Experimental Analysis of Durability Characteristics of Fly Ash and Welding slag based Geo-polymer concrete with Recycled Aggregate

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Abstract – Concrete is the most widely used construction material which required large quantities of Portland cement. The production of Ordinary Portland cement causes pollution to the environment, due to the emission of CO_2 and also large amount of natural resources is consumed for the cement production. The large global production of flyash and rapid advances in Geopolymer technology leads to the alternate material for OPC that is Geopolymer concrete (GPC). Geopolymers are showing great potential and several researchers have critically examined the various aspects of their viability as binder material. Increase in population growth is leading to increase in various demands like cultivation, transportation, construction etc. Nowadays, there is a tremendous increase in the demand for construction works like residential buildings, bridges, dams, roads etc. and because of this increase in demand the availability of sources for concrete ingredients is getting difficult. Hence people are looking for alternative sources for the concrete ingredients in order to full fill their requirements. This project is focused on the feasibility study of Fly ash and Welding slag based Geopolymer Concrete with Recycled Aggregate to find durability characteristics to promote the applications of green materials in civil infrastructures. The main objective of this investigation is to find out optimum mix design of geopolymer concrete specimens. Concrete composing three different molar of sodium hydroxide (NaOH) which is 8M, 10M and 12M were adopted. A series of tests conducted to determine the durability characteristics like sorptivity, porosity, carbonation and water absorption of Geopolymer concrete. Natural coarse aggregates were replaced with 10% of Recycled aggregates and welding slag was used as fine aggregates. Based on the experimental results, the fly ash and welding slag based Geopolymer concrete with three different molarities showing good durability results compare to conventional concrete. From the results of water absorption, porosity and sorptivity study, the best mix combination is obtained in GPC_{12M}. However, GPC_{8M} and GPC_{10M} also having good durability characteristics.

Index Terms – Geopolymer, Fly ash, Welding Slag, RCA and Durability.

1. INTRODUCTION

Ordinary Portland cement (OPC) is commonly used as the binder in the production of concrete. It is well known that the manufacture of OPC not only consumes a significant amount of natural resources and energy but also releases a substantial quantity of greenhouse gases. The geopolymer technology shows considerable promise for application in concrete industry as an alternative binder to the Portland cement in terms of global warming, the geopolymer concrete significantly reduce the CO2 emission to the atmosphere caused by the cement industries. Geopolymer is a type of alumino-hydroxide product having ideal properties of rock-forming elements. The main advantage of geopolymer concrete is that it is eco-friendly. The properties of geopolymer include high early strength, low shrinkage, freeze-thaw resistance, sulphate resistance and corrosion resistance.

Several studies have been carried out to reduce the use of Portland cement in concrete to address the global warming issues. These include the utilization of supplementary cementing 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. Production of concrete also uses sand and aggregate from quarrying operations that are energy intensive and may release high level of waste materials. Furthermore, the shortage of natural construction materials in many regions has led to long-distance haulage and significantly increased costs. Growing environmental awareness, the need to ensure sustainability of construction materials, and public concern to safeguard the countryside limit the use of quarrying sites and encourage the construction industry to look for alternative materials.

In countries like India and elsewhere, the natural aggregate resources remarkably waning day by day due to high demand of construction activities in recent years. On the other hand, million tonnes of construction and demolition (C&D) residues are generated. So, there is a need for potential use of C&D waste as a major resource of aggregates for the production of new concrete. However, utilization of recycled aggregate (RA) in concrete has become more common practice, all over the world. Generally lower-grade applications of recycled aggregate concrete have been reported by many researchers, but higher grade activities are rarely reported, because of its effects on workability, strength and durability.

Used together, Geopolymer concrete and recycled concrete aggregate eliminate the need for Portland cement and makes use of waste materials. Significant research has been conducted into both recycled concrete aggregate (RCA) ordinary Portland cement concrete and geopolymer concrete. Along with this combination, welding slag used as fine aggregates instead of normal sand.

1.1 Geo-polymer Cement

Geo-polymer cement is an innovative material and a real alternative to conventional Portland cement for use in transportation infrastructure, construction and offshore applications. It relies on minimally processed natural materials or industrial byproducts to significantly reduce its carbon footprint, while also being very resistant to many of the durability issues that can plague conventional concretes.

Geo-polymer cement requires an alumina silicate material, a user-friendly alkaline reagent (sodium or potassium soluble silicates with a molar ratio MR SiO_2:M_2O>1, 65, M being Na or K) and water. Room temperature hardening relies on the addition of calcium cations, essentially iron blast furnace slag.

Geo-polymer cements cure more rapidly than Portland-based cements. They gain most of their strength within 24 hours. However, they set slowly enough that they can be mixed at a batch plant and delivered in a concrete mixer. Geopolymer cement also has the ability to form a strong chemical bond with all kind of rock-based aggregates

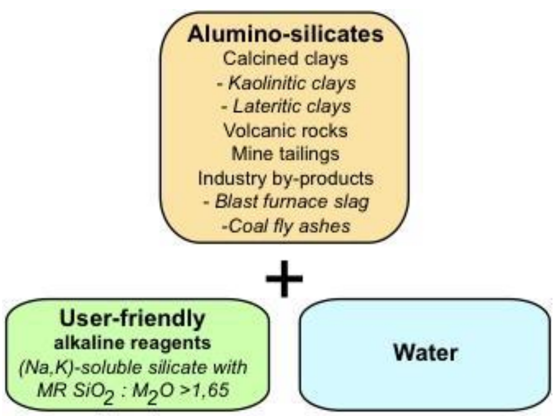

Fig 1 Composition of Geopolymer cement

There is often confusion between the meanings of the two terms 'Geo-polymer cement' and 'Geo-polymer concrete'. A cement is a binder whereas concrete is the composite material resulting from the addition of cement to stone aggregates

1.2 Geoplymer Cement Categories

1. Slag-based geo-polymer cement
2. Rock-based geo-polymer cement
3. Fly ash-based geo-polymer cement
    a. type 1: alkali-activated fly ash geo-polymer
    b. type 2: slag/fly ash-based geo-polymer cement
4. Ferro-sialate-based geo-polymer cement

1.2.1 Slag-based Geo-polymer cement

The first Geopolymer cement developed in the 1980s was of the type (K,Na,Ca)-poly(sialate) (or slag-based Geo-polymer cement) and resulted from the research developments carried out by Joseph Davidovits and J.L. Sawyer at Lone Star Industries, USA and yielded to the invention of the well known Pyrament cement. The American patent application was filed in 1984 and the patent US 4,509,985 was granted on April 9, 1985 with the title 'Early high-strength mineral polymer'.

1.2.2 Rock-based geo-polymer cement

The replacement of a certain amount of MK-750 with selected volcanic tuffs yields geo-polymer cement with better property and less CO_2 emission than the simple slag-based geo-polymer cement.

1.2.3 Fly ash-based geo-polymer cements

Later on, in 1997, building on the works conducted on slag-based geo-polymeric cements, on the one hand and on the synthesis of zeolites from fly ashes on the other hand, Silverstrim et al. and van Jaarsveld and van Deventer developed geo-polymeric fly ash-based cements. Silverstrim et al. US Patent 5,601,643 was titled 'Fly ash cementitious material and method of making a product'.

Two types based on Class F fly ashes:

1.3.3a. Type 1: Alkali-activated fly ash geo-polymer (user-hostile):

In general, it requires heat hardening at 60-80°C and is not manufactured separately and becomes part of the resulting fly-ash based concrete. NaOH (user-hostile) + fly ash: fly ash particles embedded in an alumino-silicate gel with Si:Al= 1 to 2, zeolitic type (chabazite-Na and sodalite).

1.3.3b. Type 2: slag/fly ash-based geo-polymer cement (user-friendly):

Room-temperature cements hardening. User-friendly silicate solution + blast furnace slag + fly ash: fly ash particles embedded in a geo-polymeric matrix with Si:Al= 2, (Ca,K)-poly(sialate-siloxo).

1.2.4 Ferro-sialate-based geopolymer cement

The properties are similar to those of Rock-based geopolymer cement but involve geological elements with high iron oxide content. The geopolymeric make up is of the type poly (ferro-sialate) (Ca,K)-(-Fe-O)-(Si-O-Al-O-). This user-friendly Geopolymer cement is on the development and pre-industrialization phase.

2. RELATED WORKS

This chapter presents a review of relevant works to bring out the background of the study undertaken in this project work, which is very helpful to understand the recent developments in Fly ash based Geopolymer concrete using recycled aggregates.

Vilas Nitivattananon and Guilberto Borongan (2007), have presented an overview and current situation of C & D waste in Asian countries focusing on technologies, good practices, policy and management in relation to the practice of waste minimization strategies: 3R principles. It also presents cases on the current practices of C & D waste in selected countries including the corresponding instruments these countries develop and implement. The information in this study has been compiled from international journals, reports and proceedings of various waste management organizations. Certain information was also received through communications by electronic mail and incorporated in the compilation of this paper. The paper is part of the study results under 3R Knowledge Hub (3RKH) project which was jointly established by partners, Asian Development Bank (ADB), Asian Institute of Technology (AIT), United Nations Environment Programme (UNEP) and United Nations Economic and Social Commission for Asia and Pacific (UNESCAP) in 2006 in Thailand. It aims to network and gather 3R resources and expertise from all sectors in Asian region. It functions as a think tank on technology, good practices, policy strategy and management, and issues related to the 3R, which promotes sustainable production and consumption of limited natural resources, and improved economic and environmental efficiency.

Monita Olivia and Hamid R. Nikraz (2011), have presented a study on the strength development, water absorption and water permeability of low calcium fly ash geo-polymer concrete. Geo-polymer mixtures with variations of water/binder ratio, aggregate/binder ratio, aggregate grading, and alkaline/fly ash ratio were investigated. The results show that the strength of fly ash geo-polymer concrete was increased by reducing the water/binder and aggregate/binder ratios; and the water absorption of low calcium fly ash geo-polymer was improved by decreasing the water/binder ratio, increasing the fly ash content, and using a well-graded aggregate. The test data indicates that a good quality of low calcium fly ash geo-polymer concrete can be produced with appropriate parameterization and mix design.

Benny Joseph and George Mathew (2012), have presented a summary of study was carried out to understand the influence of aggregate content on the engineering properties of geo-polymer concrete. Influence of other parameters on engineering properties of geo-polymer concrete such as curing temperature, period of curing, ratio of sodium silicate to sodium hydroxide, ratio of alkali to fly ash and molarity of sodium hydroxide are also discussed in this paper. In the present study, compared to ordinary cement concrete, 14.4% enhancement in modulus of elasticity and 19.2% enhancement in Poisson's ratio could be achieved in geo-polymer concrete. A geo-polymer concrete with total aggregate content of 70% by volume, ratio of fine aggregate to total aggregate of 0.35, NaOH molarity 10, Na2SiO3/NaOH ratio of 2.5 and alkali to fly ash ratio of 0.55 when cured for 24 h at 100 °C gave an average cube compressive strength of 52 MPa after temperature curing (56 MPa after 28th day). This geo-polymer concrete gave a higher value of Poisons ratio and modulus of elasticity compared to ordinary cement concrete having almost same cube compressive strength as that of geo-polymer concrete.

Roz-Ud-Din Nassar and Parviz Soroushian (2012), have proposed Strength and Durability of Recycled Aggregate Concrete Containing Milled Glass as Partial Replacement for Cement. Milled waste glass was used as secondary cementitious material towards production of recycled aggregate concrete with improved strength and durability attributes. The use of milled waste glass as partial replacement for cement is estimated to effectively overcome the limitations of recycled aggregate (higher water absorption and weak clinging mortar/ paste) paving the way for its broad-based use towards production of recycled aggregate concrete. The use of milled waste glass as partial replacement of cement in recycled aggregate concrete results in enhanced durability characteristic such as sorption, chloride permeability, and freeze–thaw resistance through improvement in pore system characteristics.

C. A. Jeyasehar et al (2013), have investigated to improve the quality of geo-polymer mortar through special treatments and study the property, particularly the acid resistance. The durability tests such as water absorption test and acid resistance test (HCl and H2SO4) are also conducted. The main focus of the investigation is on optimum utility of the available fly ash and minimizing the water absorption and attaining high compressive strength. The compressive strength of geo-polymer bricks made using 10M and 12M NaOH solution is very high comparable to that of concrete. In fact concrete is not required for normal construction. But, geo-polymer bricks with 5M NaOH solution give compressive strength comparable to that of country bricks and fly ash bricks used for normal construction. The increase in percentage of weight due to water absorption of Geo-polymer bricks is very small fraction when compared to that of other types of bricks.

E. Güneyisi et al. (2013), presented a study that reports the finding of an experimental study carried out on the durability related properties of the lightweight concretes (LWCs) including either cold bonded (CB) or sintered (S) fly ash aggregates. CB aggregate was produced with cold bonding pelletization of class F fly ash (FA) and Portland cement (PC) while S aggregate was produced by sintering the fresh aggregate pellets manufactured from FA and bentonite (BN). The durability properties of concretes composed of CB and S aggregates were evaluated in terms of water sorptivity, rapid chloride ion permeability, gas permeability, and accelerated corrosion testing after 28 days of water curing period. The results revealed that S aggregate containing LWCs had relatively better performance than LWCs with CB aggregates.

3. METHODOLOGY

Methodology explains about the type and details about the experiments. For our experiment, we are using Geo-polymer concrete with three different molarities of sodium hydroxide (NaOH) and Natural coarse aggregates were replaced with 10% of Recycled coarse aggregates and welding slag was used as fine aggregates instead of normal sand. Properties of each materials used in this study are discussed in detail.

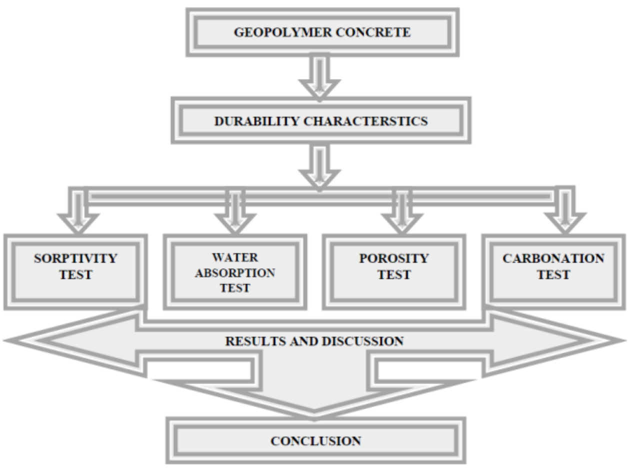

Fig 1. Flow chart of Methodology

4 RESULT AND DISCUSSION

In the present experimental analysis, the durability characteristics of fly ash and welding slag based Geo-polymer concrete was studied and the obtained results are tabulated and discussed in this chapter.

4.1 Sorptivity

Sorptivity test was carried out in accordance with ASTM C 1585-04. Table.5.1shows the weights of the specimen, table 5.2 shows the difference in weight and table 5.3 shows the Q/A values with square root of time. From the obtained values, sorption coefficient is computed from the graphs below. A graph is drawn between time and penetration depth to find the sorption coefficient. Low sorption coefficient samples are more impermeable and they show good durability performance from this short term durability characteristics are found out. The graphs are shown in figure 5.1, 5.2 and 5.3gives the sorptivity coefficient for Fly ash and welding slag based Geopolymer concrete of 8M, 10M and 12M samples.

Table.1 Weight of Specimens

S.No	Time (min)	Weight (W)	Types of moles mass(gm)		
			GPC_{8M}	GPC_{10M}	GPC_{12M}
1	0	W0	940.00	1112.00	928.00
2	1	W1	946.00	1116.00	938.00
3	2	W2	950.00	1120.00	944.00
4	5	W3	952.00	1122.00	948.00
5	10	W4	956.00	1126.00	954.00
6	15	W5	960.00	1128.00	958.00
7	30	W6	966.00	1138.00	966.00
8	45	W7	972.00	1144.00	970.00
9	60	W8	976.00	1148.00	970.00
10	75	W9	978.22	1152.00	970.00
11	90	W10	980.00	1154.00	970.00
12	105	W11	980.00	1156.00	970.00
13	120	W12	980.00	1156.00	970.00
14	135	W13	980.00	1156.00	972.00
15	150	W14	980.00	1156.00	972.00
16	165	W15	980.00	1156.00	972.00
17	180	W16	980.00	1156.00	972.00
18	210	W17	980.00	1156.00	972.00
19	240	W18	982.00	1158.00	972.00
20	270	W19	982.00	1158.00	972.00
21	300	W20	982.00	1158.00	972.00
22	330	W21	982.00	1158.00	972.00
23	360	W22	982.00	1158.00	972.00

Table.2 Difference in Weight of Specimens Q = mm^3

S.No	Time	$\sqrt{T}$	Q = mm^3 value			Area (mm^2)
			GPC_{8M}	GPC_{10M}	GPC_{12M}	
1	0	0.0	0	0	0	7854
2	1	1.0	6	4	10	7854
3	2	1.4	10	8	16	7854
4	5	2.2	12	10	20	7854
5	10	3.2	16	14	26	7854
6	15	3.9	20	16	30	7854
7	30	5.5	26	26	38	7854
8	45	6.7	32	32	42	7854
9	60	7.7	36	36	42	7854
10	75	8.7	38	40	42	7854
11	90	9.5	40	42	42	7854
12	105	10.2	40	44	42	7854
13	120	11.0	40	44	42	7854
14	135	11.6	40	44	44	7854
15	150	12.2	40	44	44	7854

16	165	12.8	40	44	44	7854
17	180	13.4	40	44	44	7854
18	210	14.5	40	44	44	7854
19	240	15.5	42	46	44	7854
20	270	16.4	42	46	44	7854
21	300	17.3	42	46	44	7854
22	330	18.2	42	46	44	7854
23	360	19.0	42	46	44	7854

Table.3 Q/A value

S.No	Time	√T	I = Q/A/Density of water x10 $^{-7}$ (mm)		
			GPC_{8M}	GPC_{10M}	GPC_{12M}
1	0	0.0	0	0	0
2	1	1.0	7.64	5.09	12.73
3	2	1.4	12.73	10.19	20.37
4	5	2.2	15.28	12.73	25.46
5	10	3.2	20.37	17.83	33.10
6	15	3.9	25.46	20.37	38.20
7	30	5.5	33.10	33.10	48.38
8	45	6.7	40.74	40.74	53.48
9	60	7.7	45.84	45.84	53.48
10	75	8.7	48.66	50.93	53.48
11	90	9.5	50.93	53.48	53.48
12	105	10.2	50.93	56.02	53.48
13	120	11.0	50.93	56.02	53.48
14	135	11.6	50.93	56.02	56.02
15	150	12.2	50.93	56.02	56.02
16	165	12.8	50.93	56.02	56.02
17	180	13.4	50.93	56.02	56.02
18	210	14.5	50.93	56.02	56.02
19	240	15.5	53.48	58.57	56.02
20	270	16.4	53.48	58.57	56.02
21	300	17.3	53.48	58.57	56.02
22	330	18.2	53.48	58.57	56.02
23	360	19.0	53.48	58.57	56.02

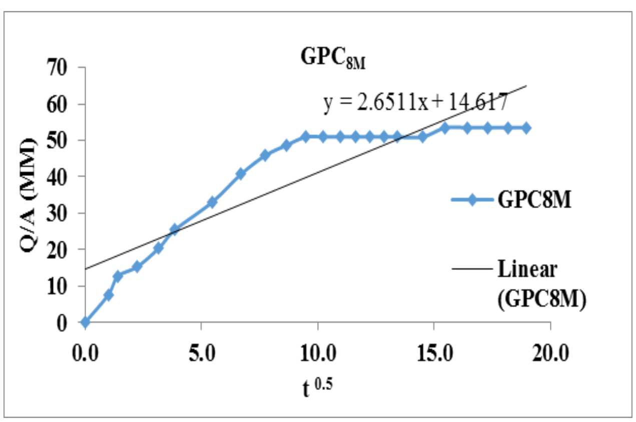

Fig.2. Sorptivity for GPC_{8M}

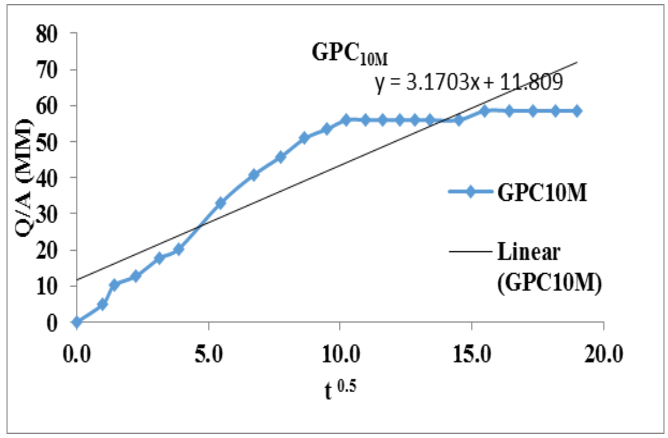

Fig.3. Sorptivity for GPC_{10M}

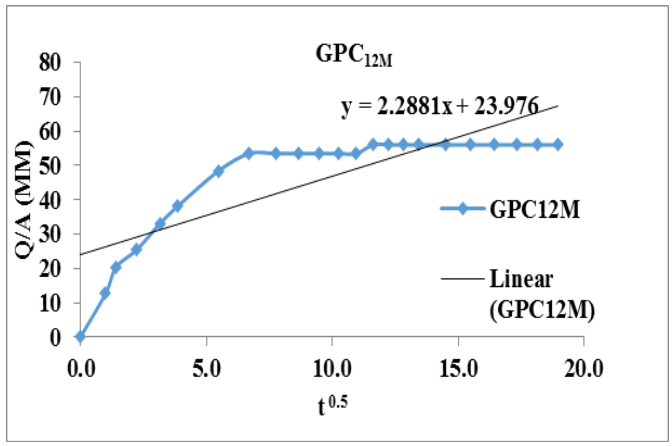

Fig.4. Sorptivity for GPC_{12M}

The sorption coefficient for GPC_{8M}, GPC_{10M} and GPC_{12M} are derived from graph. The sorption coefficient obtained varied in the range of 2.288x10^{-7} to 3.170 x10^{-7}mm/sec$^{1/2}$. It is seen from the results that the sorption coefficient for all the mixes are comparatively less than that of the control concrete. GPC_{10M} showed the highest sorptivity coefficient compare to other two concrete mixes. Conversely, GPC_{12M} displayed the lowest coefficient.

4.2 Porosity

This test method covers the determinations of density, percent absorption, and percent voids in hardened concrete. Whenever possible, the sample shall consist of several individual portions of concrete, each to be tested separately.

Table. 4 Results of Porosity test

Concrete Name	GPC_{8M}	GPC_{10M}	GPC_{12M}
Absorption after immersion, %	3.57	4.92	5.19
Absorption after immersion and boiling, %	4.16	5.76	5.89

Bulk density after immersion Mg/m3	3.17	3.23	2.42
Bulk density after immersion and boiling Mg/m3	3.18	3.25	2.44
Bulk density, dry Mg/m3	3.06	3.08	2.30
Apparent density Mg/m3	3.50	3.74	2.66
Volume of pore space (voids), %	12.73	17.71	13.56

Table 5.4 shows the result of Porosity values obtained by standard test method for Density, Absorption, and Voids in hardened concrete ASTM C642 – 13. The percentage of volume of pore space is relatively high in GPC_{10M} and low in GPC_{8M}. The high value of porosity may be due to the tendency of the particles to clump together while mixing, entrapping water filled spaces, which consequently turn into voids.

4.3 Water Absorption

The 15mm x 15mm x 15mm size cubic after casting were immersed in water 24 hours for ambient curing. Test specimens were oven dried at 105^0C for 24 hours duration using hot air oven. After oven dry the specimens were immersed in water for 24 hours duration. Absorption characteristic of concrete will be evaluated by difference in weight of specimen after complete drying in oven at 105^0C (W_D) and weight after immersion in water (W_S). Water absorption test was carried out for 8M, 10M and 12M concrete specimens to find the durability are given below.

$$\% \text{ water absorption} = [(W_S – W_D) / W_S] \times 100$$

Where,

W_S = Initial weight of cubic in grams (weight of saturated specimen).

W_D = Oven dry weight of cubic in grams.

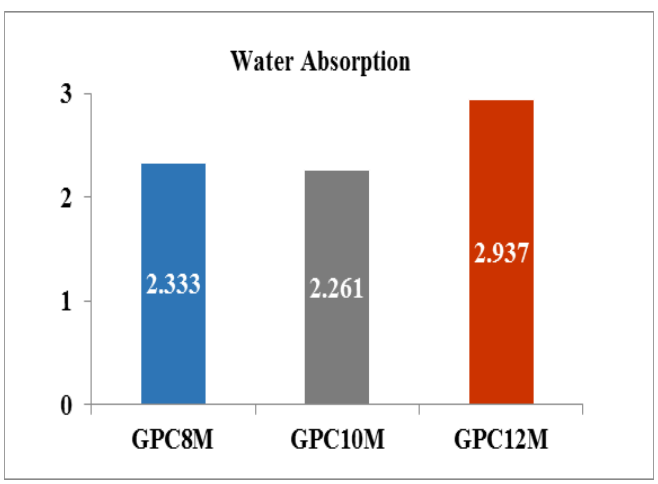

Fig.5. Water Absorption Test

4.4 Carbonation

This test is carried out to determine the depth of concrete affected due to combined attack of atmospheric carbon dioxide and moisture causing a reduction in level of alkalinity of concrete. A spry of 0.01% solution of phenolphthalein is used as pH indicator of Geopolymer concrete after 14 days of ambient curing. It is noted that the color of concrete is changed to pink. The change of colour of concrete to pink indicates that the concrete is in the good health.

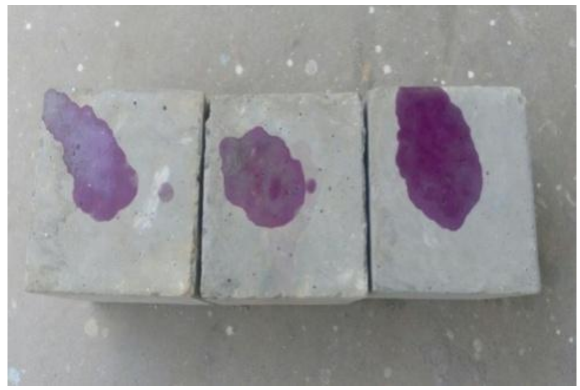

Fig.6. Carbonation Test

5. CONCLUSION

The main objective of the study was to find an optimum mix design of Geo-polymer concrete with fly ash, welding slag and recycled aggregates. Experimental concrete specimens consist of three different molar of sodium hydroxide (NaOH) which is 8M, 10M and 12M were adopted. It helps to reduce the use of conventional material in concrete to promote the applications of green materials in civil infrastructures. Durability is an important parameter which gives the life time of the concrete, without losing its strength. In our experimental investigation, durability is tested by carbonation, water absorption, porosity and sorptivity test. Here all samples are 100% replaced with welding slag as fine aggregates and 10% of normal coarse aggregate was replaced by recycled coarse aggregates. The average density of fly ash-based geo-polymer concrete is similar to OPC concrete. Due to the high viscosity of geo-polymer concrete, no appreciable slump value could be obtained. The fresh geo-polymer workability was actually poor. The mixes were stiffer than the OPC concrete due to lack of water content, and also the cohesive sodium silicate used in the fly ash geo-polymer system. It is seen from the results that the sorption coefficient for all the mixes are comparatively less than that of the control concrete. GPC_{10M} showed the highest sorptivity coefficient compare to other two concrete mixes. Conversely, GPC_{12M} displayed the lowest coefficient. The porosity values obtained for Geo-polymer concrete specimens using the ASTM standard method are in good agreement compare to conventional concrete. In water absorption study, the percentage of water absorption is less in fly ash and welding slag based Geo-polymer concrete blocks when compared to conventional cement concrete blocks. In carbonation test, color of concrete is changed to pink. The change of color of concrete to pink indicates that the durability of concrete will be good. Based on the experimental results, the fly ash and welding slag based Geo-polymer concrete with three different molarities showing good durability results compare to conventional concrete. From the results of water absorption, porosity and sorptivity study, the best mix combination is obtained in GPC_{12M}. However, GPC_{8M} and GPC_{10M} also having good durability characteristics.

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