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Mechanical properties of fly ash based geopolymer concrete with full and partial cement replacement

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HIGHLIGHTS

- 18 concrete mixtures were produced mechanical properties of geopolymer concrete.
- Key factors are binder material, cement replacement ratios, and activator ratio.
- It was found that mechanical properties achieved at a replacement ratio of 50%.

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ABSTRACT

Concrete is the most widely used building material in the construction of infrastructures such as buildings, bridges, highways, dams, and many other facilities. The increasing of worldwide production of ordinary Portland cement (OPC) to meet infrastructure developments indicates that concrete will continue to be a chosen as the most common material of construction in the future. The production of cement consumes a lot of energy and increase CO_2 emission to the atmosphere. Another alternative to make environment-friendly concrete is the development of geopolymer which is an inorganic alumina-silicate polymer, synthesized from materials of geological origin or by-product materials such as fly ash which is rich in silicon and aluminum. In this paper 18 concrete mixtures were produced to evaluate the effect of key parameters on the mechanical properties of concrete and its behavior. The study key parameters are; binder material content, cement replacement ratios, and the activator solution ratio as a fly ash based geopolymer. The test results showed that replacement of fly ash as-based geopolymer improved the mechanical properties of concrete. Compressive strength, splitting tensile strength, flexural strength and bond strength are on higher side for 50% replacement as compared to those produced from 0%, 25%, 75% and 100% cement replacement ratio.

1. Introduction

Concrete production and industry increases daily due to the high demand of infrastructure services [1,2]. The projections for the whole increase in the cement industry will hit the 6 Gt/year [3]. It is well known that CO_2 emissions contribute about 65% of global warming and t is predictable to increase by 100% by 2020 [4]. The cement industry produces many other environmentally harmful products like sulfur dioxide (SO_3) and nitrogen oxides (NO_x) [5] which contribute to the global warming factors [6–9]. The contamination raised from cement production pushed the concrete community to find many alternatives to decrease the CO_2 emission. One of those solutions is the geopolymer concrete. The cement industry contributes around 2.8 billion tons of the greenhouse gas emissions annually, or about 7% of the total man-made greenhouse gas emissions to the earth's atmosphere [1].

Geopolymer concrete research that has been developed o at Curtin University of Technology was triggered by several studies on the geopolymer paste previously conducted by others [10] used slag to produce geopolymer binders to be used as a supplementary cementing material (SCMs). Geopolymer has been using as an adhesive in strengthening structural members and showed [11] that the compressive strength after 14 days was in the range of 5–10 MPa. Production of geopolymer concrete takes into account various factors t to be considered and which has a great impact on the strength; the mixing procedure and the CaO content found in the fly ash. The higher the content of CaO, the higher strength and lower the porosity. In addition to the aforementioned factors, it was found by [12] that the curing temperature and time have a great influence on the strength as well. To obtain a very high

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strength in geopolymer concrete, it is recommended to add the two solutions of NaOH + Na_2 $O.SiO_2$. as an activator solution for cement hydration [13] and that will help obtaining an optimum strength at 60 °C for a curing time of 48 h by mixing fly ash, kaolinite, sodium silica solution, NaOH, and water. The 60° is the temperature needed to start the geopolymerization process.

The addition of sucrose and citric acid as an alternative admixture in fly ash based geopolymer has portrayed an encouraging results, particularly in the modification of rheological properties of geopolymer paste [14]. Sucrose tends to provide a retardation effect to the plastic geopolymer paste, while citric acid can be used to accelerate the stiffening process. Even though improvement on the compressive strength was not optimized, sucrose-added specimens have a comparable compressive strength to the control specimen. The additional precipitation of dissolved species in the presence of sucrose has also affected the evaluation of porosity characteristic. Contrasting to citric acid, sucrose-added specimen has an unconventional relationship between porosity and compressive strength, where smaller porosity is correlated with lower compressive strength [14]. Nevertheless, these chemical reagents have presented a prospective future as the alternative admixture basis in geopolymer binder [14].

In this study concrete mixtures were prepared and tested to investigate the mechanical properties of geopolymer concrete and its behavior under a partial and complete replacement of cement. The key parameters were; the binder material content, cement replacement ratios, and the activator solution ratio from fly ash based geopolymer as will be discussed on the coming section.

2. Experimental program

2.1. Material properties and mix proportions

Table 1 shows the mix proportions used in this study. Ordinary Portland cement type (I) with high grade 52.5N and fly Ash (FA) was used as cementitious materials. The chemical compositions and physical properties of the cementitious materials are listed in Table 2. For all test specimens, a constant w/c ratio of 0.5 was used. Sand with grain size smaller than 5.0 mm was used. Uncrushed natural gravel graded from 4.76 mm to 15.0 mm was used as a coarse aggregate. Fly ash (FA) used in this study in conformance with ASTM C-618 [15]. The chemical and physical properties of fly ash are shown in Table 3. The alkali used consisted of a mixture of NaOH, and Na_2SiO_3 solution. NaOH pellets of 98% purity were used to make NaOH solution of desired molarity. The Na_2SiO_3 solution had 34.64% SiO, 16.27% Na2O and 49.09% Water. The specific gravity of alkali liquid solution with molarity 10 was 1.54.

The mixing procedure used for geopolymer concrete is similar to that of conventional P-C concrete. Mixing of all the materials has been done in the laboratory at room temperature. The fly ash and the aggregate were mixed together in concrete pan mixture. The mixing was allowed to continue for about 3 to 4 min. The alkaline solution was prepared one day before mixing and was added with additional water during the mix. The liquid component

Table 2
Properties of cement.

Property	Results	E.S.S limits*
Consistency of standard cement paste	Water content as percentage by weight of cement = 0.5%	26%–33%
Setting time	Initial = 1 h, 30 min	Min. 45 min
	Final = 4 h, 30 min	Max. 10 h
Compressive strength	3 days = 250 kg/cm^2	Min. 180 kg/cm^2
	7 days = 340 kg/cm^2	Min. 270 kg/cm^2
Fineness of cement	3300 cm^2/gm	Min. 2750 cm^2/gm

* E.S.S: Egyptian standard specifications.

Table 3
Physical and chemical properties of Fly Ash.

Property	Measured Value
Physical properties	
Color	Grey (Blackish)
Specific gravity	2.13
Chemical properties	
Silica (SiO_2)	57.9
Iron Oxide (Fe_2O_3)	5.07
Alumina (Al_2O_3)	31.11
Calcium Oxide (CaO)	1.29
Magnesium Oxide (MgO)	0.97
Total Sulphr (SO_3)	0.05
Sodium Oxide (Na_2O)	0.09
Potassium Oxide (K2O)	1.0
Loss on ignition(LOI)	0.8
CL	0.04

Table 1
Mix proportions.

Group		Cement (kg/m^3)	Fly ash (kg/m^3)	Solution (kg/m^3)		Water (kg/m^3)	Sand (kg/m^3)	Gravel(kg/m^3)	Gravel(kg/m^3)
				NaOH	LSS			4.76-10 mm	10–15 mm
Group(1)	G10	300	0	0	0	150	809.70	607.27	607.27
	G125	225	75	11.786	29.46	125.19	795.35	596.51	596.51
	G150	150	150	23.57	58.93	100.38	780.99	585.74	585.74
	G175	75	225	35.36	88.39	75.57	766.64	574.98	574.98
	G1100	0	300	47.14	117.86	50.76	752.29	564.22	564.22
Group(2)	G225	225	75	9.64	24.10	129.70	795.73	596.79	596.79
	G250	150	150	19.29	48.21	109.40	781.76	586.32	586.32
	G275	75	225	28.93	72.32	89.11	767.79	575.85	575.85
	G2100	0	300	38.57	96.43	68.81	753.83	565.37	565.37
Group(3)	G30	350	0.00	0.00	0.00	175.00	765.85	574.39	574.39
	G325	262.5	87.5	13.75	34.38	146.06	749.11	561.83	561.83
	G350	175	175	27.5	68.75	117.11	732.36	549.27	549.27
	G375	87.5	262.5	41.25	103.13	88.17	715.62	536.71	536.71
	G3100	0	350	55	137.50	59.23	698.87	524.15	524.15
Group(4)	G425	262.5	87.5	11.25	28.13	151.32	749.56	562.17	562.167
	G450	175	175	22.5	56.25	127.64	733.26	549.95	549.95
	G475	87.5	262.5	33.75	84.38	103.96	716.97	537.72	537.72
	G4100	0	350	45	112.50	80.28	700.67	525.50	525.50