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# Experimental Study on Geopolymer Concrete with recycle Aggregate

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## Abstract

Construction industry uses Portland cement which is known to be a heavy contributor to the CO2 emissions and environmental damage. Incorporation of industrial wastes like demolishedold concrete, silica fume (SF) and fly ash (FA) as supplementary cementing materials (SCMs) could result in a substantial reduction of the overall CO2 footprint of the final concrete product. However, use of these supplementary materials in construction industry especially in the making of concrete is highly challenging. Significant research efforts are required to study the engineering properties of concrete incorporating such industrial wastes. Present research is an effort to study the properties of concrete incorporating industrial wastes such as demolished concrete, SF and FA.

Recycled coarse aggregate (RCA) concrete construction technique can be called as 'green concrete', as it minimizes the environmental hazard of the concrete waste disposal. Indian standard recommends target mean compressive strength of the conventional concrete in terms of water cement ratio (w/c). The behavior of RCA concrete, prepared from two samples of parent concrete having different age groups, is investigated, to propose the relationship of compressive strength with water cement ratios, in the present study. Number of recycling may influence the mechanical properties of RCA concrete. The influence of age and number of recycling on the properties such as capillary water absorption, drying shrinkage strain, air content, flexural strength and tensile splitting strength of the RCA concrete are examined. While the compressive strength reduces with number of recycling gradually, the capillary water absorption increases abruptly, which leads to the conclusion that further recycling may not be advisable?

Previous studies show that the properties of RCA concrete are inferior in quality compared to NCA concrete. The improvement of properties of RCA concrete with the addition of two ureolytic-type bacteria, Bacillus subtilis and Bacillus sphaericus to enhance the properties of RCA concrete. The

experimental investigations are carried out to evaluate the improvement of the compressive strength, capillary water absorption and drying shrinkage of RCA concrete incorporating bacteria. The compressive strengths of RCA concrete are found to be increased by about 20% and 35% at the cell concentrations of 106 cells/ml for the two bacteria. The capillary water absorption as well as drying shrinkage of RCA are reduced when bacteria is incorporated. The improvement of RCA concrete is confirmed to be due to the bacterial mineral precipitation as observed from the microstructure studies such as EDX, SEM and XRD.

The mechanical properties, such as compressive, flexural and tensile splitting strength, of SF concrete considering the 10% additional quantity of cement as recommended by International codes, by partial replacement of slag cement on low to medium strength concrete, have not been investigated so far. The present study investigates the mechanical properties of medium strength SF concrete made as per this construction practice by partial replacement of slag cement. Effect of SF on compressive, flexural and tensile splitting strength of hardened concrete is examined. Seven concrete mixes are prepared using Portland slag cement (PSC) partially replaced with SF ranging from 0 to 30%. The mix proportions were obtained as per Indian standard IS: 10262-2009 with 10% extra cement when SF is used as per the above the construction practice. Optimum dosages of SF for maximum values of compressive strength, tensile splitting strength and flexural strength at 28 days are determined. Results of the present study are compared with similar results available in literature associated with Portland cement. Relationships, in the form

of simplified equations, between compressive, tensile splitting and flexural strengths of SF concrete are proposed.

Several studies related to sustainable concrete construction have encouraged the usage of industrial waste products such as SF and FA. Design of structures, made using such SF and FA concrete, for an acceptable level of safety, requires the probabilistic descriptions of its mechanical properties. For this purpose, an extensive experimental programme was carried out on compressive strength, flexural strength and tensile splitting strength properties of SF and FA concrete. The probability distribution models are proposed based on the three goodness-of-fit tests such as Kolmogorov-Sminrov, Chi-square and loglikelihood tests. The proposed probability distributions are used to study performance of typical buildings made of SF and FA concrete through seismic fragility curves and reliability indices

# INTRODUCTION

## 1.1 BACKGROUND

Cement concrete has been regarded as a synthetic stone prepared by integrating Portland cement (PC), fine aggregate, coarse aggregates and water to make a mouldable mixture since 19th century. Concrete is termed to be an essential material used in diverse construction which includes industrial and infrastructural sectors, as it is derived from the natural materials accessible globally. Concrete is utilized above all other man-made materials in the world. For a human, over a tonne of concrete is manufactured annually on the earth; creating concrete as the second largest utilized material on globe next to water. The increasing demand for concrete due to the growing demands of infrastructure has led to the increased production of cement.

## 1.2 PORTLAND CEMENT CONCRETE (PCC)

In the production of PCC, the embodied energy (EE) requirement varies between 400 and 600 kWH/m3 of concrete, and the corresponding embodied carbon-di-oxide (ECO2) was reported to be between 75 and 176 kg CO2 per tonne of concrete emitted and depends on the variety and technique used for arriving the mix. As a result, there is a pressing requirement for producing eco-friendly concrete; thereby, limiting ECO2 emission and EE of concrete. The environmental facets of concrete are in recent concern in the view of developing an eco-friendly material for construction has become the task of many researchers globally.

## 1.3 NEED OF ALTERNATE FOR PORTLAND CEMENT (PC)

There is a continuous technological advancement and integration of modern technology in the cement industry. In India, only 7% of the volume in industry is derived from traditional wet and semi-dry course technology, and remaining 93 % of the volume is rooted in modern and eco-friendly dry process technique. The issue behind the production of cement is not only the most energy intensive materials utilized in construction, but also responsible for some carbon-di-oxide (CO2) emission which contributes to about 65 % of global warming among the green house gases (GHG) and second only to fossil fuels. This has led the PC industry unfit for the existing thoughts and concepts of a sustainable industry. In the production of Portland Pozzolana Cement (PPC), addition of high proportion of pozzolanic materials has enhanced the condition considerably. Yet, there is a vital requirement to find an alternate for PC to facilitate the construction industry to be eco-friendly, which should also hold acceptable mechanical and 3 durability properties which are analogous and possibly better than usual concrete made of cement.

## 1.4 GEOPOLYMER (GP) AS REPLACEMENT FOR PC

With the intention of curtailing the utilization of cement as a binder, an alternate material which is rich in Silicon (Si) and Aluminum (Al) or an industrial byproduct like fly ash (FA), Rice Husk Ash (RHA), ground granulated blast furnace slag (GGBFS), etc. which can be used as source material, making it to react with an alkaline solution and the chemical reaction shaped is of polymerization product termed as Geopolymers was first established by Davidovits in 1978 (Davidovits, 1994a). He also illustrated the geopolymers as a group of mineral binders with synthetic arrangement closely resembling zeolites with an amorphous structure. In contrast to PC, GPs does not require calcium-silicate-hydrate (CSH) gel in the arrangement of matrix and strength development, but operate under the poly-condensation of Si and Al precursors to attain the necessary mechanical strength.

## 1.5 DESIRABLE CHARACTERISTICS OF GPC

It has been acknowledged that any material developed to be utilized as a binder should be eco-friendly and suitable if it satisfies the following attributes:

- It should preferably be acquired from broadly existing waste byproducts from industries.
- Reduced Embodied energy requirement.
- Chemical activators for producing binding system should be frequently obtainable.

Competent of accepting common filler materials such as sand, natural crushed granite aggregates, and recycled concrete aggregates.

- Prolonged stability of the produced binding arrangement.

- The concrete made by utilizing newly formed binder should be similar or
- superior than PC based concrete in respect of:
- Developing environment for the production of fresh mixes
- Curing regime and period of curing
- Strength development rate with age

**Strength properties namely**

- Compressive strength
- Split tensile strength
- Flexural strength

**Durability properties namely**

- Diffusion of
- Moisture / Water
- Chloride ions

**Resistance against**

- Sulphate attack
- Acid attack
- Corrosion attack

## 1.6 RESEARCH SIGNIFICANCE

The study on the properties of geopolymer concrete is of ultimate significance to instill assurance in builders and engineers. Abundant available literatures point towards the use of fly ash as source material in the production of geopolymer concrete cured under elevated temperature condition with little on other materials. In this regard, the work in tend was to utilize slag as a replacement for fly ash in the production of geopolymer concrete, as India is one among the leading manufacturer of steel globally where slag comes out as by-product. The use of construction and demolition waste concrete turns to be the research interest, this work is conducted to evaluate the use of recycled concrete aggregate derived from laboratory waste concrete on the strength and durability properties of GPC.

## 1.7 OBJECTIVES:

The objectives of the present study are:

1. To distinguish the remarkable factors that influence the properties of fly ash and GGBFS based GPC.
2. To facilitate the advancement of this innovative material later on to the construction industry.

### 1.8 METHODOLOGY:

This section introduces the points of experimental investigations carried out on the test samples to examine the fresh and hardened properties of GPC with fly ash and GGBFS as source material with natural and recycled concrete aggregates. An effort was made to evaluate the workability, strength and durability properties of GPC at different liquid-binder ratios, binder content, and sodium hydroxide concentration at different ages; and the results were compared. The workability was assessed by slump test, strength-related characteristics namely compressive strength, split tensile strength and flexural strength; and durability characteristics namely absorption characteristics, sorptivity, and resistance to acid, chloride, sulphate, and corrosion attack were studied. Minimum of three specimens were tested for each mix for each test, and the tests were conducted as per specifications

## 2. LITERATURE REVIEW

### 2.1 MAJOR CONCERNS OVER CEMENT CONCRETE

#### 2.1.1 Environmental Concerns

Concrete is probably the main profuse building material and PC, a principal constituent of concrete, is the main quantity of building material generated globally. The increasing demand for the cement will make ecological issues not just as accessibility of raw materials (limestone), but also increases the CO2 emission to the atmosphere and increased demand for energy in the manufacturing of Portland cement. The manufacture of Portland cement needs huge amount of energy; in the meantime it transmits immense sum of CO2 to the atmosphere due to the calcination reaction during its manufacturing process.

#### 2.1.2 Durability Concerns

Concrete made with PC can be durable under mild exposure condition when properly designed. Conversely, it has been extensively renowned that the traditional concrete may undergo deterioration under severe exposure condition in the form of chloride, acid, and sulphate attack. The popular chemical attacks on concrete are as response between the cement matrix and the aggressive agents, while reactions may also occur with the aggregates namely alkali aggregate reaction. In cement concrete, calcium-silicate-hydrate (CSH) and the Portlandite (Ca(OH)2) are the chief hydration products which govern the strength and the binding characteristics as well as highly susceptible to chemical degradation when exposed to severe environmental conditions.

## 3. METHODOLOGY

### 3.1 INTRODUCTION

This part displays the improvement of the procedure of producing geopolymer concrete. At the time of 2011, very few information and skill for making ground granulated blast furnace slag (GGBFS) based geopolymer concrete were accessible in the distributed writing. Because of this absence of data, furthermore, the distributed papers on geopolymers accessible around then generally reported the utilization of fly ash or metakaolin as source material of geopolymer concrete. In addition, a large portion of the data accessible was a piece of the patent writing or economically arranged examination, and numerous points of interest were kept undisclosed.

Consequently, the present study adopted a thorough experimentation process so as to build up the geopolymer concrete innovation in view of fly ash and GGBFS. The aim of the work was to distinguish the remarkable factors that influence the properties of fly ash and GGBFS based GPC. Beyond what many would consider possible, the technology that is right now being used to make and test ordinary Portland cement (OPC) was utilized. The point of this activity was to facilitate the advancement of this innovative material later on to the construction industry.
In spite of the fact that GPC can be made utilizing different source materials, the current work utilized just low calcium (ASTM Class F) fly ash and GGBFS. Likewise, as on account of OPC, the aggregates involve 75 – 80% of the concrete mass. With a specific end goal to curtail the impact of the aggregates on the properties of geopolymer concrete made of fly ash and GGBFS, the study utilized aggregates from a single source.

In developing the concrete mix for Geopolymer Concrete (GPC), it is necessary to select proper ingredients, evaluate their properties, and understand the interaction among the different material for optimum usage. The ingredients used for this investigation are cement, fly ash, ground granulated blast furnace slag (GGBFS), fine aggregate, coarse aggregate (CA), recycled concrete aggregate (RCA), sodium hydroxide, sodium silicate, distilled water, and chemical admixtures. The performance requirements of concrete may involve enhancement of the following:

- Simplicity of placing and compaction with no segregation
- Long-term mechanical characteristics
- Premature strength
- Hardness
- Degree of stability
- Long-lasting durability characteristics
- Longer service life

Effective production of GPC is achieved by carefully selecting, controlling and proportioning all the ingredients. In order to achieve GPC, optimum proportion must be selected, considering the characteristics of cementitious materials, aggregate quality, paste proportion, aggregate-paste interaction, activator type, dosage, and meticulous care in mixing and handling.

## 3.2 INGREDIENTS USED

### 3.2.1 Cement

Ordinary Portland Cement (OPC) of grade 53 confirming to IS 12269 was utilized in the study. The physical properties and chemical composition of OPC are given in Table 3.1 and 3.2.

**Table 3.1. Physical properties of 53 grade OPC**

| | | |
|---|---|---|
| Specific gravity | 3.13 | 3.1 – 3.15 |
| Fineness, m2/kg | 310 | ≥ 225 |
| Initial setting Time, Minutes | 40 | ≥ 35 |
| Final setting Time, Minutes | 258 | < 600 |
| Standard consistency, % | 28 | 30 – 35 |
| Soundness, Le-chatelier, mm | 3 | < 10 |

### 3.2.2 Fly Ash

Fly ash of class F type confirming to IS 3812 and ASTM C618 was obtained from National Thermal Power Plant located in Bilaspur, The physical properties and chemical composition of fly ash are given in Table 3.2.

**Table 3.2. Physical properties of Class F Fly ash**

| COMPONENT | RESULT OBTAINED | REQUIREMENTS OF IS : 12269 |
|---|---|---|
| Specific gravity | 2.10 | ---- |
| Fineness, m2/kg | 525 | ≥ 320 |
| Bulk density, kg/m3 | 1197 | ----- |

### 3.2.3 Ground Granulated Blast Furnace Slag (GGBFS)

Ground granulated blast furnace slag (GGBFS) in dry densified form confirming to IS 12089 was obtained from Salem Steel Plant, Bhilai, Chhattisgarh India. The physical properties and chemical composition of GGBFS are given in Table 3.3.

**Table 3.3. Physical properties of GGBFS**

| COMPONENT | RESULT OBTAINED | REQUIREMENTS OF IS : 12269 |
|---|---|---|
| **Specific gravity** | 2.80 | ---- |
| **Fineness, m2/kg** | 445 | ≥ 225 |
| **Bulk density, kg/m3** | 1222 | ----- |

### 3.2.4 Fine Aggregate

Fine aggregates are the results of natural disintegration of rock. Locally available river sand conforming to Grading Zone III as per Table 4 of IS 383 with specific gravity of 2.58 was used as fine aggregates. The physical properties of fine aggregate are given in Table 3.4 17

**Table 3.4. Physical properties of fine aggregate sample**

| COMPONENT | RESULT OBTAINED | REQUIREMENTS OF IS : 12269 |
|---|---|---|
| Specific gravity | 2.58 | ≥ 2.60 |
| Fineness modulus | 2.56 | 2.30 – 3.10 |
| Bulk density, kg/m3 | 1696 | ----- |
| Water absorption, % | 1.37 | ----- |
| Grading | III | I – IV |

### 3.2.6 Recycled Concrete Aggregate (RCA)

Recycled concrete aggregate was acquired from the demolished construction waste with specific gravity 2.44 and fineness modulus 6.45 was utilized as recycled aggregate in this work (Figure 3.2). The properties of the recycled aggregates used in this are given in Table 3.8 and the gradation curve is shown in Figure 3.1.

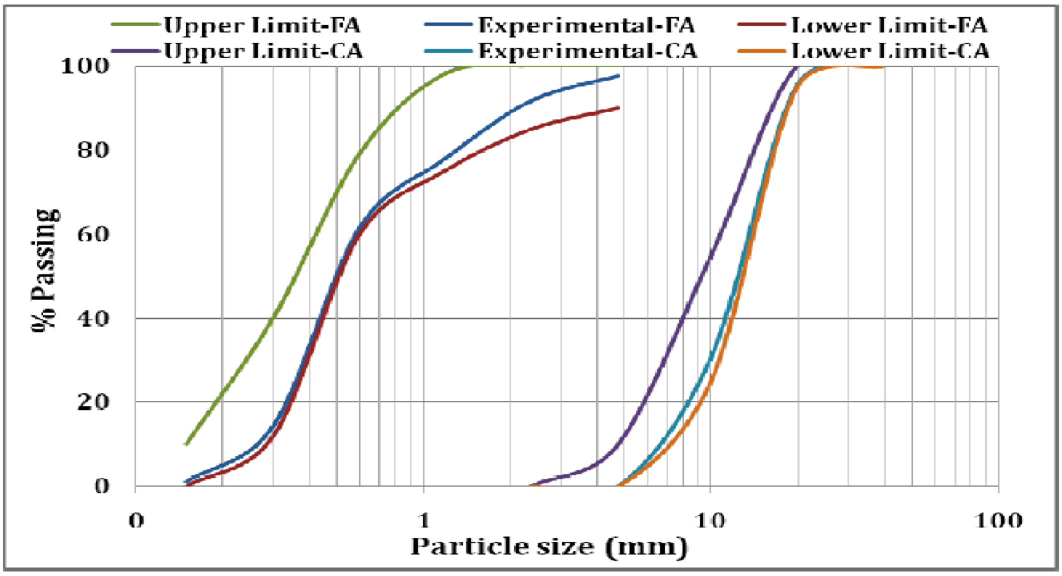


**Figure 3.1 Grading curves of aggregates used in the study**

**Figure 3.2 Sample of RCA used in the study**

**Table 3.8. Properties of Recycled Concrete Aggregate sample**

| COMPONENT | RESULT OBTAINED | REQUIREMENTS OF IS : 12269 |
|---|---|---|
| Specific gravity | 2.46 | ≥ 2.60 |
| Bulk density, kg/m3 | 1271 | ----- |
| Water absorption, % | 3.88 | ≥ 3.00 |

### 3.2.7 Activator Solution (AS)

A progression of activator solution has been utilized, and most of the past explorations demonstrated that the enactment of NaOH by Na2SiO3 results in enhanced strength. The alkali actuation of fly ash and slag was carried out by utilizing economically accessible 99% pure NaOH flakes and Na2SiO3 solution made out with 28% SiO2, 11.2% Na2O and 60.8% H2O content by mass. The modulus of silica, which is the ratio between SiO2 and Na2O was observed to be 2.5.

### 3.2.8 Superplasticizer (SP)

Superplasticizer (chemical admixture) based on polycarboxylic ether (PCE) type with commercial name Glenium B233, which is of light brown liquid with 1.08 relative density, chloride ion content of less than 0.2% and pH value 6 was used in this study complies with IS 9103 and ASTM C494.

### 3.2.9 Reinforcing Steel

Steel bars with 12 mm O were used as tension reinforcement; whereas, 8 mm O bars were placed in compression zone with 6 mm O bars as shear reinforcements in the beams.

### 3.3 Mix Design and its Proportions

Geopolymer Concrete (GPC) represents a rather recent development in the technology of concrete materials and it is a non-cement based binder, which has the most attractive properties amid fresh and hardened phases. GPC is far better than conventional CC as the elements of GPC contribute most ideally and effectively to the different properties. To produce GPC mix, it is essential that all its constituents perform to their maximum limits; so that, superior mechanical and durability properties are achieved. Hence, it requires careful selection and proportioning of the ingredients.

The proportioning of GPC blend is a procedure by which one lands at the right mix of source material, aggregates, type and concentration of activator solution and chemical admixtures for making concrete as indicated in the given details. The reason for mix proportioning is to acquire an item that will perform as per certain prerequisites; the most crucial necessities are being the workability of fresh mix, strength, and durability of hardened concrete. Another motivation behind mix proportioning is to get a solid blend fulfilling the execution necessities at the lower conceivable expense by selecting accessible materials.

### 3.3.1 Concepts of Mix Design for GPC

As there is no standard mix design procedure for geopolymer concrete, the previous literatures stated that the mixes were arrived on trial and error basis. The main difference between the mix design of GPC and CC is the emphasis laid on performance feature. In GPC, besides strength, durability concerns were given supreme significance. Towards achieving GPC of high durability, the mix design of GPC was carried out based on the following considerations:

- The maximum size of coarse aggregates should be restricted to 16 mm, as smaller size aggregates are required for achieving higher strength.

 The fine aggregate utilized for GPC ought to be legitimately graded in order to give least voids proportion and be free from pernicious materials like mud, sediment content, chloride contamination, etc. GPC contains large amount of very fine particles and hence, use of coarser sand is required for achieving higher strength and durability with improved workability of concrete.

 The workability of the concrete mix should be good enough to obtain good compaction.

 Proper curing regime of concrete should be established.

### 3.3.2 Method of Mixing

In the outline of GPC mix, 75% of the complete mixture is composed of the combined fine and coarse aggregates by mass. This amount is used as a part of concrete made with PC, in which it will be in the range of 70 to 80% of the whole mix by mass. 24% of the total aggregates were taken as fine aggregate. From the past literatures, unmistakably, the fresh density of GPC is similar to that of concrete made with PC (2400 kg/m3). The collective mass of alkali liquid and geopolymer source material can be arrived with the knowledge of fresh density of concrete.

### 3.3.3 Trial Mix Proportions for GPC

Initially, to assess the effect of replacing fly ash with GGBFS as geopolymer source material for the production of GPC, the mass and proportion of GSM, aggregates and alkali liquid were calculated keeping alkaline liquid to GSM as 0.50. To acquire the mass of NaOH and $Na_2SiO_3$ solutions, the proportion of $Na_2SiO_3$ to NaOH solution was taken as 10 and 12.5 M, alkali ratio of 1.0 and 1.5 with six levels (0%, 20%, 40%, 60%, 80% & 100%) of variations of fly ash replacement with GGBFS.

**Table 3.9. Details of the trial mixes**

| Mix | BFS0 | BFS20 | BFS40 | BFS60 | BFS80 | BFS100 |
|---|---|---|---|---|---|---|
| **GGBS %** | 0 | 20 | 40 | 60 | 80 | 100 |
| **Fly Ash %** | 1000 | 80 | 60 | 40 | 20 | 0 |
| **AS/GSM** | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 |
| **Unit content of ingredients used in the mixes, kg/m3** | | | | | | |
| **GGBS** | 0 | 77.4 | 154.8 | 232.2 | 309.6 | 387 |
| **Fly Ash** | 387 | 309.6 | 232.2 | 154.8 | 77.4 | 0 |
| **FA** | 432 | 432 | 432 | 432 | 432 | 432 |
| **CA** | 1368 | 1368 | 1368 | 1368 | 1368 | 1368 |
| **AS** | 213 | 213 | 213 | 213 | 213 | 213 |
| **Weight proportion of ingredients used in the mixes** | | | | | | |
| **GGBS** | 0 | 0.2 | 0.4 | 0.6 | 0.8 | 1 |
| **Fly Ash** | 1 | 0.8 | 0.6 | 0.4 | 0.2 | 0 |
| **FA** | 1.08 | 1.08 | 1.08 | 1.08 | 1.08 | 1.08 |
| **CA** | 3.42 | 3.42 | 3.42 | 3.42 | 3.42 | 3.42 |
| **AS** | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 | 0.55 |

### 3.4 Experimental Investigations

This section introduces the points of experimental investigations carried out on the test samples to examine the fresh and hardened properties of GPC with fly ash and GGBFS as source material with natural and recycled concrete aggregates.

An effort was made to evaluate the workability, strength and durability properties of GPC at different liquid-binder ratios, binder content, and sodium hydroxide concentration at different ages; and the results were compared. The workability was assessed by slump test, strength-related characteristics namely compressive strength, split tensile strength and flexural strength; and durability characteristics namely absorption characteristics, sorptivity, and resistance to acid, chloride, sulphate, and corrosion attack were studied. Minimum of three specimens were tested for each mix for each test, and the tests were conducted as per specifications.

#### 3.4.1 Test on Workability

The fresh concrete property of geopolymer mixes was measured in the form of workability with the help of slump cone test, which was carried out as per IS 1199 and ASTM C143/C143M specifications.

#### 3.4.2 Strength Characteristics

##### 3.4.2.1 Cube Compressive Strength

The compressive strength of concrete mixes was studied using cubes of size 150 mm x 150 mm x 150 mm in accordance with IS 516. All the cubes were cured under ambient temperature condition. For each trial mix, the average of three specimens were taken to determine the compressive strength at the age of 7 and 28 days of curing loaded under 3000 kN capacity compression testing machine (CTM). The arrangement of the cube in the CTM before loading is shown in Figure 3.3.

**Figure 3.3. Compression test on cube specimen**

The experiments were performed at a consistent stress following the sample which has been kept at the center in the CTM. The load was applied continuously till its direction gets reversed. The reversal of load direction demonstrates that the sample has failed. The load at that instant was noted which was recorded as ultimate load, which when divided by the cross-sectional area of the plane perpendicular to the axis of loading is equivalent to the compressive strength of concrete.

#### 3.4.2.2 Split Tensile Strength

This method is used to evaluate the indirect tensile strength of concrete. The test was performed on 100 mm O and 200 mm height concrete cylinders as per IS 5816 and ASTM C496 at the age of 28 days ambient curing with the aid of CTM of 3000 KN capacity. The load was applied progressively until the cylinders split, and the subsequent load was recorded.

#### 3.4.2.3 Flexural Strength

Flexural strength of the concrete mixes was evaluated using prismatic specimens of size 100 mm x 100 mm x 500 mm as per IS 516 after 28 days of curing, with the aid of 1000 kN capacity Universal Testing Machine (UTM) by subjecting the concrete specimens under four-point loading.

### 3.4.3 Durability Characteristics

#### 3.4.3.1 Saturated Water Absorption (SWA)

Saturated Water Absorption (SWA) tests on concrete mixes were executed using cube specimens of 100 mm x 100 mm x 100 mm size after 28 days curing in accordance with ASTM C642. The mass of the cube specimens were measured before drying. Then, the cubes were dried at 105 oC in a hot air oven and continued, until the mass distinction of two progressive estimations at 24 hours interim concurred nearly. Next, the samples were allowed to cool under room temperature and after that submerged in water. The samples were taken out at standard interim duration, surface was dried utilizing a perfect fabric, and then weighed. The testing for water absorption is shown in Figure 3.4. This procedure was sustained until the weights got to be steady (completely soaked). The variation in the mass of the saturated and the oven dried specimens, at the rate of oven dry mass provides the water absorption which was computed.

**Figure 3.4. Samples tested for their water absorption properties**

(a) specimens kept in oven

(b) specimens immersed in water

#### 3.4.3.2 Sorptivity

The amount of diffusion of water through the pores on concrete by capillary suction was quantified by sorptivity. While the growing amount of water which infiltrated per unit surface area of exposed specimen 'q' is plotted aligned with the square root of time of exposure 'SQRT(t), the subsequent chart may possibly be estimated by a straight line going towards the origin. The rate of diffusion of water through the pores can be calculated from the slope of the straight line drawn through the origin, which is termed as sorptivity. In the current investigation, the sorptivity test was carried out on cylindrical specimens of 100 mm diameter by 50 mm thick according to ASTM C1585 by drying the specimens at 105 oC in an oven to consistent mass, and afterward inundating them in water in the wake of cooling the samples to room temperature and computing the mass increment at standard interim of time, for a period of two hours.

#### 3.4.3.3 Acid Resistance

As there is no standard test procedure for acid attack on concrete, the resistance of the concrete specimens to the acid exposure in the current investigation was carried out by submerging the concrete specimens in sulphuric acid solution of pH = 4 for a period of 90 days. The testing media was replaced every 15 days with the fresh solution to maintain the pH level. The test was conducted on the cube specimens of size 100 mm x 100 mm x 100 mm after 28 days of curing. The weight of the specimens was measured before submerging in two percent by weight of sulphuric acid solution (Figure 3.10) over a span of 90 days continuously. Subsequently, the samples from the acid solution were taken out, their surfaces were cleaned, finally the weight was taken, and the specimens were subjected to compressive load. The percentage variation in weight and the compressive strengths were computed.

### 3.4.3.4 Sulphate Resistance

The resistance to sulphate attack was estimated in accordance with ASTM C88. Concrete cylinders 100 mm O and 50 mm in height were prepared and cured for 28 days under ambient temperature condition. The mass percentages of the sulphate solutions were maintained at different level in order to maintain the same concentration of SO42- in both sodium sulphate (Na2SO4) and magnesium sulphate (MgSO4) solutions. The solutions were changed periodically in order to maintain the same concentration throughout the exposure period. After 28 days curing, the initial observations were made, and the specimens were immersed in Na and Mg sulphate environment for 3 months at ambient conditions.

The dimensions and mass variations were checked at regular intervals and repeated for a period of 3 months. Then the samples were dried, and the variations in the dimension and mass of the specimens were determined. In addition to these, the strength of the specimens was determined using compression test. The loss in the strength was measured by sulphate deterioration factor, which is the percentage variation in strength of the specimens after immersion in sulphate solution with that of immersed in water at age “t”.

## 4. CONCLUSIONS AND SCOPE OF FUTURE WORK:

Geopolymers can be portrayed as alkali enacted aluminosilicate cementitious binders. The improvement and comprehension of geopolymer technology are of critical interest on the grounds that these new materials can be made cost-focused to OPC, while displaying predominant mechanical properties and excellent resistance to chemical attack with lower carbon impression. This thesis presents the experimental investigations to check the suitability of ground granulated blast furnace slag as a geopolymeric source material to produce geopolymer concrete.

### 5.1 Conclusions

From the above experimental investigations carried out, the following main conclusions can be drawn:

1 The workability of the fly ash based GPC mixes decreases with an increase in the GGBFS content. Higher viscosity and rapid binder formation also get resulted from the increase in the GGBFS volume. The increase in the NaOH concentration and alkaline ratio also results in the reduction of slump.

2 The mechanical properties of fly ash based GPC increases with an increase in the replacement of fly ash by GGBFS and 100% replacement level produces maximum strength. The compressive strength of the GPC mixes produced more than 70% of its 28 days strength and increases with the increasing volume of GGBFS content.

3 The strength properties of GPC mixes improves with an increase in the volume of slag content from 350 to 400 kg/m3 and reduces at 450 kg/m3, whereas the durability properties improves with an increase in the volume of slag content.

4 Higher NaOH concentration (in terms of molar) results in improved mechanical and durability characteristics of GGBFS based geopolymer concrete with natural aggregates.

5 The excellent resistance of the GPC mixes under acid environment is mainly due to the very low calcium oxide content and that of the sulphate environment is mainly due to the absence of sulphate deteriorating factors.

6 The reduction in the slump was significantly reduced with the use of superplasticizer at increasing RCA volume.

7 Similar to the mechanical properties, the load carrying capacity of the beams increases with an increase in the NaOH concentration. At 14 M NaOH concentration, it was found to be 53% more than cement concrete beam.

8 The deflection and ductility properties of GPC beams improve with an increase in the volume of RCA content, and the span/deflection values were found to be within the acceptable limits.

9 The ultimate load carried by the GPC beams increases with an increase in the RCA content, and the beam with 75% RCA content carries 23% more load than GPC beam made with natural aggregate and 87% more than cement concrete beam.

10 However there is an improved flexural deflection at ultimate stage with an increase in the volume of RCA, and the impact of considering RCA has a pivotal outcome on the flexural property of the beams.

**5.2 Recommendations for Future Work**

1 The behavior of the material subjected to thermal exposure needs to be evaluated.

2 The possibility of replacing natural sand with industrial waste.

3 GPC can be made with Sodium hydroxide alone as activator solution instead of blending with sodium silicate resulting in greater reduction in the overall cost of the construction.

4 The activator solutions can be derived from the glass and rayon industry needs to be evaluated.

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