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Strength and Shrinkage Characteristics of Geo-Polymer Concrete

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Abstract: Geo-polymer concrete (GPC) is a concrete manufactured without using cement. This type of concrete has environmental benefit as it has very low greenhouse gas emission compared to that resulted from the production of Portland cement. In addition, it also utilizes the by-product materials which make it more environmentally friendly. Geo-polymer concrete in the present study is manufactured by using the industrial by products such as Ground Granulated Blast Furnace (GGBS), fly-ash as source materials which are rich in silica and aluminum; alkaline solution and aggregates normally used for ordinary Portland cement concrete. In this paper, the strength and drying shrinkage characteristics of geo-polymer concrete have been compared with that of ordinary Portland cement concrete.

Keywords: *Geo-polymer concrete, Drying shrinkage, Fly-ash*

1. Introduction

Concrete is the most used material after water. Energy consumption for the manufacture of cement is next to steel and aluminum. 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. For every ton of OPC produced, almost a ton of CO_2 is liberated. More than 7% of world CO_2 production is mainly because of the production of Portland cement. As per the studies done by McCaffrey, R. (2002) CO_2 contributes to 65% of global warming among the greenhouse gases [1]. Therefore, there is a need to find a substitute for Portland cement in order to make the construction industry eco-friendly.

In 1978, Davidovits proposed that a polymeric reaction between alkaline liquids with silicon and aluminum which is a major constituent of fly-ash and rice-husk ash yielded binding material. He termed these binders as geo-polymers. Palamao et.al, (1999)suggested that OPC can be replaced by pozzolonas such as blast furnace slag after activating using alkaline liquids to form binder [2]. In this work, low-calcium (ASTM Class F) fly ash and Ground granulated blast furnace slag (GGBS) geo-polymer is used as the binder to produce concrete. The binding material so formed binds the aggregates and other unreacted materials to form geo-polymer concrete. The manufacture of geo-polymer concrete is carried out using the usual concrete technology methods.

Shrinkage is the decrease in volume of the concrete with time. Unlike creep, shrinkage is independent of the external action of the concrete. Neville A.M (2000) showed that there are three types of shrinkage namely plastic shrinkage, carbonation shrinkage and drying shrinkage. When concrete is in plastic state due to evaporation or suction of water by underlying soil or concretePlastic shrinkage occurs. When carbon dioxide of environment reacts with hydrated cement carbonation occurs which leads to shrinkage. Drying shrinkage is the decrease in volume which is mainly caused by the loss of water from the gel pores during the process of drying. Drying shrinkage plays a major role in total long-term shrinkage. Factors which affect the drying of concrete also affect the magnitude and rate of development of drying shrinkage. Type of cement, cement or binder quantity, quantity of water, water to binder ratio, aggregate type and its size are the factors which affects the drying shrinkage [7].

Steenie Edward Wallah (2009) has done study on Geo-polymer concrete where he used low-calcium fly ash as its source material, alkaline solution and aggregates normally used for OPC concrete. He found that heat-cured fly-ash based geo-polymer concrete showed very low drying shrinkage strain. The drying shrinkage strains varied slightly over the period of measurement and the value at one year measurement is only around 100 micro strains. The test measurement at one year for all test series of specimens with different compressive strength, which were produced from different mixtures and curing types, do not have significant difference. The values of drying shrinkage strain predicted using Gilbert Method is much higher, about five to seven times of the measured drying shrinkage strain [3].

Lee et.al, (2014) have investigated the microstructure and shrinkage characteristics of alkali-activated fly ash/slag (AFS) pastes and mortars. The AFS mixtures were produced by mixing fly ash, slag, sodium silicate with distilled water. They found that chemical shrinkage of the alkali-activated fly ash/slag paste was lower than that of the OPC paste (0.06–0.10 mL/g), whereas the autogenous shrinkage of the AFS paste was higher than that of the OPC paste. With the increase in the slag or sodium silicate content, the total porosity decreased and, simultaneously the mesopore volume decreased, as the matrix became denser due to the formation of more reaction products. The AFS mortar showed a higher level of drying shrinkage than the OPC specimen, which may have been caused by the higher capillary stress resulting from the higher mesopore volume of the AFS mortar compared to that of OPC mortar [4].

In this paper the strength and drying shrinkage characteristics of geo-polymer concrete specimens have been compared with Ordinary Portland cement concrete specimens.

2. Experimental Methodology

2.1. Materials

2.1.1. Fly-ash

Fly ash (class F) produced by Raichur Thermal Power Station, Karnataka is used in the current study. It has specific gravity of 2.26 and Blaine's surface area of 3225 cm^2/gm.

2.1.2. Ground Granulated Blast Furnace Slag (GGBS)

GGBS obtained from Jindal Steel plant Bellary, Karnataka. Specific gravity of GGBS was found to be 2.74. Chemical properties of GGBS are given in the table 1**.**

2.1.3. Aggregates

Locally available clean river sand is used as fine aggregate in the present study. Specific gravity and fineness modulus are found to be 2.64 and 2.66 respectively. Crushed granite of 20mm down size has been used as coarse aggregate. Specific gravity and fineness modulus are found to be 2.71 and 7.06 respectively. Both coarse and fine aggregates conformed to IS 383:1970 [5].

Table 1 *Properties of GGBS*

Characteristics/ Chemical requirements	Requirements as per BS: 6699	Test Results
Fineness (m^2/kg)	275 (min)	393
Insoluble Residue (%)	1.5 (max)	0.62
Magnesia Content (%)	14.0 (max)	7.61
Sulphide Sulphur (%)	2.00 (max)	0.52
Sulphite Content (%)	2.50 (max)	0.33
Loss of Ignition (%)	3.00 (max)	0.24
Maganesse content (%)	2.00 (max)	0.11
Chloride content (%)	0.10 (Max)	0.011
Glass content (%)	67 (min)	90
Moisture content (%)	1.00 (Max)	0.13
$CaO+MgO+SiO_2$	66.66 (Min)	75.96
$CaO+MgO/SiO_2$	>1.0	1.32
CaO/SiO_2	<1.40	1.09

2.1.4. Alkaline Solution

Catalytic system consisting of hydroxide-silicate based solutions of high alkalinity has been chosen. A mixture of analytical grade NaOH (97% purity) pellets and sodium silicate solutions is used in the present investigation as the catalytic liquid.

2.1.5. Superplasticizer

A sulphonated naphthalene polymer based high range water reducing agent conforming to the ASTM C-494 standard is used [6].

2.2. Mix design

Conventional concrete has been designed for M40 grade as per IS10262:2009 using Ordinary Portland Cement (OPC). For GPC, initial mixes have been done with proportions available in the literature and checking the mix design by absolute volume method. Several trials are carried out to finalize the order of mixing the ingredients. Such trials on sample preparing indicated that mixing NaOH pallets with sodium silicate solution prior to the addition of solid reactants (starting materials like Fly ash and GGBS) can generate a homogeneous paste and also result in geo-polymer mix of higher compressive strength.

2.2.1. Concrete Mix

Mix proportions for Geo-polymer concrete G40 and conventional concrete M40 is given in the table2 and table 3 respectively.

Table 2 *Mix proportions for G40.*

Materials	Quantity (kg/m^3)
GGBS	275
Fly ash	275
Coarse aggregates	850
Fine aggregates	555
NaOH pellets	19.25
Na_2SiO_3 solution	75
Water	170
Superplasticizer	6.05

Table 3 *Mix proportions for M40*

Materials	Quantity (kg/m^3)
Cement	415
Fine aggregates	632
Coarse aggregate	1190
Water	158
Superplasticizer	3.1125

2.3. Specimens

For both control mix and GPC, cubes of size 150mmx150mmx150mm, beams of size 500mmx100mmx100mm and cylinders of size 300mmx150mm were cast.

2.4. Curing condition

Conventional method is followed for OPC specimens i.e. curing in water tank whereas GPC specimens were kept in open air after de-moulding till the test.

2.5. Tests conducted on GPC and control mix specimens

After specified curing period, the concrete specimens were tested for compressive strength, split tensile strength, flexural strength and shrinkage.

3. Experimental Results

3.1. Workability

During the present investigation GPC mixes were found to be workable, highly viscous and have very good flow ability.

3.2. Density

Wet and dry density of GPC was found to be 2350 kg/m^3 and 2270 kg/m^{3}respectively.

3.3. Compressive strength

GPC specimens were failed in the same pattern as that of OPC specimens when tested for compressive strength. Compressive strength test values for GPC and control mix are shown in the Figure 1.

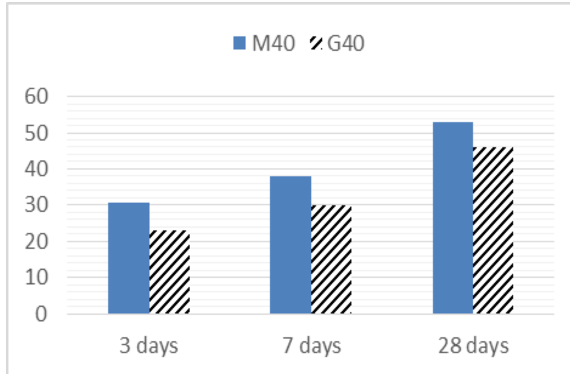

Figure 1 *Compressive strength for M40 and G40*

3.4. Tensile and flexural strength

Split tensile and flexural strength of GPC after 28 days were found to be 2.97 N/mm^2 and 3.97N/mm^2 and for control mix 2.79 N/mm^{2}and 5.59N/mm^{2}respectively.

3.5. Drying shrinkage

For monitoring the drying shrinkage of the specimens, 500mmx100mmx100mm size beams were used. After de-moulding the concrete specimens, the gauge length of 200mm was fixed by gluing DEMEC (Demountable Mechanical) buttons on the surface of the specimens. The initial gauge length was measured and consecutive readings were carried out at every 5days for duration of one month. The change in length was measured by means of a dial gauge extensometer with 200 mm gauge length which has a capacity of measuring 0.002 strain. Beam specimens for measuring Drying shrinkage are given in Figure 2.

Figure 2.*Buttons glued on the surface of the beam for measuring drying shrinkage*

Drying shrinkage values of Geo-polymer concrete and conventional concrete are shown in Figure3.

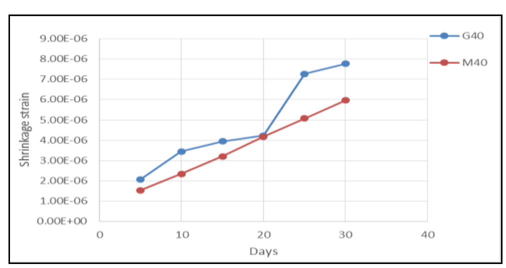

Figure 3 *Drying shrinkage strain for GPC and control mix*

4. Conclusion

In the present study, the strength and drying shrinkage characteristics of geo-polymer concrete specimens have been compared with Ordinary Portland cement concrete specimens. Based on the test results the following conclusions were made.

Geo-polymer concrete undergoes marginally higher drying shrinkage than that of ordinary Portland cement concrete due to the higher powder content, during initial 30 days. Rate of increase in compressive strength of GPC is same as that of OPC. Flexural strength of GPC was found to be marginally lower than OPC specimens.

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