STUDY ON THE MECHANICAL PROPERTIES OF GGBS AND FLY ASH BASED GEOPOLYMER CONCRETE

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Abstract: Over the decades, Conventional Concrete (CC) has evolved as a game changer in the modern construction industry for its unparalleled merits in terms of performance and durability. Yet this material is observed as one of the most disastrous materials to the environment through mammoth consumption of natural resources for its manufacture. Concrete is also proven for its huge impact on the carbon footprint of a tonne of Carbon Dioxide for every tonne of Concrete produced. Geopolymer Concrete (GPC) is proven to address the latter issue with negligible Carbon emissions, yet it isn't able to see the light of the world for possessing certain drawbacks including not having a Standard Design mix procedure to achieve a Target Mean Strength, demanding Oven Curing for the first 24 hours, and other minor drawbacks. This study aims to address both issues by designing the GPC of G30 Grade with reference to M30 CC with the specifications mentioned in IS:10262-2019 by altering certain materials and compositions. GPC is subjected to ambient curing and is assessed for Mechanical properties in comparison with M30 CC. The optimum GPC mix capable of matching the performance of CC in these parameters would be suggested for further studies.

Key Words: Ambient Curing; Geopolymer Concrete; Global Carbon Emissions; IS: 10262-2019; Mechanical Assessment; M30 Conventional Concrete, Spray Curing.

1. INTRODUCTION:

Ever since the time of its invention, Conventional Concrete (CC) has emerged and evolved as ground-breaking technology in the construction industry owing to its superior simplicity in erection [1] outstanding Mechanical and Durability Properties [2], and an extensive range of applications. This material has today not just emerged as one of the most consumed materials on the planet after water [3] but is also one of the significant contributors of Carbon Emissions with about a tonne of Emissions per every tonne produced [4].

CC accounts for approximately 8% of Global Carbon Emissions, driven by an annual global consumption of around 4.4 Billion Metric Tonnes, and this quantity is expected to touch 5.5 Billion Tonnes by the end of 2050 [5]. European Space Agency has recently identified an Ozone Hole spanning 26 million Sq. kilometers in Antarctica [6] where Concrete production could also be considered as a noteworthy factor contributing to this environmental concern. The primary source of CO_2 emissions in concrete production can be attributed to the production of clinker during cement manufacturing [7]. Additionally, the carbonation process in the long run [8], and other factors like the transportation of raw materials and waste concrete disposal, contribute to these emissions. Additionally, the manufacture of CC demands a significant scale of natural resources including Limestone [9], Aggregates [10], and Fresh Water [11].

The process of geopolymerization coined by J. Davidovits [12-15] eventually paved the way for the invention of Geopolymer Concrete (GPC), which is theoretically an efficient alternative to CC., since the manufacture of GPC doesn't demand any scope of Natural resources such as

Limestone. Yet previous research works recommend manufacturing using Cementitious Materials such as Fly-Ash [16-18], Ground Granulated Blast Furnace Slag [19], Metakaolin [20,21], and Silica Fume [22] which were originally Industrial Scrap materials.

This study has noticed the significant and practical drawbacks being faced by GPC which are preventing it from seeing the light of the world:

1. Not having a proper and Authenticated Design Mix procedure to achieve a Target Mean Strength.
2. Demanding Oven or Steam Curing for at least 24 Hours, which is almost impossible for in-situ applications.

A few other reasons include the direct use of harsh chemicals like Sodium Hydroxide and its manufacture being laborious and unsafe, yet inevitable.

Among the intensive Literature conducted and analyzed, GPC was not cast and tested using an authenticated standard design mix procedure (to achieve a target Mean Strength), but based on certain trial and error methods., Yet Patankar et.al [23] and Pavitra Parthasarathy et.al [24] have presented their GPC design mix procedures where the former's methodology has stated the proportions ranging from M20 to M40, whereas the latter's results have ranged between 23 to 53 MPa., but both the methodologies have recommended Oven Curing at 60˚C which is a practical setback.,

2. OBJECTIVES:

Therefore, this study has set its motto, to achieve a standard Design Mix Procedure that doesn't demand Oven Curing the objectives are as follows:

- To design and manufacture CC of M30 Grade using IS:10262-2019 [25] and observe its Mechanical Properties.
- To attain the design mix of G30 GPC using the same composition of M30, by altering certain materials and compositions based on certain assumptions which are stated in the methodology
- To achieve the optimum mix of G30 whose Mechanical and Durability Properties have come closer to or even better than that of M30 CC.

The optimum G30 Mix would be recommended for further applications and test procedures.

3. MATERIALS USED:

a) Cement:

Ordinary Portland Cement confining to the Grade OPC 53; satisfying the Physical Standards and Chemical Composition specified in IS:12269-2013 [26] and IS:269-2015 [27] is employed for this study for the manufacture of CC.,

b) Fly Ash:

For the manufacture of the GPC, fly ash is used as the key Cementitious material. It is collected and transported from NTPC Ramagundam. This fly ash has completely satisfied all the Physical standards and chemical composition standards as per IS: 3812-2013 Part-I [28] and Part-II [29].

c) GGBS:

Ground Granulated Blast Furnace Slag (GGBS) is used as another key ingredient for the manufacture of GPC which is collected from the Local RMC Plant. The Physical Standard and Chemical Properties of this GGBS as per recommendations of IS: 16714-2018 [30] are perfectly satisfied.

d) Aggregates:

The study has employed Coarse Aggregates sourced from the Railapur Rock Quarry, adhering to the Physical Properties outlined in IS: 383-2016 [31], To enhance the uniformity of the concrete mix, a combination of 20mm and 10mm aggregates is used in a ratio of 60:40.

River sand, sourced from a local Ready Mix Concrete (RMC) plant, conforms to the specifications laid out in IS: 383-2016 [31] and is utilized for this study.

e) Water:

Potable Water free from harmful acids, salts, and biological matter and having a pH of 7.5 [32] is used in the manufacture of CC and GPC.

f) Alkaline Activators:

Alkaline Activators of Sodium Hydroxide (NaOH) and Sodium Silicate (Na_2SiO_3) are used for the manufacture of GPC. NaOH is manufactured using Sodium Hydroxide Pellets to achieve 6 and 8M of NaOH Solution the Solid Content of NaOH per liter is mentioned in Table: I below. Sodium Silicate Solution of 50.32% Solid Content is used for this study.

Table**: I:** Solid Content for Various Molarities of NaOH [33]

Molarity	**Solid Content of NaOH (grams/litre)**
6M	240
8M	320

4. METHODOLOGY:

a) Mix Design Proportions of M30 Conventional Concrete:

With the specifications outlined in IS: 10262-2019 [25], the CC of M30 Grade is designed and the corresponding proportions are provided in Table: II below. Following standard practice, the casted specimens underwent spray curing [34].

Table: II: Design Proportions of M30 CC

Material	Cement	Fine Aggregate	Coarse Aggregate		Water
Mass (in kg/m^3)	450	710	1060		197
			20mm Aggregates: 636	10mm Aggregates: 424	
Ratio	1: 1.57: 2.35: 0.45				

b) Mix Design Composition of Geopolymer Concrete:

Using M30 Mix Proportions, To achieve the G30 Concrete through partial and full replacement of certain materials, such as Cement with GGBS and Fly Ash (in the proportions of 100:0, 75:25, 50:50). By using the ratio of NaOH: Na_2SiO_3 ratio as 1. By replacing the Water Content with the Alkaline activator solutions and adding extra water if necessary. By adopting the Molarity of NaOH from 6 and 8M. Also, through subjecting the specimens to Ambient Curing, where the mean temperature was 25˚C. The Design Mix Proportions of the GPC for 100:0, 75:25, and 50:50 compositions are hereby presented in Tables: III, IV, and V below.

TABLE: III

Design Mix Proportions of GPC for GGBS: Fly-Ash = 100: 0

Molarity of NaOH	Material Mass (in kg/m^3)									
	GGBS	Fly-Ash	Fine Aggregate	Coarse Aggregate		NaOH		Na_2SiO_3		Extra Water Needed
				20mm	10mm	Solid	Water	Solid	Water	
6M	450	0	710	636	424	23.64	74.86	49.57	48.93	73.21
8M	450	0	710	636	424	31.52	66.98	49.57	48.93	81.09

TABLE: IV

Design Mix Proportions of GPC for GGBS: Fly-Ash = 75: 25

Molarity of NaOH	Material Mass (in kg/m3)									
	GGBS	Fly-Ash	Fine Aggregate	Coarse Aggregate		NaOH		Na_2SiO_3		Extra Water Needed
				20mm	10mm	Solid	Water	Solid	Water	
6M	337.5	112.5	710	636	424	23.64	74.86	49.57	48.93	73.21
8M	337.5	112.5	710	636	424	31.52	66.98	49.57	48.93	81.09

TABLE: V

Design Mix Proportions for GPC of GGBS: Fly-Ash = 50: 50

Molarity of NaOH	Material Mass (in kg/m3)									
	GGBS	Fly-Ash	Fine Aggregate	Coarse Aggregate		NaOH		Na_2SiO_3		Extra Water Needed
				20mm	10mm	Solid	Water	Solid	Water	
6M	225	225	710	636	424	23.64	74.86	49.57	48.93	73.21
8M	225	225	710	636	424	31.52	66.98	49.57	48.93	81.09

5. RESULTS AND DISCUSSIONS:

The Mechanical results of GPC Specimens in comparison with the M30 CC are hereby presented:

a.) Compressive Strength Results:

Following the prescribed curing periods of 7, 14, and 28 days for both CC (under spray Curing) and GPC (Under Ambient Curing) cube specimens admeasuring 150*150*150 mm have undergone compressive testing as per the guidelines outlined in IS: 516-1959 [35]. Fig:1 below illustrates the comparative Compressive Strength results between GPC and CC.

Referring to Fig:1 below, it can be noted that the Compressive Strength of CC at the end of 28 days is found to be 34.13 MPa. On the other hand, the compressive performance of GPC in all the cases (6M and 8M) with Fly-Ash: GGBS ratios (100:0, 75:25, 50:50) was satisfying. In the

6M @ 100:0, compressive strengths have consistently surpassed CC at 7 days (51.84 MPa), 14 days (52.30 MPa), and 28 days (54.03 MPa). The 8M @ 100:0 mix, records an even higher strength of 66.20 MPa at 28 days. GPC specimens of 75:25 and 50:50 exhibited intriguing trends. The former maintains competitive strengths (61.83 MPa at 28 days), while the latter experiences a dip in early strength (22.23 MPa at 7 days) but rebounds later (38.13 MPa at 28 days). But in all the cases, GPC has experienced early strength, closer to Target mean Strength and even better which is remarkable.

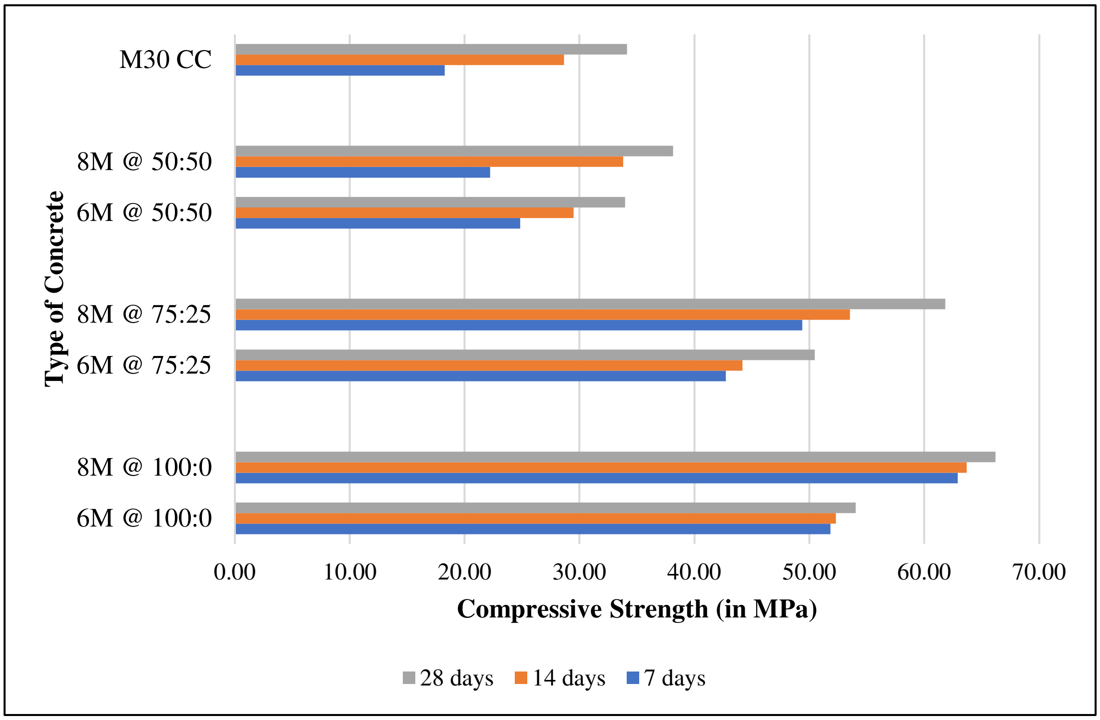

Fig: I Compressive Strength Results of GPC at 100:0, 75:25, and 50:50 V/s. M30 CC

b.) Split Tensile Strength Results:

Following the designated curing periods of 7, 14, and 28 days for both CC and GPC, for cylinder specimens with a diameter of 150 mm and a height of 300 mm, the specimens were prone to the Split Tensile testing by the guidelines specified in IS: 516-1959 [35]. Fig:2 below presents the comparative split tensile strength results of GPC about CC.

From the below Fig:II, it is evident that the Split Tensile Results of the CC at the end of 28 days was 2.76 MPa, which satisfies the tensile strength recommendation as IS: 456-2000 [ ] with 8.05% of the characteristic compressive strength ., Observing the results of GPC Specimens the 6M @ 100:0 mix, tensile strengths consistently outshine CC at 7 days (4.21 MPa), 14 days (4.49 MPa), and 28 days (4.67 MPa). Elevating the NaOH concentration to 8M @ 100:0 further amplified the tensile strength, yielding an impressive result of 5.02 MPa at 28 days. GPC with GGBS: Fly Ash ratios of 75:25 and 50:50 revealed dynamic tensile strengths. The 75:25 ratio maintained competitiveness (4.92 MPa at 28 days), while the 50:50 ratio experienced a dip in early strength (2.37 MPa at 7 days) but rallied later (2.78 MPa at 28 days). Yet the performance of 8M @ 50:50 was very close to that of M30 CC.

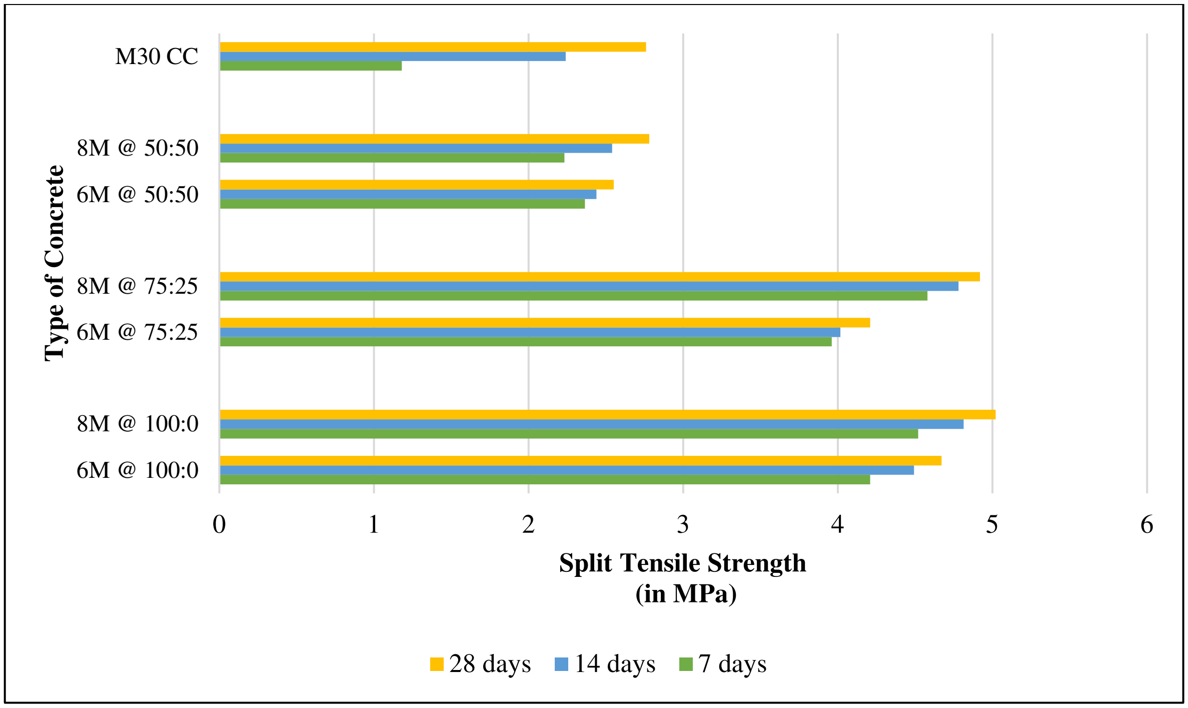

Fig: II Split Tensile Strength Results of GPC at 100:0, 75:25, and 50:50 V/s. M30 CC

iii.) Flexural Strength Results:

Following the designated curing periods of 7, 14, and 28 days for both CC and GPC, prism specimens measuring 750*150*150mm were subjected to Flexural testing as per the guidelines outlined in IS: 516-1959 [35]. Fig: 3 below illustrates the comparative Flexural Strength results of GPC about M30 CC.

Observing Fig-III below, the Flexural Strength of CC at the end of 28 days was 4.22 MPa (with enhanced performance than the recommendations of IS:456-2000). Looking into the GPC performance, in 6M @ 100:0 GPC, the flexural strengths have consistently outperformed CC at 7 days (5.21 MPa), 14 days (5.53 MPa), and 28 days (5.67 MPa). Uplifting the NaOH concentration to 8M @ 100:0 further amplified the flexural strength results with 8.02 MPa at 28 days. The 75:25 ratio has again maintained competitiveness (7.92 MPa at 28 days), while the 50:50 ratio experienced a modest early strength decrease (3.15 MPa at 7 days) but showcased improvement later (5.48 MPa at 28 days).

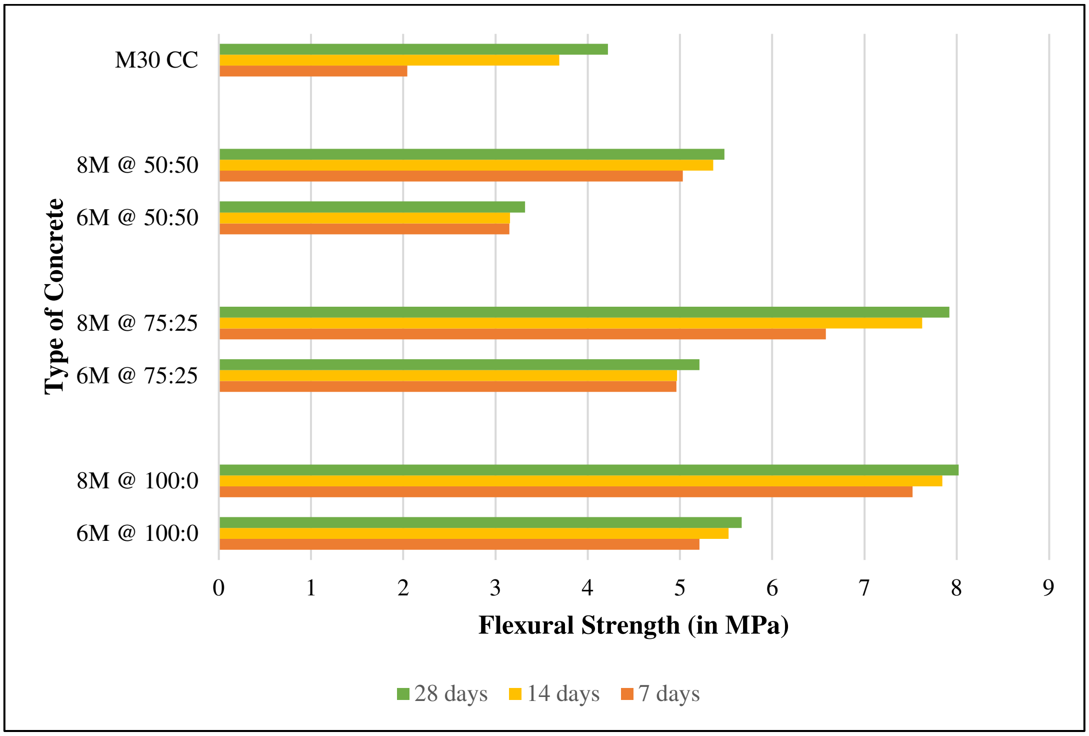

Fig: III Flexural Strength Results of GPC at 100:0, 75:25, and 50:50 V/s. M30 CC

CONCLUSIONS AND RECOMMENDATIONS

- This study has hit the bull's eye by addressing the two major drawbacks of GPC. The GPC is developed by altering the compositions and materials of the design mix of M30 CC. The GPC specimens were subjected to ambient curing, overriding the regular practice of Oven Curing, thus leading to more practical viability.
- This detailed investigation highlights GPC's better Mechanical Properties and flexibility over CC, emphasizing its potential for robust and flexible applications in the construction industry.
- GPC has proved the fact of minimal consumption of natural resources like water for mixing and curing. It also emits almost negligible CO2 into the atmosphere, thus emerging as a green material.
- The results of 8M @50:50 are closer to that of M30 CC, whereas 8M @100:0 are almost twice that of needed.
- Further analysis can be done for the durability assessment of GPC specimens to adjudge the practical performance.
- Similar replacements can be done for the other Grades of Concrete Mix (CC) derived from IS: 10262-2019.

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