IJRAR.ORG E-ISSN: 2348-1269, P-ISSN: 2349-5138

INTERNATIONAL JOURNAL OF RESEARCH AND ANALYTICAL REVIEWS (IJRAR) | IJRAR.ORG

An International Open Access, Peer-reviewed, Refereed Journal

STUDY OF FLY ASH BASED GEOPOLYMER CONCRETE

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ABSTRACT: This report discusses the use of fly ash-based geopolymer as an alternative to ordinary Portland cement for making concrete, with a focus on its engineering properties and performance in comparison to traditional concrete. Ordinary Portland cement is known to contribute to environmental pollution due to the emission of CO2 during its production. In contrast, fly ash is a by-product of the coal industry and is readily available around the world. Geopolymer concrete is a sustainable alternative that can utilize fly ash as a primary ingredient, potentially reducing the carbon footprint associated with traditional concrete production. It discusses the properties of geopolymer concrete are enhanced by various factors, which play a crucial role in its performance. The geopolymer concrete under investigation has a specified compressive strength of 30 MPa, which is an important parameter for assessing its structural performance. The report compares geopolymer concrete with traditional normal concrete in terms of compressive strength, splitting tensile strength, NDT (Rebound hammer Test). This comparison helps assess the suitability of geopolymer concrete for various applications. The study explores different curing methods, such as thermal curing at 90°C for 8 hours, sunlight curing, oven curing and pond curing. Curing is an important aspect of concrete production as it influences the final properties and durability of the material. All tests and experiments are conducted in accordance with relevant Indian standards, ensuring that the geopolymer concrete's performance is assessed in line with local industry regulations and quality requirements. In summary, this report presents a comprehensive examination of fly ash-based geopolymer concrete, including its engineering properties and performance characteristics. It also assesses the environmental benefits and sustainability of using fly ash as a primary component in concrete production.

Index Terms – Fly Ash, Compressive Strength, Split Tensile Strength, Rebound Hammer Test, Mix Design, Curing

I. INTRODUCTION

In the construction industry worldwide, Ordinary Portland Cement (OPC) is the most commonly used concrete material. With the rapid urbanization of countries, the demand for OPC has been increasing, leading to a rise in concrete consumption. However, the production of OPC is associated with significant greenhouse gas emissions, contributing to global warming. It's estimated that OPC production accounts for about 7% of total greenhouse gas emissions, which is a major concern. To address this issue, it is necessary to reduce or replace cement in concrete with alternative cementitious materials such as fly ash, GGBS, rice husk ash, etc.

Fly ash, which is a byproduct of coal burned in electricity generating power plants, is one such alternative material. Annually, approximately 780 million tonnes of fly ash are generated worldwide, but only a small portion, around 17-20%, is utilized. In India, around 226.13 million tonnes of fly ash are produced in the year 2019-20 of which 35-50% is used in concrete and soil stabilization, leaving a significant amount to be disposedof as waste material and it is predicted to be around 300-400millions tonnes by the year 2025.The term "Geopolymer" was introduced by Joseph Davidovits in 1978. Geopolymers are a family of carbon-related polymers formed by the polymerization of source materials and an alkaline solution. This project specifically uses fly ash as the source material, which contains silica and alumina. The geopolymerization reaction occurs between the source material and the alkaline activator solution in a highly alkaline medium, resulting in the formation of a three-dimensional polymer structure with Si-O-Al-O bonds. This structure produces alumina silicate gel, which acts as the binding agent for Geopolymer concrete.

1.1 GEOPOLYMER

Geopolymers are inorganic polymer materials with an amorphous structure and a chemical composition similar to zeolites. According to Joseph Davidovits, these materials are created by mixing an alkaline solution with source materials, which can include fly ash, Ground Granulated Blast Furnace Slag (GGBS), and rice husk ash. The source materials used in geopolymer formation typically have a higher percentage of silicon (Si) and aluminum (Al).

Geopolymers can be classified into three different structures based on the ratio of silicon to aluminum (Si/Al) in their compositions:

a) Poly(sialite) structure (-Si-O-Al-O-): This structure consists of a chain of silicon and aluminum atoms linked by oxygen atoms. It forms the basis for one type of geopolymer.

b) Poly(sialate-siloxo) structure (-Si-O-Al-O-Si-O-): In this structure, silicon and aluminum atoms are connected by oxygen atoms, with silicon atoms also bonded to other silicon atoms. This results in a more complex structure compared to the poly(sialite) form.

c) Poly(sialate-disiloxo) structure (-Si-O-Al-O-Si-O-Si-O-): This structure is even more intricate, with silicon and aluminum atoms linked by oxygen atoms, and silicon atoms forming bonds with multiple silicon atoms. It is the most complex of the three geopolymer structures.

In summary, geopolymer materials are created through the reaction of an alkaline solution with source materials like fly ash, GGBS, or rice husk ash, which have higher Si and Al content. The resulting geopolymer structures can be classified into three categories based on their Si/Al ratios, each with distinct properties and applications.

1.2 OBJECTIVE OF STUDY

The objectives of using fly ash-based geopolymer concrete typically include the following:

- To study a concrete without using cement (Geopolymer concrete).
- Evaluating the mechanical properties of fly ash-based geopolymer concrete, including its compressive strength, Split tensile strength and NDT (Rebound Hammer Test).
- Optimizing the mix design of geopolymer concrete to achieve desired mechanical properties
- Address the problem of waste disposal from mineral extraction and industrial processes by utilizing these waste materials in the production of Geopolymer concrete, thus promoting sustainability and environmental responsibility.

2. MATERIALS USED

2.1 FLY ASH: Fly ash is a byproduct generated in the combustion process of coal in thermal power plants. It consists of extremely fine particles and contains various inorganic materials. The classification of fly ash is based on its calcium oxide (Cao) content:

- Low-Calcium Fly Ash (Class F): This type of fly ash contains less than 10% calcium oxide (Cao). It is also known as Class F fly ash. Class F fly ash is typically characterized by its pozzolanic properties, which meansit can react with lime and water to form cementitious compounds. This type of fly ash is commonly used as asupplementary cementitious material in concrete production to enhance its properties.
- High-Calcium Fly Ash(Class C): High-calcium fly ash contains a higher Cao content, typically ranging from 15% to 30%. It is referred to as Class C fly ash. Class C fly ash has both pozzolanic and self-cementing properties, as it can form cementitious compounds not only through reaction with lime but also through its intrinsic self-cementingproperties. Class C fly ash is used in various construction applications, including in the production of concrete,where it can serve as a cement replacement or as a supplementary cementitious material.

2.2 COARSE AGGREGATE

The material that remains on a 4.75mm sieve in a particle size analysis is typically referred to as coarse aggregate. Coarse aggregate is used in construction for various purposes, including in the production of concrete. The sizes of coarse aggregates are typically designated by the maximum particle size present in the aggregate mix.

(a) Type: Crushed Nature
(b) Maximum Size: 20mm
(b) Water Absorption: 0.45%

2.3 FINE AGGREGATE

In particle size analysis, the material that remains on a 4.75mm sieve is typicallyreferred to as fine aggregate. Fine aggregate is a crucial component in concrete and other construction materials. Natural river sand confirming to grading zone-1 as per is code 383:2016

(a) water content: 2.1% (b) Fineness modulus: 2.89

2.4 ALKALINE ACTIVATOR

(a) SODIUM HYDROXIDE SOLUTION

Sodium Hydroxide, also known as caustic soda, is an inorganic compound with the chemical formula NaoH. It's a strong, caustic base and alkali salt, usually found in the form of white solid pellets, flakes, or granules. In the case of our fly ash-based polymer concrete, which is a uniform material, the primary purpose of using sodium hydroxide is to activate the sodium silicate. Therefore, it is recommended to use sodium hydroxide with a purity level ranging from 94% to 96% to keep costs down. For example, for 13 molar NaoH concentration we will have to take 520 gm NaoH solid in 1 liter of solution.

(b) SODIUM SILICATE SOLUTION

Sodium Silicate is employed, which is the common name for a compound known as sodium metasilicate (Na_2Sio_3), also referred to as water glass or liquid glass. This sodium silicate is available in a liquid or gel form. When applied to concrete, it serves to substantially reduce porosity. The specific sodium silicate used in this investigation has a ratio of 2.0 between Na_2O and Sio_2, which indicates the molar ratio of sodium oxide (Na_2o) to silicon dioxide (Sio_2) compound.

2.1 WATER

In the context of geopolymer concrete, clean potable water is used for mixing. The primary role of water in the geopolymer mixture is to facilitate the creation of workable concrete while it is in a plastic state, meaning when it can be molded and shaped. However, the water used in the mixture does not contribute significantly to the concrete's strength in its hardened state. Therefore, it is essential to useclean, drinkable (potable) water for the mixing process.

3. METHODOLOGY

There is no established mix design procedure for geopolymer concrete using fly ashand alkaline liquid. In 2008, Rangan proposed a mix design method based on their earlier research, which focused on the impact of combined aggregate mass on the compressive strength of geopolymer concrete. Theresearch found that, for locally available materials, an optimal mix required 77% of the mass to be made up of combined aggregates to achieve a cohesive mix that yielded better results. In summary, the mix design procedure suggested by Rangan was based on this previous research, emphasizing the importance of the percentage of combined aggregates for achieving the desired concrete properties.

The experimental work maintains the following parameters at a constant level, as previously described in the earlier investigation:

(a) Cement replacement is consistently at 100% by using fly ash.

(b) The type of alkaline activators used remains Sodium Hydroxide and Sodium Silicate.

(c) The mass ratio of Sodium Silicate to Sodium Hydroxide is consistently set at one.

(d) The concentration of Sodium Hydroxide is kept constant and measured in terms of molarity.

(e) The concentration of Na2O and SiO2 in the sodium silicate solution remains unchanged.

(f) Curing time, including both the duration and temperature, is maintained at a consistent level throughout the experiments. In essence, these parameters are standardized and do not vary in the experimental work.

3.1 MIX DESIGN FOR GEOPOLYUMER CONCRETE

Drawing from the experimental investigation conducted in the current study, the following steps have been implemented by S.V. Patankar et.al. S.V. Patankar “Mix Design of Fly Ash Based Geopolymer Concrete December 2014.PP 1619-1634 Based on the mix design steps outlined in the previous section, a sample mix proportioning for M30 grade geopolymer concrete is conducted using the proposed method.

The mix design for M30 grade geopolymer concrete is based on the following initial data

(a) The characteristic compressive strength of the geopolymer concrete is set at 30 MPa.

(b) Curing is accomplished through oven curing at 90 °C for 8 hours, and testing is performed after 7 days and 28 days.

(c) Workability: 25–50% (In Term of Flow Workability)

(d) The solution-to-fly ash ratio by mass is fixed at 0.35.

(e) The sodium silicate-to-sodium hydroxide ratio by mass is maintained equal to one.

3.2 COMPUTATION OF INGREDIENTS MATERIALS FOR LABORATORY WORK

150mmx150mmx150mm cubes were casted.
Volume of 1 Cube = 0.15 x 0.15 x 0.15 = 0.003375 m3
Volume For 3 Cubes = 3 x 0.003375 = 0.010125 m3

Therefore for 3 cubes required quantity of material is as shown below:
1. Coarse Aggregate = 1157 x 0.010125 = 11.70 kg
2. Fine Aggregate = 623 x 0.010125 = 6.31 kg
3. Fly Ash = 485 x 0.010125 = 4.911 kg
4. Alkaline Liquid = 170 x 0.010125 = 1.72 kg
5. Water =16 x 0.010125 = 0.162 kg

Fly Ash: Fine Aggregate: Coarse Aggregate: Water: Alkaline Solution = 1:1.29:2.38:0.03:0.3
Similarly, we have calculated the quantities of ingredient materials for the other concrete mixes.

3.3 RESULTS AND DISCUSSION

(A) COMPRESSIVE STRENGTH

The compressive strength of a material is a measure of its ability to withstand a uniaxial compressive stress before it fails. This strength is often determined through strength tests on cubic specimens. The compressive strength is calculated by dividing the failure load (in newtons, N) by the cross-sectional area (in square millimeters, mm^2) that resists the applied load. The compressive strength is usually determined on 150 mm cube specimens, and it's tested according to the ASTM C 39 standard. Testing is typically done after 7 and 28 days of water curing. To ensure accuracy and reliability, three specimens are usually tested at each age, and the average of these values is reported as the compressive strength of the material.

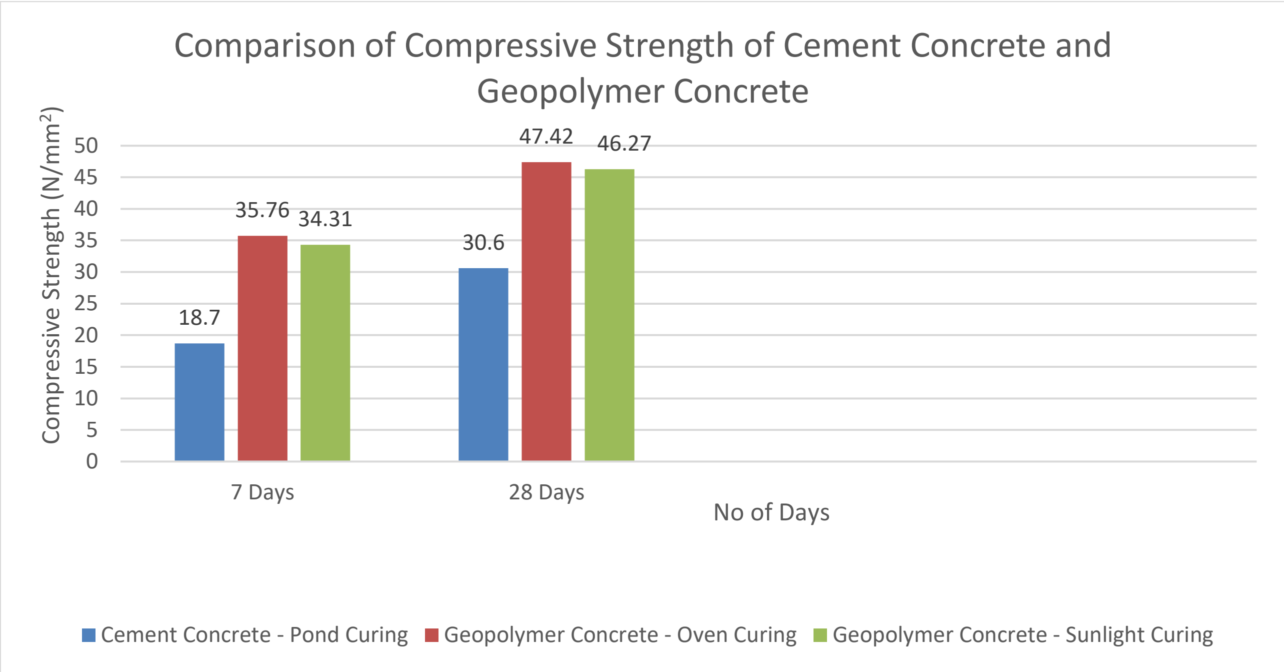
C = P / (Area of the cube in mm^2) C is the compressive strength in Mega Pascals (MPa
P is the load applied to the cube specimen in newtons (N).
A is the area of cube in millimeter (mm).

Table 01: Cement Concrete of Size 150mmx150mmx150mm at 7 Days and 28 Days of Testing

S.NO	W/C	Types of Curing	Days of Testing	Compressive Strength (N/mm^2)
1	0.45	Pond	7	18.1
2	0.45	Pond	7	19.0
3	0.45	Pond	7	18.9
4	0.45	Pond	28	29.6
5	0.45	Pond	28	30.1
6	0.45	Pond	28	30.5

Table 02: Geopolymer Concrete Cubes of Size 150mmx150mmx150mm at 7 Days And 28 Days ofTesting

S.NO	S/F	Types of Curing	Days of Testing	Compressive Strength(N/mm^2)
1	0.35	Oven	7	36.75
2	0.35	Oven	7	34.69
3	0.35	Oven	7	35.86
4	0.35	Sunlight	7	33.69
5	0.35	Sunlight	7	35.00
6	0.35	Sunlight	7	34.24
7	0.35	Oven	28	48.71
8	0.35	Oven	28	46.34
9	0.35	Oven	28	47.22
10	0.35	Sunlight	28	46.36
11	0.35	Sunlight	28	46.92
12	0.35	Sunlight	28	45.57



The compressive strength results for different curing methods are as follows:
Cement Concrete (Pond Curing)-The compressive strength at 7 days and 28 days is 18.7Mpa and 30.6 MPa respectively. Geopolymer Concrete (Oven Curing)-The compressive strength after curing at 90°C in an oven for 8 hours and then allowing it to cool down to room temperature or curing for 28 days in an oven is 47.42 MPa.Geopolymer Concrete (Sunlight Curing)-The compressive strength at 28 days of sunlight curing is 46.27 MPa.When comparing the results to the target strength for M30 grade geopolymer concrete, it is observed that Geopolymer concrete with Oven Curing is 23.90% more than the target strength (38.25). Geopolymer concrete with Sunlight Curing is 20.90% more than the target strength. These results fall within the acceptable limits defined by IS 456-2000, which allows for variations of up to +/- 15% from the target strength.

(B) SPLIT TENSILE STRENGTH

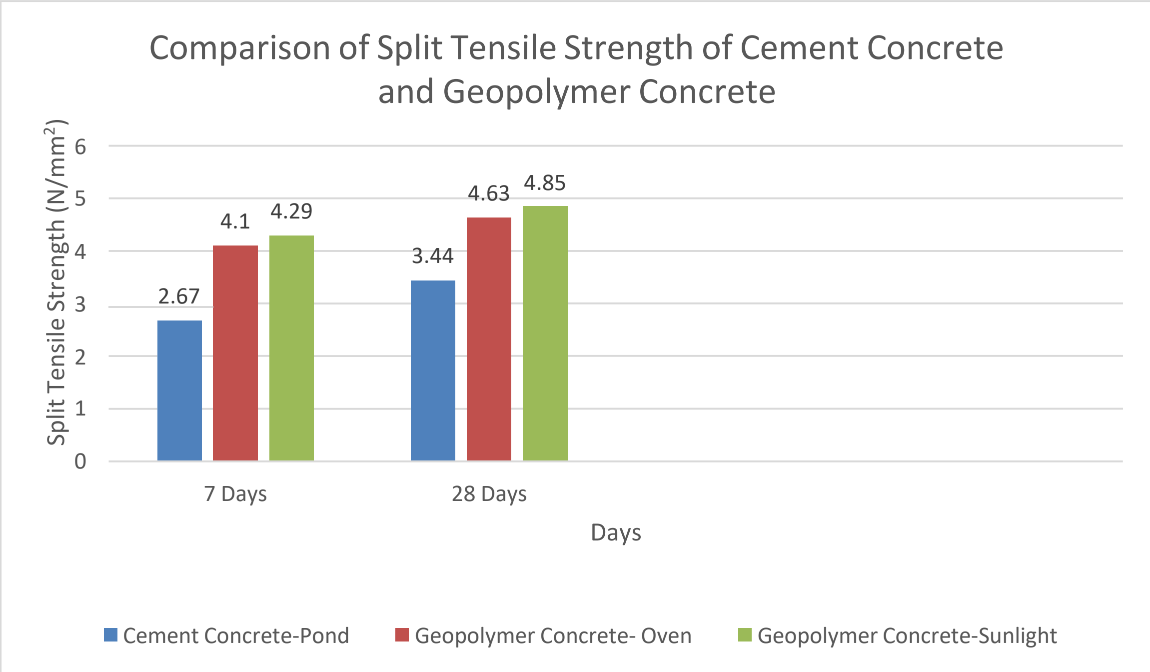
Tensile strength is indeed an important property of concrete, although it is generally considered a weak point in its mechanical behavior. Concrete is a strong material in compression, but it is relatively weak in tension due to its brittle nature. This means that concrete is not well-suited to resisting direct tensile forces, which can lead to the development of cracks. When subjected to tensile forces, such as stretching or bending, concrete tends to fail by cracking and eventually breaking.

Table 03: Cement Concrete Cylinder of Size 150mmx300mm at 7 Days And 28 Days of Testing

S.NO	W/C	Types of Curing	Days of Testing	Split Tensile Strength (N/mm^2)
1	0.45	Pond	7	2.78
2	0.45	Pond	7	2.63
3	0.45	Pond	7	2.61
4	0.45	Pond	28	3.59
5	0.45	Pond	28	3.43
6	0.45	Pond	28	3.30

Table 04: Geopolymer Concrete Cylinder of Size 150mmx300mm at 7 Days And 28 Days of Testing

S.NO	S/F	Types of Curing	Days of Testing	Split Tensile Strength (N/mm^2)
1	0.35	Oven	7	4.10
2	0.35	Sunlight	7	4.29
3	0.35	Oven	28	4.63
4	0.35	Sunlight	28	4.85



The provided information compares the split tensile strength of different types of concrete under different curing conditions. Let's break down the comparisons:

Cement Concrete (Pond Curing)-The split tensile strength at 28 days pond curing is 3.44 MPa.

Geopolymer Concrete (Oven Curing)-The split tensile strength of geopolymer concrete cubes, when cured at 90°C in an oven for 8 hours and then cooled down to room temperature over 28 days is 4.63 MPa.

Geopolymer Concrete (Sunlight Curing)-The flexural strength of geopolymer concrete cubes at 28 days of sunlight curing is 4.85 MPa. Now, let's compare these results to the target strength of 3 MPa.

In the case of Cement Concrete - Pond Curing, the strength is higher than the target strength (4.10 MPa > 3 MPa). For Geopolymer Concrete - Oven Curing, the strength is significantly higher than the target strength (4.63MPa > 3 MPa), and it is mentioned that the cubes were exposed to high-temperature curing.

In the case of Geopolymer Concrete - Sunlight Curing, the split tensile strength is also significantly higher than the target strength (4.85 MPa > 3 MPa). In other words, both geopolymer concrete curing methods, i.e., Oven Curing and Sunlight Curing, have considerably exceeded the target strength of 3 MPa. Specifically, Geopolymer Concrete Sunlight Curing has a 61.7% higher strength compared to the target, while Geopolymer Concrete - Oven Curing has a 54.33 % higher strength compared to the target. This indicates that these geopolymer concrete mixtures have performed exceptionally well in terms of tensile strength, exceeding the specified requirements by a substantial margin.

(C) REBOUND HAMMER TEST

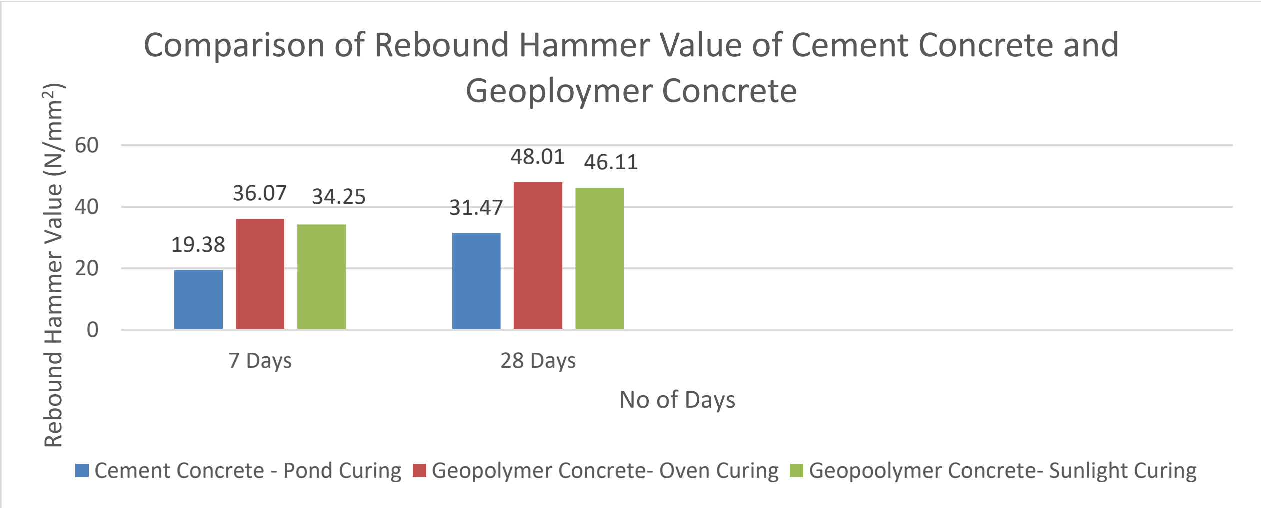
The Rebound Hammer Test, also known as the Schmidt Hammer Test, is a widely used non-destructive testing (NDT) method to assess the compressive strength and quality of concrete. The test is based on the principle that the rebound of a spring-loaded mass striking the concrete surface provides an indication of the concrete's compressive strength.

Table 05: Cement Concrete of Size 150mmx150mmx150mm at 7 Days and 28 Days of Testing

S.NO	W/C	Types of Curing	Days of Testing	Rebound Hammer Value (N/mm^2)
1	0.45	Pond	7	19.38
2	0.45	Pond	28	31.47

Table 06: Geopolymer Concrete Cubes of Size 150mmx150mmx150mm at 7 Days And 28 Days of Testing

S.NO	S/F	Types of Curing	Days of Testing	Rebound Hammer Value (N/mm^2)
1	0.35	Oven	7	36.07
2	0.35	Sunlight	7	34.25
3	0.35	Oven	28	48.01
4	0.35	Sunlight	28	46.11



The provided information compares the rebound hammer value of different types of concrete under different curing conditions.

Cement Concrete (Pond Curing)-The rebound hammer value at 28 days pond curing is 31.47Mpa here value increases with comparison to compressive strength of cement concrete. Geopolymer Concrete (Oven Curing)- The rebound hammer value of geopolymer concrete cubes, when cured at 90 °C in an oven for 8 hours and then cooled down to room temperature over 28 days is 48.01MPa. Geopolymer Concrete (Sunlight Curing)- The rebound hammer value of geopolymer concrete cubes at 28 days of sunlight curing is 46.11MPa. Here, rebound hammer value of geopolymer concrete at 7 days and 28 days is slight increases with comparison to compressive strength of geopolymer concrete in case of oven curing while in sunlight curing value of rebound hammer decreases with comparison to compressive strength of geopolymer concrete at 7 days and 28 days of curing.

4. CONCLUSIONS

The experimental investigation yields several important conclusions:

- The study analyzed various aspects of geopolymer concrete, including its material properties, mix design, and a comparison of mechanical properties (compressive strength, split tensile strength and NDT) with conventional concrete.
- Geopolymer concrete of M30 grade was found to exhibit significant improvements in strength compared to the target strength of cement concrete. It demonstrated a 22.47% higher compressive strength and a remarkable split tensile strength also increases.
- Rebound hammer value of geopolymer concrete at 7 days and 28 days is slight increases with comparison to compressive strength of geopolymer concrete in case of oven curing while in sunlight curing value of rebound hammer decreases with comparison to compressive strength of geopolymer concrete at 7 days and 28 days of curing.
- Test results indicate that fly ash-based geopolymer concrete outperforms conventional concrete in terms of compressive strength and split tensile strength. This suggests that geopolymer concrete can be a superior construction material in certain applications.
- Geopolymer concrete has the potential to address waste disposal issues associated with the byproducts of mineral extraction and industrial processes, such as fly ash. This demonstrates a sustainable and environmentally friendly aspect of geopolymer concrete.
- The use of geopolymer concrete can contribute to a reduction in carbon dioxide emissions. This is particularly important in the construction industry as it can help mitigate the environmental impact associated with traditional cement production.
- The weight of geopolymer concrete is lighter than cement concrete.

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