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AN EXPERIMENTAL STUDY ON SLAG BASED GEOPOLYMER CONCRETE

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الملخص

فى هذا البحث تم إستخدام خبث الأفران المطحون كمكون رئيسى بديل عن الأسمنت حيث أن إنتاج الأسمنت يستهلك كمية ملحوظة من المصادر الطبيعية و الطاقة و يكون مسئول عن إنبعاث ثانى أكسيد الكربون. لذلك يعتبر الخرسانة الجيوبلمرية مواد صديقة للبيئة و تعتبر كحل لمشكلة التلوث. البرنامج العملى عبارة عن صب واختبار ستة خلطات من الخرسانة الجيوبولمرية بمتغيرات مختلفة. تم استبدال 50 % من كمية الرمل بخبث ووجد ان مقاومة الضغط قلت بمقدار 50 كجم/سم-2. تم اضافة نسب متغيرة من الأسمنت إلى الخلطة ووجد إن عند زيادة الأسمنت بنسبة 10 % من الخبث تؤدى إلى زيادة ملحوظة فى مقاومة الضغط . و أخيراً تم اضافة ملدنات إلى الخطة ووجد أ ن عند زيادة الملدن بنسبة حوالى 3 % من الخبث تؤدى إلى زيادة كبير فى التشغيلية. ثم تم عمل اختبارات مقاومة الضغط عند الـ 7 أيام و الـ 28 يوم ووجد أن الخرسانة الجيوبلمرية تعطى مقاومة مبكرة مقارنة بالخرسانة التقليدية حيث مقاومة الضغط عند الـ 7 أيام تكون حوالى (83% – 95%) من مقاومة الضغط عند الـ 28 يوم. تم عمل اختبارات لتحديد مقاومة الإنحناء ، مقاومة الشد و معاير المرونة من الخرسانة الجيوبلمرية و تمت مقارنتها بمعادلات الكود المصرى.

ABSTRACT

Ordinary Portland cement is the main binder material in manufacture of concrete, however, the production of OPC is responsible for carbon dioxide emission and consumes significant amount of natural resources and energy, therefore, the use of ground granulated blast furnace slag as a alternative binder material in production of environmentally friendly concrete has emerged as an innovation solution to pollution problem. A number of pre-test mixes of geopolymer concrete were made to determine suitable mix proportions and the suitable curing system. Six geopolymer concrete mixes with various variables were cast and tested. First variable was replacement 50% of sand with slag and was found that the compressive strength decreased about 50 kg/cm^2. Second variable was adding cement as variable ratios of slag and was found that the compressive strength had noticeable increasing till 10% of slag. Third variable was adding super plasticizer about 3% of slag leading to noticeable enhancement in workability. All mix design was tested to determine slump, 7 and 28 day compressive strength and found that the mixtures achieved early compressive strength compared to traditional concrete where the compressive strength at 7 days about (83%-95%) of compressive strength at 28 day. Flexural strength at 28 days, splitting tensile at 28 days and modulus of elasticity at 28 days were tested for two chosen mix design and compared to equations of Egyptian code.

KEYWORDS: Alkali activated slag (AAS), Geopolymer concrete, Ground granulated blast furnace slag (GGBFS), OPC and Replacement 50% of sand

1. INTRODUCTION

The demand of concrete is increasing over the world because it is used in the construction of many infrastructures such as bridges, highways, dams, and urban facilities. However, the production of OPC consumes significant amount of natural resources and energy and releases large amount of carbon dioxide (CO_2). Manufacturing of ordinary Portland cement (OPC) involves mining, crushing and grinding limestone and shale, which are burned in a rotary kiln to convert the limestone into lime via a process known as calcination and finally grinding the resulting cement clinker with gypsum and clay, these ingredients are "cooked" at temperatures up to 1500◦C, which is responsible for the majority of the CO_2 emission. During production of Portland cement, large amounts of greenhouse gases (GHG) release, mainly carbon dioxide (CO2), and contribute to about 7 % of global anthropogenic CO_2 emissions and accounts for 4 % of man-made global warming [1]. The contribution of OPC manufacture to carbon emissions is at the second place just after fossil fuels. Every ton of Portland cement replaced with supplementary cementitious materials such as fly ash, slag, rice husk ash, clay, etc. is estimated to avoid the emission of about one tone of CO2 to the atmosphere [2]. Over the last two decades, geopolymer concretes appeared as novel engineering materials with the potential to become a substantial element in an environmentally sustainable construction and building products industry. Geopolymer concrete is the result of the reaction of materials containing aluminosilicate with alkalis to produce an inorganic polymer binder. To save the environment from global warming and to prevent further depletion of natural resources should be found alternative material for OPC. Geopolymer concrete (GPC) is an alternative for cement with waste materials such as fly ash and GGBFS. Ground granulated blast furnace slag (GGBFS) is such pozzolanic material which can be used as a cementitious ingredient in either cement or concrete composites. GGBFS is a by-product in the manufacture of pig iron, the amounts of iron and slag obtained are of the same order. Slag is defined as "the non-metallic product consisting essentially of calcium silicates and other bases that is developed in a molten condition simultaneously with iron in a blast furnace. The slag is a mixture of lime, silica, and alumina, the same oxides that make up Portland cement, but not in the same proportion. It was found that GGBS gave high early compressive strength, corrosion resistance better than OPC concrete, better crack resistance and long-term durability because of GGBFS are more homogeneous and well-bonded to the aggregate [3]. Also, GGBFS gave better sulphate attack, tensile strength and higher temperature resistance more than OPC concrete [4].

2. EXPERIMENTAL PROGRAM

The experimental program consists of two main phases as following: The first phase presents the used materials in geopolymer concrete and its properties, the method of mixing, casting and curing of geopolymer concrete and all mixtures which did in the laboratory. The second phase presents the tests on the specimens and their results which included the tests of compressive strength at 7 and 28 days, splitting tensile strength, flexural strength and modulus of elasticity of the geopolymer specimens. six standard cubes 150 x 150 x 150 mm for compressive strength at 7 and 28 days, six standard cylinders 150 mm diameter and 300 mm height for splitting tensile strength, modulus of elasticity and one prism 100*100*500 mm for flexural strength were cast.

2.1 MATERIALS

GGBFS is an industrial substance by-product of rapid water cooling of molten iron at temperature about (1500 °C to 1600 °C). GGBFS was used as the main source of aluminosilicate material for making geopolymer concrete specimens and it is available in Iron and Steel Factory, Helwan Governate. Ordinary Portland cement (OPC) with grade (42.5N) was used as an additive to enhance the compressive strength of the mixture. Ordinary Portland cement (OPC) was produced by El-Suez Cement Company. Chemical compositions of cement and GGBFS are illustrated in Table (1),). A mixture of sodium hydroxide (NaOH) and sodium silicate (Na_2SiO_3) solutions was used as the activator solution with ratio 1:3. The concentration of sodium hydroxide solution was 12 Molar for all mixtures. The basalt coarse aggregate with maximum size 10 mm and natural fine aggregate with fineness modulus 2.1 were obtained from National Research Center laboratories and all results fall in the limits of the Egyptian code [9].

Table (1), Chemical Composition of GGBFS and OPC

Composition by weight (%)	**GGBFS**	**OPC**
Silicon oxide SiO_2	36	21.0
Aluminum oxide Al_2O_3	9.48	6.1
ferric oxide Fe_2O_3	0.8	3.0
Calcium oxide CaO	37.7	61.5
Magnesium oxide MgO	4.51	2.1
Sulfur oxide SO_3	2.29	2.5
Sodium oxide $N\ a_2O$	0.83	00
Potassium oxide K_2O	0.47	0.3
Manganous oxide MnO	4.55	-
Barium oxide BaO	2.36	-
Titanium dioxide TiO_2	0.71	-
Strontium oxide SrO	0.09	-
Zirconium dioxide ZrO_2	0.06	-
Phosphorus pentoxide P_2O_5	0.06	-
Loss on ignition	0.01	2.4

2.2 CONCRETE MIXES

All mix designs were gotten by trial method with constant ratio for slag and aggregate 1:1:2 (slag: fine aggregate: coarse aggregate) respectively with constant ratio for alkaline solution 0.5 of (slag and cement if was there) for all mixtures. The solution consisted of sodium hydroxide and sodium silicate with constant ratio 1:3 (sodium hydroxide: sodium silicate) respectively. Sikament-163 used as superplasticizer with ratio 3% of slag in one mixture to enhance workability. Table (2) show the proportions details for 1 m3 of concrete.

Table (2), Geopolymer concrete mixture proportions

No	Slag (kg/m^3)	Cement (kg/m^3)	Fine Agg. (m^3)	Coarse Agg. (m^3)	Super plasticizer (litre)	NaOH (litre)	Na_2SiO_3 (litre)	Water (litre)
1	523	-	523	1046	-	66	198	15
2	816	-	272	1088	-	68	204	-
3	775	41	272	1088	-	68	204	-
4	715	79	272	1088	-	68	204	9
5	653	163	272	1088	-	69	207	-
6	653	163	272	1088	26	57	171	-

2.3 MIXING, CASTING AND COMPACTION OF GEOPOLYMER CONCRETE

The method of manufacturing of Geopolymer concrete as the same conventional techniques as Portland cement concrete as following: Firstly, slag, fine aggregate and coarse aggregate were mixed together in the dry condition in the pan mixer for three minutes and the coarse aggregate should be in saturated-surface-dry (SSD) condition. Secondly, the liquid solution which was consisted of Hydroxide Sodium (NaOH) and Silicate Sodium (Na_2SiO_3) was prepared. sodium hydroxide solution should be prepared 24 hours before casting. The solution was mixed with extra water and super plasticizer if mixture need that. Thirdly, the liquid solution was added with the dry mixture and mixed for another four minutes as shown in figure (1). Finally, the fresh concrete shall be filled into the cube molds in 3 layers in standard six cubes (150 *150*150) mm for each mix. Each layer should be compacted by not less than 35 blows by hand such as the usual methods used in the case of Portland cement concrete as shown in figure (1). we measured the workability of the fresh concrete by the conventional slump test shown in figure (2). When the time of wet-mixing time increased the compressive strength of geopolymer concrete increased [10].

a) The mixing process **b) compaction of fresh geopolymer concrete**

Figure (1), Mixing and compaction of geopolymer concrete

2.4 SPECIMENTS CURING

The system of curing for cubes which were remolded after 24 hours from casting. We tried more than method in curing and they are: Submerge the cubes in water for one day and that method give bad results. Curing in small oven for 8 hours at 80 ^oC then exposing to sun rays until the testing after (7 and 28) days and that method give bad results too maybe because it was in winter. Curing in small oven for 24 hours at 80 ^oC

and that method give bad results too. Curing in steam for three days and that method give the best result then leaving them in the temperature of the room about 25 ºC until testing day. Through the last methods we depend on the fourth method as shown in figure (2).

Figure (2), The steam curing tank

2.5 CONCRETE TESTS

Slump test, compressive strength, flexural strength and modulus of elasticity tests were conducted on specimens as shown in figure (3). Slump tests were conducted according to standard specification ASTM C143/C143M-03[11]. Compressive strength tests were conducted according to standard specification BS EN 12390-3:2009 [12]. Flexural strength tests were conducted according to standard specification ASTM C78/C78M-18[13]. Modulus of elasticity standard tests were conducted according to standard specification ASTM C469-14 [14]. Splitting tensile strength tests were conducted according to standard specification ASTM C496-14 [15].

a) Slump test

b) Compressive strength test

c) Flexural strength test

d) **Modulus of elasticity**

e) Splitting tensile strength

Figure (3) Tests of specimens

3. RESULTS

3.1 Workability

As shown in table (3) adding of Sikament-163 as superplasticizer about 3% of slag lead to noticeable enhancement in workability. Increasing alkaline activator liquid lead to increase the workability of specimens.

3.2 Compressive strength

The results of the compressive strength were shown in figure 4 and table (3). We can show that the compressive strength of geopolymer concrete at 7 days represented about (83% to 95%) of the compressive strength at 28 days and that mean geopolymer concrete had early compressive strength more than traditional concrete which has the compressive strength at 7 days about (80% to 85%) according to Egyptian code. Replacement 50% of sand with slag lead to decrease in the compressive strength about 50 kg/cm^2. When cement was added with ratios (5%, 10% and 20%) of slag, the compressive strength increased about (19%, 49% and 53%) respectively compared to mix design 2. Hence, we can conclude that adding cement with ratio of 20 % of slag not effective.

Table (3), The results of compressive strength at 7 days and 28 days

Mix No	Strength (kg/cm2)		Slump	Notes
	at 7 days	at 28 days	(cm)	
1	339	360	20	-
2	285	310	7	rep 50 % of sand with slag
3	341	370	6	used cement 5% of slag - rep 50 % of sand with slag
4	423	461	12	used cement 10% of slag - rep 50 % of sand with slag
5	429	476	9	used cement 20% of slag - rep 50 % of sand with slag
6	405	484	25	used cement 20% of slag - rep 50 % of sand with slag

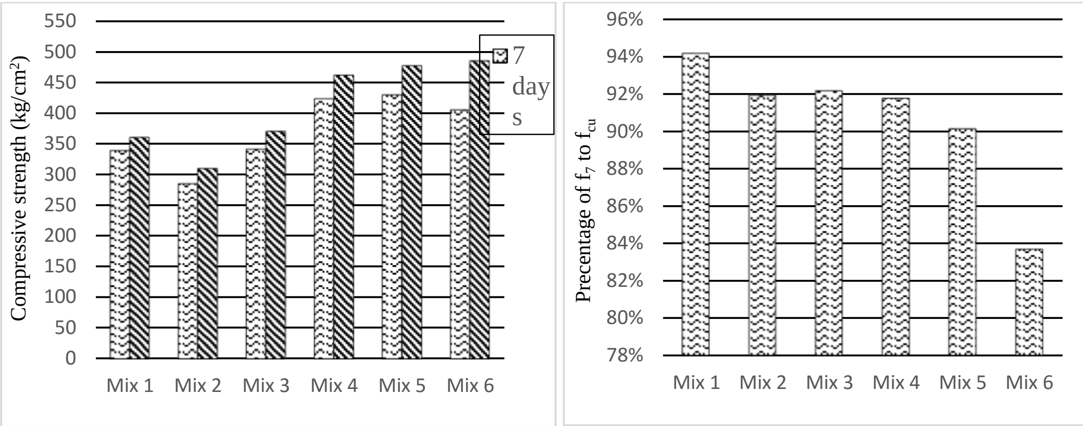

Figure (4), Difference between compressive strength at 7 and 28 days

3.3 Splitting tensile strength

The results of the splitting tensile strength were shown in figure table (4). The geopolymer concrete showed lower values of splitting tensile strength compared to values of conventional concrete at ECP 203 [9]. The splitting tensile strength of geopolymer concrete with compressive strength 46 MPa to 36 MPa were 1.65 MPa and 1.3 MPa respectively with ratio 3.6 % of compressive strength. While the ratio of splitting tensile strength at ECP 203 [9] in the range of 5 % to 10% of compressive strength on the contrary to another research [5] and compatible with research [5].

3.4 Modulus of elasticity

The results of modulus of elasticity were shown in table (4) and figure (5). The geopolymer concrete showed lower values of modulus of elasticity compared to values of conventional concrete at ECP 203 [9]. Modulus of elasticity for geopolymer concrete with compressive strength 46 MPa, 36MPa were 9455 MPa and 5422 MPa respectively, While the values of modulus of elasticity according to ECP 203 [9] were 29842 MPa and 26400 MPa respectively and that is compatible with another research [7] and [8]. Modulus of elasticity is actually sensitive to aggregate and mixture proportions of concrete.

3.5 Flexural strength

The results of Flexural strength were shown in table (4) and figure (6). From the geopolymer concrete showed lower values of flexure strength compared to values of conventional concrete at ECP 203 [9]. The flexure strength of geopolymer concrete with compressive strength 46 MPa to 36 MPa were 3.9 MPa and 2.8 MPa respectively with ratio 8.5 % and 7.8 % respectively of compressive strength. While the values of flexural strength at ECP 203 [9] equal 4.07 and 3.6 respectively according to equation $F_{ctr}=0.6\sqrt{F_{cu}}$ and value about 10 % of compressive strength.

Table (4), The physical properties of geopolymer specimens

Mix design No.	Compressive strength (MPa)	Splitting tensile strength (MPa)	Modulus of elasticity (MPa)	Flexural strength (MPa)
Mix no. 2	36	1.30	5422	2.8
Mix no. 4	46	1.65	9455	3.9

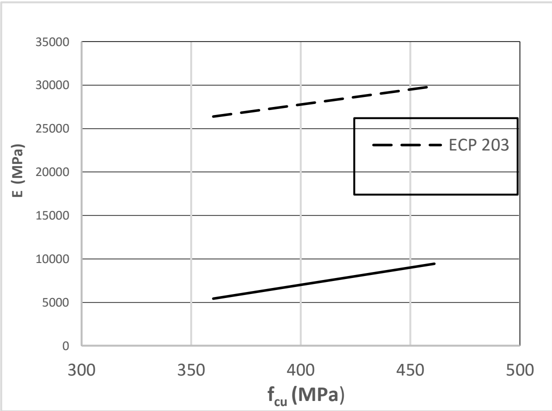

Figure (5), comparison between ECP and tested results in modulus of elasticity test

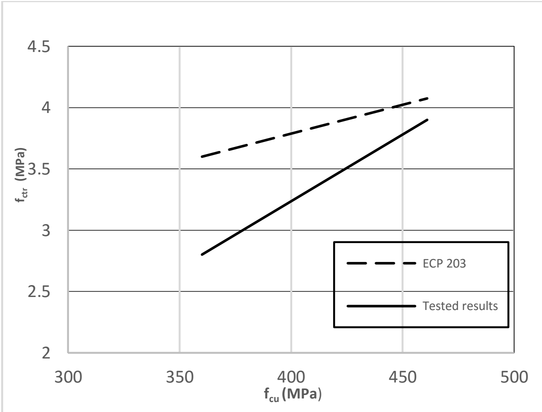

Figure (6), comparison between ECP and tested results in flexural strength test

6. CONCLUSIONS

From the analysis and discussion of test results obtained from this research, the following conclusions can be drawn:

1. adding amount of Sikament-163 super plasticizer to the mixture up to approximately 3% of slag content improved workability of fresh geopolymer concrete.
2. Increasing sand replacement ratio with slag to 50% by weight of sand decreased the compressive strength about 50 kg/cm^2, less than the mixture without sand replacement.
3. Increasing the ratio of alkaline solutions to slag content (L/B) improved workability of fresh geopolymer concrete without need to a extra water.
4. The compressive strength of geopolymer concrete at 7 days represented about (83% to 95%) of the compressive strength at 28 days and that mean geopolymer concrete had early compressive strength.
5. Exposure samples to steam curing at 60^{o}C for 3 days leads to the highest compressive strength for all samples compared to other methods.
6. Increasing of slag replacement ratio with OPC increased the compressive strength.
7. The geopolymer concrete showed lower values of splitting tensile strength compared to values of conventional concrete at ECP 203 on the contrary to another research [6] and compatible with research [5].
8. The geopolymer concrete showed lower values of flexure strength compared to values of conventional concrete at ECP 203.
9. The geopolymer concrete showed lower values of modulus of elasticity compared to values of conventional concrete at ECP 203 and that is compatible with another research [7] and [8].

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