Investigation of strength and impact characteristics of blended Self cured concrete

Udaya Banu T¹, Rajamane N P², Gobinath R³ and E Sudharshan⁴
¹Research Scholar, SRM Institute of Science and Technology, Chennai
²Professor, SRM Institute of Science and Technology, Chennai
³Department of Civil Engineering, S R Engineering College, Warangal, Telangana, India.
⁴Sumathi Reddy Institute of Technology for Women, Warangal, India

Email id: banurai2007@gmail.com

Abstract: Concrete is widely accepted as a durable construction material and being used across the globe for Civil engineering construction. Production of concrete is proved to be unsustainable owing to high amount of CO₂ release and solutions being promoted to make it sustainable, also concrete strength and durability enhancement needed to be envisaged due to increased demand. Several attempts were made to produce concrete using multiple admixtures, in this research work we had made an attempt to develop a Geopolymer based concrete (cementless) by incorporating Ground granulated Blast Furnace slag and fly ash with alkaline binder solution prepared in different molarities (10M, 12M, 14M). The mixture is casted and tested for strength and impact resistance after curing for 28 days in sunlight (non-thermal curing). Promising results were obtained in this study with 11M and 14M solutions based geopolymer concrete showing good strength results concerned with compressive and impact strength. Specifically, designed impact strength testing equipment is used in this study which is a novel work done and a cylindrical specimen of 100 mm diameter and 50 mm thickness is used to study impact resistance of concrete.

1. Introduction
Civil engineering industry, in particular construction segment is rapidly growing in India due to rapid industrialization and increased spending due to several reasons[1]. Newer constructions required demanding materials that will withstand expected loading during its life cycle, the need for high strength materials is steadily raising[2]. Among all construction materials, concrete is playing key role considering all type of construction projects, it is mainly made up of a binder (cement), aggregates and a reactive element (water)[3,4]. Consequently, cement become the most produced material in terms of tons per year production worldwide which equals 5 billion tonnes a year[5]. This increases the thrust on resource consumption and leads to natural resources depletion, to avoid this construction companies and materials providers are focussing on sustainable production of construction materials while managing the mechanical properties with more durability and workability[6]. At present an estimated amount of 7% CO₂ emission is only due to the cement production and its components manufacturing, any newer mechanism if obtained that may require longer service life of structures and more sustainable will be a welcome measure[7,8]. Usage of fly ash is an established process which dates to the starting of 20th century and the merits and demerits of using it is also well documented. Despite the researcher works done, the outcomes received, yet the usage of fly ash as a replacement
material is still at 35% of total mass of cement produced. Considering this scenario many studies already have evaluated the usage of sustainable materials in blended concrete, it was found that replacement of cement with fly ash up to 55% in tandem with limestone will lower concrete’s global warming potential [3-Celik]. Blending slag with high strength concrete can also reduce the life-cycle energy and considerable amount of CO₂ emissions [9]. Rivera et al. studied and conveyed that nearly 728 kg of fly ash can be added to 1 m³ of concrete (30 MPa). In general fly ash is added with a slag which is an industrial product and used as mineral admixture in the concrete, they have combined advantages in terms of enhancing strength and durability, reducing CO₂ emissions, low material costs, increased workability coupled with late-age strength generation. Also, it is found that this addition reduces the carbonation resistance and hence a balanced approach is highly suggested[10].

Geopolymers are chemical compounds that are inorganic in nature and has binding capacity, they were developed by Daviavovits in 1970’s. They are formed by a process involving chemical reaction between aluminosilicate oxides and an alkali solution under high level of alkaline condition which yields polymeric structures that are three dimensional in nature and containing Si-O-Al bonds[11,12]. Geopolymeric compounds reduces the generation of CO₂ emission by 5-6 times than the generic cement production and its also being investigated widely[13,14]. Also, many industrial by products like slag, silica fume, mineral admixtures, electric arc furnace slag were also being added in geopolymer concrete that makes it more durable and sustainable[15]. In geopolymer concrete the binding is not done by cement, its replaced fully or partially by alkaline binder solution which is made by premixing two or more adhesive compounds (NaOH and Na₂SiO₃, elastomers etc). Binding nature of the activator varies according to the molarity of the solution and composition of the mixture and it varies accordingly[16,17]. Geopolymer is also added with various mineral and chemical admixtures including meta kaoline, silica fume, ground granulated blast furnace slag, cement industry waste, precipitated silica etc[18,19]. Geopolymer does not require curing like conventional concrete due to the absence of cement which produces hydration effect that requires water, but they were mostly thermal cured to increase the polymerisation reaction Concerned with Geopolymer concrete the water to geopolymer ratio is taken in the range of 0.25 to 0.5 in several research works and the molarity of the alkali solution is also varied to check the strength and durability variation[20]. Yet the reaction involves some amount of water need to be stored, not many research works were done to analyse the need of water for Geopolymeric materials[21]. In few research works, curing compounds (gel or liquid) is added or sprayed over the concrete to avoid evaporation of water from the surface and to enhance the chemical reaction, it increases the saturation of binder inside the concrete and reduces autogenous shrinkage[22].

In this research we had researched the impact of self curing compound addition in geopolymer concrete that is impregnated with GGBS and fly ash combined with generic geopolymeric alkali solution with varying molarity range[23]. Studies were conducted as per Indian standard procedure to obtain the strength characteristics of geopolymer concrete and also impact strength is arrived using specially designed impact testing machine24].

2. Materials and methods

Admixtures were added in concrete to induce specific strength or durability conditions, yet not all admixtures can provide a holistic solution[25]. In this research we had attempted to manufacture a concrete with multiple admixtures to compensate the ineffectiveness of one admixture by addition of a compensating admixture so that the density of the concrete is good with enhanced flowability. To arrive the proposed design, we had added fly ash (C-Class, High calcium) and Ground Granulated Blast Furnace Slag (GGBS- Chemical grade) to the concrete. Also, locally available M Sand is used as fine aggregate with basalt rock based coarse aggregate (12.5 mm size), for increasing the workability superplasticizer obtained from local chemical shop is added at required proportions while mixing of concrete.
2.1 Aggregates
Recent splurge in the construction industry increased the demand for natural river sand which is rapidly depleting due to high rate of consumption. To avoid this natural resources research works were done to promote alternate fine aggregate and the viable one found to be as Manufactured sand or simply M-Sand which is powdered form of natural rock which is sieved to required specification and requirement[26,27]. It is found to be a quality substitute for the natural sand and used in several research works and also in production purpose for generating concrete. In this research locally available M-Sand is obtained from crusher unit which is passed through to 2 mm sieve and used for the study. The fineness of used M-Sand is found to be 2.78, with a specific gravity of 2.69 and it has a water absorption value of 2%. The sand is stored in closed environment to avoid moisture penetration and any other components mixing with it.

![Grain size distribution and EDAX for M-Sand](image)

Figure 1. Grain size distribution and EDAX for M-Sand

Strength of concrete mainly depends on coarse aggregate and the binder, effective coarse aggregate will increase the strength and also stops voids by proper gradation, in this work we had used basalt rock based coarse aggregate obtained from local crusher unit. All the aggregates are properly washed off before mixing to avoid any deleterious content presence in concrete which may react with the chemicals added. Aggregate added has a specific gravity of 2.9 with water absorption value of <1% and have fineness modules 5.9. Throughout the study graded aggregate is used with proper mixer of 20mm, 12.5 mm and 10 mm aggregates in a predefined proportion to enhance density of concrete. The impact strength of aggregate used is 25% and the abrasion value is 28%, it also has a crushing strength of 7.6%.

2.2 Fly ash
Any type of concrete needs a good binder, cement is used widely as binder due to its nature of binding and durability[28]. Yet, research works being conducted to substitute the cement by replacing it with supplementary cementitious material such as fly ash, calcined clay etc. This not only enhances the strength but also makes the concrete sustainable material with reduced CO2 emission. The primarily available supplementary cementitious material concerned with India is fly ash which is available in considerable quantity for the usage. Fly ash a type of ash obtained from fuel ash that is precipitated using electro static precipitators in industries and coal firing power stations, this is generally a byproduct/ waste material and in recent days it found the usage in concrete due to its pozzolanic nature.
Development of sustainable concrete is the primary aim of this research and fly ash proved to be a viable and sustainable material. Many researchers had produced concrete using large volume of fly ash and incorporated the properties of high-performance concrete with good mechanical properties, reduced permeability, enhanced durability and also eco-friendly. In this work we had added class-c flyash obtained from nearby thermal power plant which has a specific surface area of 710 m$^2$/kg, having specific gravity of 2.39 and the loss of ignition value of 17%. Flyash obtained is stored in polythene bags without getting affected by atmospheric moisture and dryness is ensured before adding it to concrete.

2.3 Ground-granulated blast-furnace slag
GGBS which is also called as GGBS are obtained by cooling the molten iron slag from a blast furnace in water, to produce a glassy, granular product which is then dried & crushed into a fine powder. It is purchased from a local supplier from Coimbatore, India in powder form and stored in cool, dry place without contact with moisture[29]. The bulk density of GGBS is found to be 1130 kg/m$^3$ and it has a fineness of 340 m$^2$/kg with a specific gravity of 2.91. Stored GGBS is added in required proportions to the concrete using weight-based measurement, GGBS is a proven filler and strength enhancer concerned with concrete durability enhancement it performs better than any admixture.

2.4 Viscosity modifying agent
Several researchers found that the addition of an ash into concrete reduces its workability but increases density and strength, to avoid this addition of a viscosity modifying agent is mandatory, in this research we had added Master Glenium 8233 is added to the concrete in required proportions. The superplasticizer is added in liquid format by premixing it with concrete mix, the plasticizer used is slightly acidic in nature and it not only increases workability and also enhance the long-term strength of concrete.

2.5 Geopolymer activators and curing agents
Geopolymer concrete is prepared by using activators which serves as binders by the chemical reaction formed between them, in this research we had used 10M,12M and 14 M solutions prepared by using NaOH and Sodium Silicate (Na$_2$SiO$_3$) obtained from chemical companies( Commercial grade). The Sodium hydroxide reaction is exothermic in nature and hence its obtained and stored in watertight containers until its mixed to prepare activator solutions. Sodium silicate used in this study is also commercial grade. Design of geopolymer concrete is done with reference to the available literature and previous research expertise since the design of Geopolymer concrete varies according to the nature of binder used and cannot be fixed. The mix design is done to obtain a design strength of M40 using the geopolymer concrete. In addition to the alkali activators we had added PEG400 (Poly ethylene Glycol) as self-curing agent in tandem with the admixtures and the binding agent at a fixed
proportion (3% of weight). Geopolymer concrete is generically heated or thermally cured but in this the curing is done naturally in normal sunlight unlike generic Geopolymer concrete. Hence the curing agent also plays a key role in increasing the curing of concrete, in this study we found that the setting time is slightly increased but the strength is achieved within short period.

After the materials were weight properly using pre-calibrated weighing balance, they are placed in a neatly dried tray except the binder solutions which is placed in plastic buckets which are dried and cleaned thoroughly. All admixtures and aggregates are mixed first in ground then placed in a concrete mixture, then the binder solution is added slowly to the dry mixture. Alkaline solution is prepared before 24 hours and kept ready for mixing before the dry mixing of other admixtures. Mixing is done fully until proper mixing is done and the plasticizer is added and allowed to mix for ten minutes fully to ensure proper mixing of all materials, plasticizer and also the binders. Any patches or volume gaps found inside the mixer is duly addressed by using cleaned steel rods and a complete, proper mixing is ensured. The prepared concrete is then taken for compaction nature studies (workability) using Indian code provisions and the concrete from the workability test is placed in the concrete mould which are well cleaned and oiled. The mould were kept in open, clean and moisture free levelled surface. The concrete specimens are kept away from sunlight to avoid moisture escaping and covered with polythene sheets on top to avoid water evaporation. Once the concrete is set, they were removed with utmost care from the mould (demoulding) and kept in same platform after cleaning the surface and allowed it to cure naturally rather than applying thermal curing. During this process testing is done in two stages, one to understand the nature of fresh concrete and next to obtain the hardened concrete properties.

3. Results and Discussion
Primary aim of this work is to obtain information related to usage of curing agent in geopolymer, considering that there is not much literature available up to the knowledge of researchers this objective is kept as primary focus. Also, the secondary focus is to derive the impact resistance characteristics of the Self curing agent added geopolymer concrete. Fig 3 shows the scanning electron microscope image of the concrete with only fly ash and with GGBS and the density, packing of concrete is very clear with this image, it contains less porosity. These materials added to concrete serves as proper binder/filler to enhance the density which in turn will increase the durability of concrete. Throughout the study the concrete is cured in open air and under sunlight, which is natural source of heat energy, hence structural alteration/damage due to generic thermal curing of concrete is avoided.

Figure 3. SEM image of Geopolymer concrete with fly ash and with GGBS
Geopolymer concrete is mixed in the concrete mixer (pan type and electrical operated as per the process described in materials section, the prepared concrete is placed in the mould after completion of workability test through slump cone test (IS 1199 (1959): Methods of sampling and analysis of concrete) since the primary focus of this work is on strength and impact characterization much testing on workability is beyond the scope of this work. Fig 5 indicates the slump value of concrete for various molarity of alkaline solution added, it is found that increasing molarity increases the workability, but its uncertain since the addition of superplasticizer might be a reason. It is found that 14 M solutions gives better workability while placing of concrete and also has good strength characters.

Strength characterization of the cured concrete is done as per IS 516 (1959): Method of Tests for Strength of Concrete which allows using cubical specimen of size 150X150X150 for testing. In this work we had used the same size mould which are pre cured under sunlight for 28 days (Generally Geopolymer does not require 28 days curing). The curing agent is added into the concrete while mixing and its allowed to react with the geopolymerisation process. The cubes were demoulded and wiped with cloth, and painted with white cement to notice the cracking pattern and the crack propagation. Also the flexural strength test is conducted with prism shaped samples of size 150 X 150 X 700 mm which followed the same process and cubical specimens before testing. Fig 6 and fig 7 shows the compressive strength and flexure strength variation according to the molarity of the solution used, it is proved that higher molarity solutions gives more strength and the molar concentration have impact in geopolymerisation process.

**Figure 4.** Workability of concrete for various molarities
Figure 5. Compressive strength of concrete with various molarities

Figure 6. Flexural strength of concrete with various molarities

Geopolymer concrete does not contains a strong binder such as cement, the binding action is purely due to the polymerization process which may be hindrance in absorbing the vibration and impact loading. To understand the behavior of concrete under impact loading a specially designed impact testing machine equivalent to drop hammer test is casted in house. The machine contains a steel ball with a holder to hold the ball during impact loading, the machine has a dropping hammer whose height can be varied from 45 cm to 75 cm and the hammer has a weight of 2.5 kg. Geopolymer concrete is casted in cylindrical specimen of size 100 mm diameter and 50 mm height in plastic mould designed for this study. For every test 3 samples were used and an average reading is taken, the samples were casted and cured for 28 days before conducting the test. The energy absorbed, number of blows required for initial crack and final crack is calculated for various specimens.
In this work we found that the molarity increase also increases the impact energy and the number of blows required for the initial and final crack. Table 1 shows the impact energy absorbed by the specimen for a drop hammer weight of 2.5 kg dropped at a height of 45 cm and the number of blows taken for final failure.

| Mix proportions | Number of blows | Impact energy at failure kg.cm |  |
|-----------------|-----------------|--------------------------------|---|
|                 | At initial crack (N1) | At failure (N2) | (Weight of hammer X no of blows X drop height) |
| 10 Molarity     | 9               | 12                 | 1350                          |
| 12 Molarity     | 11              | 13                 | 1462                          |
| 14 Molarity     | 13              | 16                 | 1800                          |

It is found in this study that the impact energy is absorbed as a proportionate to the binding capacity increase and the geopolymerisation enhancement through increased molarity. Also, it is to be noted that the study is limited to a maximum of 14 Molarity and studies should be done with higher molarity to obtain the real impact of increasing molarity more than 14M.

4. Conclusion
Studies were conducted to obtain the strength and impact characteristics of Geopolymer based concrete added with self-curing agent in this study. The following results were obtained from the study:

1) There is possibility of addition of curing agent to the Geopolymer concrete is its not cured thermally like generic curing process. The curing compound visibly supports the holding of water that is required to manage the water-alkali solution compounding.
2) The slump value increases with the molarity of the alkali solution and hence a value of more than 12 M is prescribed for producing Geopolymer concrete in addition with other mineral admixtures.
3) Compressive strength of the concrete increases with the molarity of the alkali solution and also this confirms with other studies
4) Flexure strength of the concrete increases with the molarity of the alkali solution and this confirms with the other studies done
5) Impact strength is studied in this research with a modified scale specimen, not many studies were done for analysing and its found that the increasing molarity increases the impact strength also. This may be due to the densification process that occurs in the concrete.

Considering the above mentioned results, we strongly suggest promoting self curing compounds usage either internally or spraying over the specimens to avoid escape of water and to increase the concrete strength.

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