of Na_2SiO_3/NaOH solutions is taken as 2.5. Extra water was added 15% by weight of cementitious material to get desirable workability for all the mixes. Table 3 shows the mix proportions.

Table.3.Mix Proportions

Mix ID	Proportion	Fly ash (kg/m^3)	GGBS (kg/m^3)	Natural sand (kg/m^3)	Ceramic waste (kg/m^3)	NaOH (kg/m^3)	Na_2SiO_3 (kg/m^3)	Alkaline Liquid (kg/m^3)
M_1	$FA_{100}C_0$	7.02	1.75	12.344	0.000	0.903	2.257	3.16
M_2	$FA_{90}C_{10}$	7.02	1.75	11.106	1.234	0.903	2.257	3.16
M_3	$FA_{80}C_{20}$	7.02	1.75	9.872	2.460	0.903	2.257	3.16
M_4	$FA_{70}C_{30}$	7.02	1.75	8.638	3.702	0.903	2.257	3.16
M_5	$FA_{60}C_{40}$	7.02	1.75	7.404	4.936	0.903	2.257	3.16
M_6	$FA_{50}C_{50}$	7.02	1.75	6.170	6.170	0.903	2.257	3.16

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 waste, fine aggregate and coarse 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 cubes of standard size 150 mm x 150 mm x 150 mm. Totally 36 cubes were cast with 6 cubes for each mix ratio. Out of 36 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.1. shows the mortar cubes made with different mix proportion.

Fig.1.Concrete cubes made with different mix proportions

5.0 Experimental Investigations

Compressive Strength Test

The compressive strength is the ratio of the maximum load to the surface area of the 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 concrete 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.2. shows the compressive strength test values of concrete cubes.

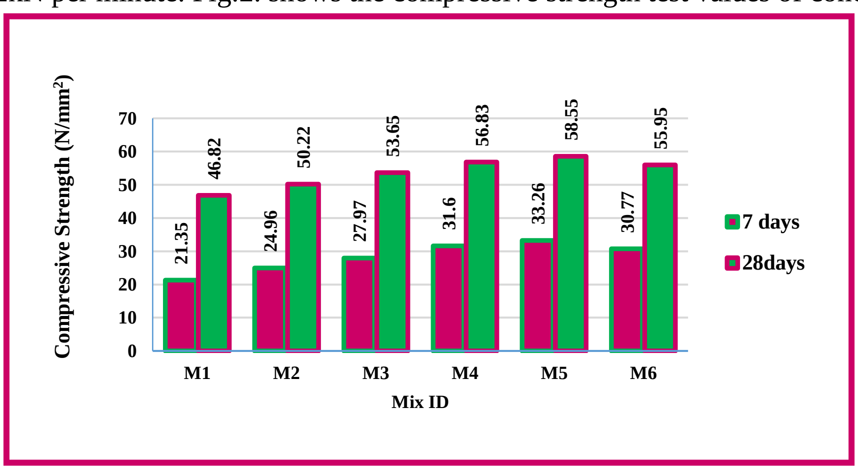

Fig.2. Effect of ceramic powder content on compressive strength

Compressive strength of ambient cured geopolymer concrete at 28 days ranges from 46.82 – 58.55 MPa. The maximum compressive strength of 58.55 MPa is obtained for the mix M5 and minimum compressive strength of 46.82 MPa is obtained for the mix M1. The compressive strength test results of geopolymer concrete shows that,the percentage of strength to the conventional concrete by 10%, 20%, 30%, 40% and 50% replacement of fine aggregate by ceramic waste are 7.2%, 14.5%, 21.3%, 25% and 19.5%.

Split Tensile Strength Test

The split tensile strength test was carried out as per IS 5819: 1999. Cylindrical concrete specimens 150 mm in diameter and 300 mm in height were cast. The specimens were tested for split tensile strength using universal testing machine at the age of 7 and 28 days.

Fig.3. Cylinder Specimen under test

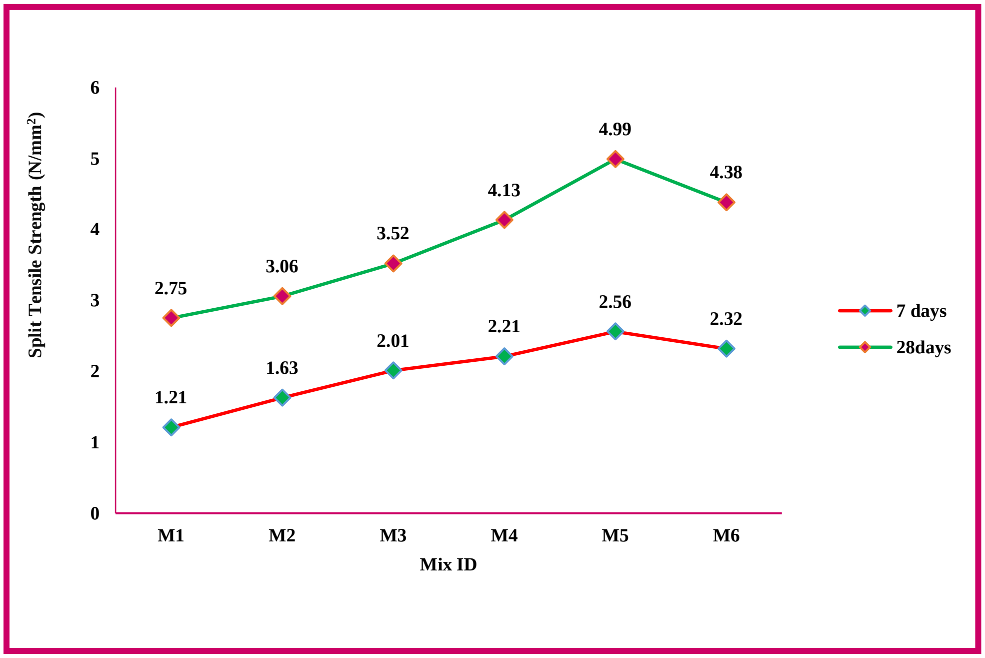

Fig.4. Effect of ceramic powder content on split tensile strength

The split strength test results of geopolymer concrete shows that,the percentage of strength to the conventional concrete by 10%,20%,30%,40% and 50% replacement of fine aggregate by ceramic waste are 11.2%,28%,50%,81,4% and 59.2%.

Flexural Strength Test

The flexural strength test was carried out as per IS 516: 1959. Prism specimens of 100 mm in width, 100 mm height and 500 mm in length were cast. The specimens were tested for flexural strength using flexural testing machine at the age 28 days.

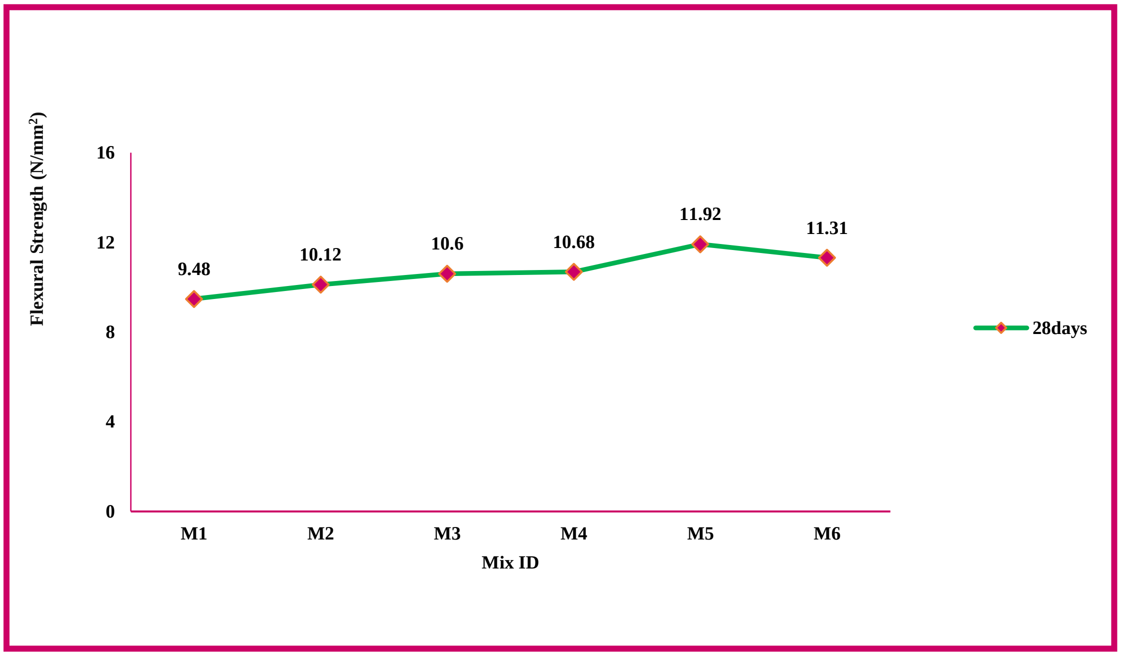

Fig.5. Effect of ceramic powder content on Flexural strength

6.0 Conclusion

- The strengths of geopolymer concrete increases with increases in quantity of ceramic waste fine aggregate content up to 40%.
- The compressive strength of geopolymer concrete increases when the replacement of fine aggregate with ceramic waste aggregate up to 40% replaces by the weight of fine aggregate further replacement of fine aggregate with ceramic waste aggregate decreases the compressive strength.
- The geopolymer concrete made of 60% fine aggregate and 40% ceramic waste produce the maximum strength of all mix proportions.
- The split tensile strength and flexural strength are increases when the replacement of fine aggregate with ceramic waste aggregate up to 40% replaces by the weight of fine aggregate.
- Compressive strength of ambient cured geopolymer concrete at 28 days ranges from 46.82 – 58.55 MPa.
- Utilization of ceramic waste as a replacement material for fine aggregate is a possible alternative solution for the safe disposal of ceramic waste.

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