

Mechanical Properties of Geopolymer Concrete Made at Ambient Temperature with Fly Ash AND GGBFS

Shivshankar Padmakar Shukla¹, Somanagouda.R. Takkalaki²

¹ PG Student , B.R.Harne College of Engineering & Technology,
Mumbai, Maharashtra 421503, India

² Department of Civil Engineering, B.R.Harne College of Engineering & Technology,
Mumbai, Maharashtra 421503, India

Abstract - The geopolymer concrete is formed by reacting alkaline solutions with silicon, alumina, and calcium products. Here, a number of experiments were conducted by ambient curing to find the suitable percentage proportion of fly ash and ground granulated blast furnace slag (GGBFS) to get the desired strength with conventional concrete. Here By conducting short-term and long-term tests, efforts to find the most suitable proportion of fly ash and GGBFS give the closest strength results to conventional concrete. In this study, using geopolymer concrete (GPC) mixes of 70:30 % fly ash: GGBFS and M20 grade concrete, mechanical and durability tests were conducted.

Keywords: Fly ash; Geopolymer concrete; Ground granulated blast furnace slag (GGBFS).

1. INTRODUCTION

Concrete is an essential material in the construction industry, but conventional concrete uses ordinary Portland cement (OPC), whose production releases a significant amount of carbon dioxide (CO₂). This contributes to global warming and creates environmental concerns. Therefore, sustainable alternatives to cement are needed. In 1988, Davidovits introduced the concept of geopolymer binders using silica- and alumina-rich materials. Geopolymer concrete is produced by replacing cement with industrial by-products such as fly ash and ground granulated blast-furnace slag (GGBFS), which react with alkaline solutions to form a binding material. The use of geopolymer concrete helps reduce CO₂ emissions and provides an effective solution for the disposal of industrial waste. It can achieve good strength and mechanical properties comparable to conventional concrete. Large-scale utilization of fly ash and GGBFS also reduces the demand for cement and conserves natural resources. Thus, geopolymer concrete is a sustainable and environmentally friendly alternative for modern construction.

2. MATERIALS

The ingredients used to produce geopolymer concrete are class F-fly ash, GGBFS, artificial sand (crushing bigger aggregates), coarse aggregate, NaOH (sodium hydroxide) solution, Na₂SiO₃ (sodium silicate) solution, water, and super plasticizer.

2.1 Fly ash

In this investigation work, class F fly ash ASTM: 618 (2003) was obtained from a Coal fired electric power station located at Raichur, Karnataka, India. The ingredients details of fly ash are in Table 1.

2.2 Ground granulated blast furnace slag (GGBFS)

GGBFS has near white color and a bulk density of 1200 kg/m³. The chemical and ingredients details of GGBFS are detailed Table 1.

Table 1: Chemical ingredients of fly ash and GGBFS

CHEMICAL PROPERTIES	Fly ash	GGBFS
LOSS ON IGNITION	0.77	2.11
SiO ₂	62.11	43.42
Al ₂ O ₃	27.46	12.53
Fe ₂ O ₃	4.56	0.81
CaO	0.85	40.33
MgO	0.57	0.70
Na ₂ O	0.05	0.255
K ₂ O	1.165	0.345
TiO ₂	1.085	0.45
Mn ₂ O ₃	0.035	0.135
SO ₃	0.35	0.335

2.3 Fine aggregates (FA)

In the present research, artificial sand conforming to the zone II (manufactured sand from crushing bigger aggregates/rock pieces) was used as FA, and the specified experimental results were taken as per IS: 383 (1970). Artificial FA having a specific gravity of 2.83 and a fineness modulus of 2.68 is obtained.

2.4 Coarse aggregate

In the current research, locally available crushed stone aggregate of 12 mm was used, and various tests were taken as per IS: 383 (1970). Coarse aggregate having a specific gravity of 2.80 and a fineness modulus of 7.0 are taken for all mix calculations.

2.5 Sodium hydroxide (NaOH)

The sodium hydroxide (NaOH) is available in white powder or fragments shape. In this research NaOH pellets is used.

2.6 Sodium silicate (Na₂SiO₃)

The sodium hydroxide (NaOH) is available in white powder or fragments shape. In this research NaOH pellets is used.

2.7 Water

In the current work, regular river water is used and it satisfies as per IS: 456 (2000).

2.8 Super plasticizer

SNF-Sulphonated Naphthalene Formaldehyde.

SNF based solutions are high-performance admixtures used in concrete that are made from Sulphonated Naphthalene Formaldehyde (SNF)

3. PREPARATION OF ALKALINE SOLUTION

Calculation of molarity of NaOH.

$M = \frac{\text{gm solute or molecular mass}}{\text{solution volume for 1 liter of water}}$, $10 M = 40 \times 10 = 400 \text{ gm}$ in a 2:1 ratio, Na_2SiO_3 and NaOH are used.

4. MIX-DESIGN OF GPC

The GPC is totally distinct from that of cement concrete. The mix design is made using the available guidelines. In this study, four different binder material mixtures are used and all proportions are kept at 10 molar of NaOH. The mixes are designated as M1 for proportions of fly ash and GGBFS of 70:30 throughout the research work. The (F/B) fluid /binder ratio ratio was taken 0.55 by keeping the binding solution to binder ratio constant. Extra water content of 2.088 kg/m^3 and SP added of 2 % by weight of the binding material were also used to achieve the required fresh properties of GPC. The GPC mix details are given in Tables 2 and 3.

4.1 Mixing and testing of GPC and CC

In the present research, it is proposed to recognize suitable mix proportions from different proportions of fly ash and GGBFS of geo-polymer concrete by the experimental process. An Indian Standard Code, IS: 10262 (2009). is used for mix design. The test cubes and cylinders were cast using mix proportions.

After arriving at the final mix design, three cubes and three cylinders of cement concrete (CC) and twelve cubes and twelve cylinders of geo polymer concrete (GPC) are cast. Then, cement concrete cubes are placed for 28 days in water. The GPC cubes are kept at laboratory temperature. The CC proportions for cube molding were 1:1.42:3.08 (M20) by mass (cement: FA: CA), with a W/C (Water/Cement) of 0.5 for CC and 0.55 for GPC. Both NaOH solution and Na_2SiO_3 are mixed together to form an alkaline/binder solution. This solution is then used for GPC.

Table 2: Mix design of GPC (All quantities in terms of kg/m^3)

Mix	M
F/B	0.56
FLYASH	220.53
GGBFS	94.51
AS	712.53
CA	1322.92
MOLARITY	10.00
N2OH	15.53
Na_2SiO_3	49.82

ADDITIONAL WATER	2.089
SP (%)	2

Table 3: Mix design of CC M20 grade concrete (All quantities in terms of kg/m3)

MATERIALS	CONTENT
Cement	316
Artificial sand (FA)	447.4
Coarse aggregate (CA)	970.3
Water	157.7
Superplastizer (SP)	3.475
W/C	0.5

5. RESULTS AND DISCUSSION

This section discusses the effect of GPC with different proportions of binders, which gives better and more suitable strength with respect to CC used in construction industries.

5.1 Compressive strength test of CC and geopolymer mixes

The strength behavior in CC and GPC. This work compares the CC strength of M20 grade with the best combination to replace cement by mix M, which is 70:30 % (fly ash: GGBFS). The comparative observed values are detailed in Figure 1, and its values are from Table 4. The maximum strength was observed by increasing the quantity of GGBFS due to increases in the viscosity of the mix.

5.2 Split tensile strength test of CC and GPC

Figure 2 represents the experimental reports of the split tensile strength test; also, the values are drawn from the experiment and Table 4. It provides results on split tensile strength, which is not significantly different from CC with different proportions of binders.

Table 4: Strength behavior of GPC and CC

Mix No.	P _{uc} N/mm ²	P _{ust} N/mm ²	% of Weight Loss	RCPT Charge Passed in Coulombs
CC	31.62	3.58	1.09	2836
M	49.90	3.53	0.31	2916

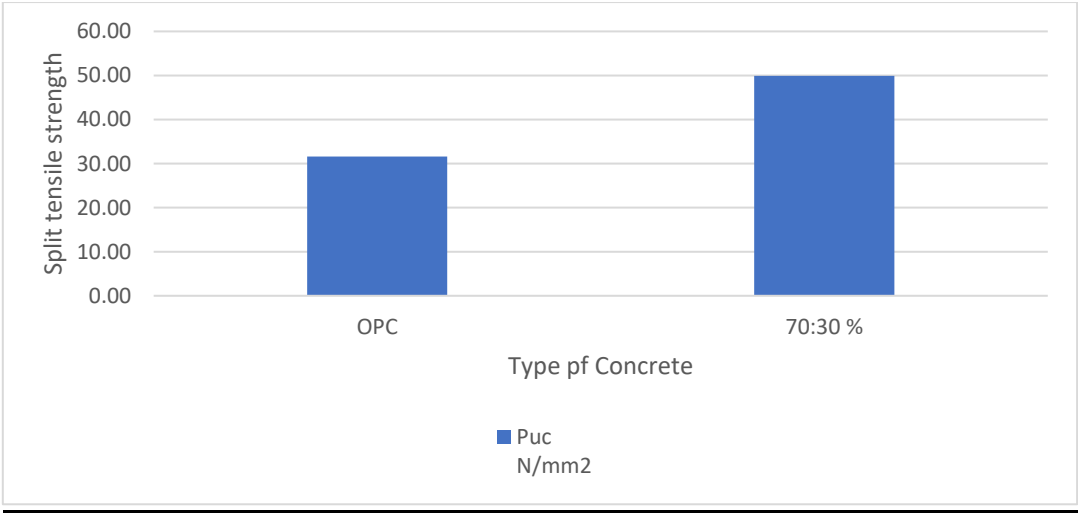


Figure 1: Pcu results of CC and GPC of cubes

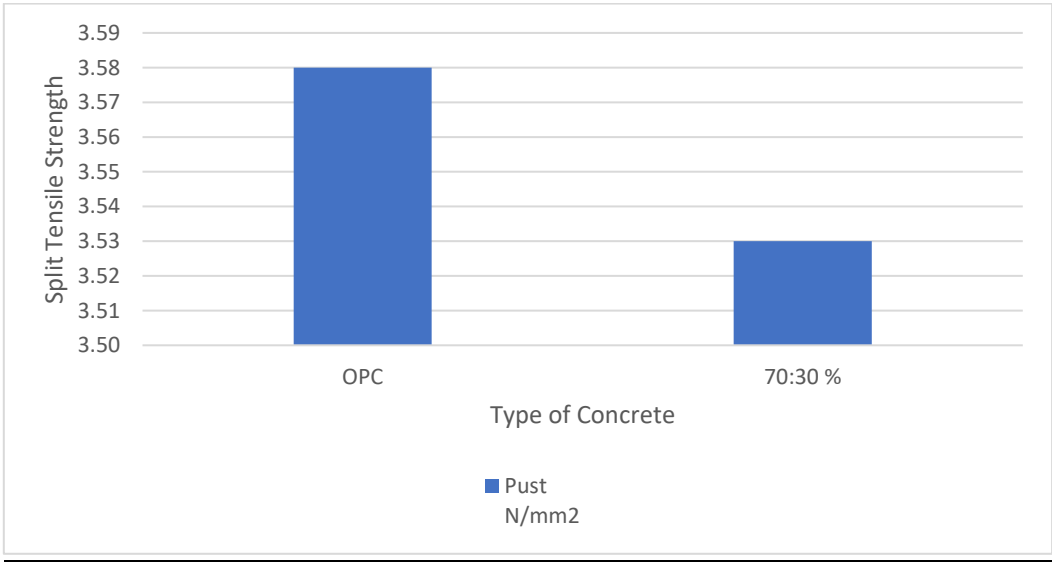


Figure 2: Pust results of CC and GPC cylinders

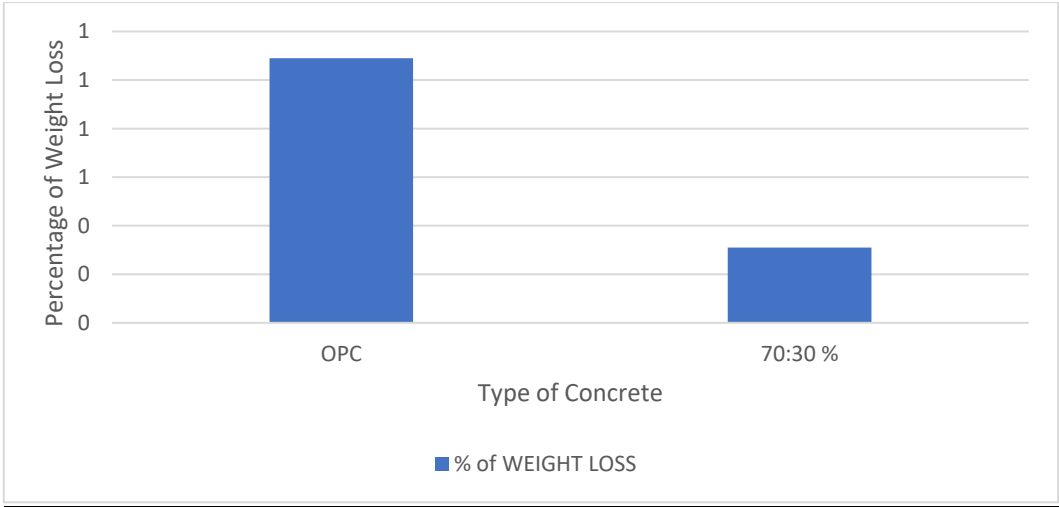


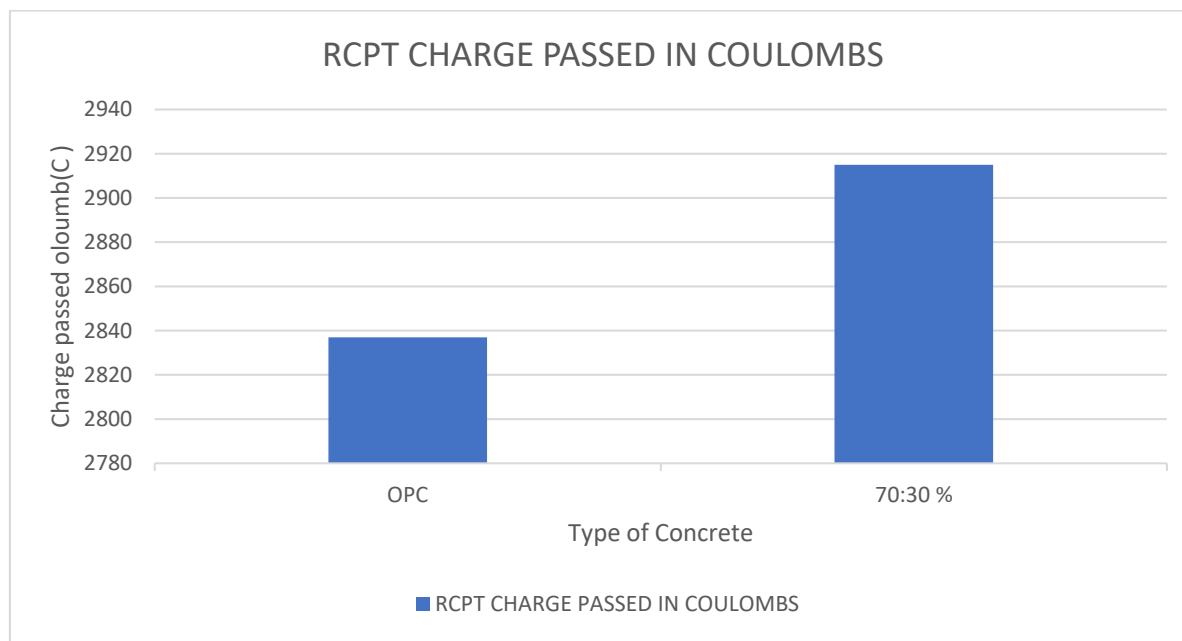
Figure 3: Percentage of mass loss of CC and geopolymer concrete mixes

5.3 Split tensile strength test of CC and GPC

Acid tests were carried out according to ASTM: G20 (2020) [20] to determine the weight loss of different types of concrete. Acid test experimental reports are detailed in Table 4.

5.4 RCPT of CC and geopolymer mixes

The work carried out according ASTM: C1202-97 (2003). Test results of rapid chloride penetration test (RCPT) for several types of concrete are detailed in Table 4 and Figure 4. The reports of the experiment work this comparative study demonstrates that RCPT test of conventional and geopolymer concrete behave similar.



6. CONCLUSION

- 1) The compressive strength of GPC increases with the addition of GGBFS, along with a faster setting rate.
- 2) The split tensile strength of GPC shows a slight increase with the addition of GGBFS in different proportions.
- 3) GPC shows better resistance to acid attack compared with conventional concrete.
- 4) The RCPT results of GPC and conventional concrete are nearly similar in terms of charge passed (Coulombs).
- 5) Geopolymer concrete containing fly ash and GGBFS is a suitable and sustainable replacement for conventional M20-grade concrete.

7. REFERENCES

- [1] Shivendra Singh Rathore et.al, "Influence of recycled coarse aggregate on properties of fly ash and slag-based geopolymer concrete cured under oven and ambient temperature", World Journal of Engineering, ISSN: 1708-5284, Issue 6 March 2024.
- [2] Min Yu et.al, "Residual mechanical properties of GGBS-FA-SF blended geopolymer concrete after exposed to elevated temperatures", School of Engineering, Computing and Mathematics, University of Plymouth, Plymouth PL4 8AA, UK, Issue 2024.
- [3] N. Anil Kumar Reddy et.al, "Comparative study on mechanical properties of fly ash & GGBFS based geopolymer concrete and OPC concrete using nano-alumina", Department of Civil Engineering, VNR Vignana Jyothi Institute of Engineering & Technology, Hyderabad 500090, India, 399-404, Issue 31 January 2022.

- [4] Alaa M. Morsy et.al, “Mechanical Characteristics of GGBFS/FA-Based Geopolymer Concrete and Its Environmental Impact”, American Society of Civil Engineers (ASCE), 27(2): 04022017, Issue 2022.
- [5] Manvendra Verma et.al, “Effect of ground granulated blast furnace slag and fly ash ratio and the curing conditions on the mechanical properties of geopolymer concrete”, International Federation for Structural Concrete, Structural Concrete. 2021;1–15, Issue 05 February 2021.
- [6] Sourav K. Das et.al, “Siliceous fly ash and blast furnace slag based geopolymer concrete under ambient temperature curing condition”, International Federation for Structural Concrete, Structural Concrete. 2020;1–11, Issue 02 January 2020.
- [7] P. Somiyadevi et.al, “Durability Performance of Geopolymer Concrete under Sulphate and Acid Exposure”, International Journal of Engineering Science and Computing (IJESC), Volume 09, ISSN: 2321-3361, Issue April 2019.
- [8] Yao Ding et.al, “Fracture properties of slag/fly ash-based geopolymer concrete cured in ambient temperature”, Construction and Building Materials 190 (2018) 787–795, Issue 20 September 2018.
- [9] Yi-Fang Cao et.al, “Effect of calcium aluminate cement on geopolymer concrete cured at ambient temperature”, Construction and Building Materials, Issue December 2018.
- [10] Huang Ji Zhuang et.al, “Resistance of geopolymer mortar to acid and chloride attacks”, 6th International Workshop on Performance, Protection & Strengthening of Structures under Extreme Loading, PROTECT2017, 11-12 December 2017, Guangzhou (Canton), China
- [11] Lateef Assi et. al, “Investigation of early compressive strength of Fly ash based Geopolymer Concrete”, Issue 2016.
- [12] J. Guru Jawahar et.al, “Strength properties of fly ash and GGBS based Geo polymer Concrete”, Asian Journal of Civil Engineering, Volume 1, Issue 2016.
- [13] Subhash V. Patankar et.al, “Mix Design of Fly Ash Based Geopolymer Concrete”, Advances in Structural Engineering, Issue December 2014.
- [14] Miss. Sapna Rathod et.al, “A Comparative Study on Strength and Durability Aspects of fly ash- GGBS based Geopolymer Concrete over Conventional Concrete”, International Journal of Engineering Research and Technology (IJERT), Volume 6, ISSN0: 2278-0181, Issue 6, June 2017.
- [15] Ukesh Praveen Patnam et.al, “Mechanical properties of fly ash and GGBS blended Geo-polymer Concrete using different fine aggregates”, International Journal of Engineering Research & Technology (IJERT), Volume 3, e-ISSN: 2395-0056, p-ISSN: 2395-0072, Issue 6, June 2016.
- [16] Pradip Nath et.al, “Effect of GGBFS on setting, workability and early strength properties of fly ash geopolymer concrete cured in ambient condition”, Construction and Building Materials 66 (2014) 163–171, Issue 12, June 2014.
- [17] N A Lloyd et.al, “Geopolymer Concrete with Fly Ash”, Curtin University of Technology, G P O Box U 1987, Perth 6845, Western Australia, The University of Wisconsin Milwaukee Centre for By-products Utilization, Second International Conference on Sustainable Construction Materials and Technologies June 28 - June 30, 2010, Università Politecnica delle Marche, Ancona, Italy.
- [18] Yoon-moon Chun et.al, “Sustainable Construction Materials and Technologies”, Sustainable Construction Materials and Technologies – Chun, Claisse, Naik & Ganjian (eds) © 2007 Taylor & Francis Group, London, ISBN 978-0-415-44689-1.
- [19] P. Duxson et.al, “Geopolymer technology: the current state of the art”, Article in Journal of Materials Science · May 2007.
- [20] IS: 456 (2000). “Plain and reinforced concrete code for practice”, Bureau of Indian Standards, New Delhi, India.
- [21] IS: 383 (1970). “Specification for coarse and fine aggregates from natural source for concrete”, Bureau of Indian Standards, New Delhi, India.