Mechanical properties of geopolymer concrete and Portland cement concrete

Karim Mohsen, Khalid Morsy, Ihab Fawzy, Ibrahim A. Yousif

Abstract— Portland cement is used as the primary binding agent in the creation of concrete, which is thought to be one of the main factors contributing to global warming. Given that the cement industry is proven to be responsible for around 8% of the world's CO2 emissions, a number of solutions have been put out to lessen the environmental impact of the production of concrete. Alkali-activated concrete has received a lot of interest recently as a potential replacement for Portland cement. It is a new, ecologically friendly inorganic binder created by activating alumino-silicate source material with an alkaline solution. Although a thorough evaluation of the mechanical characteristics of geopolymer concrete is necessary for the right design of concrete structural components, there are few test results available in the literature. The behavior of both Portland cement concrete and geopolymer in compression and flexure has been investigated during the course of this study. The obtained mechanical results showed that geopolymer concrete had higher compressive strength and lower flexural strength than Portland cement concrete at the same binder content.

Index Terms— Geopolymer concrete (GPC), Conventional Concrete (CC), compression behavior, Flexural behavior, Fly Ash, Alkali activation, Mechanical properties.

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1 INTRODUCTION

The manufacturing of cement, which is regarded as the primary component of Portland cement concrete (PCC), provides the greatest challenge in the fight against climate change because the global demand for it appears to be insatiable. Portland cement (PC) accounts for around 10–12% of the volume of concrete. (PC) demand has lately surged, leading to an increase in PC production, which now exceeds 3 billion tons annually [1] and it is predicted that PC demand will increase to be over 6 billion tons per year in the upcoming forty years.

PCC has also performed badly in acidic or sulphate environments, especially in marine structures. PCC is vulnerable to acid attack because it contains components that are made of calcium. Calcium compounds dissolve rapidly in an acidic environment, leading to increased porosity and rapid deterioration. [2]. Undeniably, PCC cracking and corrosion have a significant impact on the service life cycles, durability, design life, and safety of the product. Due to PCC's substantial disadvantages, researchers made the decision to look for a practical solution that may be used as a useful replacement for traditional concrete in order to ensure structural durability and environmental sustainability. On of the leading solutions is the replacement of cement with another binder which it’s manufacture process would be more environmentally friendly. The use of alternate binders and raw ingredients in the cement manufacturing process can drastically reduce CO2 emissions. These alternative binders have the ability to reduce gases without sacrificing cement characteristics while also improving the behavior of cement mortar. It was investigated that usage of geopolymer may decrease the amount of emissions of carbon dioxide by up to 64 % compared to the use of cement [3]. Moreover, from an economic view, the price of source materials is lower than cement, for example, the price of geopolymer concrete which depended on fly ash as aluminosilicate material is cheaper than conventional concrete by 10-30% after taking into consideration the price of alkaline activator [4]. An examination of the literature revealed that geopolymers had great mechanical strength and durability. High performance in acid and sulphate conditions, tolerance to great temperatures, and high early strength. Due to these qualities, geopolymer is a practical substitute in a variety of industrial applications, such as waste management, plastics, nonferrous foundries and metallurgy, civil engineering, automotive and aerospace, art and decoration, and building retrofitting.

2 EXPERIMENTAL PROGRAM

2.1 Material Charcterization

Geopolymer concrete was produced using pure ground granulated blast furnace slag (GGBFS) and Fly ash (FA) were employed as constituents because they possessed both cementitious and pozzolanic properties. The GGBFS is made of calcium (37.50%), silicate (35.10%), and alumina (16.90%), according to X-Ray fluorescence (XRF) test. The Fly ash binder with a low calcium content was also used as another constituent in preparation of GPCs. The FA is made of calcium (1.90%), silicate (53.50%), and alumina (27.80%), according to X-Ray fluorescence (XRF) test. Sodium hydroxide solution (NaOH) (60.25% Na2O, and 39.25% H2O) and sodium silicate solution (11.98% Na2O, 31.00% SiO_2, and 57.00% H_2O) were used as liquid activators. Ordinary Portland cement concrete was produced using cement as the main binder while the activator was only by using water to form hydration products. Table 1 summarize the composition of GBFS, FA and Portland cement using X-Ray fluorescence (XRF) test. The locally available natural sand with a nominal maximum particle size of 5 mm and the crushed

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limestone with a nominal maximum size of 10 mm were used for fine aggregate and coarse aggregate, respectively.

Table 1
Chemical composition of GBFS, FA and PC

Materials	Sio$_2$	Al_2O_3	CaO	MgO	Fe_2O_3	MnO	TiO_2
GBFS	35.10	16.90	37.50	7.85	1.30	0.52	0.23
FA	53.50	27.80	1.90	0.90	11.20	0.20	3.20
PC	19.02	4.34	63.25	0.77	3.45	0.26	0.28

GBFS: Granulated Blast Furnace Slag
FA: Fly Ash
PC: Portland cement

2.2 Mixtures Proportions

Two types of industrial waste materials (FA and GBFS) were used to prepare the geopolymer concrete mix design. The water-to-FA or GBFS, alkaline-to-FA or GBFS, SS/SH and all other factors affecting the mix design of geopolymer concrete were selected based on a comprehensive trial mixture [5]. All aggregates were batched in a saturated surface dry state. Table 3 summarize the mix proportions of two geopolymer concrete mixes and one Portland cement concrete mix which were prepared during the course of this study.

Table 2
Mix proportions of GPC and PCC (Kg/m3)

Components	SGC	FSGC	PCC
GBFS	450	270	0
FA	0	180	0
PC	0	0	450
Na2SiO3	131	131	0
NaOH	41	41	0
Water	112	112	198
F.A	547	547	703
C.A	1093	1093	1055
Admixtures (% from cement weight)	0	0	1

SGC: Slag based geopolymer concrete
FSGC: (Fly ash + slag) based geopolymer concrete
PCC: Portland cement concrete
F.A: Fine Aggregate
C.A: Coarse Aggregate

3 RESULTS AND DISCUSSION

3.1 Compressive Strength Development

According to BS EN 12390-1, test specimens for compressive strength were cast into steel moulds that were 100 x 100 x 100 mm in size. The compressive strength of the three mixes was evaluated at ages of 1, 3, 7, 28 and 90 days using three samples of each mix at each testing age. The findings are shown in Fig. 1. Mix (SGC) (100 percent GBFS) had the maximum compressive strength after 28 days; it was 60.0 MPa. After 28 days, the compressive strengths of the (FSGC) mix and (PCC) mix were 49.0 MPa and 43.0 MPa, respectively. After 28 days, the specimens prepared with (40 percent FA & 60 percent GBFS) displayed a compressive strength that was nearly 20% lower than specimens prepared with (100 percent GBFS). Increased GBFS content was found to have a beneficial impact on the concrete specimens' compressive strength. Early compressive strength of specimens rose together with the amount of GBFS, reaching 29.7 MPa at age 24 hours as opposed to 20.3 MPa with 40 percent of FA. At ages of 3, 7, 28, and 90 days of ambient temperature curing for geopolymer concrete specimens and water curing for Portland cement concrete specimens, similar trends in the growth of compressive strength were also seen. This was found to be in agreement with the findings of Tanakorn et al. [6] and Sanjay al [7]. The rise in CaO contents and decline in SiO2 levels in the concrete's matrix were responsible for this improvement in compressive strength with the increase in GGBFS concentration. Additionally, an increase in GGBFS concentration produced a high CaO to SiO2 ratio of up to 0.95, which resulted in the development of a greater amount of C-(A)-S-H gel in the concrete mixture [8], [9].

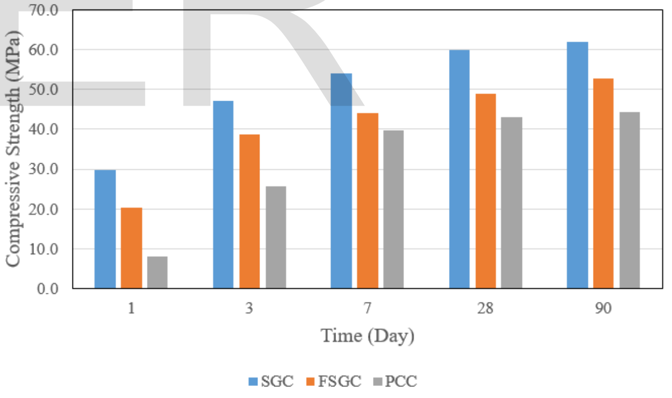

Fig 1. Compressive Strength development for concrete mixes with time

4 FLEXURAL STRENGTH

The modulus of rupture (fr) can be used to determine the tensile resistance capability of concrete. Utilizing prismatic beams of 150 x 150 x 500 mm and put through a three-point loading test in accordance with ASTM C293 standard, the modulus of rupture was measured. The average of the three sets of specimens from each mix that were tested for each of the curing ages is given. Fig. 2 displays the test results for each age for all mixtures. Geopolymer concrete had a lower modulus of rupture than Portland cement concrete. The modulus of rupture for PCC at the age of 28 days is larger than the modulus of rupture for SGC and FSGC by percentages of 26.9% and 45.8%, respectively. While at the age of 28 days, the modulus of rupture for SGC is 14.9 percent larger than that of FSGC. At ages of 3 and 7 days, similar trends in the development of flexural strength were also seen. The increase in the CaO level in the concrete network, might be primarily responsible for the observed improvement in the flexural strength of the GPC containing higher GGBFS content.

The plasticity of concrete [10] showed that the tensile capacity of concrete is dependent on the cohesion (c) between cementitious material and aggregate particles and the angle of friction (ϕ) along the micro and macro cracks. As a result, the tensile capacity of concrete is significantly affected by cohesion nature of the binder. Although no reliable data for (c) of geopolymer concrete is available in the literature, it would be assumed that the value of (c) for geopolymer concrete has a lower level to that of PCC.

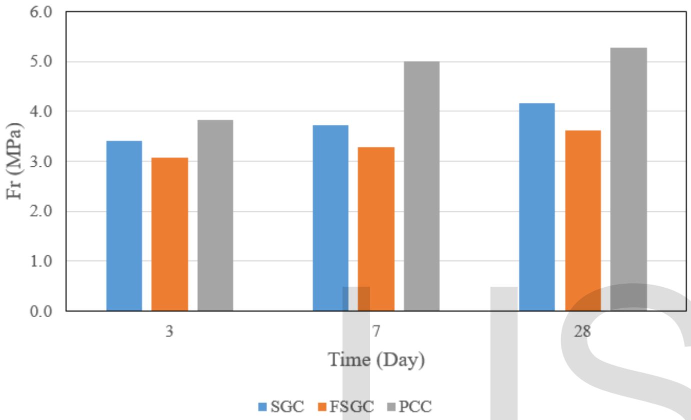

Fig 2. Flexural Strength for concrete mix

5 CONCLUSIONS

This paper compares the behavior of FSGC and SGC concrete with normal PCC concrete in compression and flexure. The following conclusions are drawn from the test results.

1. The replacement of GBFS with 40% FA reduced the compressive strength by a value of 18.3% after 28 days.
2. By incorporating the GBFS, the intensity of the geopolymerization can be increased. It was discovered that the increased dissolution and precipitation of Al2O3 and SiO2 were caused by an increase in the calcium concentration.
3. The 90-day compressive strength of SGC and FSGC mixes achieved around 3-7% increase compared to the 28-day compressive strength which indicates that the 28-day compressive strength can be considered as the characteristic compressive strength for geopolymer concrete.
4. Geopolymer concrete mixes cured at ambient temperature achieved higher compressive strength than conventional concrete at the same binder content.
5. Geopolymer concrete mixes cured at ambient temperature achieved lower flexural strength than conventional concrete at the same binder content.

6 DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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