

AN EXPERIMENTAL STUDY ON REPLACEMENT OF RCA IN GEOPOLYMER CONCRETE INSTEAD OF COARSE AGGREGATE

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Abstract : Globally, the employment of concrete significantly high-strength concrete has been increasing day-by-day thanks to fast industrial enterprise and infrastructural developments. a huge amount of natural coarse mixture is needed for creating concrete to fulfill the massive demand. The natural resources of coarse mixture are depleting apace everywhere the globe and desperately have to be compelled to be preserved. On the opposite hand, ample tonnes of construction and demolition (C&D) wastes are being generated from totally different sources. The disposal of those large quantities of C&D waste is motility an enormous downside to the native administration and surroundings. Further, there are areas wherever the natural coarse aggregates are scarcely on the market and are hauled from long distances. These problems got to be addressed desperately. A review of the literature suggests that getting the coarse aggregates from C&D waste may be a attainable resolution to those problems. Therefore, within the gift work, associate degree experimental try has been created to utilize the recycled coarse mixture (RCA) from C&D waste to the utmost attainable extent for manufacturing the high-strength concrete.

The experimental work has been distributed in 2 phases: (i) Influence of process technique on RAC and (ii) Influence of blending approaches on RAC. the combo proportion of M75 grade was unbroken constant throughout the study. First, the influence of process technique on the properties of high-strength RAC has been studied to pick out the foremost appropriate processed recycled mixture for creating high-strength concrete. within the second part, the influence of assorted two-stage mixture approaches on the properties of high-strength RAC has been studied to pick out the foremost acceptable two-stage mixture approach at the moment the resultant concrete mixes are: i) Mechanical properties (Compressive Strength, Flexural strength, Split enduringness, ii) sturdiness properties (Acid Resistance, ocean Water Resistance) are studied. And compared with nominal cement concrete

IndexTerms - Component,formatting,style,styling,insert.

I. INTRODUCTION

Concrete, the preponderantly used construction material within the world has gained its quality owing to its multiple edges like comparatively low value of production, easy handling, capability to be moulded into desired form, action of desired strength starting from low to terribly high, utility and sturdiness. The principal ingredient of concrete is cement, usually standard hydraulic cement (OPC) that acts because the binder and holds the aggregates intact. however sadly, OPC is found to be related to some adverse effects on setting. the assembly of OPC is extremely energy intensive and emits high quantity of CO₂ into the atmosphere that contributes considerably to the 'Green House' result. Bhanumathidas & Mehta (2001) declared that the assembly of {1} t of cement consumes nearly concerning 1.5 ts of earth minerals and additionally one tonne of CO₂ is discharged into the atmosphere. The raw materials needed for cement production are non-renewable and are depleting at a fast rate. however at constant time, variety of business and agro wastes with inherent building material properties are created copiously. however they're largely disposed into landfills. using such by-merchandise as alternates for cement has numerous edges together with conservation of setting, property of resources and finding the disposal drawback of by-products. significantly in Bharat, with the ever growing demand for cement to catch the quickly developing constructions and infrastructure comes, the Impact created by OPC on the setting is very large. Hence, there's an on the spot necessity to manage the usage of OPC by developing potential alternates for it. in this context, intensive researches are being disbursed round the world in analysing the probabilities of victimization substitute materials for OPC concrete. One such different is 'geo compound concrete' (GPC) that utterly eliminates OPC in its production.

1.2 GEOPOLYMER CONCRETE

In 1978, Joseph Davidovits (1999) projected that it's potential to supply binders ensuing from the chemical process reaction between base-forming liquids and source that are wealthy in oxide and aluminum. He coined the term 'geo-polymer' to explain this family of mineral binders that possess a chemical composition the same as zeolites however exhibiting associate degree amorphous microstructure. Paloma et al (1999) prompt that pozzolanic materials like furnace scoria may be activated with the assistance of base-forming liquids to supply binders that may utterly replace OPC in concrete production. Contrastive to OPC concrete (OPCC), the principal binders in GPC don't seem to be calcium-silicate-hydrates (C-S-H). Instead, associate degree aluminosilicate compound gel shaped by tetrahedrally-bonded Si and aluminum with atomic number 8 atoms shared in between acts the binder. The 2 vital constituents of GPC are source and base-forming liquids. The source should be wealthy in Si (Si) and aluminum (Al). These may be of earth science origin like metakaolin or by-product materials like ash, Ground coarse furnace scoria (GGBS), oxide fume, rice-husk ash, etc. The base-forming liquids are based mostly from soluble alkali metals sometimes being metallic element or atomic number 19. The most common base-forming liquid used could be a combination of metallic element or hydrated oxide in conjunction with metallic element or atomic number 19 salt correspondingly.

1.3 SIGNIFICANCE OF THE STUDY

Black Rice Husk Ash (BRHA) is associate degree agro-industrial waste generated from rice edge business. It's obtained by incinerating the rice husk. The resultant ash from this combustion method includes a high content of international organisation burnt carbon. Consequently, the employment of BRHA as a construction material is extremely restricted, even if it's high oxide content concerning ninetieth. Although, many researchers together with (Chatweera & Lertwattanaruk 2011; Piyaphanuwat & Asavapisit 2009) have reported that the addition of BRHA in concrete has improved its sturdiness property. In GPC, most of the analysis works are created on ash {based|based mostly|primarily based mostly} geo polymers and sometimes on GGBS based geo polymers. As per the author's data, no revealed works are out there associated with the employment of BRHA in geo compound concrete. During this gift study, industrial waste that is Ground coarse furnace scoria (GGBS) and agro waste that is Black Rice Husk Ash (BRHA) were used as source to supply geo compound concrete. GGBS was unbroken because the base material during which BRHA was supplemental in numerous percentages. The geo compound concrete specimens were subjected to a variety of check ways to establish their performance in numerous strength and sturdiness conditions. The results of this investigation might give helpful information on the strength and sturdiness of geo compound concrete that has been developed from GGBS and BRHA, that are basically industrial by-products. Such tested scientific info on geo compound concrete can facilitate in dynamic the perception of typical concrete and additionally a broader recognition of this material in sensible applications.

OBJECTIVES OF THE STUDY

Geo polymer concrete not only proves to be an efficient substitute to OPC concrete but also alleviates the disposal problem associated with industrial by-products like GGBS and BRHA, by making use of them as chief ingredients for concrete which are generally getting dumped as wastes otherwise. The other specific objectives of the study are as follows:

- To develop geo polymer concrete mixtures using GGBS and BRHA.
- To study the Influence of salient parameters on the compressive strength of the geo polymer concrete.
- To study the performance of the geo polymer concrete under different durability criterion.
- To identify a suitable mix proportion for the geo polymer concrete

II. LITERATURE REVIEW

The production of cement is increasing concerning third-dimensional each year (McCaffrey 2002). The assembly method of 1 metric ton of cement emits concerning one metric ton of CO₂ into the atmosphere, ensuing from the de-carbonation of rock within the oven throughout the manufacture of cement and also the combustion of fossil fuels (Roy 1999).

The yearly international cement production of one.6 billion tonnes is to blame for concerning seven-membered of the whole CO₂ emission into the atmosphere. cement production isn't just one of the foremost energy -intensive

processes however is also to blame for huge quantity of greenhouse emission. The assembly of 1 metric ton cement utilizes nearly 4GJ energy (Mehta 2001).

India is that the second major cement manufacturing country next to China and has 137 massive and 365 mini cement plants. It's expected that the business can still increase the annual cement output in coming back years and India's cement production can grow at a Compound Annual rate of growth (CAGR) of around twelve-tone system throughout 2011-12 - 2013-14 to succeed in 303 Million Metric Tonnes. Cement producing Association (CMA) is targeting to realize 550 MT capacities by 2020 (Vora 2011).

Malhotra (2004) declared that the economic developments in China and India area unit moving the surroundings adversely in 2 ways in which. First, the installation of recent cement plants is increasing well the CO₂emissions, and second, terribly massive capability thermal power stations end in accessibility of big amounts of ash and bottom ash that aren't being recycled properly.

Most of those ashes area unit being drop in lagoons, lowland sites and abandoned quarries. Thus, probably valuable cementing resources area unit being wasted in only the countries that require it most to cut back the greenhouse emission emissions, and to form economical and sturdy concrete structures. He conjointly prompt some measures through that the cement and concrete business will contribute towards reducing CO₂emissions. They embody,

Use less OPC.

Use a lot of supplementary cementing materials.

Use less unit water content by victimisation a lot of water reducers and super plasticizers.

2.1.1 Incorporate recycled aggregates in concrete.

Use chrome steel reinforcement in essential elements of structures to form them a lot of sturdy.

2.1.2 Where attainable, specify strength acceptance criteria on fifty six or ninety one days rather than 28 days.

2.1.3 Use light-weight concrete wherever attainable.

For manufacturing eco-friendly concrete, Mehta (2002) prompt the employment of fewer natural resources, lesser energy utilization and diminution of CO₂emissions. consistent with McCaffery (2002), the CO₂emissions from cement industries may be decreased by reducing the amount of calcined material in cement, by reducing the quantity of cement in concrete and by limiting the quantity of buildings utilizing cement concrete.

The solution offered by Davidovits (1993) is that, introduction of low CO₂geopolymeric cements in industry would cut back the CO₂emissions contributed by the cement and concrete industries the maximum amount as eighty to ninetieth and would permit the boom of concrete infra-structures in international economics

2.2.1 General

Ground coarse furnace scoria (GGBS) may be a by-product obtained from the furnace scoria throughout the creating of iron. The building material properties of furnace scoria were discovered within the late 19th century and it's been wide utilized in cement and concrete producing for over a hundred years. To provide GGBS, the coarse furnace scoria is dried then ground to a fineness kind of like that of standard cement. In concrete creating, GGBS is usually utilized in combination with cement. The magnitude relation of GGBS and cement may be varied counting on the technical needs for a selected application (Civil & Marine 2007).

In India, about 7.8 million tonnes of furnace scoria is made annually. The disposal of the scoria as a waste fill may be a drawback and related to variety of environmental hazards. With the projected growth and development within the industry, the quantity of GGBS production is probably going to extend several folds and environmental drawback can therefore create a bigger threat (Tamilarasan & Perumal 2010).

2.2.2 Composition of GGBS

IS 12089-1987 defines scoria as, "a non-metallic product consisting basically of glass containing silicates and aluminates of lime and different bases, as within the case of furnace scoria, that is developed at the same time with iron in chamber {furnace} or disposal iron furnace. coarse scoria is obtained by more process the melted scoria by apace chilling or ending it with water or steam and air". It conjointly offers the limiting price of the compounds metallic element compound five.5%, mineral terrorist organization and sulfide sulphur 2%.

The chemical parts of GGBS area unit usually CaO (30%-48%), MgO (28%-45%), Al₂O₃(5%-18%) and SiO₂(1%-18%), and these area unit chiefly same as that of cement (Wang and Reed, 1995). different minor parts like Fe₂O₃, MnO, TiO₂ and SO₃ are conjointly gift in GGBS. The compositions don't vary very much like long because the sources of ore, coke and flux area unit consistent (Bye 1999).

2.2.3 GGBS in Concrete

The reaction between GGBS and water yields final product kind of like that of product of cement association. the foremost variations between the 2 reactions area unit the speed and intensity of the reaction. Besides, GGBS

conjointly exhibits pozzolanic reaction within the presence of hydroxide (Mindess Darwin & Young 2003). The reaction between OPC and GGBS can have a minimum of 3 components; cement association, scoria hydraulic reaction and scoria pozzolanic reaction (Feng et al2004).

For aggressive surroundings, combination of GGBS and OPC area unit most popular instead of victimisation OPC alone in concrete. Also, studies on concrete with Portland scoria cement containing concerning 50-65% GGBS tested the standard of concrete to be higher. The take a look at results more showed that, with increase in

III. MIX DESIGN

3.1 Ground Granulated Blast Furnace Slag(GGBS)

GGBS conforming to the specifications of IS 12089-1987 was used as the primary binder to produce GPC in which BRHA was replaced from 0% to 30%. GGBS was obtained from JSW cements limited, Bellari, India. The chemical composition and physical properties of GGBS were tested (as per ASTM D3682-01) in SGS Laboratories, Chennai and are given in Table 3.1.

S. No	Property	Value
1.	Silicon-di-Oxide (SiO ₂)	31.25 %
2.	Aluminium tri oxide (Al ₂ O ₃)	14.06 %
3.	Ferric Oxide (Fe ₂ O ₃)	2.80 %
4.	Calcium Oxide (CaO)	33.75 %
5.	Magnesium Oxide (MgO)	7.03 %
6.	Loss on Ignition	1.52%
7.	Specific gravity	2.61
8.	Blaine fineness	4550 cm ² /g

Table 3.1 Properties of GGBS

3.1.1 Black Rice Husk Ash (BRHA)

BRHA was obtained from a rice mill near Karaikudi. It was finely ground in a ball-mill for 30 minutes and passed through 75 μ sieve (Rashid et al, 2010) before using in GPC production. The chemical composition and physical properties BRHA were tested (as per ASTM D3682-01) in SGS Laboratories, Chennai and are given in Table 3.2.

S. No	Property	Value
1.	Silicon-di-Oxide (SiO ₂)	93.96 %
2.	Aluminium tri oxide (Al ₂ O ₃)	0.56 %
3.	Ferric Oxide (Fe ₂ O ₃)	0.43 %
4.	Calcium Oxide (CaO)	0.55 %
5.	Magnesium Oxide (MgO)	0.40 %
6.	Loss on Ignition	9.79%
7.	Specific gravity	2.14
8.	Blaine fineness	5673 cm ² /g

3.1.2 Aggregates

Natural river sand conforming to Zone II as per IS 383 (1987) with a fineness modulus of 3.54 and a specific gravity of 2.61 was used as fine aggregate. Crushed granite coarse aggregate conforming to IS: 383 (1987) was used. Coarse aggregate of maximum nominal size 20 mm, with a specific gravity of 2.72 and fineness modulus of 6.29 was used. The aggregates were tested as per IS2386 (1963).

3.1.3 Alkaline Solution

A mixture of sodium hydroxide and sodium silicate was used as the alkaline solution. Commercial grade sodium hydroxide in pellets form (97%- 100% purity) and sodium silicate solution having a composition of 14.7% Na₂O, 29.4% SiO₂(total solids = 45.4%) and 55.6% water by mass were used. The alkaline liquid to binder ratio was fixed as 0.4 and the ratio of sodium silicate to sodium hydroxide was taken as 2.5 after conducting a lot of trials with conformance to workability and strength. The concentration of sodium hydroxide was fixed at 8 M for all the tests except the study on the influence of sodium hydroxide on the compressive strength where three different NaOH concentrations were used. High-range water-reducing naphthalene based super plasticizer was added at a dosage of 2% of the binder content to improve the workability of fresh concrete. Also extra water about 15% of binder content was added to increase the workability of the concrete.

3.3 MIX PROPORTIONS

Since there are no standard codal provisions available for the mix design of geo polymer concrete, the density of geo polymer concrete was assumed as 2400 kg/m³ and other calculations were made based on the density of concrete as per the mix design given by Lloyd & Rangan (2010). The combined total volume occupied by the coarse and fine aggregates was assumed to be 77%. The alkaline liquid to binder ratio was taken as 0.40. As there is no standard mix design procedures available to estimate the target Strength of GPC and besides this being a relatively new type of concrete that is still in developmental stage, minimum target strength was taken as 30 MPa, considering it as a regular strength concrete. GGBS was kept as the base material for making the control GPC specimens (GP). Then BRHA was used to replace GGBS in the mix in three different proportions, 5% (GPR1), 10% (GPR2) and 15% (GPR3), for the rest of the mixes used in the investigation. The mix proportions of GPC are given Table 3.3.

S. No	Quantities	Proportions (kg/m ³)			
		GP	GPR1	GPR2	GPR3
1.	GGBS	394	355	315	276
2.	BRHA	0	39	79	118
3.	Coarse aggregate	1201	1201	1201	1201
4.	Fine aggregate	647	647	647	647
5.	Sodium hydroxide	45	45	45	45
6.	Sodium silicate	113	113	113	113
7.	Super-plasticizer	8	8	8	8
8.	Water	59	59	59	59

3.4 PREPARATION OF TEST SPECIMENS

The materials for the mixes were weighed and first mixed in dry condition for 3-4 minutes. Then the alkaline liquid which is a combination of sodium hydroxide and sodium silicate solutions along with super-plasticizer were added to the dry mix. Then some extra water about 15% by weight of the binder was added to improve the workability. The mixing was continued for about 6-8 minutes. After the mixing, the concrete was placed in steel moulds by giving proper compaction. Precautions were taken to ensure uniform mixing of the ingredients. Two types of curing were used for the specimens to be tested for the study on the influence of curing temperature on the compressive strength. One set of cubes was oven cured and the other set was cured under ambient condition. For oven curing, initially the cubes were placed along with their moulds the oven immediately after casting at two different temperatures, 60°C and 90°C respectively for 24 hours. Then the cubes were de- moulded and kept as such in the oven at the same respective temperatures for another 24 hours. Then they were taken out and allowed to cure in the room temperature till the required day of testing. For the ambient curing, the cubes were kept under room temperature after casting and de- moulded after 1 day and further cured in the room temperature till the day of testing. For all other tests, the specimens were prepared by adopting the oven curing procedure at 60°C.

IV. RESULTS AND DISCUSSION

4.1 STRENGTH TESTS

4.1.1 Compressive Strength Test

Influence of sodium hydroxide concentration

The influence of molarity of sodium hydroxide (NaOH) solution on the compressive strength of GPC was studied for three different molar concentrations of NaOH viz., 5 M, 8 M and 11 M. All the specimens were heat cured at 60°C. The compressive strength results are given in Table 4.1 and the variations of compressive strength of GPC specimens corresponding to the three different molar concentrations of NaOH are shown in Figures 4.1, 4.2 and 4.3 respectively.

S. No	NaOH concentration	Mix	Average compressive strength (MPa)			
			3 days	7 days	28 days	90 days
1.	5 M	GP	56.2	60.5	62.7	65.5
		GPR1	59.9	61.7	62.2	65.1
		GPR2	39.3	43.4	43.9	44.4
		GPR3	17.1	18.6	19.9	21.0
2.	8 M	GP	60.9	66.5	69.3	72.5
		GPR1	61.3	67.5	69.7	73.4
		GPR2	43.1	46.8	52.5	54.1
		GPR3	19.7	21.5	22.9	24.3
3.	11 M	GP	67.1	72.1	74.3	77.4
		GPR1	68.1	75.5	76.3	80.0
		GPR2	49.1	55.5	56.4	59.5
		GPR3	21.4	22.3	23.4	25.8

Table 4.1 Compressive strength of GPC at different NaOH concentrati

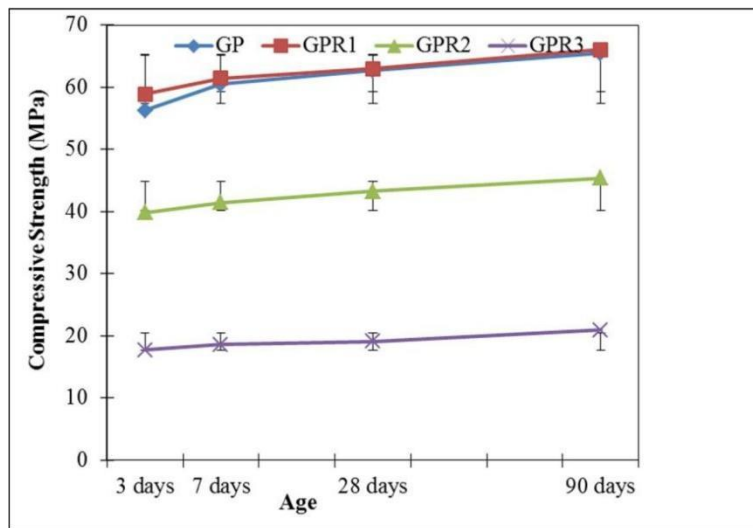


Figure 4.1 Compressive strength of GPC at 5 M NaOH concentration

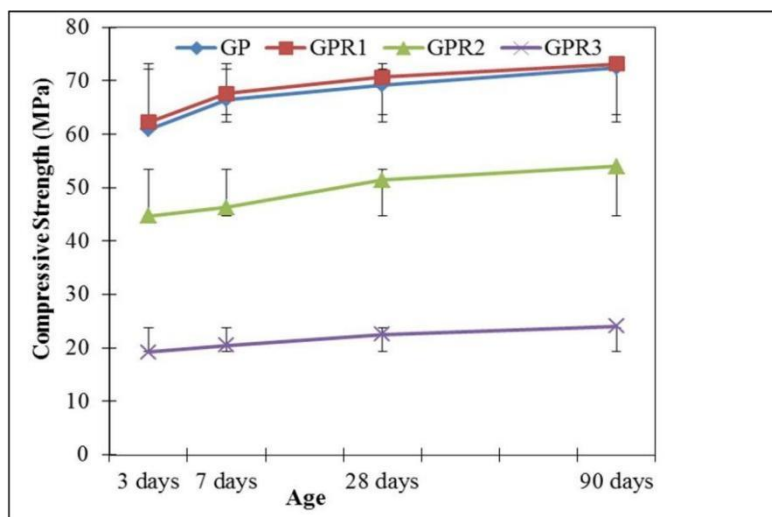


Figure 4.2 Compressive strength of GPC at 8 M NaOH concentration

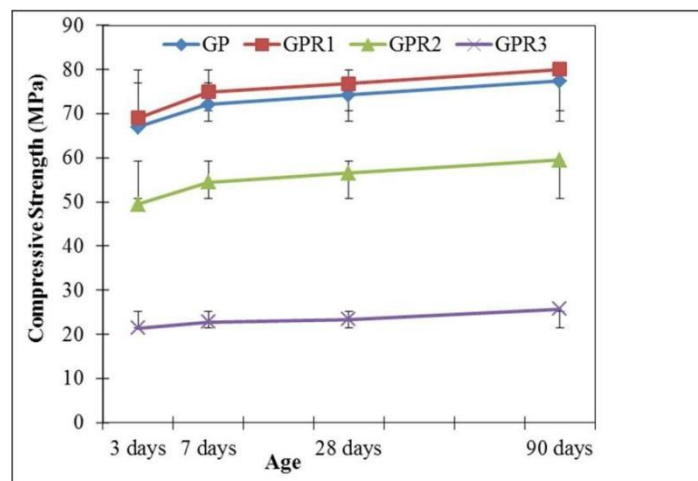


Figure 4.3 Compressive strength of GPC at 11 M NaOH concentration

From the results, it can be seen that the compressive strength of GPC increased with increase in NaOH concentration. At 28 days, the strength increase of control specimen (GP) ranged from 10 to 18% for the corresponding rise in molarity starting from 5 M to 8 M and then to 11 M. The increase in NaOH concentration could have increased the rate of dissolution of silica and alumina ions in the alkaline solution resulting in the compressive strength gain. The GPC mix developed by Rajamane et al (2012) completely using GGBS showed an average 28th day compressive strength of 63 MPa as compared to the corresponding compressive strength of 49 MPa of the control Portland pozzolana cement concrete (PPCC) used in their study. In the current study, at all three levels of NaOH molarity, the control GPC specimen (made fully with GGBS) exceeded the 28th day strength of both the GGBS based GPC and the conventional concrete of the literature referred above. This again shows that the performance of GPC is better than conventional concrete and this fact has been proved by various other researchers also.

Further, with the addition of BRHA, there is a slight increase in the compressive strength at 5% replacement level (GPR1). Comparing the control specimen GP, the 28th day strength increase for GPR1 is 0.38% at 5 M, 2.1% at 8 M and 3.4% at 11 M concentration of NaOH. The increase in molarity improves the dissolution of fine BRHA particles and accounts for the strength improvement despite the fact that it is only marginal. For the other mixes (GPR2 and GPR3), the compressive strength decreased with increase in BRHA proportion. The excessive addition of silica rich BRHA could have possibly increased the unreactive silica content in the mix which resulted in the strength reduction. But at the same time all the mixes except GPR3, surpassed the target strength of 30 MPa and strengths as high as 76.83 MPa for GPR1 and 56.61 for GPR2 at 11 M NaOH concentration could be witnessed. GPR3 did not attain any substantial strength at all three concentrations of NaOH. While observing the rate of strength gain with respect to age, the GPC achieved majority of its strength well within its first week from the time of casting. Both the control and BRHA added GPC specimens showed a similar trend of strength gain against age. For instance, at 8 M concentration, the strength increase for GP was 9.2% from 3rd to the 7th day and it was only 4.2% from 7th day to the 28th day. There was only a further 4.7% increase in strength when tested at 90 days. For GPR1 the strength increase was 8.5%, 4.6% and 4.3% at the respective time intervals. Similar trend was seen with the other mixes also. As observed by Hardjito and Rangan (2005), the chemical reaction of the heat-cured geopolymer concrete is a substantially fast polymerization process that takes place within hours and that is the main reason for the compressive strength not being influenced by age. This behaviour is apparently in contrast to the behaviour of OPC concrete, where the hydration process would continue to occur over

Influence of Curing Temperature

The influence of curing temperature on the compressive strength of GPC was studied for three different curing conditions viz., ambient, 60°C and 90°C. Concentration of NaOH was fixed as 8 M for all the specimens. The compressive strength results are given in Table 4.2 and the variation of compressive strength of GPC specimens corresponding to the three different curing conditions are shown in Figures 4.4, 4.5 and 4.6 respectively.

S. No	Curing temperature	Mix	Average compressive strength (MPa)			
			3 days	7 days	28 days	90 days
1.	Ambient	GP	44.7	47.2	52.8	54.5
		GPR1	40.4	44.9	48.3	51.6
		GPR2	12.2	15.7	18.2	19.5
		GPR3	9.1	11.8	15.5	15.9
2.	60°C	GP	60.9	66.5	69.3	72.9
		GPR1	62.5	66.6	70.7	73.2
		GPR2	43.7	46.7	52.5	53.8
		GPR3	19.5	21.5	24.6	25.3
3.	90°C	GP	63.2	66.2	73.6	74.7
		GPR1	64.8	67.9	72.3	75.3
		GPR2	41.7	47.8	51.7	53.4
		GPR3	10.5	12.9	15.9	16.5

Table 4.2 Compressive strength of GPC at different curing temperature

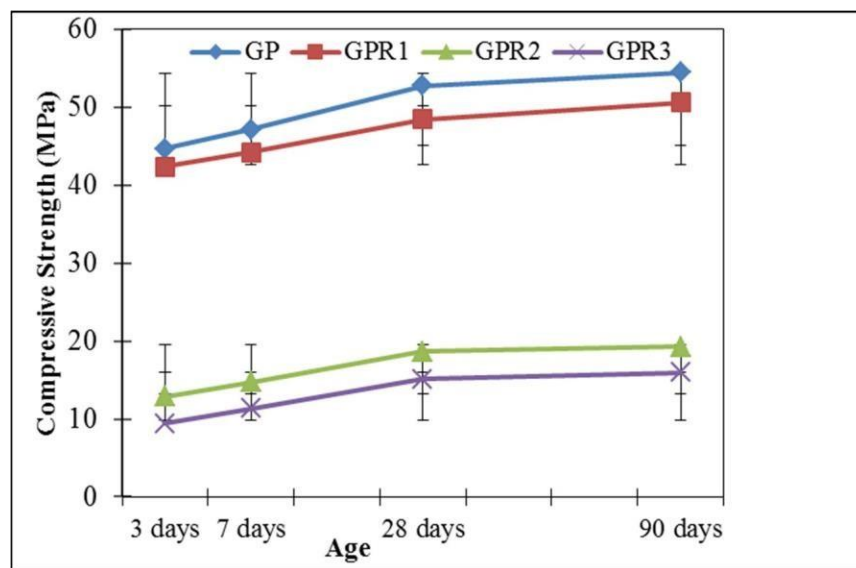


Figure 4.4 Compressive strength of GPC cured at ambient temperature

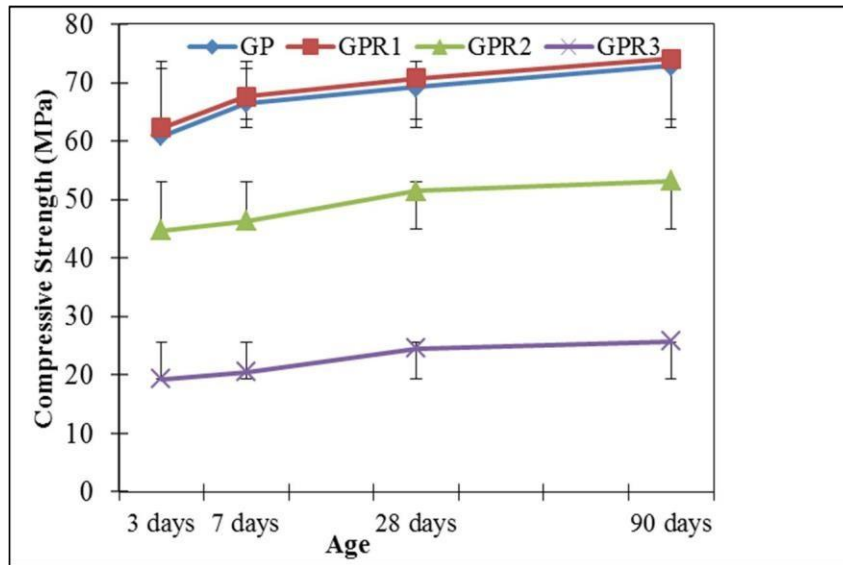


Figure 4.5 Compressive strength of GPC cured at 60°C

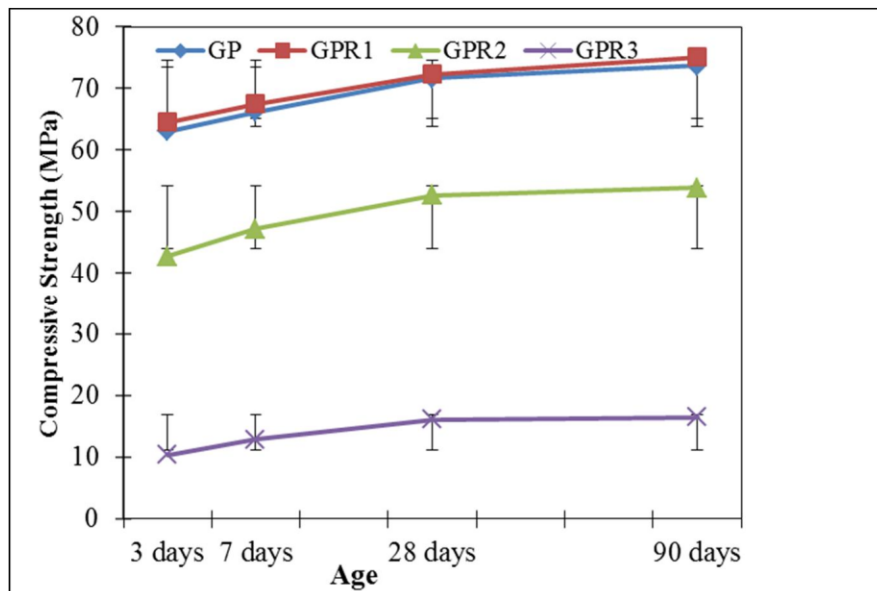


Figure 4.6 Compressive strength of GPC cured at 90°C

It can be observed that the compressive strength increased with increase in the curing temperature. The compressive strength of control GPC specimens (GP) cured at 60°C was 36% higher and it was 41% greater for those cured at 90°C, than the specimens cured at ambient temperature. At 5% BRHA replacement (GPR1), when compared to ambient curing, the strength increase was 45% and 54% for oven cured specimens at 60°C and 90°C respectively. At 10% BRHA replacement (GPR2), the strength was nearly thrice, when comparing ambient curing and oven curing at both 60°C and 90°C. There was a reduction in the compressive strength for all mixes with the addition of BRHA when cured under ambient condition. The addition of silica rich BRHA caused a rise in the un reactive silica content which further lead to inappropriate increase in the SiO₂/Al₂O₃ of the geo polymer thus creating a negative effect on the compressive strength as reported by Duxson et al (2005). At the same time, for

the oven cured specimens both at 60°C and 90°C, at 5% BRHA replacement, the compressive strength was slightly higher and comparable with that of the control mix. This is due to the positive influence of curing temperature on the setting and hardening of geo polymers (Nazari et al 2011). The higher temperature enables greater dissolution of Si and Al ions leading to the formation of a stronger polymer chain as mentioned by Kusbiantoro et al (2012). The compressive strengths of the other mixes were less than that of the control specimen. The addition of silica rich BRHA increased the SiO₂/Al₂O₃ incongruously which inhibited the geo polymer reactions and the subsequent gelation process, inspite of the temperature increase. Hence the decreasing trend in strength is observed for the increase in BRHA proportion. Another possible reason as observed by Kusbiantoro et al (2012) could be due to the differences in the solubility degree between GGBS and BRHA, as the replacement of GGBS with BRHA remarkably decreases the dissolution and poly condensation rate of alumino silicate precursors.

However, it can be seen that the BRHA added geo polymer concrete did exceed the target strength of 30 MPa and attained substantial 28th day strengths around 70.72 MPa for GPR1 and 51.46 MPa for GPR2 when cured at 60°C. When the curing temperature was increased to 90°C, there was only slight increase in the 28th day strength up to 72.34 MPa for GPR1 and 52.66 MPa for GPR2. The ambient cured specimens obtained 28th day strengths of 48.44 MPa for GPR1. The general trend of higher strengths can be attributed to the presence of additional calcium silicate hydrate gel along with the predominant alumino silicate gel which has a compacting effect on the microstructure of geo polymer (Kumar et al 2009). The 15% BRHA added GPR3 specimens did not achieve any significant strength in all three curing conditions.

Splitting Tensile and Flexural Strength Tests

The results of splitting tensile and flexural strengths of the geopolymer concrete at 3, 7 and 28 days are given in Table 4.3 and the variation of the split tensile strength and flexural strength for the various mixes are shown in Figures 4.7 and 4.8 respectively.

S. No	Mix	Split tensile strength (MPa)			Flexural strength (MPa)		
		3 days	7 days	28 days	3 days	7 days	28 days
1.	GP	6.3	6.5	6.8	5.3	5.9	6.1
2.	GPR1	6.4	6.6	6.9	5.5	6.4	7.0
3.	GPR2	3.6	3.8	4.4	3.1	3.5	4.3
4.	GPR3	0.6	0.8	1.1	0.9	1.0	1.4

Table 4.3 Splitting Tensile and Flexural Strength Tests of GPC

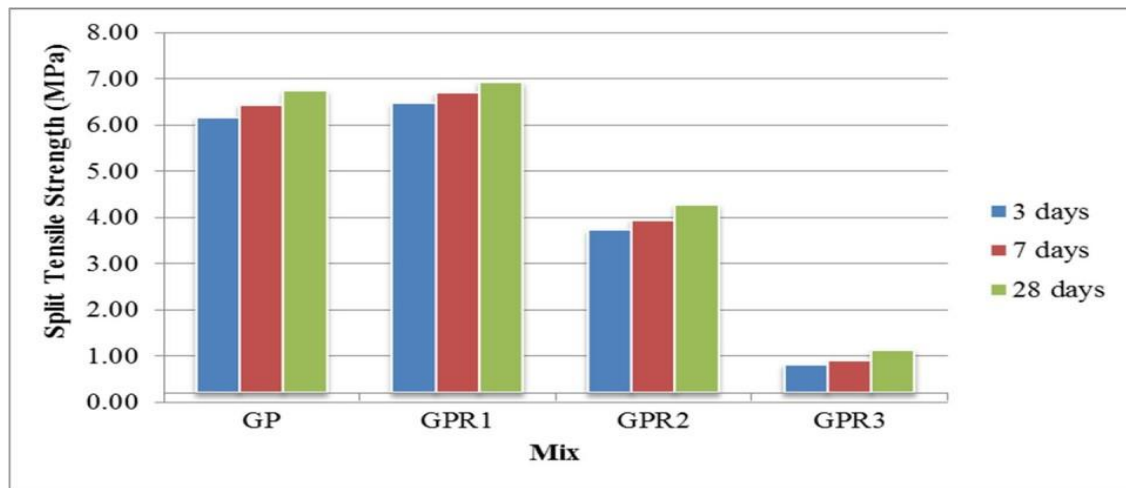


Figure 4.7 Splitting tensile strength of GPC

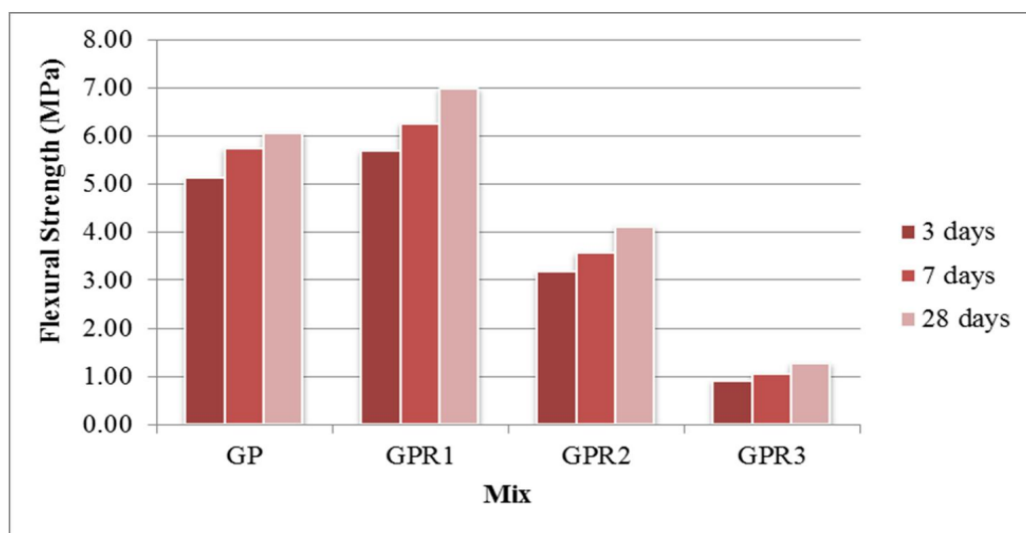


Figure 4.8 Flexural strength of GPC

When comparing the 5% BRHA replaced mix GPR1 with control mix GP, there was a slight improvement in both split tensile and flexural strengths. The heat curing of the specimens along with a suitably increased $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratio and higher fineness of BRHA particles might have assisted the dissolution of ions and poly condensation mechanism of the geopolymer framework. Also, the co-existence of the secondary calcium silicate hydrate phase along with the primary geopolymer phase is another reason for the improvement in the mechanical strength as observed by Yip et al (2005). But with further increase in BRHA content, the split tensile and flexural strength seemed to get decreased. Similar results were reported by Jing Liu et al (2014) while using palm oil fuel ash as a binder for the geopolymer concrete. The reason for the reduction in the mechanical strengths beyond 5% BRHA replacement could be due to the fact that the BRHA particles possess a different silicate structure and when the $\text{SiO}_2/\text{Al}_2\text{O}_3$ ratio exceeds very high, the kinetics of the polymerization mechanism is inhibited due to the difference in solubility of GGBS and BRHA and thus the production rate of geopolymer gel is reduced as deduced by Kusbiantoro et al (2012).

The experimental E values were then compared with the equivalent theoretical E values. The theoretical and experimental E values are given in Table 4.4.

S. No	Mix	Compressive strength (MPa)	Theoretical E (MPa)	Experimental E (MPa)
1.	GP	69.80	41773	36165
2.	GPR1	71.34	42231	38189
3.	GPR2	50.18	35418	27252
4.	GPR3	22.92	23937	17007

Table 4.4 Theoretical and experimental E values of GP

The 5% BRHA replaced mix GPR1 has a higher elastic modulus than the control mix GP. The increase in E value was about 5.7% for GPR1. Both the mixes GP and GPR1 showed E values as high as 36165 MPa and 38189 MPa respectively. The possible reason for such high values of elastic modulus could be the co-existence of the secondary C-S-H phase along with the primary geo polymer phase. The other two mixes GPR1 and GPR2 show reduced elastic modulus in comparison with the control mix. The possible reason for the decrease in elastic modulus could be attributed to the reduction in strength due to inappropriate silica-alumina ratio from excessive addition of BRHA.

Comparing the theoretical and measured E values obtained from the stress-strain curves of GPC, the actual experimental values were less than that of the predicted values. The additional strains caused from the experimental setup and loading mechanism might have been the reason for such variation between the theoretical and experimental values. Similar results are reported by Khadiraniakar & Sanni (2014) for fly ash and GGBS blended geopolymer concrete.

4.2 DURABILITY TEST

Acid Resistance Test

The weight and compressive strength losses of GPC on exposure to 3% solution of H₂SO₄ at 30, 60 and 90 days from the time of immersion are shown in Table 4.5 and the variations of the strength and weight losses are shown in Figures 4.9 and 4.10 respectively.

S. No	Mix	Weight loss (%)			Strength loss (%)		
		30 days	60 days	90 days	30 days	60 days	90 days
1.	GP	0.25	3.49	6.2	3.3	10.27	15.4
2.	GPR1	0.1	2.86	4.9	2.9	9.4	13.4
3.	GPR2	0.1	3.1	5.4	3.1	10	13.8
4.	GPR3	0.6	5.9	10.5	9.9	24	39.7

Table 4.5 Weight and strength losses of GPC on exposure to H₂SO₄

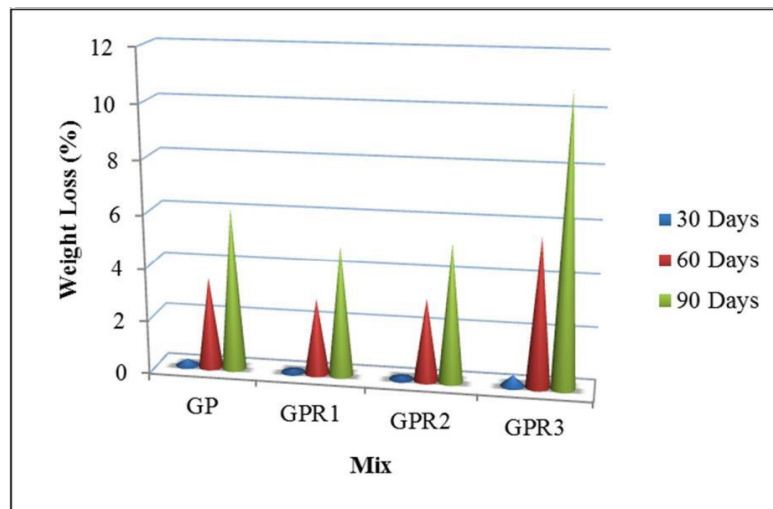


Figure 4.9 Weight loss of GPC on exposure to H₂SO₄

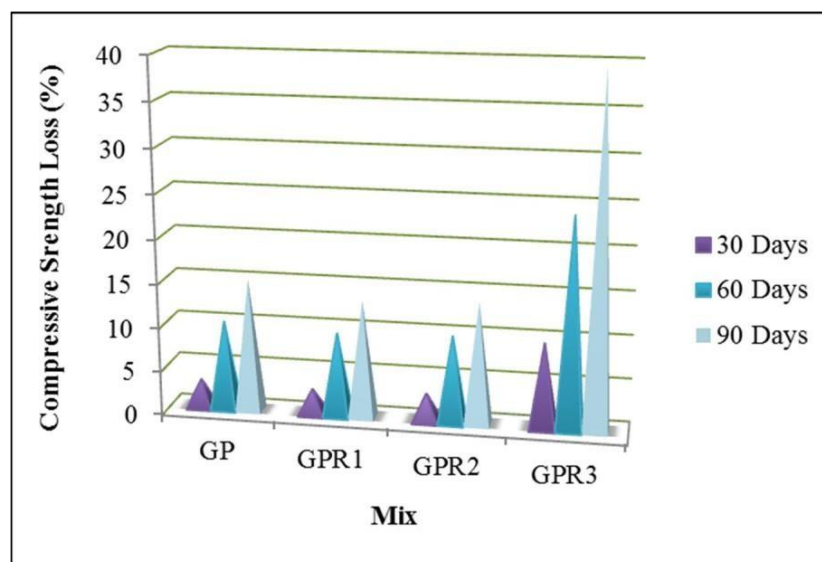


Figure 4.10 Compressive strength loss of GPC on exposure to H₂SO₄

The weight and compressive strength losses of GPC on exposure to 3% solution of HCl at 30, 60 and 90 days from the time of immersion are shown in Table 4.6 and the variations of the strength and weight losses are shown in Figures 4.11 and 4.12 respectively.

S. No	Mix	Weight loss (%)			Strength loss (%)		
		30 days	60 days	90 days	30 days	60 days	90 days
1.	GP	0	1.8	4	2.1	8.8	12.4
2.	GPR1	0	1.17	3.3	1.7	8.5	11.6
3.	GPR2	0	1.3	3.8	1.7	9.3	12.1
4.	GPR3	0.4	3.9	8.6	7.3	16.1	24.4

Table 4.6 Weight and strength losses of GPC on exposure to HCl

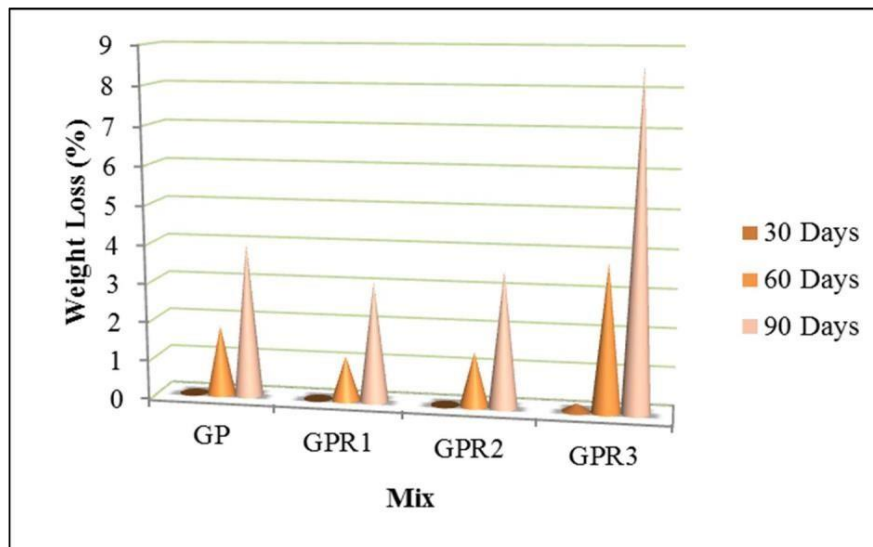


Figure 4.11 Weight loss of GPC on exposure to HCl

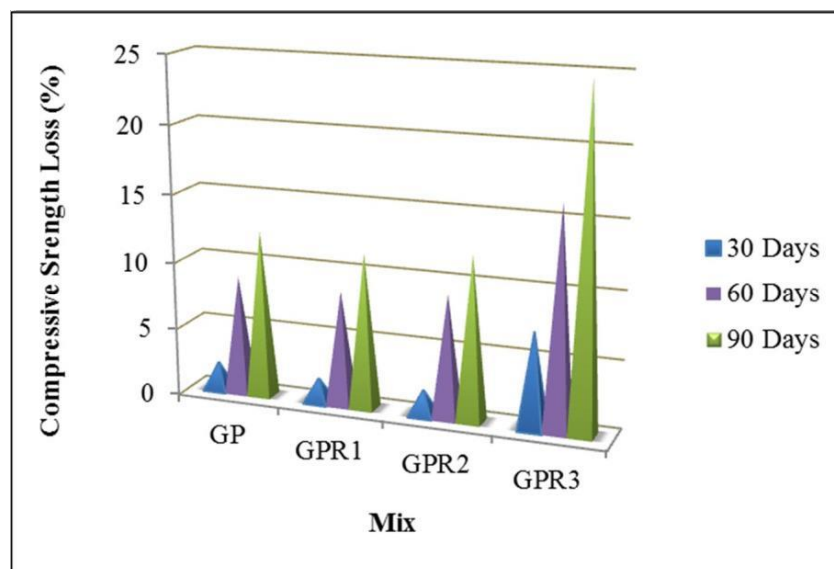


Figure 4.12 Compressive strength loss of GPC on exposure to HCl

The strength and weight loss percentages of GPC after exposure to 3% solutions of H_2SO_4 and HCl at 30, 60 and 90 days indicate that the addition of BRHA had a beneficial effect on the acid resistance of GPC. GPR1 and GPR2 specimens showed lower losses than the control specimens. The percentage strength losses of GGBS based GPC prepared by Rajamane et al (2012) after exposure of 30, 60 and 90 days to 2% H_2SO_4 were 3.7%, 10% and 11.1% (with corresponding weight losses being 0.1%, 2.7% and 4.5%). They compared their results with conventional PPC concrete where these corresponding strength loss numbers were quite high at 17.4%, 31.4% and 36.2% (with corresponding weight losses being 2.3%, 6.3% and 8.7%).

It is clear from the present study that, even on exposure to a comparably higher concentration of H_2SO_4 and HCl, the performances of BRHA added GPC samples GPR1 and GPR2 are analogous to that of the GGBS based GPC while they have performed way better than the conventional concrete from the above-mentioned literature. However, the GPR3 specimens due to their poor structural compactability did not offer much resistance against

H₂SO₄ and HCl and they exhibited higher weight and compressive strength losses at the end of 90 day exposure period.

Seawater Resistance Test

The weight and compressive strength losses of GPC on exposure to seawater at 30, 60 and 90 days from the time of immersion are shown in Table 4.7 and the variations of the strength and weight losses are shown in Figures 4.13 and 4.14 respectively.

S. No	Mix	Weight loss (%)			Strength loss (%)		
		30 days	60 days	90 days	30 days	60 days	90 days
1.	GP	0.2	4.7	8.8	6.5	13.4	22.7
2.	GPR1	0.15	4.15	7.6	5.9	11.3	19.4
3.	GPR2	0.2	5.2	9.3	6.8	14.9	25.6
4.	GPR3	0.3	8.8	17.1	9.2	26.5	42.6

Table 4.7 Weight and strength losses of GPC on exposure to seawater

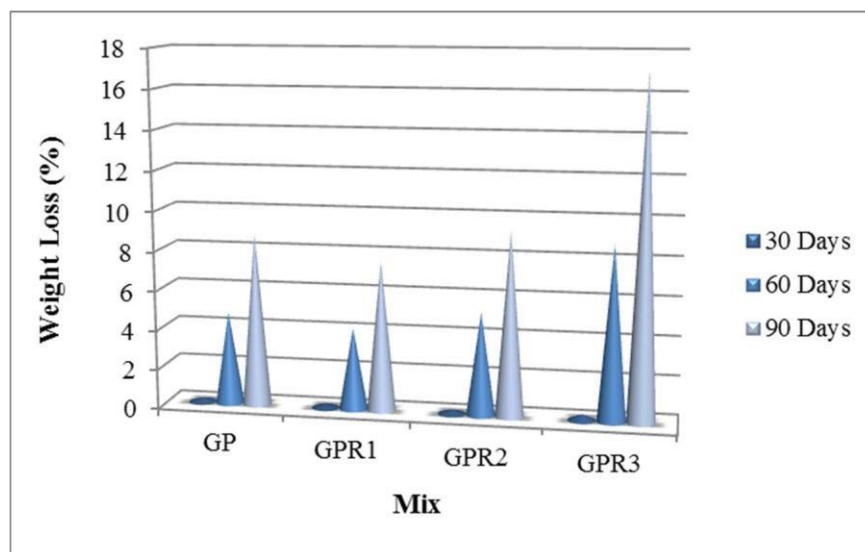


Figure 4.13 Weight loss of GPC on exposure to seawater

No significant weight losses were observed initially at 30 days of exposure. The weight and strength losses of GPR1 specimens were less than that of control specimens. The reduction in compressive strength of GPC was higher at 60 days and 90 days when compared to acid resistance test. The higher leaching of alkalis that alter the integrity of geopolymer aluminosilicate network might have contributed to the higher strength losses (Olivia & Nikraz 2013).

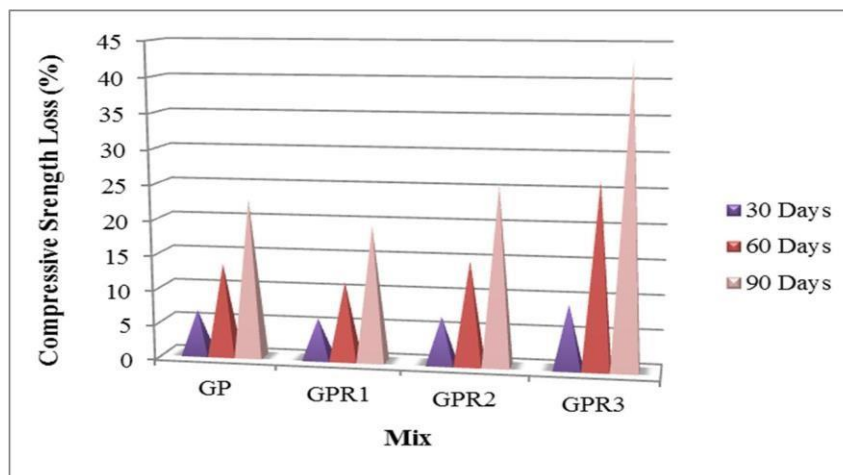


Figure 4.14 Compressive strength loss of GPC on exposure to seawater

GPR3 specimens showed greater losses in weight and compressive strength during the exposure period. The increased pores interconnectivity might have allowed rapid chloride ion movements from the outer to inner side of concrete resulting in deterioration and subsequent weight loss (Olivia & Nikraz 2013). The surface of the GPC specimens started showing visible stains at 30 days and continued to deteriorate with time. Significant surface erosion was observed after 90 days of exposure to sea water. Similar results were reported by Omer et al (2015)

V. CONCLUSION

The following conclusions can be drawn from this limited experimental investigation.

- The experimental results show that it is possible to produce geo polymer concrete possessing substantial strength and durability using GGBS and BRHA.
- Increase in NaOH concentration increased the compressive strength.
- The strength increase ranged between 10 to 18% for the corresponding rise in molarity starting from 5 M to 8 M and then to 11M.
- Oven curing resulted in higher compressive strength than ambient curing. However, ambient curing gave strength up to 53 MPa for 100% GGBS and up to 40 MPa for 5% BRHA replacement.
- While comparing oven curing at a temperature of 60°C and ambient curing, the strength increase at 28 days was 45% for GPR1 and nearly three times for GPR2 specimens.
- Increase in curing temperature to 90°C had only a moderate increase in the compressive strength. Hence oven curing at 60°C could be preferred for the GPC when BRHA is added.
- Addition of BRHA beyond 5% had a retarding effect on the compressive strength. Although up to 10% replacement, the target compressive strength was surpassed and strength as high as 51 MPa was reached at 28 days.
- The strength gain was substantial till 7 days and became moderate till 28th day. As evident from the 90th day compressive strength results, the strength gain beyond 28 days was only marginal for GPC.
- The incorporation of BRHA in geo polymer concrete increased its corrosion resistance. The corrosion initiation period was 34 days for GPR1 and 36 days for GPR2, whereas it was only 23 days for the GP specimen.
- BRHA added GPC specimens showed good resistance against acid attack and seawater attack as the weight and strength losses were lower for 5% and 20% replacement levels than the control specimens.
- Addition of BRHA beyond 10% is not beneficial in geo polymer concrete. The 15% BRHA replaced specimens neither achieved significant strength nor proved to be durable.
- From the cost perspective, there is a definite saving of cost in the production of GPC over conventional concrete. While comparing, as the grade of the conventional concrete increases the cost saving also increases for the corresponding GPC mix.
- The reflection of cost savings can be more significant if the volume of production of concrete is massive.

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