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# STRENGTH PROPERTIES OF GEOPOLYMER CONCRETE USING M-SAND BY ASSESSING THEIR MECHANICAL CHARACTERISTICS

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**ABSTRACT**

Geopolymer concrete (GPC) is a latest innovation in the construction sector and an environment friendly construction material obtained as a result of polymerization chain reaction of inorganic molecules comprising of readily available materials like low calcium fly-ash and Ground Granulated Blast Furnace Slag (GGBFS). Suitable mix of the same is prepared by adding a blended alkaline solution of ($NaOH$ + $Na_2SiO_3$). The alkaline solution of various molarities are chosen based on the molecular weight of NaOH, here this research work involves usage of 10M sodium hydroxide solution. Also, the demand for river sand (RS) has gone in great hike and ultimately become costlier and scarce in availability on account of various acts and legislations confronting illegal dredging of the same. In such a case, Manufactured sand (MS) is an economic alternative to river sand in concrete. The ultimate objective of this research paper is to focus the eco-friendly alternative material for cement and river sand by introducing Geopolymer concrete with manufactured sand as a complete replacement for fine aggregate and thereby assessing the strength properties by establishing their mechanical properties and comparing the same with nominal cement concrete mix (CM). Concrete mix design of G30 was done based on Indian standard code (IS 10262). Concrete cubes and cylindrical specimens were casted and tested for attaining the mechanical properties at two curing time period of 28 and 56 days, by varying the percentage of binder as 100% Fly ash (GP-1) and GGBFS (GP-2) each, and in the ratio 50:50 (GP-3) of the same.It was seen that, all mix involving M-sand as fine aggregate showed increased compressive strength results irrespective of the binder replacement. The increase in compressive strength from RS to MS was in the range of13.56% and 13.07% at 28 and 56 day curing period respectively for all the three GP mixes. However, conventional concrete mix involving OPC showed increased strength with river sand mix. Unlike compression test results, split tensile values showed strength hike from RS to MS for only two mixes (GP-2 and GP-3) in the range 9.34% and 9.04% at 28 and 56 day curing period respectively. The areas and tests involving decline in strength characteristics of GP with respect to conventional ones showed much reduced levels of decline in case of m-sand mix in contrary with that of the river sand mix. Test results, therefore, confirm that M-sand replacement by 100% is effective and considered nominal. Also, the GPC being the better option to OPC in the longer run both economically and with respect to environment friendly aspects reducing the carbon footprint up to 80%.

**Keywords:** geopolymer concrete (GPC), ordinary portland cement (OPC), manufactured sand (MS), river sand (RS), ground granulated blast furnace slag (GGBFS), alkaline solution (NaOH)

## INTRODUCTION

The at most issue related to excess consumption of cement is the emission of $CO_2$ and other greenhouse gases ultimately leading to environmental degradation. Global warming being the need of hour and which in turn has made the world's industrialists to make efforts underway to enhance eco-friendly construction materials, conserving the rapid exhaust of natural non-renewables. A study reveals, the annual emission rate of carbonate burns in cement industries contributes around five to eight percent of the world's greenhouse gas emissions and also it has become the second largest consumable next to water. Assessing the current scenario, polymer based concrete has become the most viable choice to look after as an alternate to conventional ordinary Portland cement concrete (OPC).To start with the carbonate footprint contributed every year, statistical data reveals that every year, ordinary Portland cement (OPC) production increases by 2.6 billion tonnage. Also, for every single ton quantity of cement produced, the amount of carbonate burns emitted equals the same quantity of produced raw material. At the same time the by-product materials like fly ash, GGBFS, metakaoline, rice husk ash, silica fume etc, generated from various industries have rapidly increased and not being effectively utilized. It is usually being buried as landfills which in turn has affected many aquifers and fresh water sources leading to many disposal problems. Proven studies reveal that the greenhouse emissions are minimized up to 80% by the application of Geopolymer concrete in contrary with the OPC, since it doesn't involve any carbonate burns in it. On account of this, Geopolymers are showing great potential and various research has been proposed by examining their viability as a binding material.

The concept of polymer based concrete was invented by chelokovski in 1950 and later it was coined as Geopolymer by a French professor Davidovits in 1978.Geopolymer Concrete is an innovative material replacing conventional concrete which does not involve any quantum of OPC as a binder, rather the binding properties are produced by the reaction of an alkaline liquid along with a source material rich in silica and alumina. These silica and alumina gets mainly dissolved in the alkaline activator (NaOH) solution and polymerization process is undergone then.

Also, the availability of the river sand has reached an alarming state in the current scenario and has created a huge demand for the same in construction sector and it has led to an ecological imbalance. So there is a need for using 'clean sand' in the construction industry. As the exhaustion of river sand, manufactured sand is an alternative to the river sand for solving the demand problem. At present, various projects including major government sectors around the world have insisted the use of manufactured sand looking forward for its consistent gradation and zero impurity.

## REVIEW OF LITERATURE

C. Sashidar *et al*. investigated the fresh and hardened properties of self-compacting geopolymer concrete (SCGC) made of GGBFS and fly ash (FA) in the ratio 50:50 by varying the molarity of sodium hydroxide (NaOH) between 8 to 12M under ambient room temperature. It was inferred that, increase in molarity of NaOH decreased the fresh properties and increased the strength aspects of SCGC. Addition of GGBFS made the mix to attain early strength at ambient room temperature. No adverse effects were noticed on replacement of manufactured sand for conventional river sand [1].

J. Gomathi and J. Doraikannan studied the modern construction material Geopolymer concrete (GC) and also analyzed the scarcity experienced in the availability of river sand and thereby making an effective alternate by involving manufactured sand (MS) in various proportions and determining the mechanical properties by obtaining test results on flexure, split tensile and modulus of elasticity. The ultimate aim of this research was to determine an optimum replacement level of MS in GC. It was inferred that, proportion of m-sand was directly proportional to the workability. Maximum value on split tensile strength and compressive strength was obtained as 4.2 and 29.8 respectively at 75% replacement of MS by river sand. Hence it was concluded as 75% was the optimum effective replacement level for river sand by MS [2].

R. Janani and A. Revathi studied the concept behind the innovative concept on geopolymer concrete (GC) which uses fly ash (FA) instead of cement for the binding property. The alkaline solutions NaOH and $Na_2SiO_3$ were forming a gel like substance on reaction with fly ash which contributed for the binding property. Also they studied the alternate type of geopolymer obtained with m-sand which is an alternate for river sand which is under great demand and scarcity. The strength properties were analyzed between nominal and alternate geopolymer concrete (GC). It was evident that, the compressive, tensile and flexural test results of the casted cubes were increased in the order of 9%, 12% and 10% respectively when MS was fully replaced for river sand (RS). Hence it was concluded as geopolymer concrete as an effective alternate for conventional concrete which involves use of Portland cement and thus leading to decreased pollution by reducing carbon emissions [3].

M.I. Abdul Aleem and P.D. Arumairaj, investigated polymer based geopolymer concrete using m-sand. The SEM images of fly ash and manufactured sand were verified in this study. It was also shown that, the various mechanical properties like compressive, split tensile and flexural strength test results of geopolymer concrete with m. sand were increased in the order of 136%, 50% and 100 % respectively with respect to nominal concrete. Hence it was concluded as geopolymer concrete with m. sand as an effective alternate for conventional concrete which involves use of Portland cement and thus leading to effective usage of waste artificial materials which leads to dumping problems leading to environmental degradation [4].

S. Nagajothi and S. Elavenil made a study on the strength assessment of geopolymer concrete (GC) involving low calcium fly ash as a replacement for binding material and artificial material m. sand for conventional river sand. Concrete mix design for the range of M30 was made as per Indian standard code (IS10262). Concrete cube specimens (100x100mm) and cylinders (150x300mm) were casted and their respective mechanical properties were assessed for 7 & 28 day curing periods by varying the percentage of m. sand as 0%, 20%, 40%, 60%, 80% and 100% in the mix and the optimum percentage replacement was determined. The compressive strength and split tensile results increased with increased proportions of m. sand over river sand in the mix. It was concluded that optimum percentage was complete replacement of river sand by m. sand (100%) [5].

Pattanapong Topark-Ngarm *et al*. made a special variety of geopolymer concrete by using special grade fly ash with higher calcium content obtained from the ash waste left overs of the Mae Moh power plant from northern Thailand. The aspects like bond, setting time and strength aspects were analyzed for different molarities. Curing methodology utilized were of two strategies namely heat curing 60 ±2°C for 24 hour time period, while the other one being conventional curing at 23± 2°C.The results proved that usage of high-calcium based fly ash, gave increased strength values along with greater bonding characteristics between the concrete and rebar. Also, the fresh properties of the same showed that the setting time was reduced in the range of 28-50minutes, as the level of calcium content in the mix was high. All mechanical properties were significantly high in high calcium geopolymer concrete for the mix pertaining to 15 molarity NaOH solution. when compared to that of nominal concrete [6].

Gaurav Nagalia et al. involved different alkali solutions like NaOH, KOH, $Ba(OH)_2$ for making geopolymer concrete by blending both class C fly ash (9.42% Calcium oxide) and class F (1.29% Calcium oxide) and specimens were casted and cured in different experimental conditions. Also a different methodology namely X-ray diffraction (XRD) and scanning electron microscopy (SEM) was involved to identify geopolymeric matrix. They inferred that the microstructural properties played a major role on the compressive strength and setting time values. It showed that high CaO content in the fly ash resulted in geopolymer concrete of increased strength. Also, the results showed that, NaOH in

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comparison with other alkali solutions showed significant results in terms of mechanical properties comparable to Ordinary Portland Cement (OPC). The research also involved microstructural level study involving usage of X-ray diffracted image and scanning electron microscopy analysis along with dispersive spectroscopy. The results showed the formation of $NaAlSi_3O_8$ feldspar and water causing hydration of silicates resulting in increased compressive strength characteristics [7].

David W. Law *et al.* studied determination of the durability characteristics of geopolymer concrete such as water sorptivity, chloride diffusion, carbonation, and rapid chloride permeability etc, based on the alkalinity ratio between the alkali solutions (NaOH & Na2SiO3) which was in the range between 0.75-1.25. Microstructure analysis was obtained by scanning electron microscopy (SEM images). Significant increase in strength parameters for alkali ratio 0.75 to that of 1.25, which has been concluded as a result of increased dissolution of fly ash particle in the mix due to increased alkalinity and reaction rate. Also, the results on rapid chloride diffusion showed almost similar values for all geopolymer concrete (GC) mixes and were comparable to that of Portland concrete. Carbonation testing showed that initial pH value in GC was lesser in contrary to that of OPC but however in the long run after carbonation, the final pH was optimum in protecting the reinforcement within the mix. The results proved that, the mixes having alkali ratios of both 1.00 and 1.25 showed similar durability properties comparable to ordinary cement concrete, while the mix with 0.75 ratio depicted reduced durability characteristics. However, as a concern over long run, it has been suggested that the GC with alkali ratio 1.00 and 1.25 as an optimum range with respect to corrosion by chloride attack over the reinforcements as a result of long term chloride diffusion coefficient [8].

M. Albitar *et al.* investigated on the hardened and fresh properties of geopolymer concrete (GC) using fly ash of class F. The study involved making various trial mixes to determine optimum water to binder ratio and superplasticizer to binder ratio and their effects on workability and strength aspects of the GC. The research work involved use of naphthalene sulphonate polymer based superplasticizer and determination of split tensile, flexural characteristics and modulus of elasticity of the proposed concrete mix and comparing the same with the predicted ordinary portland cement concrete (OPC). Naphthalene sulphonate polymer based superplasticizer didn’t exhibit significant effect over workability (slump), but still showed adverse effects on the strength aspects of the mix. The various results on the mechanical properties showed improved values in contrary with OPC. Also, the elastic modulus and poisson’s ratio of the GC were similar to that of OPC. It was concluded that the stress-strain curve of conventional concrete can be used with acceptable accuracy to assess the stress-strain curve for the proposed mix [9].

Zvezdana Basˇcˇarevic *et al*. studied the resistance level of aluminosilicate based geopolymer concrete mixes (GC) made of two types of fly ash samples to sulphate attack by the aid of Na2SO4 solution for a 365 day time period. Analysis of the same was carried out using optical emission spectroscopy which resulted in evolving a new compound namely aluminosilicate gel, silicon. It was seen that geopolymer subjected to sulfate solution made the breaking of –Si–O–Si– bonds in the aluminosilicate gel structure. The GC mix subjected to sulphate attack experienced around 10% decreases in the strength parameters. Reduced strength characteristics for GC mix which was less porous were observed only at the end of 365 days but however the highly porous mix showed decrease in strength at the end of 28 day testing itself. The intrusion of sulphate ions in to the mix caused leaching of Na and Si from the concrete mix as a result of increase in pH in the mix during the attack of Na2SO4 solution [10].

## MATERIALS AND THEIR PROPERTIES

Design quantity values

| | | |
|---|---|---|
| Binder content | = | 380.66 Kg/m$^3$ |
| Coarse aggregate | = | 1386 Kg/m$^3$ |
| Fine aggregate | = | 462 Kg/m$^3$ |
| Sodium hydroxide | = | 62.66 Kg/m$^3$ |
| Sodium silicate | = | 156.65 Kg/m$^3$ |
| Superplasticizer | = | 3.04 Kg/m$^3$ |
| Mix proportion | = | 1: 1.21: 3.64 (Binder: Fine aggregate: Coarse aggregate) |

### Overall mix proportion

The following Table-1 shows the overall nomenclature of the mixes proposed and their denotations based on the fine aggregate and binder replacements.

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**Table-1.** Overall mix proportions.

| Conventional mix (CM) and Geopolymer mix (GP) | | | | | | |
|---|---|---|---|---|---|---|
| **Cement** | **GGBFS %** | **Fly ash (FA) %** | **M.sand (MS) %** | **R.sand (RS) %** | **Description** | **Denotations** |
| **Binder** | | | **Fine aggregate** | | | |
| 100% | 0% | 0% | 0% | 100% | R.S. Conv.mix | CM-1 |
| 100% | 0% | 0% | 100% | 0% | M.S. Conv.mix | CM-2 |
| 0% | 0% | 100% | 0% | 100% | R.S. F.A mix | GP - 1 |
| 0% | 0% | 100% | 100% | 0% | M.S. F.A mix | |
| 0% | 100% | 0% | 0% | 100% | R.S.GGBS mix | GP - 2 |
| 0% | 100% | 0% | 100% | 0% | M.S.GGBS mix | |
| 0% | 50% | 50% | 0% | 100% | R.S. FA:GGBS(50:50) mix | GP - 3 |
| 0% | 50% | 50% | 100% | 0% | R.S. FA:GGBS(50:50) mix | |
| Denotions: M.S - Mechanical sand; R.S - River sand; FA - Fly ash | | | | | | |

**Fly ash**

Generally, two types of flyash such as Class C and Class F are available in market and thereby used relatively according to the type of concrete mix under study. This research work involves low calcium fly ash (class F) as shown in Figure-1. The chemical and physical properties of the same conforming to IS 3812 - 2003 are tabulated in Table 2 and 3.

**Figure-1.** Fly ash powder sample.

**Table-2.** Chemical composition of Fly ash.

| 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 | 3.47 | 1.3 | 29.61 | 0.31 | 0.54 | 10.72 | 0.27 | 0.53 | 1.76 | 1.45 |

**a-Loss of ignition**

**Table-3.** Physical properties of Fly ash.

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

**Alkali solution (NaOH & $Na_2SiO_3$)**

The alkaline nature in the concrete mix for polymerization chain reaction to happen is maintained by the use of sodium hydroxide and sodium silicate mix. The solution of NaOH is prepared by dissolving the calculated quantity of pellets in one litre of water which is based on the molarity (M) of solution chosen.10M NaOH solution was taken for this investigation. The molar ratio of Si to Na used was 2. The final blending of both sodium hydroxide and silicate solution was prepared 1 hour prior to mix and it is as shown in Figure-2.

**Figure-2.** Blended alkali solution (NaOH and $Na_2SiO_3$).

**Fine aggregate**

Fine aggregate was utilized by both river and manufactured sand (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". The physical parameters of both are shown in Table-4.

**Table-4.** Physical parameters of Fine aggregate.

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

**Coarse aggregates**

Crushed granite stones of size 20mm and a specific gravity of 2.73 chosen as coarse aggregate. Aggregates passing through 20mm and retained over 14.5 mm sieve was chosen as shown in Figure-3. Table-5 shows the properties of coarse aggregates.

**Figure-3.** Coarse aggregate sample 20mm passed and 14.5mm retained.

**Table-5.** Physical parameters of fine aggregate.

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

**Super plasticizer (SP)**

As the mix pertaining to Geopolymer mix is not involving any water content in it, the viscousity required is provided only from the alkaline solution added, hence suitable superplasticizer (CONPLAST-430) is added to the mix as shown in Figure-4. The physical and chemical properties of the same is shown in Table-6.

**Figure-4.** Superplasticizer sample (CONPLAST-430).

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**Table-6.** Physical and Chemical composition of Superplasticizer.

| S. No. | Description | Results obtained |
|---|---|---|
| 1. | Appearance | Brownish lazy liquid |
| 2 | pH | 6.00 |
| 3 | Specific Gravity | 1.20 to 1.22 @ 300°C |
| 4 | Total Solids | 45% |
| 5. | Chloride content | Nil |
| 6. | Air entrainment | Approx. 1% additional air is entrained |

## CASTING OF SPECIMENS

### Mixing

The selection and proportioning of both fine and coarse aggregates were made in accordance with making of conventional OPC concrete. The aggregates and binder (Fly ash/GGBS) were mixed initially dry in the laboratory mixer for about three to five rotations until all the coarse aggregate became well bonded with the binder and fine aggregate particles, as shown in Figure-5. The liquid component of the mix (i.e.), NaOH - $Na_2SiO_3$ - SP mixture was added then followed by three to five rotations.

(a) (b)

**Figure-5.** (a) Dry mix of R-sand aggregate-binder mix (b) Dry mix of M-sand aggregate-binder mix.

### Placing

The fresh fly ash based geopolymer concrete mix was sufficiently handled for a period of atleast two hours without any sign of setting and degradation in initial strength parameters. In contrary, the fresh GGBFS mix attained its initial setting in quick succession of within 5 minutes. However the retarding agents were suitably used in order to make the mix to be workable until being placed. Whereas the mix pertaining to (50:50) proportion of Fly ash and GGBFS was comparatively workable and stable for a period of 15 to 20 min. The concrete mix prior to placing over moulds is shown in Figure-6.

(a) (b)

**Figure-6.** (a) Full Fly ash based Geopolymer mix (b) Full GGBFS based Geopolymer mix.

### Casting

Casting pertaining to total 8 mixes were scheduled and casted periodically starting initially with conventional concrete specimens comprising of nominal OPC as binder and nominal water cement ratio of 0.35 was employed in this case. This was followed by full GGBS and GGBS-Fly ash (50:50) proportion mixes, which comprises of binder being replaced with GGBS and Fly ash as 100% and 50% respectively and also each of the same being designed for both river sand and M-sand as

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fine aggregate.A total of 112 cubes (100x100x100mm), 64 cylinders (100x200mm) and 32 big cylinders (150x300mm) were casted.Each mix comprises of 14 cubes (7no. for 28 day and 7 no. for 56 day); 8 cylinders (4 no. for 28 day and 4 no. for 56 day) and 4 big cylinders (2no. for 28 day and 2 no. for 56 day). Figure-7 shows the finished moulds after placing concrete.

(a) (b)

**Figure-7.** (a) Finished cube moulds with fresh concrete (b) Finished cylinder moulds with fresh concrete.

**Curing**

The specimens upon demoulding were subjected to oven curing for a period of 24hours by maintaining a constant temperature of 60°C. This ambiance is provided in order to accelerate the polymerization reaction within the specimens as soon as demoulded. Later, the specimens were kept in ambient room temperature (25 ± 2°C) for rest of the curing period up to 28 and 56 day time period. The view of specimens under oven curing is shown in Figure-8 and the view of specimens kept in ambient room temperature is shown in Figure-9.

(a) (b)

**Figure-8.** (a) Oven under operation at 60°C (b) Specimens arranged inside oven for a period of 24 hours.

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(a) (b)

**Figure-9.** Specimens kept under ambient curing room temperature (25±2°C).

## EXPERIMENTAL TESTING AND RESULTS

### General

This chapter presents the results of the experimental thesis work carried out with both Conventional (OPC) and Geopolymer mixes (GPC) as explained in the earlier chapters. The various mechanical and durability properties of the casted specimens under various tests after achieving desired strength post curing, over the proposed time period of 28 and 56 day span are depicted in detail with suitable graphical plots.

### Testing parameters

### Mechanical properties

The mechanical properties involved determination of strength by carrying out compression test, split tensile test and modulus of elasticity for the casted cubes and cylinders at 28 and 56 day time period.

- **Compressive strength**

The cube specimens were tested under monotonic loading increasing stepwise until failure. The rate of loading was in the range of 1.0mm/min. the capacity of the Compressive testing machine (CTM) was 2000kN. The specimens were placed centrally along their axis over the loading plate. Figure-10 shows the experimental setup of cubes under compression test. Figure-11 shows the comparison of compressive strength at 28 and 56 day over the various mixes and it was clearly shown that all mix involving M-sand as fine aggregate showed increased compressive strength results irrespective of the binder replacement. However, conventional concrete mix involving OPC showed increased strength with river sand mix, showing enhanced behaviour of cement involved mix with river sand when compared with manufactured sand. This proves the better bonding of river sand when cement was the binder material. The important property of Geopolymer mix in contrary with conventional mix is that, the 28 day ultimate strength is easily achievable within a short span of 24 hours and also there wasn't much increase in 56 day strength after reaching the ultimate strength after 28 days. The average increase in strength from 28 to 56 day strength for all Geopolymer mixes was 12.46% and 11.04% for R.S and M.S. mixes respectively. In contrary it differed in the range 0.5% and 10.2% for R.S and M.S. respectively for the conventional mix.

Also it was proven that the compressive strength of Geopolymer mix was much higher than the conventional concrete mix for two mixes involving 100% GGBS and Fly ash - GGBS (50:50) proportion as binder replacements. The mix pertaining to full fly ash (100%) was not able to exhibit any comparable result due to its poor binding nature when it is used completely without any aiding compounds as fly ash lacks lime content, which forms the major constituent for imparting strength properties and making the binder sound. Also, fly ash used in this research has excess quantity of alumina ($Al_2O_3$ - 29.61%) above the limits allowable for conventional binder (3-8%), which makes the binder weak and unsound.

**Figure-10.** Experimental setup for compressive strength assessment.

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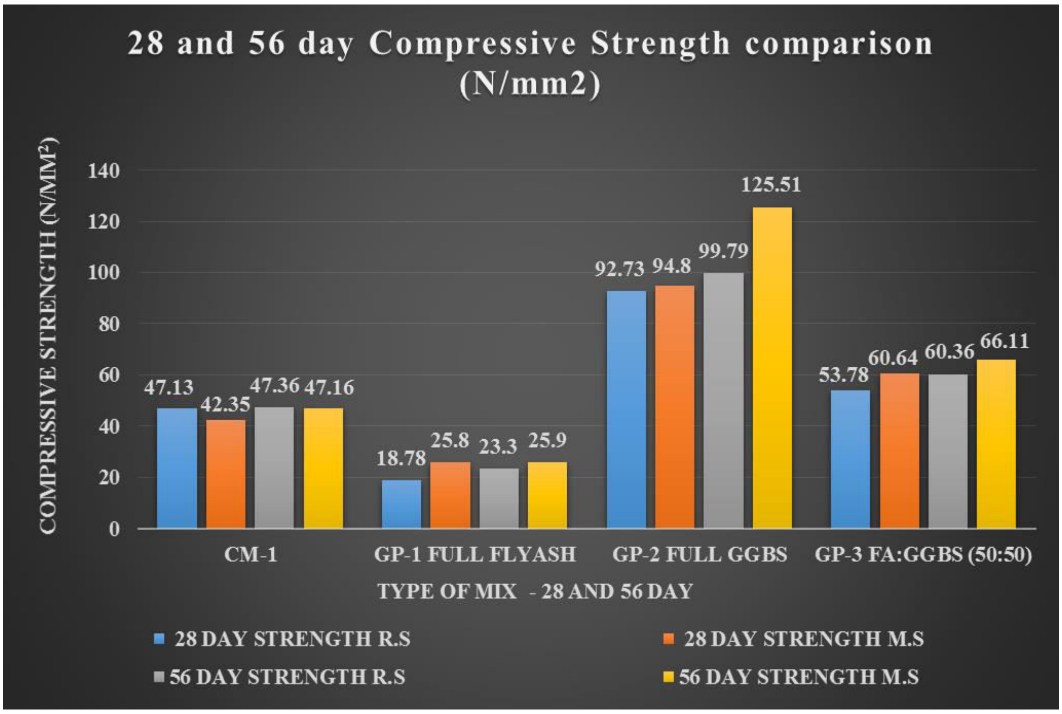
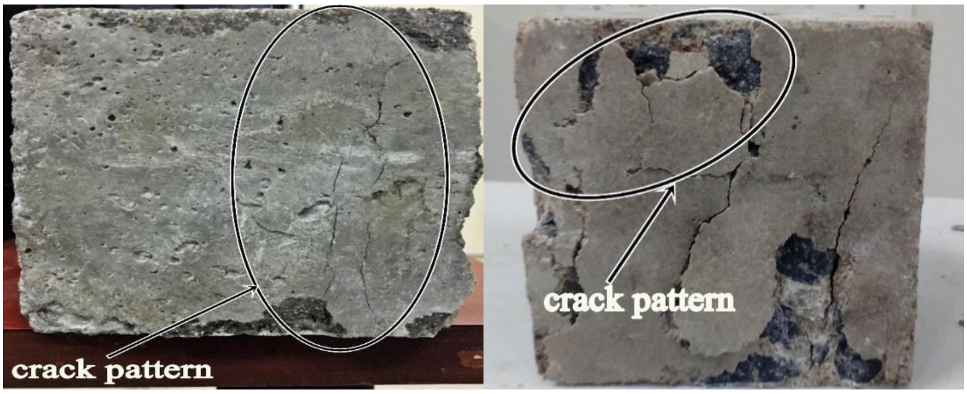



**Figure-11.** 28 and 56 day compressive strength comparison for various mixes.

The typical failure mode exhibited for various mixes were noted and typical shear failure across the surface boundaries occurred for conventional mixes (CM-1&2) and for full GGBS mixes (GP-2) as shown in Figure-12. Whereas brittle failure occurred for full fly ash mixes (GP-1) and mix corresponding to FA: GGBS (50:50) (GP-3) as it contains fly ash having excess quantity of iron oxide ($Fe_2O_3$ - 10.72%), which is above the permissible limits (5-6%) and hence reducing the hardening properties of the binder and hence leading to easy disintegration as shown in Figure-13.




(a) (b)

**Figure-12.** (a) Surface crack pattern of conventional concrete cube sample (CM-1&2) (b) Surface crack pattern of Full GGBS GPC cube sample (GP-2).

(a) (b)

**Figure-13.** (a) Brittle crack pattern of Full Fly ash concrete cube sample (GP-1)
(b) Brittle crack pattern of Fly ash: GGBS (50:50) GPC cube sample (GP-3).

- **Split tensile strength**

The cylindrical specimens were tested for splitting tensile strength check by applying progressive load across the longitudinal section of the cylindrical specimen. The specimen was tested over the compressive testing machine (CTM) of 2000kN capacity by placing suitable base plates above and below the specimen making uniform loading area longitudinally in order to make a uniform splitting of the specimen across its longer edge. Figure 14 shows the split tensile experimental setup made. Similar to compressive strength values, splitting strength also showed increase in strength for M-sand mixes in all Geopolymer mixes (GP). However, conventional concrete exhibited increased values for mix involving river sand as fine aggregate.

**Figure-14.** Experimental setup for split tensile strength assessment.

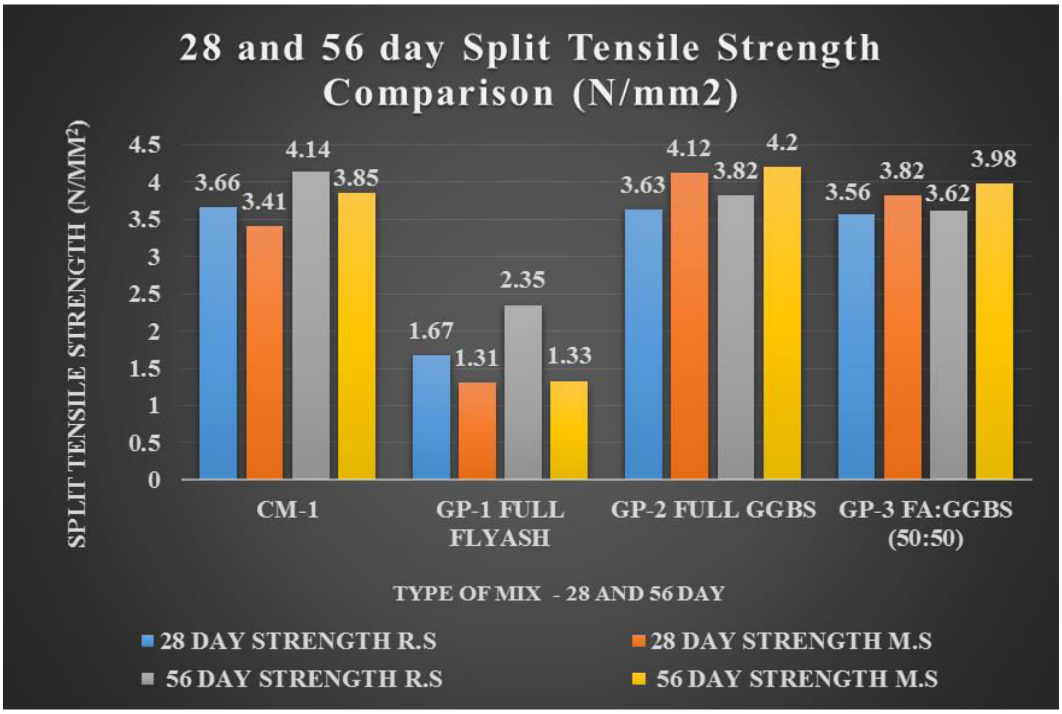



**Figure-15.** 28 and 56 day split tensile strength comparison for various mixes.

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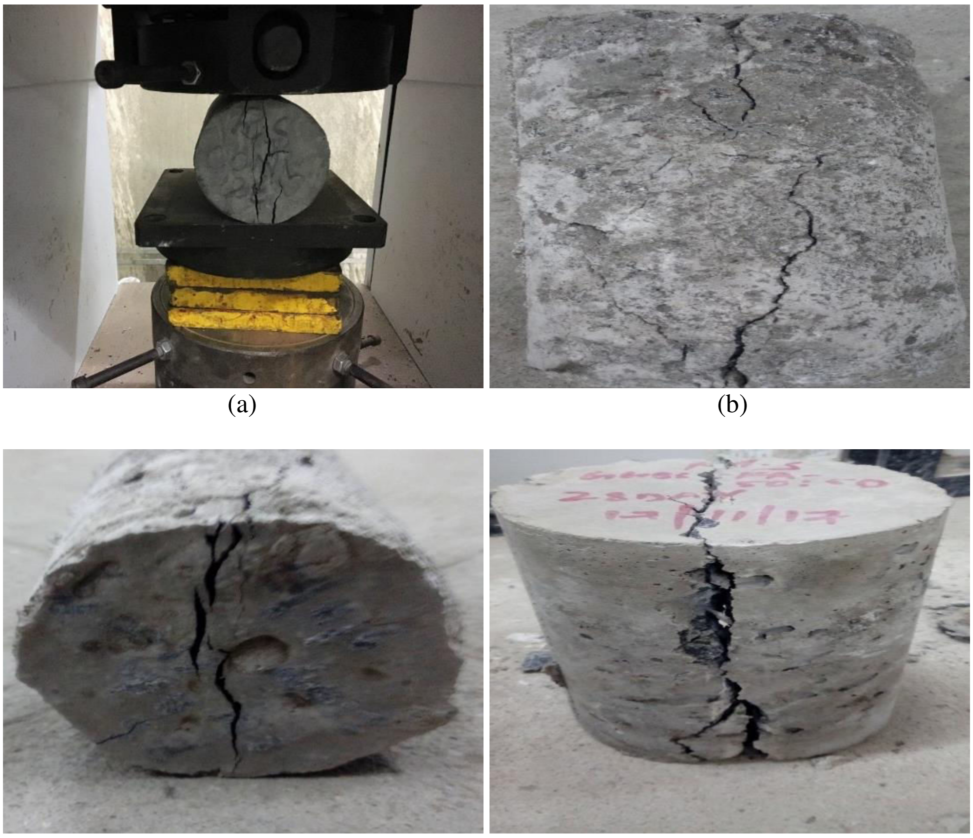
The above Figure-15 shows the graphical plot comparison of the 28 and 56 day split tensile strength of various mixes. The splitting of specimens for the various mixes is shown in Figure-16. The splitting tensile strength of conventional and GP-1 mix showed an average decline in strength for 28 and 56 day from R.S to M.S. in the range of 6.91% and 32.4% respectively. Also, GP-2 and GP-3 mixes exhibited an increase in strength from R.S to M.S in the range 10.47% and 7.92% at 28 and 56 day respectively. This clearly shows the ability of GP concrete to withstand tensile loading and perform better than conventional mixes.



(a) (b)

(c) (d)

**Figure-16.** (a, b) Split ends of cylinder specimens - Conventional and Full Fly ash mix (CM & GP-1) (c, d) Split ends of cylinder specimens - Full GGBS and Fly ash: GGBS mix (GP-2 &3).

- **Modulus of elasticity**

Modulus of elasticity is defined as the stress of the material by stain of the material when the load is applied. As per IS 516:1959 the young's modulus of elasticity is determined by casting cylinder specimens (150x300mm) properly compacted without any voids or honeycomb formation over its surface. Minimum of two to three samples are to be cast and cured for a period of 28 and 56 days. The testing is related with compressive strength assessment along with measuring the displacement by providing loading stepwise in any convenient manner and measuring the same by fixing a dial gauge setup over a frame with fixed gauge length and the entire frame was fixed exactly half way through the specimen. Figure-17 shows the test setup of the Cylinder specimen with the dial gauge attached to it in an extensometer with the gauge length of 150mm.At every interval of 10kN loading and the displacement were noted down up till the 1/3 of the total compressive strength. The dial gauge reading is converted to millimetre; the dial gauge reading divided by the gauge length gives the strain length and the load divided by area of the cylinder gives the stress. The series of reading is taken to form the stress-strain relationship. The modulus of elasticity with the reference to the tangent drawn to the curve is known as tangent modulus and with reference to the slope of the line is known as secant modulus. Secant modulus is generally used to determine the modulus of elasticity.

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(a) (b)

**Figure-17.** (a, b) Testing setup for MOE analysis.

The compression peak value was also noted for every specimen to assess the maximum loading capacity for each cylinder. The graphical plot showing the comparative secant modulus of elasticity of 28 and 56 day curing period is depicted in Figure-18.

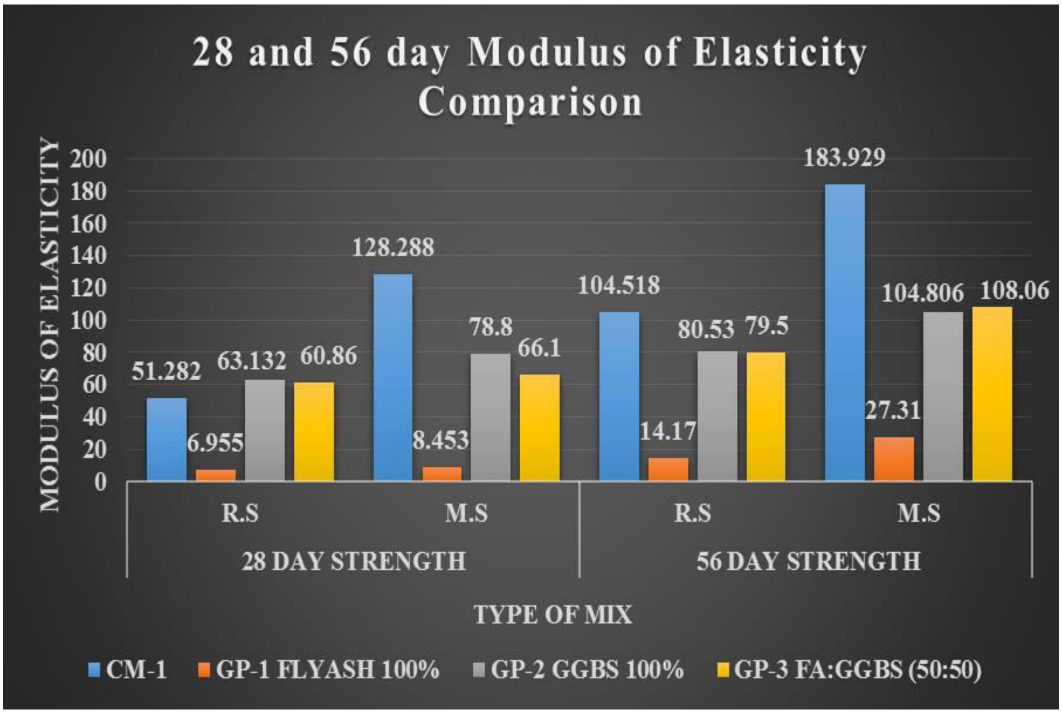


**Figure-18.** 28 and 56 day modulus of elasticity comparison for various mixes.

The secant modulus of elasticity of various mixes are depicted in the above graphical plot, the comparative data between R.S and M.S shows that M-sand values corresponding to all mixes were higher than river sand mix in both 28 and 56 day curing categories. The maximum difference in range happened for conventional mix for which the M.S mix increased by a factor of 51.60% in comparison with R.S and similarly it differed in the range 32.92%, 21.52% and 17.18% for GP-1, GP-2 and GP-3 respectively.

## DISCUSSIONS

### Mechanical properties

Results of compressive strength analysis (figure 11) indicated that, the strength variation with respect to river sand and manufactured sand for the various geopolymer mixes after 28 and 56 days showed increased values for m-sand in contrary with river sand in the range 18.62%, 11.33% and 10% for GP-1, 2 and 3 respectively. However, conventional mix with river sand exhibited better compression values than m-sand in an average range 5.28% at both levels of curing.

As split tensile strength analysis is concerned, unlike compression these results (Figure-15) indicated that, the strength variation between river and manufactured sand was increasing for m-sand for only two GP mixes (GP-2&3) in the range 10.47% and 7.92% respectively.

Modulus of elasticity represented as secant modulus (Figure-18) represented that, all mixes (CM and GP) showed better elastic modulus for the mixes pertaining m-sand in contrary with river sand, which varied by a maximum range of 51.60% for conventional mix followed by 32.92%, 21.52% and 17.18% for GP-1,2 and 3 respectively.

## CONCLUSIONS

The proposed manufactured sand subjected to use after the basic tests of quality for all the tests of this research work has shown enhanced strength values irrespective of the binder replacements in the various designed GP mixes. Also, the areas and tests involving decline in strength characteristics of GP mix with respect to conventional ones showed much reduced levels of decline incase of m-sand involved mix in contrary with river sand involved ones. Hence, m-sand replacement by 100% can be effective and considered as a nominal level of replacement for both conventional as well as geopolymer mix.

On the whole, assessing the alarming state of the eco system the step towards bringing an ecofriendly construction material of geopolymer concrete by making use of an emerging material (manufactured sand) as an alternate for river sand which is in the verge of becoming extinct was performed by eradicating the cement usage and also their strength and performance based characteristics were studied and proved in equivalence and better in many aspects than the conventional concrete.

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