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# DURABILITY STUDIES ON SUSTAINABLE GEOPOLYMER CONCRETE

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*Abstract* – *Concrete is over utilized material by the construction industry and hence its production might become difficult since raw materials required in the manufacture of cement, river sand are not available in abundance. Since there is shortage of good quality River sand, it is overpriced even for the low quality river sand. Because of this reasons, M-sand find its way to substitute River sand as its properties are almost similar to river sand. Along with M-sand, the other material which can be used as fine aggregate is Pond ash. Concrete is usually delivered by utilizing the ordinary Portland cement (OPC) as the binder. There are many ecological issues connected with the manufacture of OPC i.e. calcination of limestone and ignition of fossil fuel releases 1 ton carbon dioxide for every 1 ton of OPC manufactured affecting the ecological balance. The use of GPC contributes to the environment in two way: first carbon dioxide released during the cement production gets reduction, Second ill effects and dumping of fly ash, pond ash in the region of thermal power plant can be eliminated.*

*Previous studies on the properties of heat-cured geopolymer concrete have shown superior results which mainly finds application in precast industry. In present study, ambient curing was adopted to obtain geopolymer concrete which can be used for normal construction. The main objective is to achieve the sustainable geopolymer concrete and to carry out comparative study on durability properties of geopolymer concrete and normal strength concrete when exposed to acid, sulphate, chloride and fire.*

*Key Words: Geopolymer concrete, Ambient curing, GGBS, Fly ash, M-sand, Pond ash.*

## 1.0 INTRODUCTION

In setting awareness to the ill impacts of the over usage of common assets, eco-accommodating advances are to be produced for viable administration of these resources. Development industry is one of the real clients of the regular assets like cement, sand, rocks, clays and different soils. The steadily expanding cost of construction materials used in concrete, has constrained the development architect to consider ways and method for diminishing the unit cost of its creation. In the meantime, expanding modern techniques in the center areas like energy, steel and transportation has been responsible for the creation of expansive sums like fly ash, blast furnace slag, silica fume.

The increasing demand for the environmental friendly construction has been the driving force for development of sustainable and economical building materials. The adverse aspects influencing the development are performance of the materials under different and special user conditions, economic aspects as well as environmental impact aspects. Cement is an energy consuming and high green-house gas emitting product. Geo-polymers are gaining increased interest as binders with low $CO_2$ emission in comparison to Portland cement. Geo-polymers also exhibit superior engineering properties compared to cement. Low calcium fly-ash based geopolymer concrete has been reported to have excellent compressive strength, resistance to acid, sulphate, chloride and corrosion [1].

Despite the fact that Ordinary Portland Concrete (OPC) is widely used in concrete industry since many decades, it releases green-house gases into the atmosphere at the time of manufacturing. Geopolymer concrete is the recent technology used to reduce OPC concrete. Fly ash reacts with alkaline solutions to form a cementitious material; fly ash based geopolymer does not emit carbon dioxide. In this project, pond ash is considered as partial replacement for sand as fine aggregate in the geopolymer concrete. Fly ash and pond ash are residues from combustion of coal [2].

## 2.0 EXPERIMENTAL PROGRAM

### 2.1 Materials

43 Grade (Zuari cement) ordinary portland cement was used for NSC. The water used in the mix design was potable water, free from suspended solids and organic materials. Fly ash, Pond ash are the by-product of thermal power plant, disposal of which is still a problem. Ground

 

granulated blast furnace slag (GGBS) is a by-product from the blast-furnaces used to make iron. To obtain economical mix, manufactured sand (M-Sand) and Pond Ash was used as fine aggregate both in NSC and GPC, their proportion for each mix is given in Table 1. The coarse aggregates used were 12.5mm downsize. In order to increase the workability of the mix, super plasticizer Conplast SP – 430; 2.0% by mass of fly ash was added.

## 2.2 Production of GPC

In the production of GPC, Fly ash and GGBS are the materials activated using sodium hydroxide and sodium silicate by polymerization process to obtain similar properties as such in NSC. Before 24hrs of manufacture of GPC, Sodium hydroxide flakes (14M) concentration was dissolved in water. On the day of obtaining GPC, sodium silicate solution (97% pure) was mixed with sodium hydroxide solution in the ratio of 2.5. Free water and super plasticizer mixed was added to pan mixer, to obtain workability. Two different mixes were obtained in GPC and NSC as shown in Table 1.

## 2.3 Experiments

For all the mixes 100mm cubes were casted to compare the strength and durability properties. In all the mixes; a) 3 cubes each for 7 day, 14 day, 28 day compressive strength b) 6 cubes for fully saturated water absorption (SWA) test c) 6 cubes each for acid, chloride, sulphate resistant test d) 3 cubes each for 2hrs, 4hrs to check fire resistance, were casted. GPC (GPC30, GPC40%PA) cubes were demoulded two days after casting and kept in ambient temperature for 28 days curing. NSC (NSC 30, NSC40%PA) cubes were demoulded one day after casting and kept in water tank for 28 days curing.

In acid, chloride, sulphate resistant test carried out on all four mixes, alternate day wetting and drying was done for 28 days and for every week the loss in weight was taken. All the four mixes (NSC30, GPC30, NSC40%PA, GPC40%PA), total 24 cubes i.e. 6 cubes in each mix of same concrete nomenclature were kept in electrical furnace at varied time (2hrs & 4 hrs) and temperature (300°C & 600°C). After removal of cubes from furnace, out of 6 cubes in each type of concrete, 3 cubes are subjected to water cooling (WC) and other 3 to air cooling (AC).

## 3.0 MIX PROPORTIONS FOR GPC AND NSC

Table 1: Details of GPC and NSC Mix proportions (kg/m³)

| Materials | NSC30 | GPC30 | NSC 40% (PA) | GPC 40% (PA) |
|---|---|---|---|---|
| Coarse aggregate (12.5mm downsize) | 873.06 | 967.68 | 873.06 | 967.68 |
| Fine aggregate(M-sand) | 900.00 | 760.32 | 540.00 | 456.19 |
| Pond ash (PA) | - | - | 360 | 304.13 |
| Cement | 379.22 | - | 379.22 | - |
| Fly ash | - | 346.84 | - | 346.84 |
| GGBS | - | 86.71 | - | 86.71 |
| Sodium silicate solution | - | 170.32 | - | 170.32 |
| Sodium hydroxide solution(14M) | - | 68.13 | - | 68.13 |
| Super plasticizer (SP-430) | - | 6.50 | - | 6.50 |
| Extra water | - | 57.5 | - | 75 |
| Alkaline solution/(FA+GGBS) | - | 0.55 | - | 0.55 |
| W/C ratio | 0.55 | - | 0.55 | - |

## 4.0 RESULTS AND DISCUSSION

## 4.1 Compressive Strength

Table 2: shows the compressive strength of NSC and GPC at different curing periods

| Mechanical property | Age(Days) | Mix type | | | |
|---|---|---|---|---|---|
| | | NSC30 | GPC30 | NSC 40PA | GPC 40PA |

| | | | | | |
|---|---|---|---|---|---|
| Compressive strength (MPa) | 7 | 28.12 | 28.12 | 17.98 | 22.89 |
| | 14 | 31.72 | 34.66 | 20.60 | 27.61 |
| | 28 | 39.57 | 49.70 | 28.12 | 34.66 |


Fig-1 Compression test on GPC and NSC

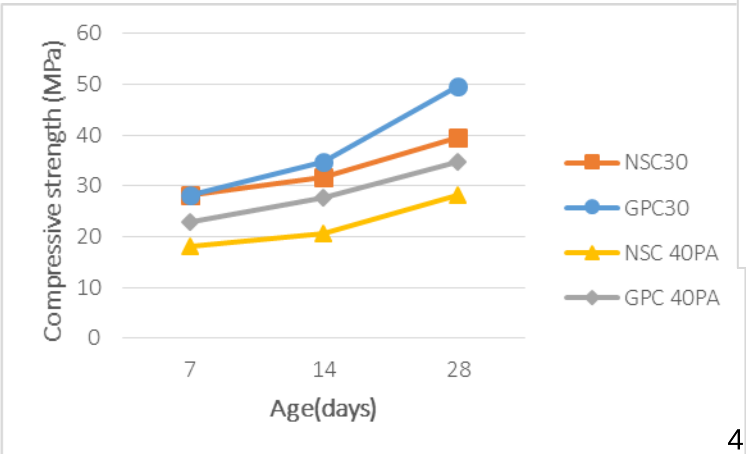

Fig-2 Compressive strength versus Age

## 4.2 Saturated Water Absorption Test

Table 3: shows the percentage saturated water absorption of GPC and NSC after 28 days curing

| Specimen No | NSC30 | GPC30 | NSC 40% (PA) | GPC 40% (PA) |
|---|---|---|---|---|
| 1 | 6.49 | 5.67 | 8.37 | 7.62 |
| 2 | 6.33 | 5.68 | 7.82 | 7.65 |
| 3 | 6.33 | 6.00 | 8.00 | 7.96 |
| 4 | 6.22 | 5.58 | 7.95 | 6.03 |
| 5 | 6.41 | 5.62 | 8.40 | 7.35 |
| 6 | 6.21 | 5.30 | 7.92 | 5.97 |
| Average | 6.33 | 5.64 | 8.08 | 7.10 |

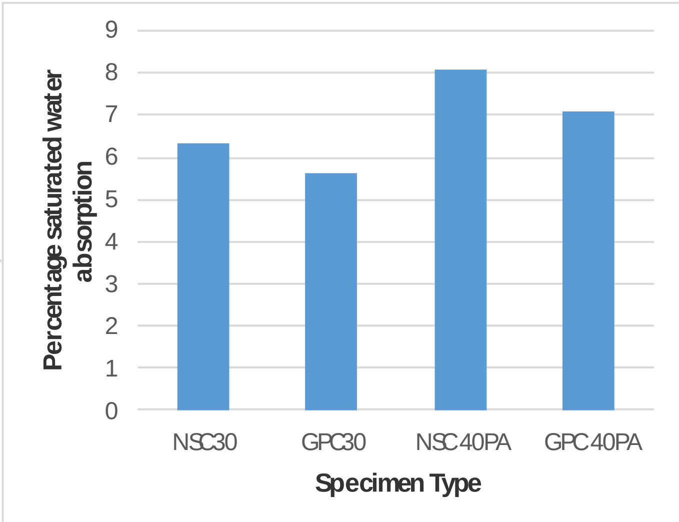

Fig-3 Water Absorption test

## 4.3 Fire Resistance Test


Fig-4 Specimen kept in Furnace and oven at 600°C and 300°C

 

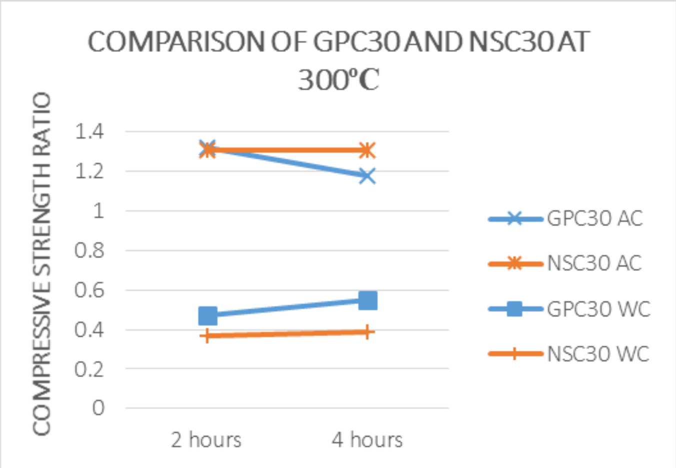


Fig-5 Comparison of GPC30 and NSC30 at 300°C for AC and WC

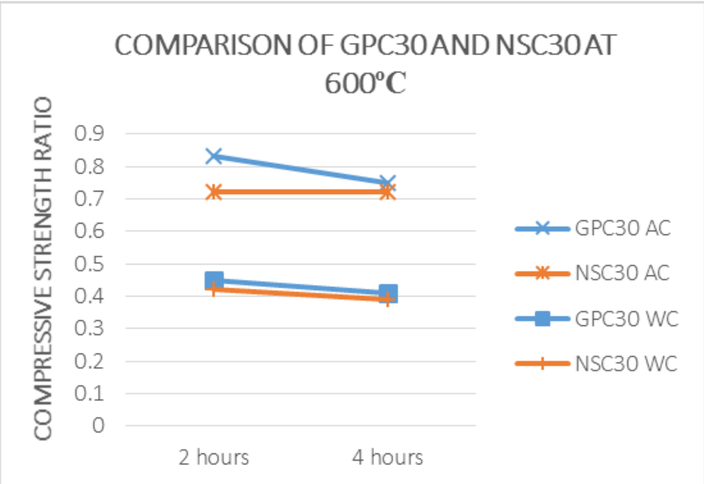


Fig-6 Comparison of GPC30 and NSC30 at 600°C for AC and WC

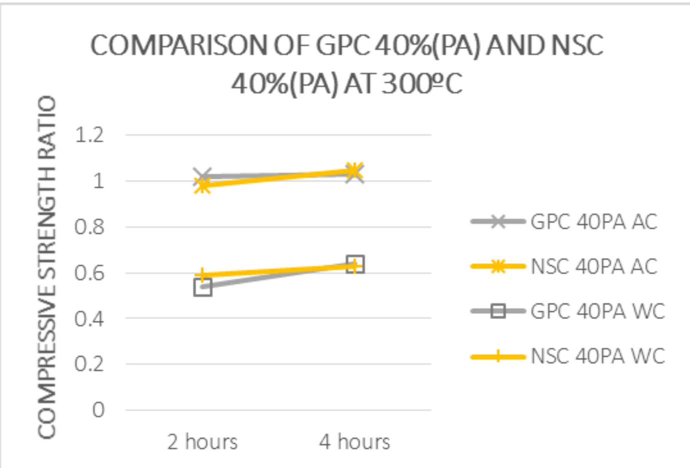


Fig-7 Comparison of GPC 40% (PA) and NSC 40% (PA) at 300ºC for AC and WC

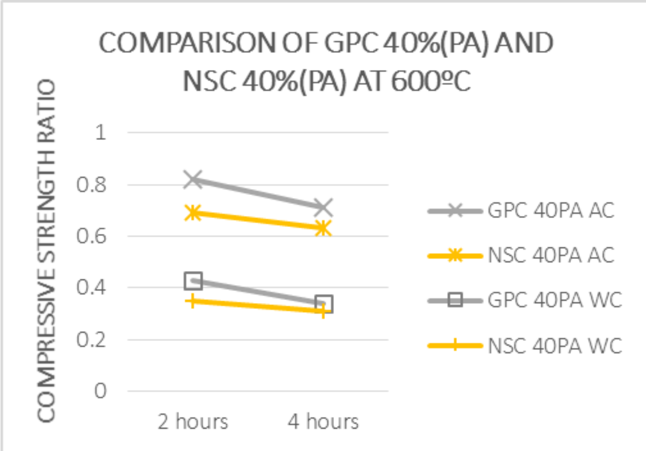


Fig-8 Comparison of GPC 40% (PA) and NSC 40% (PA) at 600ºC for AC and WC

## 4.4 Acid Resistance Test

Table 4: shows the average weight loss for the cubes immersed in HCl

| No. of days of curing in acid (HCl) | Average weight loss (%) | | | |
|---|---|---|---|---|
| | GPC 30 | NSC30 | GPC 40PA | NSC 40PA |
| 7 | 0.18 | 2.02 | 0.12 | 1.65 |
| 14 | 0.11 | 2.34 | 0.22 | 1.90 |
| 21 | 0.46 | 2.91 | 0.13 | 1.89 |
| 28 | 0.25 | 2.77 | 0.13 | 1.88 |

 

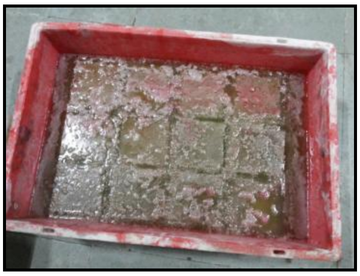

Fig-9 Cubes in acid solution

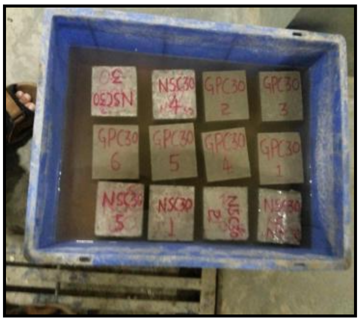

Fig-11 Cubes dipped in NaCl solution


Fig-10 Percentage weight loss versus age

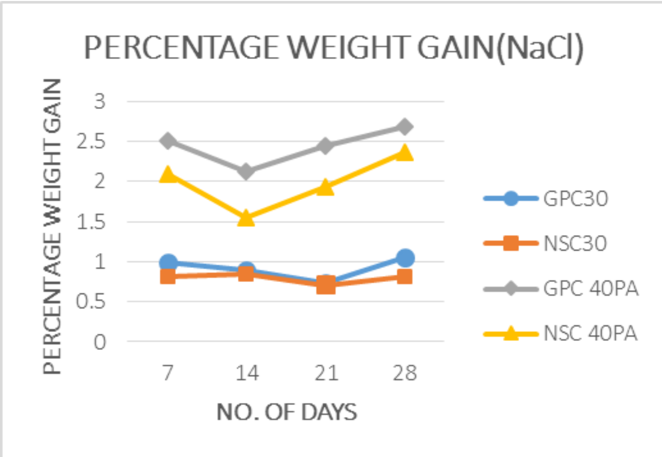


Fig-12 Percentage weight gain versus age

### 4.5 Chloride Resistance Test

Table 5: shows the average weight gain for the cubes immersed in NaCl

| No. of days of curing in Chloride solution(NaCl) | Average weight gain (%) | | | |
|---|---|---|---|---|
| | GPC30 | NSC30 | GPC 40PA | NSC 40PA |
| 7 | 0.99 | 0.81 | 2.51 | 2.09 |
| 14 | 0.90 | 0.85 | 2.13 | 1.55 |
| 21 | 0.73 | 0.71 | 2.45 | 1.94 |
| 28 | 1.06 | 0.82 | 2.69 | 2.36 |

### 4.6 Sulphate Resistance Test

Table 6: shows the average weight gain for the cubes immersed in $MgSO_4$

| No. of days of curing in sulphate solution($MgSO_4$) | Average weight gain (%) | | | |
|---|---|---|---|---|
| | GPC30 | NSC30 | GPC 40PA | NSC 40PA |
| 7 | 0.81 | 0.64 | 1.29 | 1.14 |
| 14 | 0.99 | 0.58 | 1.06 | 0.89 |
| 21 | 0.77 | 0.50 | 1.16 | 0.86 |
| 28 | 0.88 | 0.49 | 1.31 | 0.91 |

Fig-13 Cubes in $MgSO_4$ solution

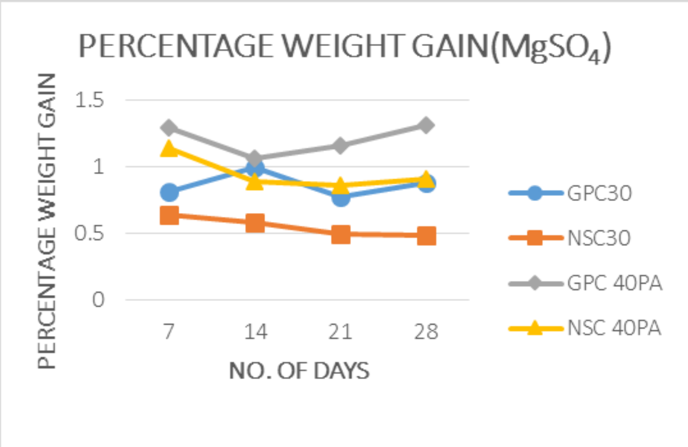


Fig-14 Percentage weight gain versus age

## 5.0 CONCLUSIONS

### 5.1 Conclusion From Strength Results

The main objective of the study was to develop sustainable GPC with the use of fly ash, GGBS, pond ash and M-sand. Compressive strength and durability properties of GPC was compared with that of Normal strength concrete.

The results of compression test on GPC cubes exposed to air curing, indicate that the development of M30 strength can be achieved without curing at high temperature.

It was also observed that GGBS plays a prime role in increasing the compressive strength of the concrete and addition of GGBS in GPC showed better results in case of ambient curing than in heat curing.

It was noticed from the trial mix while obtaining sustainable mix, that higher concentration of sodium hydroxide solution results in higher compressive strength of geopolymer concrete but it should be limited to 16M as higher molar solution costs more.

Higher ratio of sodium silicate-to-sodium hydroxide ratio by mass increases the compression strength of geopolymer concrete and also makes it economical as sodium silicate is cheaper than sodium hydroxide.

### 5.2 Conclusions From Durability Tests

Durability of concrete is equally important to that of strength of the concrete for the structure to have long life. Durability test like acid test (HCl), chloride test (NaCl), sulphate test ($MgSO_4$), fire resistance test and saturated water absorption test were conducted on both GPC and NSC.

Deterioration was more pronounced in NSC specimens immersed in HCl solution. But in case of GPC specimen very minute change was observed.

More weight gain in GPC specimens immersed in NaCl and $MgSO_4$ was observed when compared to that NSC specimens. This is the reason for increase in strength of GPC when tested for 28 days after immersing the specimens in NaCl and $MgSO_4$.

From saturated water absorption test, it can be noticed that SWA of GPC at 28 days is about 10.90% less than that of NSC which may be due to less porous nature of GPC. Even SWA of GPC with 40% PA was about 12.15% less than that of NSC.

From the fire resistance test, it was observed that the GPC cubes showed significant resistance at 300ºC and 600ºC in case of both water and air cooling. Pond ash based GPC showed lesser strength than GPC 30 at both the temperature. It can be observed from the results that GPC is superior to NSC when exposed to higher temperature.

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