

Mechanical properties of geopolymer concrete with varying cement content using flyash and ground granulated blast furnace slag

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Abstract

In the recent past, the importance of geopolymer concrete as an eco-friendly product to replace portland cement concrete is continuously increasing over time. Yet less research effort has been invested in this area compared with some topical issues in civil engineering. Thus, the objective of this article is to analyse the mechanical properties of geopolymer concrete where the cement is replaced by fly ash and ground granulated blast-furnace slag (GGBS). Sodium silicate and sodium hydroxide 8 molarity solution was used. The compressive strength of a cube in an 8 molarity solution was measured for various mixtures (i.e. G50F50 where G and F stand for GGBS and flyash, respectively while the numerical value denotes the cement percentage) and the cement contents (i.e. 0, 10, 20, 30, 40%). The cube specimens are 100mmx100mmx100mm with the ambient curing at 35-40°C. In total, 9 cubes, 3 beams and 3 cylinders are cast at 7days, 14days and 28days while the compressive strengths of different mixes and cubes are calculated. For 28days, beams and cylinders are measured for flexural and tensile strength. The compressive strength at 7,14 and 28 days nearly doubled the target strength by using geopolymer concrete instead of normal concrete. Compressive strength is about 10% higher at 7 and 14days and 20% higher at 28days after replacing 40% of the cement. Flexural strength increased by 50% when 40% of the cement was replaced but split tensile strength only increased by 1%.

Keywords: Geopolymer, concrete, mechanical properties, sodium hydroxide, sodium silicate, GGBS, flyash.

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1. Introduction

In the past few years, activities on environmentally-friendly building construction have been constantly gaining attention due to the general rise of cement prices in response to economic forces. Besides, the global trend towards reducing the effect of global warming on the environment due to building construction has forced researchers and practitioners to re-examine construction mixes towards greener practices, and concurrently enhance the mechanical properties of the construction materials (Kumar et al., 2018). Research has confirmed the release of CO₂ emissions is a greenhouse gas from concrete associated with global warming, which should be eradicated (The Concrete Conundrum, 2022; Environmental Impact of Concrete, 2022). Interestingly, the Portland cement concrete is a focus of increasing interest from researchers and practitioners.

Consequently, geopolymer concrete has been introduced towards eradicating this problem of emission of greenhouse gases. Geopolymer is an eco-friendly product to replace Portland cement concrete (Ganesh and Muthukannan, 2018; Renganathan et al., 2016; Ling, 2018). Geopolymer concrete is a cutting-edge building material with inorganic molecules and could be made from fly ash and ground granulated blast furnace slag (GGBS) (Rebeiz et al., 2004; Rajamane et al., 2009; Ralli and Pantazopoulou, 2021; Gencel et al., 2021). Unfortunately, fewer research efforts have been invested in this research area compared with some topical issues in civil engineering. Thus, the argument is that despite the available waste of fly ash from thermal power plants and the abundance of GGBS as waste from steel plants, the research community is yet to fully exploit the potentials of geopolymer concrete using fly ash and GGBS (Azad et al., 2021). But geopolymer concrete solutions should be pursued by researchers with great zeal. Geopolymer is found as an alkali triggering solution that polymerises materials into molecular chains to develop a hardened binder.

The objective of this paper is to analyse the mechanical properties of geopolymer concrete in an experimental investigation with fly ash and GGBS introduction to replace cement in a defined proportion. To achieve this objective, cube tests on flexural and tensile strengths were conducted on samples for 7, 14 and 28 days.

2. Literature review

A literature review was conducted on geopolymer concrete with an emphasis on flyash and the ground granulated blast furnace slag as compositions. The intent is to give an insight into the diverse approaches to promoting environmentally friendly geopolymer concrete and identify research gaps regarding geopolymer concrete development. Thus, the following is a brief literature review on the subject of investigation in this article. First, Naidu et al. (2012) investigated the strongest attributes of geopolymer concrete containing low amounts of fly ash and slag prepared in five ratios. It was reported that the formulation exhibiting higher GGBS concentration has high compressive strength. It was noticed that in just 14 days, 90 per cent of compressive strength was reached. Moreover, Supraja and Rao (2016) studied the GGBS material when it fully replaces the Portland cement and the products are bound with alkaline liquids, which are sodium silicate and sodium hydroxide. The authors considered various molarities of sodium hydroxide solutions, namely 3M, 5M, 7M and 9M. It was ascertained that the intensity of the geopolymer increases as the molarity of sodium hydroxide increases.

Besides, Patel et al. (2013) experimented with the strength of high performance concrete using GGBS and crusher sand. Moreso, Kathirvel et al. (2013) evaluated the influence of different ratios of GGBS (0-100%) on fly ash-oriented GPC under ambient temperature conditions. The influence of the quantity of alkaline activated solution of the mixture of GPC on compressive strength was investigated. Furthermore, Cui et al. (2020) experimented and statistically studied the mechanical attributes of geopolymer concretes.

Moreover, Imtiaz et al. (2020) reserved the current trends and progress concerning eco-friendly geopolymer concrete. The work concludes that the GPC features prominently as an eco-friendly material in construction activities. The attractive features, as mentioned in the work are its superior mechanical characteristics and durable attributes. Furthermore, research has placed geopolymer concrete as an adequate option for OPC concrete. However, they added that an interrupted supply of industrial and agricultural waste is required to strengthen geopolymer concrete as a viable option to the OPC concrete. Besides, Gambo et al. (2020) studied the metaklin based GPC under a high-temperature range of 200 to 800 in steps of 200 degrees centigrade. Interestingly, they concluded that at 600 and 800°C, the loss of compressive strengths for MKGC are 59.69% and 71.71%, respectively. The obtained results also indicated elevated water absorption and declined abrasion resistance.

From the foregoing, based on the literature surveyed, the present authors were unable to establish substantial literature that elaborates on the mechanical properties of geopolymer concrete with diverse cement compositions using a combination of flyash and ground granulated blast furnace slag. But this research aspect is essential in practice regarding environmentally-friendly building construction engagements. Also, the research is tied up to the economic development of the construction industry. Consequently, more studies and analyses are required to develop enhanced geopolymers with improved mechanical properties. To respond to this call and effort is invested in an experimental endeavour for this article to address this important research gap.

3. Experimental results

An experiment was conducted to determine the mechanical properties of concrete for the M30 grade of concrete mix, which included variable ratios of cement, fly ash, and GGBS with a constant proportion of fine and coarse aggregate for a water cement ratio of 0.45 and a mix ratio of 1: 1.33: 2.58. The alkaline to base material ratio is taken as 0.5:1. The alkaline solutions are made by combining an 8 molar concentration sodium hydroxide (NaOH) solution with a 1:3 weight ratio sodium silicate (Na₂SiO₃) solution. The above mix is to be prepared 24 hrs before the mix.

Table 1. Compressive strength of 7 days

Mix	Details	Specimen	Load	Average load	Compressive Strength
C-0	Cement0%	1	660	680	68
	GGBS50%	2	700		
	Flyash50%	3	680		
C-10	Cement10%	1	780	730	70
	GGBS45%	2	690		
	Flyash45%	3	720		
C-20	Cement20%	1	700	700	71
	GGBS40%	2	680		
	Flyash40%	3	720		
C-30	Cement30%	1	740	720	72
	GGBS35%	2	640		
	Flyash35%	3	780		
C-40	Cement40%	1	700	736.66	73.6
	GGBS30%	2	730		
	Flyash30%	3	780		

Table 2. Compressive strength of 14 days

Mix	Details	Specimen	Load	Average load	Compressive Strength
C-0	Cement0%	1	630	620	62
	GGBS50%	2	620		
	Flyash50%	3	610		
C-10	Cement10%	1	649	630	63
	GGBS45%	2	600		
	Flyash45%	3	650		
C-20	Cement20%	1	640	660	66
	GGBS40%	2	660		
	Flyash40%	3	680		
C-30	Cement30%	1	650	663.33	66.3
	GGBS35%	2	670		
	Flyash35%	3	670		
C-40	Cement40%	1	680	680	68
	GGBS30%	2	670		
	Flyash30%	3	690		

Table 3. Compressive strength of 28 days

Mix	Details	Specimen	Load	Average load	Compressive Strength
C-0	Cement0%	1	720	720	72
	GGBS50%	2	700		
	Flyash50%	3	740		
C-10	Cement10%	1	720	753	75.3
	GGBS45%	2	750		
	Flyash45%	3	790		
C-20	Cement20%	1	790	817	81.7
	GGBS40%	2	810		
	Flyash40%	3	850		
C-30	Cement30%	1	810	856	85.6
	GGBS35%	2	890		
	Flyash35%	3	870		
C-40	Cement40%	1	890	900	90
	GGBS30%	2	890		
	Flyash30%	3	920		

Table 4. Compressive strength comparison of 7, 14 and 28 days

Mix proportion	Compressive strength (7 days)	Compressive strength (14 days)	Compressive strength (28 days)
C-0	62	68	72
C-10	63	70	75.3
C-20	66	71	81.7
C-30	66.3	72	85.6
C-40	68	73.6	90

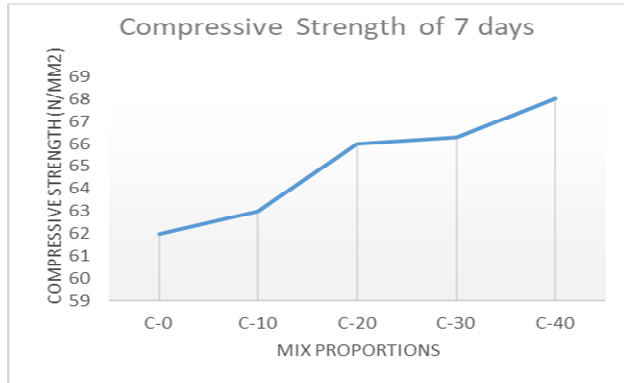


Figure 1. Compressive strength of 7 days

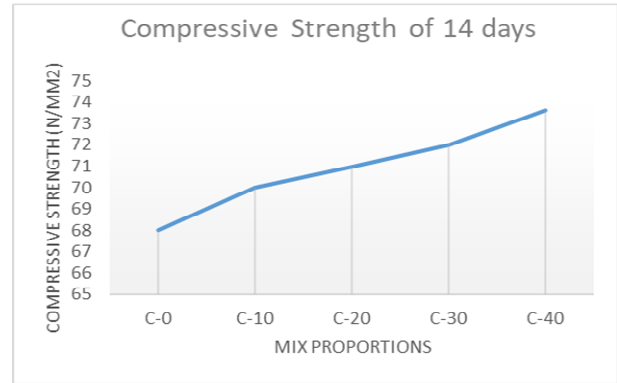


Figure 2. Compressive strength of 14 days

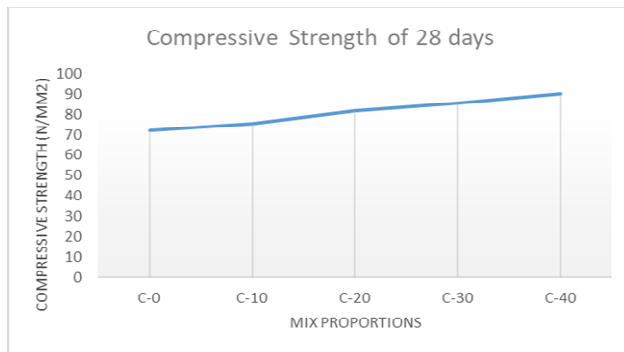


Figure 3. Compressive strength of 28 days

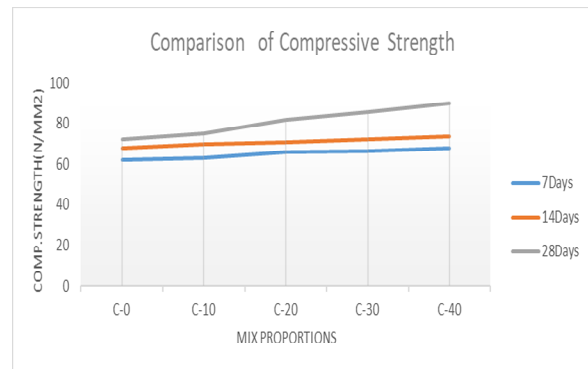


Figure 4. Comparison graphs showing 7, 14 & 28 days compressive strength

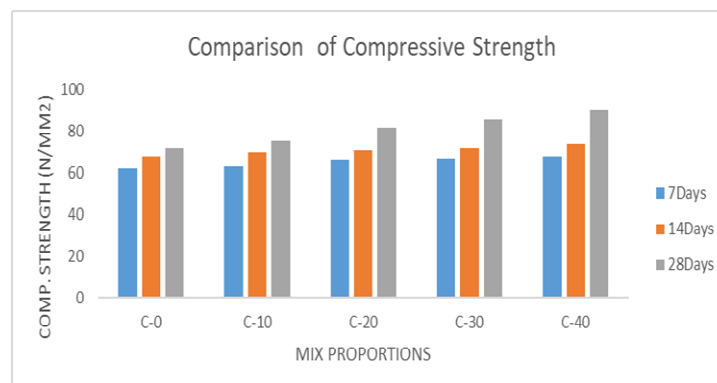


Figure 5. Comparison bar chart showing 7, 14 & 28 days compressive strength

Table 5. Flexural strength at 28 days

Mix	Details	Specimen	Load at failure	Average load	Flexural strength
C-0	Cement0%	1	7.5	7.83	4
	GGBS50%	2	8		
	Flyash50%	3	8		
C-10	Cement10%	1	11.5	10.6	5.3
	GGBS45%	2	10.5		
	Flyash45%	3	10		
C-20	Cement20%	1	11	10.8	5.4
	GGBS40%	2	10		
	Flyash40%	3	11.5		
C-30	Cement30%	1	12	11.5	5.75
	GGBS35%	2	11		
	Flyash35%	3	11.5		
C-40	Cement40%	1	12.5	12.7	6.35
	GGBS30%	2	12		
	Flyash30%	3	13.5		

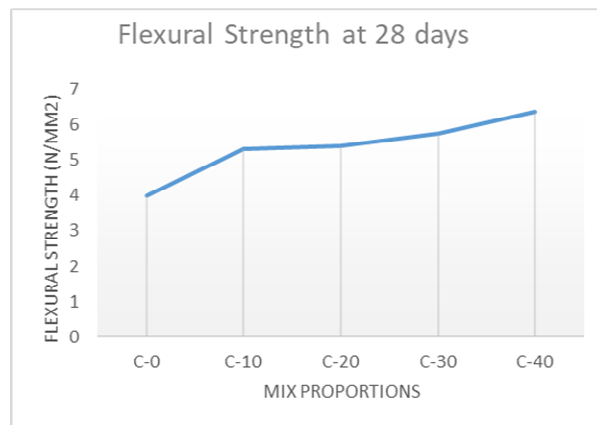


Figure 6. Flexural strength at 28 days

Table 6. Split tensile strength at 28 days

Mix	Details	Specimen	Load at failure	Average load	Split tensile strength
C-0	Cement0%	1	210	240	3.4
	GGBS50%	2	250		
	Flyash50%	3	260		
C-10	Cement10%	1	220	247	3.49
	GGBS45%	2	250		
	Flyash45%	3	270		
C-20	Cement20%	1	200	253.3	3.58
	GGBS40%	2	260		
	Flyash40%	3	300		
C-30	Cement30%	1	210	260	3.68
	GGBS35%	2	270		
	Flyash35%	3	300		
C-40	Cement40%	1	260	266.7	3.77
	GGBS30%	2	250		
	Flyash30%	3	290		

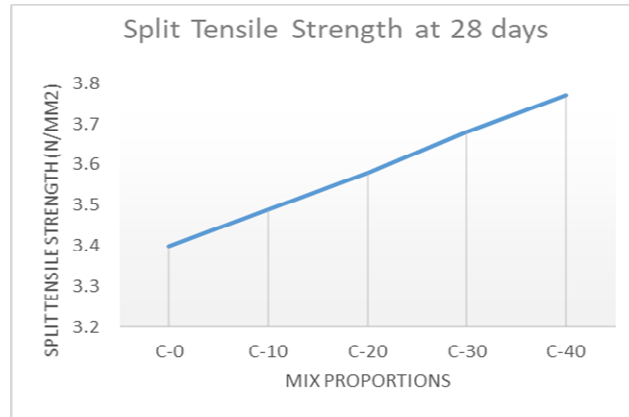


Figure 7. Split tensile strength at 28 days



Figure 8. Sodium hydroxide (NaOH) crystals



Figure 11. Failure of the cube

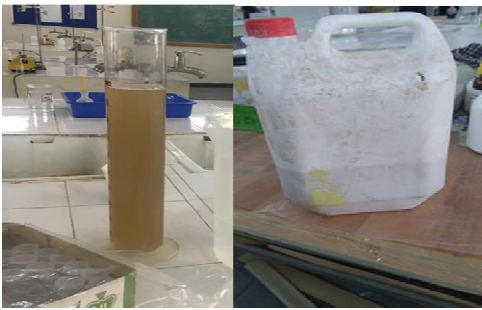
Figure 9. Sodium silicate (Na₂SO₃) Solution

Figure 12. Failure of the beam



Figure 10. Blocks kept under sunlight for curing



Figure 13. Failure of cylinder

4. Analysis and discussion of results

Up to now Geo polymer concrete is purely based on fully replacement of cement by polymers. Here an attempt has made by replacing some portion of polymers by cement. In this paper blocks have been kept under sun light instead of oven and got good results. By GPC the compressive strength at 7, 14 and 28 days has achieved almost double of target strength. Compressive strength at 7 and 14 days is almost increased by 10% by replacing the cement by 40%, whereas there is an increase of 20 % for 28 days. Flexural strength has been increased by 50% at 40% replacement of cement but Split tensile strength has been increased by only 1%.

5. Conclusion

Geo polymer concrete can be used in the same way as regular Portland cement concrete. Geo polymer concrete is a great alternative to Portland cement concrete, which emits CO₂. Fly ash-based geo polymer concrete is expected to be 10 to 30% less expensive than Portland cement concrete. Fly ash and GGBS can be combined to create a geopolymeric binder phase that can bind aggregate systems made up of sand and coarse aggregate. The compressive strength of geo polymer concrete is unaffected by the mass ratio of alkaline liquid to fly ash. GGBS was successfully used as a mineral admixture in both the microstructure modification and the polymerization phase of geo polymer concrete. It also developed excellent binding properties with alkaline liquids, resulting in improved strength and alkali activation. These geo polymer concrete constituents must be able to be mixed with a low-alkali triggering solution and cure in a reasonable period of time at room temperature. For geo polymer concrete, the alkaline to fly ash and GGBS ratios can be cured at room temperature. Ambient cured geo polymer concrete attains the maximum compressive strength at 7th day itself. The result values of compressive strength for complete replacement of cement (i.e. is G50F50) to addition of cement percentages increases. The compressive strength, flexural strength, and split tensile strength of geo polymer concrete all increase as the cement content is increased. The only default found is that geo polymer concrete has a very short initial setting period, which is a challenge when it comes to casting. Geo polymer concrete has a far lower water absorption potential than OPC-based concrete, indicating that it is more robust. Geo polymer binders can be used for a variety of different source materials and activators. As a result, geo polymer concrete made from GGBS, fly ash, and alkaline solution ushers in a new age in building.

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