# The Effect of Blended Mix ($NaOH$-$Na_2SiO_3$) Over the Compressive Strength Development of Geopolymer Concrete using M-Sand Subjected to Adverse Environments of Acid and Sulphate

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***Abstract—*** This proposed experimental investigation is to obtain the performance of geopolymer concrete (GPC) based on a binary mixture of pozzolonic materials viz, Fly Ash (FA) and Ground Granulated Blast Furnace Slag (GGBFS) in 3 different ratios: 100% (FA), 100% (GGBFS) and 50=50 ratio of both and blended with a mix of sodium silicate and sodium hydroxide solution. All the three different proportions were named as GP-1, 2 &3 mixes respectively. All these mixes were designed to grade 30 (G30) as per IS 10262, with both river sand (RS) and manufactured sand (MS) as fine aggregate and assessing their durability characteristics by compressive load bearing properties upon subjecting FA/GGBFS and Ordinary Portland Cement (OPC) concretes to be immersed in 5% (by weight) Sulphuric acid ($H_2$ $S0_4$) and Sodium Sulphate ($Na_2SO_4$) for a proposed curing period of 28 and 56 days. Standard 100mm cube specimens were involved for attaining the same. All the proposed mix-es were compared with a conventional cement concrete mix (CM) involving both (RS) and (MS). Also, the loss in weight percentage was determined for the various proposed GP and CM mixes, by calculating the weight of specimens at pre and post attack levels of acid and sulphate curing. GP specimens with M-sand showed better resistance to both acid and sulphate environment, exhibiting satisfactory compression values post attack, which was increased by a factor of 46.3% and 16.4% when compared to conventional specimens and GP specimens with river sand as fine aggregate respectively. Test results, prove that GPC as a better option to OPC with respect to both durability and economical aspects in the longer run.

***Keywords- Geopolymer Concrete (GPC), manufactured sand (MS), River sand (RS), Ground Granulated Blast Furnace Slag (GGBFS), Durability, Acid and Sul-phate attack.***

## 1. INTRODUCTION

It has been a universally known that, the conventional cement production viz., Ordinary Portland Cement (OPC), has led to increased utilization of energy and emission of high volumes of CO2 in to the atmosphere. Also, the production rate of OPC and the corresponding CO2 emission rate is approximately in the range of 1:1, i.e. for each ton of OPC being produced, the corresponding carbon dioxide equivalent turns out to be one ton as well.

Geopolymer is an innovative and emerging cement free binding material in-tended to provide a highly durable and eco-friendly substitute for conventional cement concrete viz., Ordinary Portland Cement (OPC). Davidovits (1991) ini-tially coined the term Geopolymer [1]. As the name indicates, geopolymer is syn-thesized from industrial by-products possessing highly pozzolonic characteris-tics, such as Fly Ash, Ground Granulated Blast Furnace Slag (GGBFS), Silica Fume, Rice Husk Ash etc., [2-3] which are rich in silica and alumina having alkaline acti-vators and polymerization of the same. The polymerization reaction is made available by blending alkaline solutions like sodium hydroxide (NaOH), barium hydroxide (BaOH), potassium hydroxide (KOH) etc., along with sodium silicate solution Na2SiO3. However, the predominantly used one is NaOH. 10M molar alkaline NaOH is utilized for this proposed work, which generally varies based on the molecular weight of the component being used. Duxson et al., (2007) [4] studied by their estimated calculation that the energy consumption was reduced up to 60% and also carbonate emissions up to 80% for fly ash-based geopolymer in contrary with that of OPC [5].

Also, the durability characteristics of concrete structures in highly corrosive environment have been noted for a decline at the end of 25-30 years approximately, even when they have been designed for a much higher service life. [6]. Past research has clearly explained with proven results that geopolymer concrete can be comparable in terms of both strength and durability with ordinary portland cement concrete and blended cement concretes [7, 8, 9, 10, 11, 12, 13], whereas durability aspects have been studied and investi-gated for acid attack [14, 15], sulphate attack [16].

## 2. DESIGN ANALOGY

*A. Design Mix Proportion*

Table. I shows the overall proposed mix proportions comprising both the conventional cement concrete as well as the geopolymer concrete mixes [17].

TABLE I. OVERALL MIX PROPORTION

| **Conventional Mix (CM) and Geopolmer Mix (GP)** | | | | | | |
|---|---|---|---|---|---|---|
| **Binder Content** | | | **Fine Aggregate** | | **Description** | **Mix** |
| ***Cement*** | ***GGBFS %*** | ***Fly Ash(FA) %*** | ***M.Sand %*** | ***R.Sand %*** | | |
| 100% | 0% | 0% | 0% | 100% | (RS) Conv. Mix | **CM-1[a]** |
| 100% | 0% | 0% | 100% | 0% | (MS) Conv. Mix | **CM-2[a]** |
| 0% | 0% | 100% | 0% | 100% | (RS) FA Mix | **GP – 1[a]** |
| 0% | 0% | 100% | 100% | 0% | (MS) FA Mix | |
| 0% | 100% | 0% | 0% | 100% | (RS) GGBS Mix | **GP – 2[a]** |
| 0% | 100% | 0% | 100% | 0% | (MS) GGBS Mix | |
| 0% | 50% | 50% | 0% | 100% | (RS) FA/GGBS (50/50) Mix | **GP – 3[a]** |
| 0% | 50% | 50% | 100% | 0% | (MS) FA/GGBS (50/50) Mix | |
| Denotions : **MS** – Manufactured Sand ; **RS** – River Sand ; **FA** - Fly Ash | | | | | | |

a. S. Saravanan and S. Elavenil, "Strength Properties Of Geopolymer Concrete Using M-sand By Assessing Their Mechanical Characteristics," ARPN Journal of Engineering and Applied Sciences., vol. 13, no. 13, pp. 4028-4041, July 2018.

## 3. MATERIALS

This clause defines the various materials involved for the study including the binder materials fly ash and GGBFS, fine aggregate (river sand and manufactured sand), coarse aggregate and the alkaline solution NaOH and $Na_2SiO_3$ mix.

*B. Fly ash*

This investigative study involves low calcium fly ash (class F) as shown in Fig. 1 The chemical and physical properties of the same conforming to IS 3812 – 2003 are tabulated in table II and III [17].

Figure 1. Fly ash [17]

TABLE II. CHEMICAL COMPOSITION OF FLY ASH [17]

| Sample (%) | $SiO_2$ | CaO | MgO | $Al_2O_3$ | $Na_2O$ | $K_2O$ | $Fe_2O_3$ | $SO_3$ | $P_2O_5$ | $TiO_2$ | LOI [a] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Fly ash | 49.45[a] | 3.47[a] | 1.3[a] | 29.61[a] | 0.31[a] | 0.54[a] | 10.72[a] | 0.27[a] | 0.53[a] | 1.76[a] | 1.45[a] |

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TABLE III. PHYSICAL PROPERTIES OF FLY ASH [17]

| S.No | Description | Result |
|---|---|---|
| 1. | Specific Gravity | 2.45[a] |
| 2. | Initial Setting Time | 110[a] |
| 3. | Final Setting Time | 210[a] |
| 4. | Consistency | 33%[a] |
| 5. | Class of Fly ash | Class F[a] |
| 6. | Bulk Density | 1435.28 kg/m$^3$ [a] |

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### C. *Fine and coarse aggregates*

Fine aggregates (of Zone II) passing through 4.75mm sieve was taken after catering to all norms of Indian standards as per IS 383:2016 "Coarse and fine aggregate for concrete specification". Also, Crushed granite stones of size 20mm, passing through 20mm and retained over 14.5 mm sieve were chosen [17]. The comparative physical parameters of both M-sand and river sand are tabulated in table IV. The physical properties of coarse aggregates are shown in table V.

TABLE IV. PHYSICAL PARAMETERS OF FINE AGGREGATE [17]

| Description | River sand | Manufactured sand | Standard limits as per Zone-II as per IS:383-2016 |
|---|---|---|---|
| Specific Gravity | 2.60[a] | 2.64[a] | 2.1 to 3.2 |
| Water absorption (%) | 1.02[a] | 0.05[a] | Not more than 5% |
| Surface Moisture | Nil[a] | Nil[a] | NA |
| Bulk Density (kg/m3) | 1561[a] | 1630[a] | Limit not specified |
| Bulk Density – loose condition (kg/l) | 1.58[a] | 1.63[a] | Limit not specified |
| Bulk Density – compacted condition (kg/l) | 1.77[a] | 1.80[a] | Limit not specified |
| Zone | II[a] | II[a] | NA |

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TABLE V. PHYSICAL PROPERTIES OF COARSE AGGREGATE [17]

| Sl.No | Description | Values | Reference code |
|---|---|---|---|
| 1 | Specific Gravity[a] | 2.72 | IS:2386 – 1963 part-3 |
| 2 | Water absorption (%)[a] | 0.61 | IS:2386 – 1963 part-3 |
| 3 | Surface Moisture[a] | Nil | NA |
| 5 | Fineness Modulus[a] | 2.1 | IS:2386 – 1963 part-3 |
| 6 | % Voids[a] | 39.02% | NA |
| 7 | Crushing value[a] | 27.07% | IS:2386 – 1963 part-4 |

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*D. Alkali Solution* ($NaOH$ & $Na_2SiO_3$)

Flakes of Sodium hydroxide with atmost purity upto 98% were used for the alkaline mix as shown in Fig. 2 and the chemical composition of the same is shown in table VI. On the other hand, sodium silicate was taken directly as it was in solution form. Table VII shows the physical properties of $Na_2SiO_3$. The molar ratio of $SiO_2$ to $Na_2O$ used as '2'. The molarity used for NaOH solution is 10M [17].

Figure 2. Flakes of NaOH

TABLE VI. CHEMICAL COMPOSITION OF NAOH

| Compound | Value |
|---|---|
| Sodium Hydroxide (NaOH) | 99% By Weight, Min. |
| Sodium Carbonate ($Na_2CO_3$) | 0.5% By Weight, Max. |
| Sodium Chlorides (NaCl) | 0.1% By Weight, Max. |
| Iron ($Fe_2O_3$) | 0.004% By Weight, Max. |
| Heavy Metals | 20ppm, Max. |

TABLE VII. PHYSICAL PROPERTIES OF $NA_2SIO_3$

| Technical Specification | Neutral Grade | Alkaline Grade |
|---|---|---|
| Appearance | Hazy colourless | Viscous translucent |
| Total alkalinity ( as $Na_2O$) % by mass, min | 9.00 +/- 1.00 | 15.00 +/-1.00 |
| Soluble silicate as $SiO_2$ | 29 | 33 |
| Total soluble silicate % by mass, min | 38.00 +/-1 | 48 |
| Ratio of total alkalinity (as $Na_2O$) to total soluble silica ( $SiO_2$ : $Na_2O$) | 01:30.20 | 01:02.20 |
| Specific gravity | 40+/- deg.be | 50+/-1 deg.be |

## 4. EXPERIMENTAL RESULTS

### E. *Durability Properties*

As the name indicates the durability checks involve the long term properties linked with concrete specimens subjected to adverse conditions or environment apart from normal cases. In order to investigate the same, durability checks were performed by carrying out acid and sulphate attack tests for concrete cubes of various mixes by keeping them immersed under 5% acid and sulphate solutions for a time period of 28 and 56 days and also their respective loss in weight after the proposed curing time followed by compression value post curing were noted for all mixes.

### F. *Acid Curing*

The testing requirements include preparation of an isolated curing setup comprising a mix of 5 % concentrated sulphuric acid solution over required level of water to immerse the specimens. The tanks are made isolated from other areas of the laboratory as the handling of acids need care. Fig. 3 shows the prepared of acid curing barrel. The specimens are to be placed with care inside the proposed area without splattering of the acid solution. Fig. 4 shows the comparitive graphical plot of the compression values after the 28 and 56 day acid curing period. The properties of fly ash were enhanced as the GP mix with full fly ash showed enhanced compression values followed by other geopolymer mixes, while the conventional mixes were worn out completely by not able to withstand the attack of acid and showed minimum compression values.

Figure 3. Acid curing barrel (comprising 5% Conc. Sulphuric Acid)

The reduction in weight of samples post curing period was recorded to be the highest for cement concrete mix followed by full GGBS mix and the least was noted in fly ash mix. However, strength attainment decreased rapidly over fly ash mix. Also, all mixes pertaining to M-sand experienced lesser % of weight loss when compared to river sand mix in all categories. This proves the ability of the used M-sand to withstand adverse conditions and show improved characteristics when compared to river sand (Fig. 5). Fig. 6a and 6b shows the view of specimens after taken out from curing tank after the curing period and being tested in CTM.

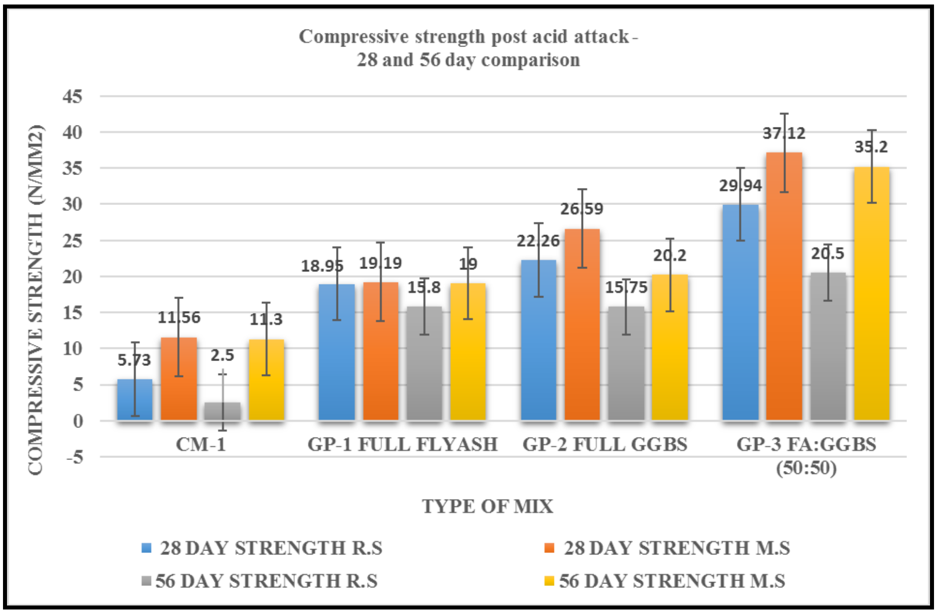



Figure 4. 28 and 56 day compression values post acid attack for various mixes

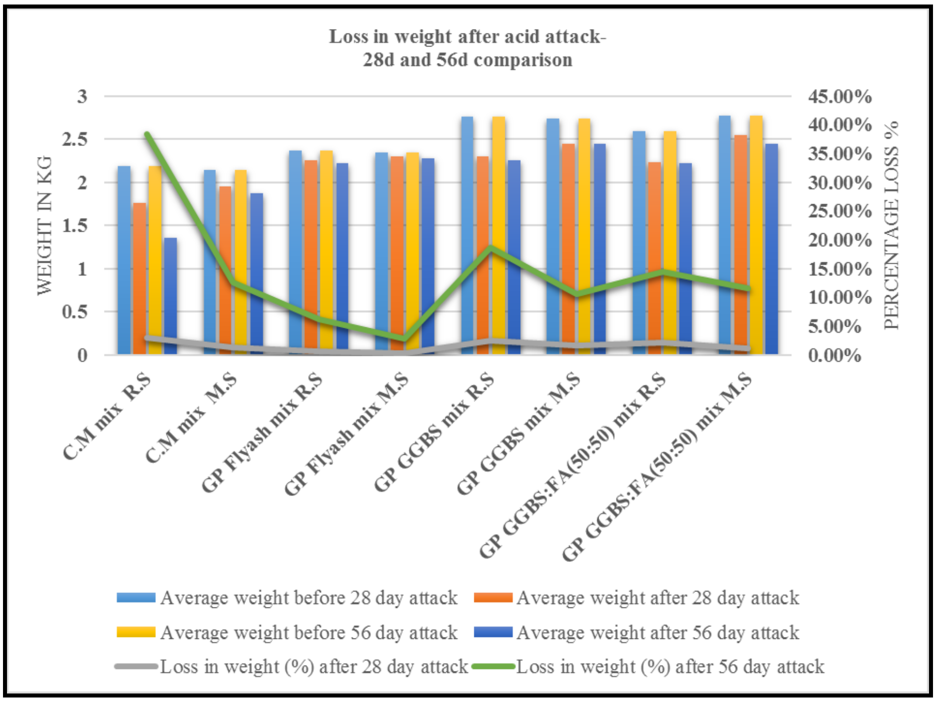



Figure 5. Loss in weight post acid attack after 28 and 56 day acid curing for various mixes

a  b 

Figure 6. (a) Compressive testing of acid cured cube specimen

(b) Cubes after removal from acid curing

*G. Sulphate Curing*

Followed by the acid curing, this methodology is carried out to know the resistance of specimens towards sulphate attack by subjecting the specimens over a solution made of 5% sodium sulphite powder over the calculated quantity of water required to immerse the specimens completely. Unlike acid curing, sulphate curing doesn't require special handling equipment as it doesn't harm directly. The intrusion of sulphate levels in to the specimen is known by measuring the loss in weight and compression values post completion of the proposed time period of curing viz., 28 and 56 days.

Unlike acid attack, sulphate showed minimum wear and tear over the specimens and the specimens showed nominal compression values as per the required level after nominal 28 and 56 day ambient curing period (Fig. 7). This proves the enhanced durability property of GP and CM mixes to sulphate attack. The loss in weight was also minimum in all the mixes with almost negligible and within the acceptable tolerance level for conventional and geopolymer mixes (Fig. 8). Fig. 9a shows the specimens upon removal from sulphate curing tank after the proposed curing period and prior to testing for compression (Fig. 9b).

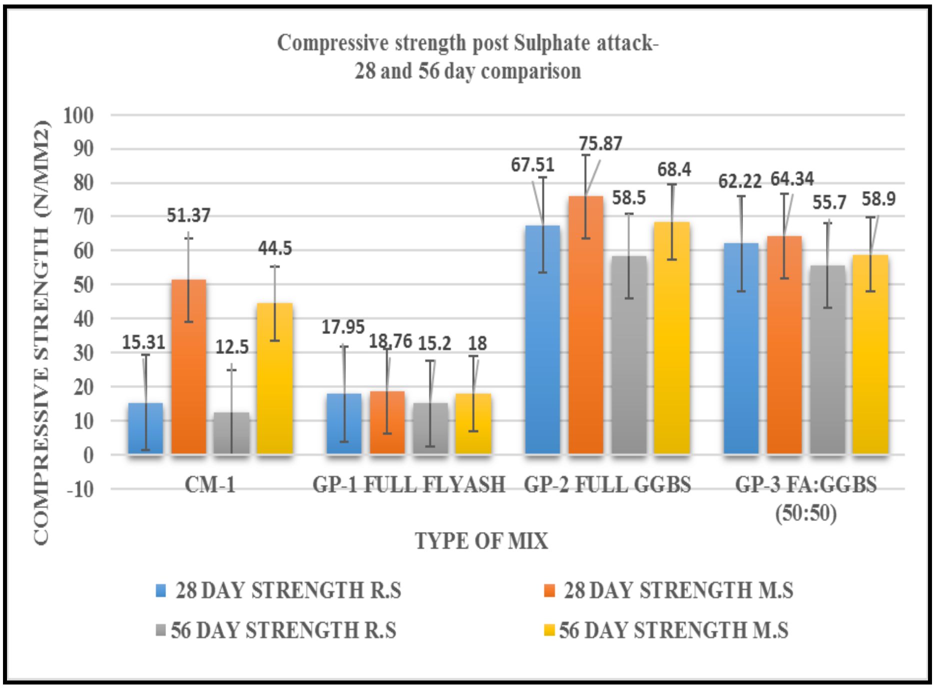



Figure 7. 28 and 56 day compression values post sulphate attack for various mixes


Figure 8. Loss in weight post sulphate attack after 28 and 56 day sulphite curing for various mixes

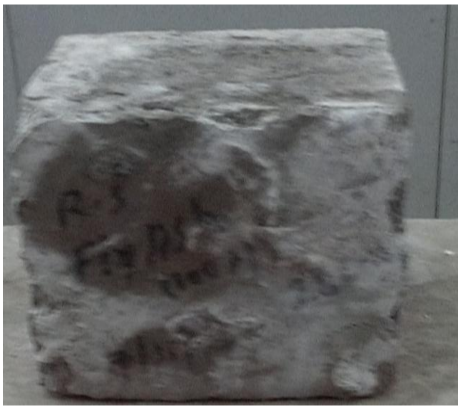
a  b 

Figure 9. (a) Cubes after removal from sulphate curing

(b) Compressive testing of sulphate cured cube specimen

## 5. DISCUSSION

*H. Durability Properties*

- Irrespective of the mix proportion, all the proposed geopolymer mix samples responded well when compared with conventional cement concrete with respect to acidic exposure, which was evident by the complete surface deterioration of the latter samples and also exhibiting negligible compressive strength values post-curing period.

- Also, the compressive strength post-attack of both acid and sulphate over all the mixes (GP and OPC) showed comparatively better values for ones involving manufactured sand as a fine aggregate when compared with the mixes involved river sand. This increase in value post-acid curing varied in the range 64.15%, 9.05%, 19.16% and 30.55% respectively for conventional, GP-1, GP-2 and GP-3. Similarly this variation with respect to sulphate attack varied as 71.05%, 9.94%, 12.75% and 4.36% respectively for conventional, GP-1, GP-2 and GP-3.

- As mentioned earlier regarding the surface deterioration of cement concrete samples over acidic exposure, this was resulting extensive loss in weight of the same which was comparatively lesser for the geopolymer concrete samples and hence showing the poor resistance of the former towards the acidic environment. However, the sulphate exposure didn't make predominant changes in the weight and surface deviations of both cement concrete and geopolymer samples and also showing satisfactory compressive strength values post-attack of the same.

- The average percentage increase in weight loss after 28 and 56-day acid attack for RS involved specimens with respect to MS involved ones for all mix types were in the range 63.46%, 55.72%, 40.64%, and 31.39% respectively for conventional, GP-1, GP-2 and GP-3. Similarly, post sulphate attack the percentage weight loss was in the range of 53.89%, 13.15%, 79.47%, and 24.36% respectively for conventional, GP-1, GP-2 and GP-3 respectively.

## 6. CONCLUSSIONS

- The manufactured sand involved in this research work as a replacement for fine aggregate after being subjected to all required tests for quality as per Indian standards showed enhanced performance in terms of strength aspects for both cement concrete and geopolymer mixes. Also, the areas in which geopolymer mix showed certain low values of strength with respect to cement concrete mix, experienced comparatively reduced levels of decline for the mix consisting M-sand rather than one having river sand. On the whole, the optimum level of re-placing manufactured sand as fine aggregate has been considered 100% for both cement concrete and geopolymer concrete mixes.

- Enhanced durability characteristics were noted for all three types of GP mix samples, which were more satisfactory than the conventional cement concrete mix samples which showed negligible compressive strength values post-acid and sulphate attack. Also, the compressive strength post-attack of both acid and sulphate over all mixes showed enhanced peaks for M-sand based mixes than the river sand based mixes and thereby showing the ability of the M-sand to withstand adverse conditions and provide better bondage with the binder.

- Control of carbon emissions by using ecofriendly materials for construction being the need of the hour, as a concluding statement, an emerging material viz., geopolymer concrete has been proposed which would replace the existing ce-ment concrete effectively in terms of strength and durability. Also, the conven-tional fine aggregate (river sand) which is becoming unavailable due to many legislations and environmental issues, has been suggested to be replaced with the proposed alternate material viz., M-sand, which was evident to serve the purpose with enhanced values of strength and durability from the tests and stud-ies conducted from this research work.

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