International Journal of Engineering Applied Sciences and Technology, 2024
Vol. 9, Issue 08, ISSN No. 2455-2143, Pages 86-96
Published Online December 2024 in IJEAST (http://www.ijeast.com)

EFFECT OF WATER-TO-GEOPOLYMER SOLIDS RATIO ON THE WORKABILITY AND STRENGTH OF FLY ASH AND GGBFS-BASED GEOPOLYMER CONCRETE

Mrs. Bandhavya G B
Assistant Professor
Navkis College of Engineering, Hassan, Karnataka, India

Dr.S.Prashanth
Professor
GEC, K R Pete, Mandya

Mrs. Lavanya H D
Assistant Professor
Department of Civil Engineering
Malnad College of Engineering, Hassan, Karnataka, India

Mr.Sandeep K
Structural Engineer,
Founder at SBC Consultancy
Hassan/Bangalore, Karnataka, India

Abstract—**Geopolymer concrete (GPC) is an emerging sustainable alternative to conventional Portland cement concrete, utilizing industrial by-products such as fly ash and ground granulated blast furnace slag (GGBFS) as binders. This study investigates the effect of varying water-to-geopolymer solids ratios and extra water addition on the workability, compressive strength, and durability of GPC cured at room and oven temperatures. Experimental results indicate that increasing the water-to-geopolymer solids ratio improves workability but reduces compressive strength. GPC samples achieved a compressive strength of 33.76 MPa at 24 hours when cured at room temperature and 45.53 MPa at 24 hours when oven-cured at 60°C. Furthermore, the water absorption of GPC cured at room temperature was significantly lower (0.28%) compared to oven-cured samples (2.57%). Durability tests confirmed that GPC exhibited excellent resistance to sulfate attack, with no noticeable weight loss or surface degradation over a 30-day period. The findings highlight the potential of GPC as a viable alternative to conventional concrete, especially in applications requiring early strength development and improved sustainability.**

Keywords— **Geopolymer Concrete, Fly Ash, GGBFS, Water-to-Geopolymer Solids Ratio, Workability, Compressive Strength, Durability, Sustainable Construction, Alkali Activation, Room Temperature Curing, Oven Curing, Sulfate Resistance**

I. INTRODUCTION

IJEAST Concrete is one of the most extensively used construction materials worldwide, traditionally relying on Ordinary Portland Cement (OPC) as its primary binder. However, the production of OPC is associated with significant environmental concerns, particularly the emission of carbon dioxide (CO_2) during manufacturing. For every ton of OPC produced, an equivalent ton of CO_2 is released, contributing to global warming. Additionally, the energy consumption required for cement production is second only to that of steel and aluminum.

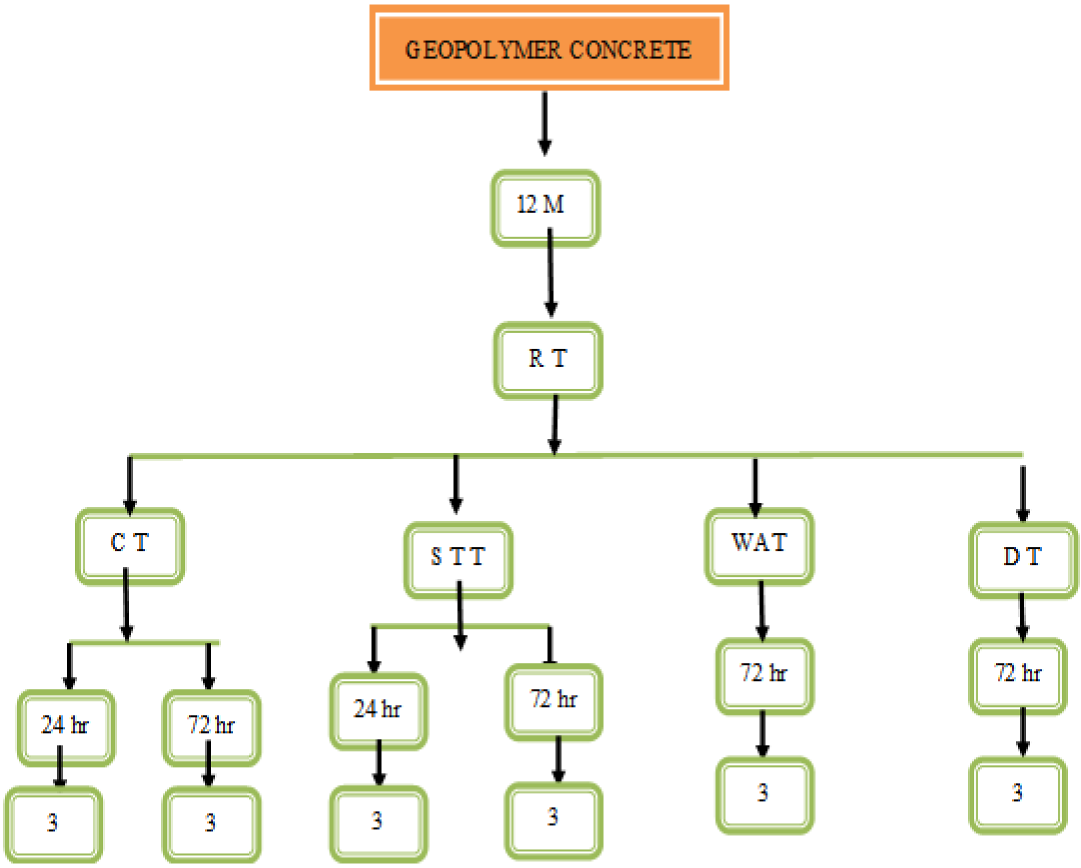
To address these environmental challenges, researchers have explored alternative binder systems that can replace OPC. One such promising alternative is Geopolymer Concrete (GPC), which utilizes industrial by-products such as fly ash and ground granulated blast furnace slag (GGBFS). GPC eliminates the need for OPC, thereby significantly reducing carbon emissions. The technology, originally introduced by

Davidovits (1988), involves an alkaline activation process, wherein silica (Si) and alumina (Al) from industrial waste materials react with an alkaline solution to form a polymeric binder. Unlike OPC, which gains strength through the hydration of calcium silicate phases, GPC relies on the polycondensation of silicate and aluminate species in the presence of alkaline activators such as sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3).
The key advantages of GPC include high compressive strength, enhanced durability, superior resistance to acid and sulfate attacks, and reduced environmental impact. Moreover, GPC exhibits low thermal conductivity and excellent fire resistance, making it suitable for a wide range of applications, including precast concrete elements, railway sleepers, marine structures, and sewer pipelines. However, challenges such as sensitivity to variations in raw material composition and the need for temperature curing limit its widespread adoption.

This study investigates the impact of water-to-geopolymer solids ratio and extra water addition on the workability, compressive strength, and durability of GPC. It aims to establish an optimized mix design that can achieve high strength at room temperature curing, thereby enhancing the practical applicability of GPC in construction.

II. PROPOSED METHODOLOGY

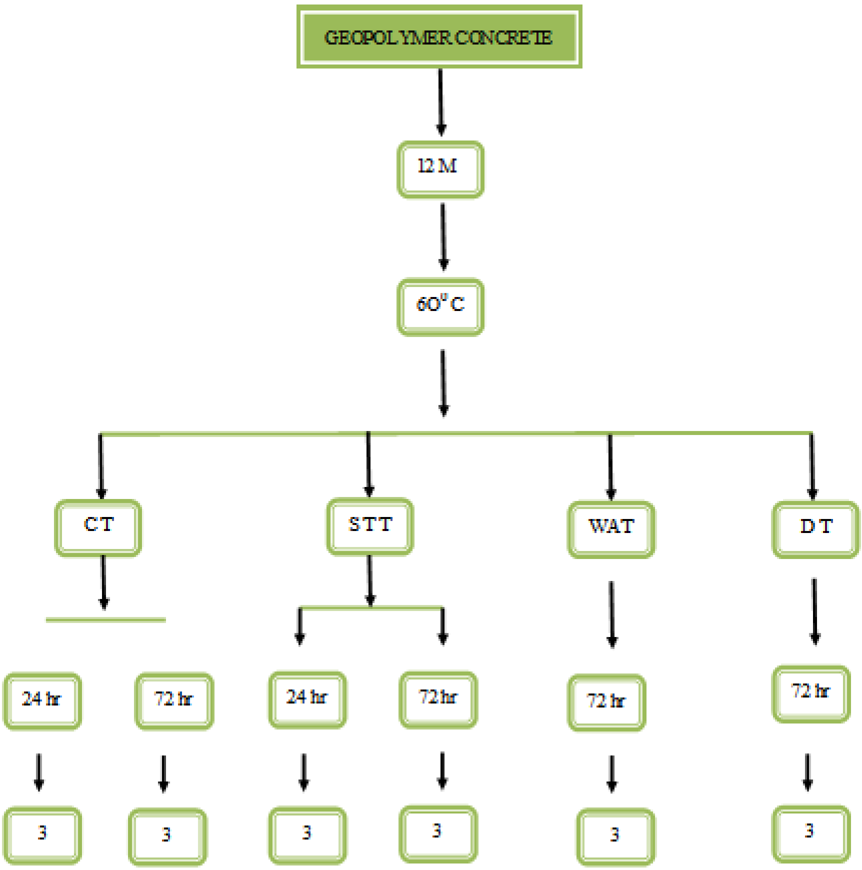
The study investigates the effect of the water-to-geopolymer solids ratio (W/GPS) and extra water addition on the workability, compressive strength, and durability of Geopolymer Concrete (GPC). The methodology is designed based on previous research findings, incorporating fly ash and GGBFS as binders and optimizing curing conditions for practical applications.



Flow Chart 2.1: Experimental Work

RT=Room temperature;
CT=Compression test;
STT=Split tensile test;
WAT=Water absorption test;
DT=Durability test

International Journal of Engineering Applied Sciences and Technology, 2024
Vol. 9, Issue 08, ISSN No. 2455-2143, Pages 86-96
Published Online December 2024 in IJEAST (http://www.ijeast.com)



Flow Chart 2.2:: Experimental Work

Fig 2.1: Working Principal.

The geopolymer binder comprises Class F fly ash and ground granulated blast furnace slag (GGBFS) as aluminosilicate sources. The alkaline activator solution consists of sodium hydroxide (NaOH) and sodium silicate (Na2SiO2), prepared with an Na2SiO2/NaOH ratio of 2.5. Fine and coarse aggregates are used in accordance with IS standards, and a superplasticizer (Glenium B233) is incorporated to enhance workability. A target compressive strength of 35 MPa is considered for mix design. The NaOH concentration is maintained at 12M, and the W/GPS ratio is varied to analyze its effect on workability and strength. The dry constituents are mixed homogeneously before the addition of the alkaline solution and super plasticizer. The mixture is blended thoroughly to achieve uniform consistency. Standard specimens are cast to assess the mechanical and durability properties:

(a) 150 × 150 × 150 mm cubes for compressive strength testing.
(b) 150 × 300 mm cylinders for split tensile strength testing.

Two curing conditions are adopted: Oven curing: Specimens are cured at 60°C for 24 hours in a controlled environment. Ambient curing: Specimens are left at room temperature (27°C) throughout the curing period. The following tests are conducted to evaluate fresh and hardened properties of GPC:

- Workability (Slump Test): Determines the consistency and flowability of fresh concrete.
- Compressive Strength (IS 516-1959): Measured at 1 and 3 days to assess early strength development.
- Split Tensile Strength (IS 5816-1999): Evaluates the tensile resistance of concrete.
- Water Absorption Test: Determines porosity and permeability by measuring absorbed water percentage.
- Durability Test (Sulfate Resistance): Specimens are immersed in a sodium sulfate (Na_2SO_4) solution for 30 days to assess deterioration resistance.

The experimental work consists of material selection, mix proportioning, specimen preparation, curing conditions, and standardized testing procedures to evaluate performance.

III. EXPERIMENT AND RESULT

The study evaluates the influence of water-to-geopolymer solids ratio (W/GPS) and extra water addition on the mechanical and durability properties of geopolymer concrete (GPC). The impact of curing conditions is also analyzed to determine the most effective approach for strength development and long-term performance. The variation in W/GPS ratio significantly affects the workability of the fresh concrete mix. As the ratio increases, the flow ability improves due to the higher liquid content, leading to better placement and compaction. However, excessive water addition results in segregation, reducing the homogeneity of the mix. The optimum W/GPS ratio ensures a balanced consistency, achieving a slump value of 190 mm, which is suitable for structural applications without compromising stability

Specimen Nos.	Weight of specimen (kg)	Density (kg/m3)	Slump in mm	Average density (kg/m3)
1	8.345	2473	170	2484
2	8.420	2495	160	

Table 3.1: **Compressive strength of the cube cured at room temperature for 1 day.**

Failure load (kN)	Area (mm2)	Compressive strength (N/mm2)	Average compressive strength (N/mm2)
870.4	150×150	38.68	39.45
905.2	150×150	40.23	

Table 3.2: **Compressive strength of the cube cured at room temperature for 1 day.**

Specimen Nos.	Weight of specimen (kg)	Density (kg/m3)	Slump in mm	Average density (kg/m3)
1	8.655	2564	75	2479
2	8.08	2394	90	

‘Table 3.3.a: **Compressive strength of the cube cured at room temperature for 3 day.**

Failure load (kN)	Area (mm2)	Compressive strength (N/mm2)	Average compressive strength (N/mm2)
1328	150×150	59	57
1241	150×150	55	

Table 3.3.b: **Compressive strength of the cube cured at room temperature for 3 day.**

Specimen Nos.	Weight of specimen (kg)	Density (kg/m3)	Slump in mm	Average density (kg/m3)
1	8.19	2347	110	2411
2	8.35	2474	100	

Table 3.4.a Compressive strength of the cube cured at oven temperature for 1 day.

Failure load (kN)	Area (mm2)	Compressive strength (N/mm2)	Average compressive strength (N/mm2)
1174	150×150	52	53.6
1241	150×150	55	

Table 3.4.b Compressive strength of the cube cured at oven temperature for 1 day.

Specimen Nos.	Weight of specimen (kg)	Density (kg/m3)	Slump in mm	Average density (kg/m3)
1	8.2	2427	51	2429
2	8.05	2430	51	

Table 3.5.aCompressive strength of the cube cured at oven temperature for 3 day.

Failure load (kN)	Area (mm2)	Compressive strength (N/mm2)	Average compressive strength (N/mm2)
1581	150×150	70	63.34
1275	150×150	56.67	

Table 3.5.b Compressive strength of the cube cured at oven temperature for 3 day.

Observation for 14M Cubes

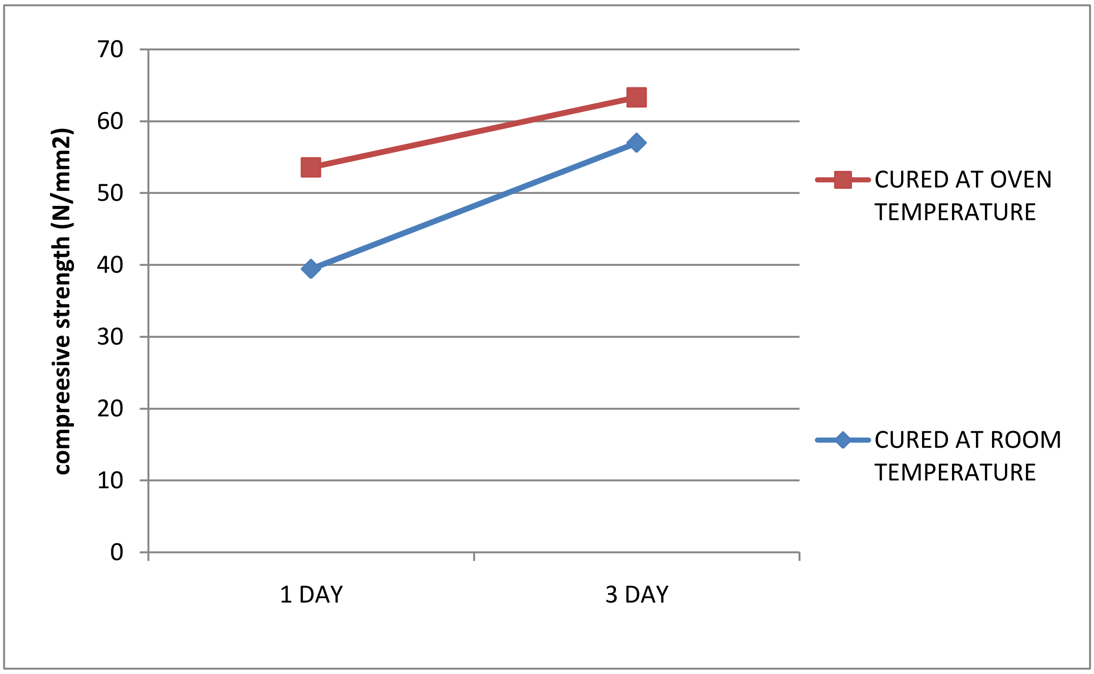


Figure 3.1 Compressive strength of the cubes cured at room and oven temperature.

The above graph shows the compressive strength for the cubes cured in oven and room temperature foe 14M. These where the trail mixes. Following tables give the compressive strength test results of geopolymer concrete cured in oven and room temperature for 1 day and 3 day of 12M of target strength of 35MPa.

Speci men Nos.	Failure load (kN)	Avg density (kg/m3)	Area (mm2)	Average compressiv e strength (N/mm2)
1	778.4	2424	150×150	33.76
2	769		150×150	
3	731.1		150×150	

Table 3.6 Compressive strength of the cube cured at room temperature for 1 day.

International Journal of Engineering Applied Sciences and Technology, 2024
Vol. 9, Issue 08, ISSN No. 2455-2143, Pages 86-96
Published Online December 2024 in IJEAST (http://www.ijeast.com)

Specimen Nos.	Failure load (kN)	Avg density (kg/m3)	Area (mm2)	Average compressive strength (N/mm2)
1	961.1		150×150	
2	1048	2378	150×150	45.53
3	1064		150×150	

Table 3.7 Compressive strength of the cube cured at oven temperature for 1 day.

Specimen Nos.	Failure load (kN)	Avg density (kg/m3)	Area (mm2)	Average compressive strength (N/mm2)
1	1127		150×150	
2	1324	2365	150×150	57.70
3	1444		150×150	

Table 3.8 Compressive strength of the cube cured at oven temperature for 3 day.

Observation for 12M Cubes
The variation found in compressive strength for the cubes cured in oven and room temperature for 1 day and 3 day is presented in the form of graph as shown in Figure 4.1. From the figure we can observe that the compressive strength of the cubes cured in room and oven temperature are nearer. There is an average increase in difference of 27.4% between the cubes cured in room and oven temperature.

The graph shows the compressive strength for the cubes cured in oven and room temperature for 1day and 3day. Sodium hydroxide and sodium silicate are the more commonly used alkaline activating agents. From literature review Anuar K.A. conducted an experimental work using RCA and WPSA cured at ambient condition. The compressive strength results for 8M and 14M cured for 1day was 11.8 N/mm2 and 13.85N/mm2. But in the present in our work for 12M the compressive strength at 1day was 33.76 N/mm2.

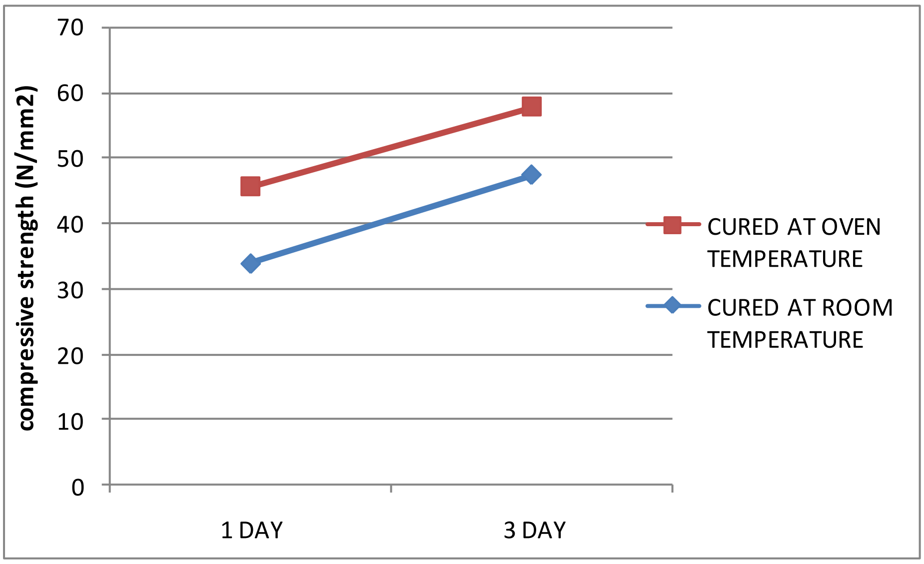


Figure 3.2 Compressive strength of the cubes cured at room and oven temperature.

Strength development is monitored at early ages to assess the effectiveness of curing conditions. Specimens subjected to oven curing at 60°C attain a compressive strength of 45.53 MPa within 24 hours, demonstrating rapid geopolymerization and enhanced early-age performance. In contrast, specimens cured at ambient temperature (27°C) exhibit a lower initial strength of 33.76 MPa, with gradual improvement over time. The differences highlight the role of heat activation in accelerating the chemical reactions, resulting in faster strength gain. Following tables give the split tensile test results of geopolymer concrete cured in oven and room temperature for 1 day and 3 day.

Specimen Nos.	Failure load (kN)	Avg density (kg/m3)	Area (mm2)	Average Tensile strength (N/mm2)
1	119.58	2351	17671	1.71
2	121.60			
3	121.53			

Table 3.9 Tensile strength of the cylinders cured at room temperature for 1 day.

Specimen Nos.	Failure load (kN)	Avg density (kg/m3)	Area (mm2)	Average Tensile strength (N/mm2)
1	127.32	2370	17671	1.81
2	127.58			
3	128.54			

Table 3.10 Tensile strength of the cylinders cured at room temperature for 3 day.

Specimen Nos.	Failure load (kN)	Avg density (kg/m3)	Area (mm2)	Average Tensile strength (N/mm2)
1	124.87	2358	17671	1.77
2	124.75			
3	125			

Table 3.11 Tensile strength of the cylinders cured at oven temperature for 1 day.

Specimen Nos.	Failure load (kN)	Avg density (kg/m3)	Area (mm2)	Average Tensile strength (N/mm2)
1	133.05	2364	17671	1.87
2	131.52			
3	131.70			

Table 3.12 Tensile strength of the cylinders cured at oven temperature for 3 days

The variation found in Tensile strength for the cylinders cured in oven and room temperature for 1 day and 3 day is presented in the form of graph as shown in Figure 3.3

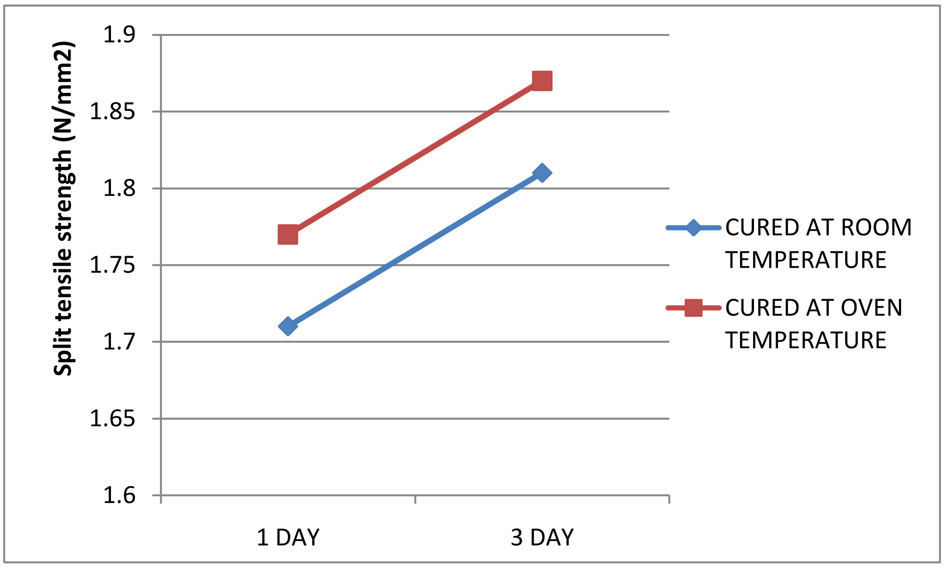


Figure 3.3 Tensile strength of the cylinders cured at room and oven temperature

The permeability of GPC is assessed through water absorption tests, which indicate the material's resistance to moisture ingress. The oven-cured specimens record a water absorption value of 2.57%, slightly higher than ambient-cured samples, which exhibit a lower absorption rate of 0.28%. The differences suggest that ambient curing results in a denser microstructure, reducing porosity and enhancing durability. Long-term durability is evaluated through sulfate resistance testing, where specimens are exposed to a sodium sulfate (Na_2SO_4) solution for 30 days. No visible surface deterioration or cracking is observed, and strength retention remains above 90%, confirming the superior chemical stability of GPC in aggressive environments. The experimental findings indicate that heat curing significantly enhances early-age strength, making it suitable for applications requiring rapid strength gain, such as precast elements. On the other hand, ambient curing improves long-term durability, making it preferable for in-situ construction where prolonged strength development is acceptable. The optimized W/GPS ratio ensures a balance between workability, strength, and durability, highlighting the feasibility of GPC as a sustainable alternative to conventional concrete.

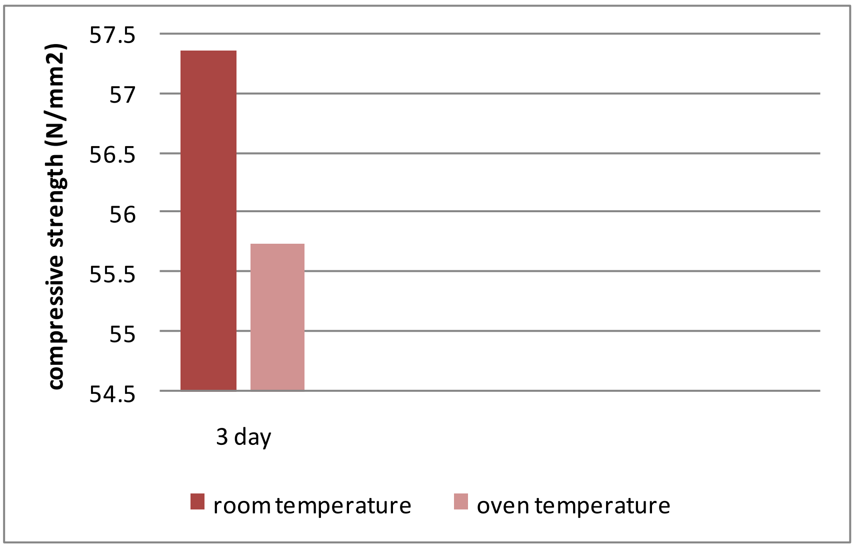


Figure 3.4 Compressive strength of the sulphate resistance test cubes cured at room and oven temperature

IV. CONCLUSION

The experimental investigation on geopolymer concrete (GPC) demonstrated the significant influence of the water-to-geopolymer solids ratio (W/GPS) and extra water addition on its fresh and hardened properties. The results indicate that workability improves with an increased W/GPS ratio; however, excessive water content leads to segregation and reduced cohesiveness. The optimized mix achieved a slump value of 190 mm, ensuring adequate consistency for placement without compromising stability. Compressive strength tests revealed that oven-cured specimens attained a strength of 45.53 MPa within 24 hours, highlighting the effectiveness of heat curing in accelerating the geopolymerization process. In contrast, ambient-cured specimens exhibited a lower early-age strength of 33.76 MPa, with gradual strength development over time. This indicates that while oven curing enhances early strength gain, ambient curing allows for steady hydration and long-term strength improvement. The trend observed in split tensile strength results was consistent with compressive strength behavior. Oven-cured specimens exhibited superior tensile strength, attributed to improved bonding within the geopolymer matrix. Meanwhile, ambient-cured specimens showed progressive strength development, making them suitable for applications where extended curing periods are feasible.

Water absorption analysis indicated that ambient-cured specimens exhibited lower permeability (0.28%) compared to oven-cured specimens (2.57%). This suggests that ambient curing results in a denser microstructure, reducing voids and enhancing durability. The sulfate resistance test further confirmed the superior durability of GPC, with specimens showing no visible deterioration or significant weight loss after 30 days of exposure to Na_2SO_4 solution. The study concludes that oven curing is highly effective for applications requiring rapid strength development, such as precast concrete elements and prefabricated structures. Conversely, ambient curing provides better long-term durability, making it preferable for in-situ construction applications. These findings highlight the potential of geopolymer concrete as a sustainable and high-performance alternative to conventional cement-based concrete, with the added advantage of reduced carbon emissions and enhanced durability.

Future research should focus on long-term performance evaluation, large-scale field applications, and the influence of different activator concentrations to further optimize geopolymer concrete for diverse construction needs.

V. REFERENCE

[1] Concrete Technology book

[2] P.K.Mehta and Paulo J.M.Monteiro, “Concrete: microstructure, properties and materials”, The McGrawHill Companies

[3] ML Gambhir, Concrete Technology, Tata McGraw Hill Companies

[4] AR Santakumar, Concrete Technology, Oxford University Press

[5] CONCRETE Microstructures, Properties and Materials, P. Kumar Mehta, Paulo J.M. Monteiro, McGraw Hill Education, 2006

[6] Dr. Haider K. Ammash, Muhammed S. Muhammed, Ali H. Nahhab, “Using of waste glass as fine aggregate in concrete”, AlQadisiya Jour- nal For Engineering Sciences Vol. 2,Year 2009

[7] Indian Standard, 1959. IS 516: Method of Tests for Strength of Concrete, New Delhi.

[8] Indian Standard, 1963. IS 2386-3: Methods of Test for Aggregate for Concrete, Part 3:Specific Gravity, Density, Voids, Absorption and Bulking, New Delhi.

[9] Indian Standard, 1963b. IS 2386–1: Methods of Test for Aggregates for Concrete, Part-1: Particle Size and Shape, New Delhi.

[10] Indian Standard, 2009. IS 10262: Guidelines for Concrete Mix Design Proportioning.

[11] Anuar K.A, Ridzuan A.R.M, Ismail S (2011). “Strength Characteristic Of Geopolymer Concrete Containing Recycled Concrete Aggregate” International Journal of Civil & Environmental Engineering IJCEE-IJENS Vol: 11 No: 01.

[12] B. Siva Konda Reddy J. Varaprasad and K.Naveen Kumar Reddy (2010). “Strength and Workability of Low Lime Fly-Ash Based Geopolymer Concrete” Indian Journal of Science and Technology Vol. 3 No. 12.

[13] Deepak Ravikumar, Sulapha Peethamparan, Narayanan Neithalath (2010). “Structure And Strength Of NaOH Activated Concretes Containing Fly Ash Or GGBFS As The Sole Binder”.

[14] Hardijito.D, Wallah S.E, Sumajouw M.J, and Rangan B.V, (2004) ”On the Development of Fly Ash-Based Geopolymer Concrete” ACI Materials Journals.

[15] Hardijito.D, Wallah S.E, Sumajouw M.J, and Rangan B.V, (2004). “On the Development of Fly Ash-Based Geopolymer Concrete” ACI Materials Journals.

[16] Hardjito.D and Rangan B.V,(2005) "Development and Properties of Low Calcium based Geopolymer Concrete" Research Report GC1 Faculty of Engineering Curtin University Perth Australia.

[17] K. Kannapiran, T. Sujatha and S. Nagan (2012). “Resistance of Reinforced Geopolymer Concrete beams To Acid And Chloride Migration” ASIAN JOURNAL OF CIVIL ENGINEERING (BHRC) VOL. 14, NO. 2 (2013) pages 225-238.

[18] Kumar S. (2013) “Experimental Investigations on Optimal Strength Parameters of Fly Ash Based Geopolymer Concrete” International Journal of Structural and Civil Engineering Reasearch, Vol. 2, ISSN 2319 – 6009.

[19] M.D. Parmar (2013) “Compressive and Tensile Strength of Geopolymer Concrete Containing

Metalized Plastic Waste" International Journal of Advanced Engineering Technology, E-ISSN 0976-3945.

[20] Monita Olivia and Hamid R. Nikraz (2011). "Strength and Water Penetrability of Fly Ash Geopolymer Concrete" ARPN Journal of Engineering and Applied Sciences VOL. 6, NO. 7.

[21] Rabbani N. (2013) "" B.V.B College of Engineering and Technology, Hubli.

[22] Davidovits, "Chemistry of Geopolymeric Systems, Terminology", Geopolymer '99 International Conference, France: 9-40 in 1999.

[23] Rangan, Hardjito, et al., "Studies on fly ash-based geopolymer concrete, Geopolymer: green chemistry and sustainable development solutions", Curtin University of Technology, 1987, Perth 6845, Australia, pp. 133-138.

[24] Hardjito, and Rangan, "Development and Properties of Low-Calcium Fly ash based Geopolymer Concrete", Research report GC-1, Curtin University of Technology, Perth, Australia, 2005.

[25] Vijai, Kumutha and B. G. Vishnuram, "Effect of types of curing on strength of geopolymer Concrete", Research report, International Journal of the Physical Sciences Vol. 5(9), pp. 1419-1423, 18 August, 2010

[26] Natali Murri, W.D.A. Rickard, et al., "High temperature behavior of ambient cured alkali-activated materials based on ladle slag", Department of Civil, Environmental and Materials Engineering, University of Bologna, Italy, 2013 (51-61).

[27] Susan A. Bernal, Ruby Mejía de Gutiérrez, John L. Provis, "Engineering and durability properties of concretes based on alkali-activated granulated blast furnace slag/metakaolin blends", Universidad del Valle, Cali, Colombia, 2012 (99-108).

[28] Nuruddin, Kusbiantoro, et al., "Development of Geopolymer Concrete with Different Curing Conditions", IPTEK, The Journal for Technology and Science, Vol. 22, No. 1, February 2011.

[29] Fareed Ahmed, M. Fadhil Nuruddin, and Nasir Shafiq, "Compressive Strength and Workability Characteristics of Low-Calcium Fly ash-based Self-Compacting" Geopolymer Concrete, International Journal of Civil and Environmental Engineering 3:2 2011

[30] Nath, P. K. Sarker, "Geopolymer concrete for ambient curing condition", Department of Civil Engineering, Curtin University, Kent Street, Bentley, WA, 6102, Australia.

[31] Ekin Altan, Sinan T. Erdogan, "Alkali activation of a slag at ambient and elevated temperatures", Middle East Technical University, Dept. of Civil Engineering, Ankara 06800, Turkey, (2012).

[32] IS 13311 part-1 (1992), "Non-destructive testing of concrete-methods of test", Ultrasonic pulse velocity, BIS New Delhi.

[33] IS 5816- 1999, "Split tensile strength of concrete", BIS New Delhi.

[34] ASTM C 1202 and AASHTO T 277, "Standard test method for electrical indication of concrete's ability to resist chloride ion penetration", American Society for testing materials standards.

[35] ASTM C 1585-11, "Rate of water absorption of concrete (Sorptivity)", American Society for testing materials standards