SUSTAINABLE CHARACTERISTICS OF FLY ASH BASED GEOPOLYMER CONCRETE INCORPORATING ALCCOFINE, ZEOLITE AND RUBBER FIBERS

GANESH BABU O[1], DANYA TR[2], SAKTHIESWARAN N[2] * , SURESH P[3] , MUTHURAMAN U[4]
[1]Department of Civil Engineering, Anna University Regional Campus Tirunelveli, Tirunelveli 627007, Tamil Nadu.
[2]Department of Civil Engineering, EGSPEC Nagapattinam, Tamil Nadu.
[3]Department of ECE, Vel Tech University Avadi Chennai, Tamil Nadu.
[4]Department of EEE, FXEC Tirunelveli, Tamil Nadu.

Development of sustainable and energy efficient construction material has been the viewpoint of research efforts worldwide in recent years. Although the use of Portland cement is unavoidable, many efforts are being made to minimize the use of Portland cement in concrete to a greater extent in infrastructure applications. It is time to utilize new technology materials like geopolymers that offer waste utilization and emissions reduction with enormous ability. An alternate binding material to the OPC has been found out known as geopolymer concrete (GPC). In this study, GPC will be made of fly ash incorporating alccofine in various percentages of 5%, 10%,15% and 20% as partial replacement to fly ash. Zeolite was partially added to fine aggregate at 10%, 20%, 30% and 40%. Rubber fibers were added at 2% by the weight of binder. Alkaline activator for geopolymerisation was prepared by mixing Sodium hydroxide solution at 10M with Sodium silicate solutions are used. Control mix is casted for M30 grade concrete. The samples are proposed to be cured by hot-curing for 24 hours thus mechanical and durability properties were examined. Addition of zeolite at 30% and alccofine at 15% is found to be an optimal content in geopolymer content and when the concentration of zeolite in geopolymer concrete is increased the slump value decreases. The rubber fiber contents kept constant at 2%, only lesser voids are generated due to improper bonding between rubber fiber particles, which does not contribute more in compressive strength. Geopolymer presents denser microstructure, lower total pore volume and optimized pore structure compared to OPC paste and therefore geopolymer concrete is much more durable in an aggressive environment.

Keywords: *Geopolymer concrete, fly ash, alccofine, zeolite, rubber fibers.*

1. Introduction

Cement industry accounts considerable share for CO_2 emission due to high environmental carbon footprint of cement which cause global warming and other worst effects. Therefore it is important to take necessary measures to reduce carbon footprints. It can be overcome through economic mix design and by using alternate binding materials for concrete such as bacterial concrete or geopolymer concrete [1,2]. It is time to benefit new technology materials like geopolymers that offer waste utilization such as industrial byproducts and emissions reduction. GPC have high strength, with good resistance to durability characteristics. The approaches of GPC are commonly formed by alkali activation of industrial alumino silicate waste materials such as Fly ash, GGBS, metakaolin, rice husk ash etc., and have a very small Greenhouse footprint when compared to conventional concretes. The exploitation of river sand endangers the stability of river banks and creates environmental problems. Hence the use of alternative materials for river sand, such as manufactured sand, industrial by products, and recycled aggregates. Among these, the use of manufactured sand is gaining high potential. The shape and texture of M-sand lead to improved strength due to better interlocking between the particles [2-4].Two main constituents of geopolymer ingredients are source materials and alkaline liquids and such source materials involves the production of binders from alumina and silica rich industrial byproducts such as fly ash, GGBS, rice husk ash, etc. and therefore, this can also be termed as sustainable geopolymer concrete [5]. Due to the chemical composition, natural zeolites are among the possible raw materials for the production of geopolymers. Zeolites are crystalline hydrated alumino-silicates, composed of silicon and aluminium tetrahedra (SiO4 and AlO4) and linked by one oxygen atom [6]. These source materials react with alkali-activating solutions such as sodium or potassium hydroxide with sodium silicate and form cross-linked three-dimensional alumino-silicate network consisting of Si-O-Al-O bonds [7-16]. Rubber fibers enhance impact resistance but reduces compressive strength [13]. The mechanism for the geopolymerisation process activation involves three major reactions (a) Dissolution of Si and Al atoms from the source material through the action of hydroxide ions (b) Orientation or condensation of precursor ions into monomers (c) Setting or polycondensation or polymerization of monomers into polymeric structures. Alccofine has higher fineness, so acts as an micro filler and is rich in alumina content which have enhanced the hydration, geopolymerisation process and early setting properties[17-24]. Alkaline solutions play a major role in geopolymerization at the early stage as it dissolves the active aluminosilicate species in the reaction [25-28]. Burning rubber creates toxic smell and emissions of lethal gases with restrictions of law in some of the countries [27]. Heat treatment is necessary to achieve desired strength adds to the

* Autor corespondent/*Corresponding author*,
E-mail: sakthistructrichy@gmail.com

energy requirement of geopolymer concrete fabrication [29]. Zeolite has the property to increase the durability cahracteristics and permeability of concrete with low water/binder ratio. They are noted for their ion- exchange and reversible properties. Industrial waste water has negative impact as it contains heavy metal ions in such conditions zeolite are used as representative solid adsorbent of metal ion [30]. A faster gain in strength is observed in slag rich geopolymer than the fly ash rich geopolymers due to the better bonding capacities [31]. The pure geopolymer network is created mainly by Si, Al and O with Na+ to balance the charge of Al [32, 33]. In this study, low calcium fly ash based geopolymer concrete at oven curing for 24 hours and ambient curing has been developed which is suitable for the construction industry. A blend of alccofine and fly ash was activated by alkaline solution to produce heat cured concrete. The properties of the binders are studied in terms of workability, mechanical and durability characteristics. The focus of the current work is to develop and characterize the properties of heat cured geopolymer concrete.

2. Experimental approach

2.1. Materials for geopolymer concrete mixture

2.1.1. Fly ash

In this study, local available low calcium class-F fly ash with specific gravity 2.84 is procured from Tuticorin thermal power plant in Tamilnadu. The chemical composition of fly ash with minimum requirements as per IS 3812: 2003 are specific gravity 2.84 and bulk density is 0.994 g/cm^3 and the Chemical composition of class F fly ash are silica 57.79%, iron oxide 7.04%, aluminium oxide 20.18%, calcium oxide 2.97%, magnesium oxide 1.98%, titanium oxide 1.03%, phosphorous 0.26%, sulphate 0.84%, alkali oxide 3.69%. Particle size distribution is shown in Table 1.

2.1.2. Alccofine

Alccofine is a microfine material which is based on low calcium silicate slag is obtained from nearby industry in the Tirunelveli district, Tamilnadu. Alccofine improves workability by reducing the water demand. Due to its unique chemistry and ultrafine particle size, GPC strength improved [23]. Alccofine produces enhanced performance as supplementary cementitious materials. Chemical properties of alccofine used are CaO 0.13%, Al_2O_3 21.40%, SiO_2 35.50%, MgO 6.20%, Fe_2O_3 1.20%, SO_3 0.13%. Physical properties of alccofine are Specific gravity 2.9, Bulk density 680 Kg/m^3, Specific surface area 1200 m^2/kg. Particle size distribution is shown in Table 1.

2.1.3. Aggregate

For the preparation of all the test specimens, good quality and well-graded aggregates in dry condition was utilized. An M-sand was collected from the local quarry dust industry of Tirunelveli and coarse aggregates with maximum size of 20mm are used. Physical properties of the fine aggregates are specific gravity of 2.73, fineness modulus of 3.6, and water absorption of 2.24%. Physical properties of the coarse aggregates are specific gravity of 2.71, fineness modulus of 4.08, and water absorption of 0.38%. Chemical properties of fine aggregate used are CaO 0.50%, Al_2O_3 2.12%, SiO_2 94.84%, MgO 0.1%, Fe_2O_3 0.81%, SO_3 0.10%, Na_2O 0.27%, K_2O 0.65%, TiO_2 0.10%, P_2O_2 0.02%, LOI 0.20%. Chemical properties of coarse aggregate used are CaO 13.31%, Al_2O_3 0.75%, SiO_2 54.32%, MgO 9.52%, Fe_2O_3 0.35%, Na_2O 0.12%, K_2O 0.08%, TiO_2 0.01%, P_2O_2 0.02%, LOI 18.01%. Both coarse and fine aggregates conform to IS 383-1970 [24]. Particle size distribution is shown in Table 1.

2.1.4. Zeolite Sand

The origin of zeolite is a rock which contains alumnium, silicon, and oxygen. This zeolite sediments bed was obtained in many regions of the world [1]. It is also used as partly replacement for fine aggregate in concrete. Specific gravity of zeolite sand is 2.7. Fineness modulus is 3.0, and water absorption is 1.5%. Chemical properties of zeolite used are CaO 2.2%, Al_2O_3 9.8%, SiO_2 60.2%, MgO 0.5%, Fe_2O_3 2.3%, Na_2O 0.3%, K_2O 4.5%, LOI 10.01%. Zeolite is partially replaced to fine aggregate at 10%, 20%, 30% and 40%. Particle size distribution is shown in Table 1.

Table 1

Particle size distribution of used materials

%	Sizes (μm)			
	Fly ash	Alccofine	M sand	Zeolite
95	0.700	0.665	0.452	0.531
90	0.658	0.623	0.416	0.496
80	0.609	0.568	0.368	0.448
60	0.540	0.490	0.304	0.377
50	0.511	0.452	0.277	0.344
40	0.481	0.410	0.251	0.310
30	0.448	0.355	0.225	0.274
20	0.409	0.275	0.196	0.232
10	0.350	0.178	0.159	0.169
5	0.298	0.133	0.134	0.128

Table 2

Quantities of materials used in this study

Mix	Molarity [M]	Binder (Kg/m^3)			Fine aggregate (Kg/m^3)		Coarse aggregate (Kg/m^3)
		Cement	Fly ash	Alccofine	M-sand	Zeolite	
M0	0	450	0	0	684.68	0	1121.21
M1	10	0	444.44	0	540	0	1260
M2	10	0	422.22	22.22	486	54	1260
M3	10	0	400	44.44	432	108	1260
M4	10	0	377.78	66.66	378	162	1260
M5	10	0	355.56	88.88	324	216	1260

2.1.5. Rubber fibers

Rubber fiber such as tires of light vehicles are cut into strips of 25.4mm x 5mm x 5mm is added at 2% by the weight of binder.

2.1.6. Alkaline activators

Sodium hydroxide and sodium silicate were used in this study as an alkaline activator which plays a vital role in the geopolymerization process. Sodium hydroxide solutions of required molarity were prepared from pellets with 98% purity and sodium silicate solution (Na_2SiO_3) (15.60% Na_2O, 30.40% SiO_2 and 54% water) were procured commercially.

2.1.7. Superplasticizer

Sodium silicate and sodium hydroxide solutions are more viscous than water; hence their use makes the GPC more cohesive and sticky than nominal mix. So, in order to improve the workability of the fresh geopolymer mix, a Naphthalene Sulphonate based water reducing superplasticizer confirming to IS 9103:1999 [17,24] is used.

2.2. Manufacture of geopolymer concrete

The mixture proportions of five GPC at 10M concentration of sodium hydroxide are studied. GPC will be made of fly ash incorporating alccofine in various percentages of 5%, 10%,15% and 20% as partial replacement to fly ash. Zeolite was partially added to fine aggregate at 10%, 20%, 30% and 40%. Rubber fibers were added at 2% by the weight of binder. Alkaline activator for geopolymerisation was prepared by mixing Sodium hydroxide solution at 10M with Sodium silicate solutions are used. Quantities of materials are prepared for all the six mixes tabulated in Table 1, while superplasticizer amount was kept at 2% of the binder content at the binder to alkaline solution ratio of 0.35. M0 is a control mix and the proportions for the OPC concrete mix were calculated based on IS 10262-2009 [27]. Quantity of Materials required per cubic meter for geopolymer Concrete according to mix design was given in Table 3.

2.3. Preparation, casting and curing of GPC specimens

Before the mixing of concrete, aggregates were prepared to the saturated surface dry condition. Sodium hydroxide solution was prepared 24 h prior to casting and mixed with sodium silicate solution at a required quantity about 1 h before actual mixing of the GPC. Rubber fibers were given treatment with sodium hydroxide to increase the hydrophilicity of the rubber surface and the bonding properties [9]. Zeolite aggregate should be soaked in water for 7 days prior to concreting to avoid autogenous shrinkage. Fly ash, aggregates and alccofine were first dry mixed, followed by addition of the activator solutions to the dry mix and the mixing continued to produce required homogeneity of GPC. Superplasticizer and any additional water were added during the mixing process. All the specimens were compacted on a vibrating table for 2–3 min. 150 mm cubes were prepared for compressive strength testing and 500 mm long beam were casted for flexural strength testing. The samples were then cured in the oven at 80° C for 24 hours and then at room temperature till the age of testing.

Table 3

Quantities of geopolymer concrete mixes

Materials	Quantity (kg/m^3)
Binder	444.44
Sodium hydroxide	44.45
Sodium silicate	111.11
Fine aggregate	540
Coarse aggregate	1260
Binder to alkaline solution ratio	0.35

3. Results and discussion

3.1. Workability

The workability of fresh GPC was determined immediately after mixing of concrete using the slump cone test. The fresh GPC mixes were found to be highly viscous. The workability of GPC mixes without alccofine M1is observed to be very low compared to control mix. In view of the results, it was observed that slump values improved by 12% in M3 compared to the control mix. As the concentration of zeolite in geopolymer concrete is increased the slump value decreases. This is due to the water absorbing capacity of zeolite [1,5]. The slump values obtained for the GPC mixes prepared with 10% alccofine and 2% plasticizer indicates less viscous and good workability. Workability values are shown in Fig.1

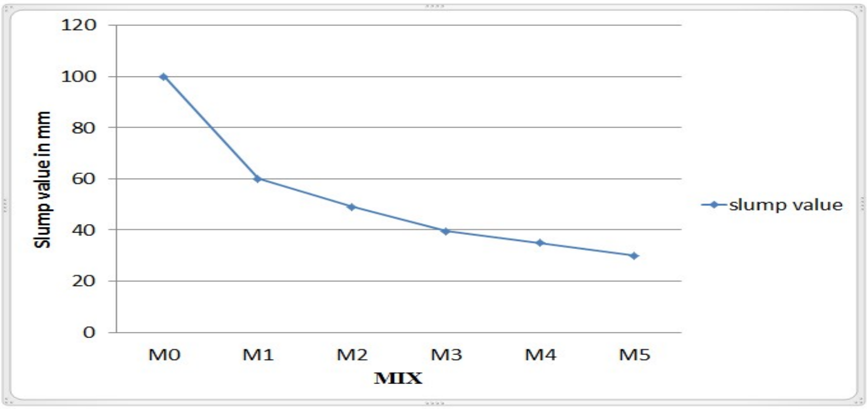

Fig.1 - Workability of the mixes

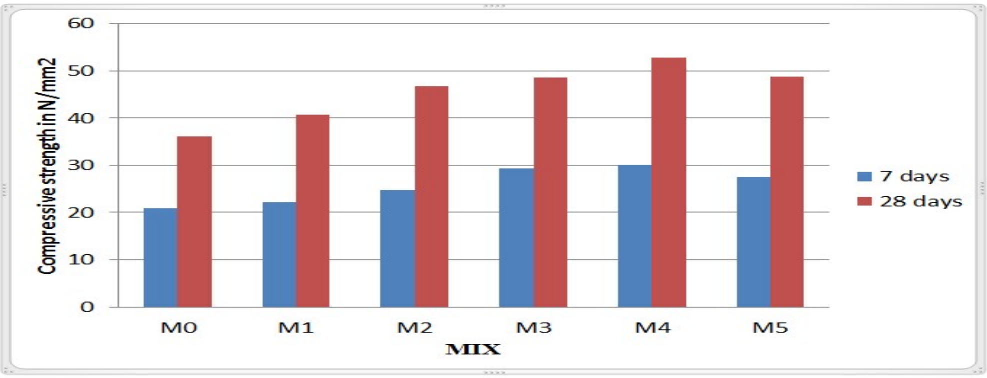

Fig.2 - 7 and 28 Days compressive strength

Fig.3 - 7 and 28 Days Split tensile strength

3.2. Compressive strength

The GPC samples of size 150X150X150 mm are tested for compressive strength in compressive testing machine of capacity 1000 KN. The testing is done on a set of three identical samples for each case at the age of 7 and 28 days. The mean values obtained for the compressive strength at 10M concentration are represented in Fig. 1. It can be seen from Fig. 1 that with increase in concentration of zeolite there was increase in compressive strength of all the mixes. This indicates that 30% zeolite may be an optimal, in order to make the GPC effective in terms of economy. This increase in compressive strength at oven curing is due to the presence of calcium in alccofine and fly ash which results into formation of CSH bond in the system apart from the NASH and CASH [14, 22]. Fly ash is the main source of the silica and alumina, which increases when the amount of fly ash is increased in the system and it influences the polymerization reaction and hence increases the NASH and CASH which results in higher strength [23]. In fact, due to the rubber fiber contents kept constant at 2%, only lesser voids are generated due to improper bonding between rubber fiber particles, which does not contribute more in compressive strength [9, 27]. Compressive strength results are shown in Fig.2

3.3 Split tensile strength test

Split tensile strength test was carried out in the cylinder specimen of height 300 mm and diameter of 150mm and are tested the specimens conforming to ASTM C39.The geopolymer concrete exhibits higher tensile strength because of the good bonding between the geopolymer paste and aggregate. In geopolymer concrete, there is a high level of geopolymeric bonding between the geopolymer paste and aggregate; therefore, during testing, when the cylinder was broken in half, none of the aggregate was pulled out. At 30% of zeolite and 15% of alccofine the split tensile strength has attained an optimum strength. Owing to the fibers bridging over the cracks, the crack opening width can be controlled. Split tensile strength results are shown in Fig.3.

3.4. Flexural strength

Flexural strength was carried out in specimen of size 150mm x 150mm x 700mm and is tested in compressive testing machine with flexural testing device. The flexural strength of the geopolymer specimens was studied and the influence of NaOH molarity, age and quantity of binder material with the inclusion of alccofine on the flexural strength was carried out at 7 and 28 days. Strength development after the completion of initial temperature curing period was not significant due to polymerization products NASH which did not react further at normal temperature. Strength properties were related to the amount of NaOH in the alkaline solution. As SiO_2/Na_2O increases then the degree of dissolution and hydrolysis accelerated [14]. Particle size is important since it determines the surface area that available for dissolution by alkaline solution [23]. The tension properties of geopolymer concrete are superior to those of OPC concrete because of the better bonding between the geopolymeric pastes and aggregate and bridging of crack property by fibers [13, 28]. Flexural strength test results are shown in Fig.4

3.5 Water Absorption Test

After specified period of 28 days, when zeolite and alccofine is not being added the water absorption is higher. This means that the material contains larger pores with greater diameter. Due to this reason fast rupture during compression occurs when additives are not added [1]. Control mix has

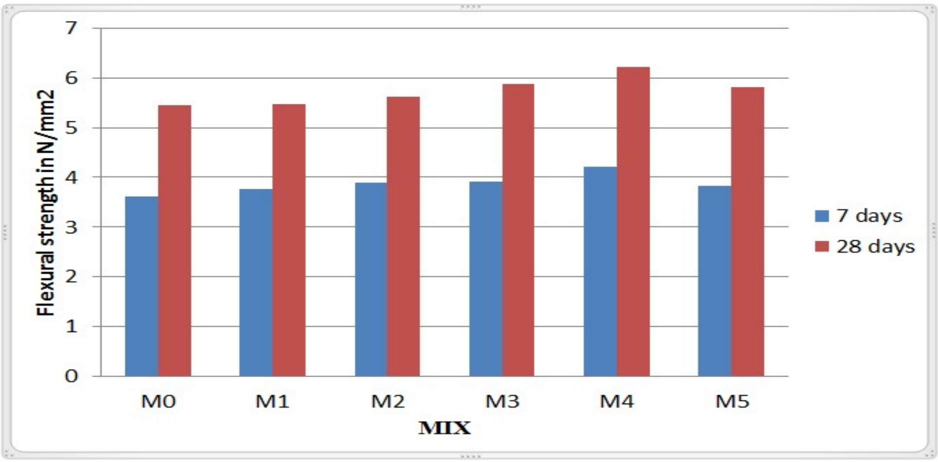

Fig.4 - 7 and 28 Days flexural strength

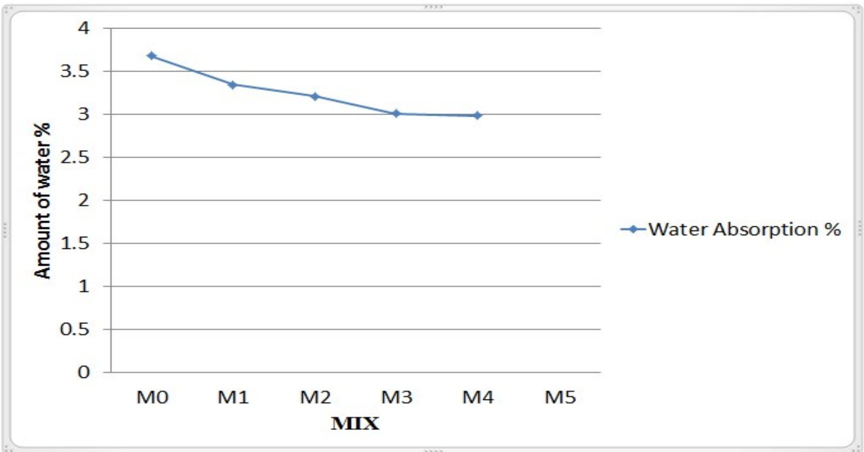

Fig 5 - Water adsorption (%) values of geopolymers at 28 days

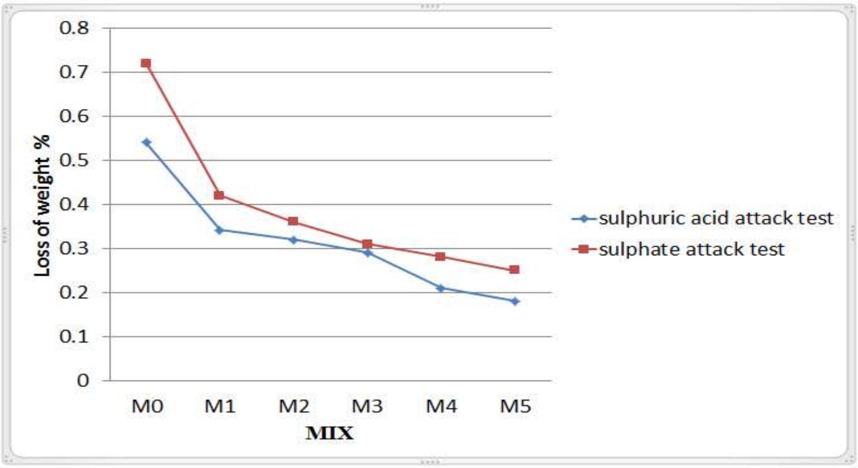

Fig 6 - Loss of weight at 28 days at sulpate test and acid test.

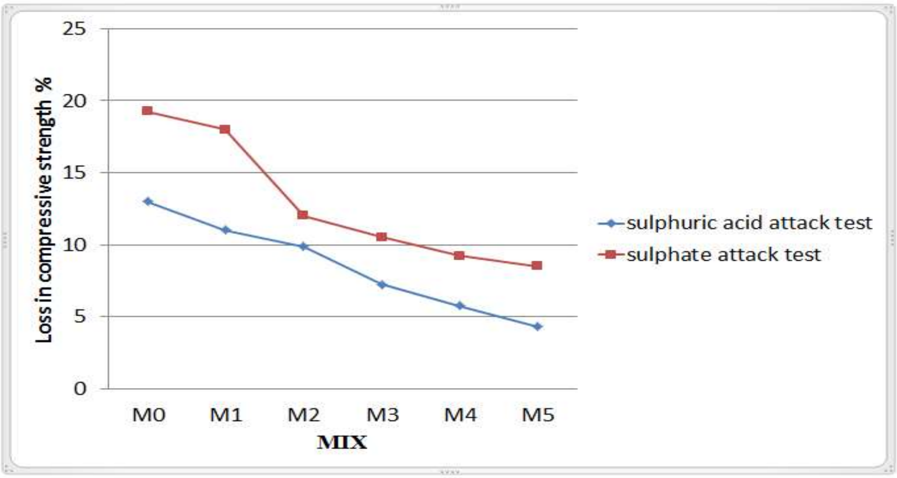

Fig 7 - Loss in compressive strength at 28 days at sulpate test and acid test

greater water absorption compared to the geopolymer mixes. Lower water absorption is because that the pozzolanic reaction occurs continuously by the production of NASH and CASH gels, which fills up the pores with the addition of alccofine and zeolite has better pore filling properties [5]. Thus, GPC is dense in nature and thus can prevent ingression of environmental effluents through its pores.

3.6 Sulphuric Acid Attack Test

Sulphuric acid attack test was conducted on all the mixes. Weight loss and loss in compressive strength of all the mixes are shown in Fig 6 and 7. As addition of zeolite increased, the mix susceptible to acid has smaller influence on strength properties due the zeolite property for the resistance of acid attack. GPC shows stability by revealing less strength loss in acidic environment. Geopolymer presents denser microstructure, lower total pore volume and optimized pore structure compared to OPC paste and therefore geopolymer concrete is much more durable in an aggressive environment [22].

3.7 Sulphate Attack Test

Sulphate attack test was conducted on all the mixes. Weight loss and loss in compressive strength of all the mixes are shown in Fig 6 and 7. As the zeolite content is increased it has only less influence in the strength properties. GPC can tolerate aggressive environments. During hydration reaction OPC yields C-S-H gels while during polymerization, geopolymer binders yield N-A-S-H, C-A-S-H or C-S-H gels. Due to the total contrast of hydration reaction and the reaction products, geopolymer binders are reported to have superior resistance towards sulfate and acid attacks [22].

4. Conclusion

The conclusions are arrived based on the experimental results for various concentrations of Sodium Hydroxide and for different combination of alccofine content with Fly Ash and results was being compared. From the observations of test results following conclusions are obtained,

1) The strength of the GPC mix with alccofine and zeolite content was increased at hot curing compared to the control mix and it was observed that the improvement in the strength was due to hydration in addition to polymerization.

2) The 28-days compressive strength of GPC is increased by 12.77%, 29.78%, 34.83%, 46.39% and 35.33% compared to the control mix and the optimum content is at 15% of alccofine and 30% of zeolite. This increase in compressive strength at oven curing is due to the compact structure of GPC with the NASH and CASH gel formation.

3) The 28-days split tensile strength of GPC is increased by 5.92%, 6.54%, 12.15%, 22.12% and 7.48% compared to the control mix and the optimum content is at 15% of alccofine and 30% of zeolite because of the good bonding between the geopolymer paste and aggregate.

4) The 28-days flexural strength of GPC is increased by 0.74%, 3.31%, 8.09%, 14.15% and 6.99% compared to the control mix and the optimum content is at 15% of alccofine and 30% of zeolite. The tension properties of geopolymer concrete are superior to those of OPC concrete because of the better bonding between the geopolymeric pastes and aggregate and bridging of crack property by fibers.

5) The mechanical properties of fly ash based GPC incorporating alccofine found to be improved. The increase in calcium content was not only due to the presence of alccofine but also due to its binder sources like fly ash which formed additional monomers which increased the rate of solidification and hence increased its strength.

6) The workability of GPC decreases with increase in the zeolite content. This is because of the water absorption capacity of zeolite. So it should be soaked in water for 24 hours before casting.

7) Water absorption was decreased for GPC by 26.03% compared to conventional concrete due to the pozzolanic action which fills the pores.

8) GPC reveal lesser influence in strength properties when contacted with Sulphuric acid and Sodium Sulphate is less 18.18% and 6.94% respectively compared to conventional concrete, with the increased addition of zeolite content proving that GPC exhibits excellent performances in aggressive environments.

9) Addition of rubber fibers to a smaller extent has less effect on strength properties as pre-treatment to rubber fibers been being given. So that sodium hydroxide would hydrolyse the acidic and carboxyl groups present on rubber surface.

10) Geopolymer concrete is more ecological and it utilizes the waste materials like Fly Ash effectively thereby reducing the risk of dumping it into sea by thermal power plants which dwindle the natural resources.

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