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Production of Geopolymer Concrete using Metakaolin blending with Slag cured at ambient temperature

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الملخص العربي :

تعتبر الخرسانه الجيوبلمريه ماده صديقه للبيئه يمكن استخدامها إلى تقليل انبعاث ثاني أكسيد الكربون الناتج عن صناعة الأسمنت.ولايقتصر مميزات الخرسانه الجيوبلمريه على جودة الخواص الميكانيكيه لها فقط بل لها مقاومه ممتازه للحريق والصدأ.إن دمج خبث الافران مع الميتاكولين في الخرسانه الجيوبلمريه له دور مهم في تصلد الخرسانه الجيوبلمريهوكذلك تحسين مقاومة الضغط لها خصوصا عند معالجتها في درجة الحرارة المحيطه.يهدف هذا البحث الى دراسة خواص الخرسانه الجيوبلمريه من حيث الهبوط ومقاومة الضغطباستخدام نسب مختلفة من خبث الافران مع الميتاكولين وكذلك استخدام نسب مختلفة من المنشطات والمولاريه لهيدروكسيد الصوديوم لانتاج خلطه خرسانيه ذات مقاومة ضغط 35 ميجا باسكالتم معالجتها في درجةالحراره المحيطه.حيث تم استخدام خبث الافران الى الميتاكولين بنسب (1:0.5), (1:1) وكذلك مولاريه لهيدروكسيد الصوديوم16,14 مولر باستخدام نسب سيليكات الصوديوم الى هيدركسيد الصوديوم (1:2) ، (1:2.5), (1:3) .وقد اتضح من النتائجان زيادة محتوى خبث الافران بالخلطه يؤدي الى تقليل التشغيليه بينما تزيد مقاومة الضغط كما اظهرت النتائج ان افضل خلطه يمكن استخدامها في درجة الحرارة المحيطةلانتائج خرسانه جيوبلمريه ذات مقاومة ضغط35 ميجا باسكال ونسبة سيليكات الصوديوم الى هيدركسيد الصوديوم (1:2.5) و مولاريه هيدروكسيد الصوديوم 16.

Abstract:

Geopolymer is an environmentally friendly material.Production of geopolymer can reduceemission of carbon dioxide caused by cement industry. Geopolymer materials have excellent mechanical propertiesas well asgood fire and corrosion resistance.Inclusion of ground granulated blast-furnace slag (GGBFS) with Metakaolin could have a significant impact on the setting and strength of geopolymer binders when cured in ambient temperature. This paper study the effect of different proportions of GGBFS and activator ratio on slump and strength properties of Metakaolin based geopolymer concrete. It aims to produce best mix with compressive strength 35 MPa using Metakaolin , slag cured atambient temperature, using ratios Metakaolin to slag (1:0.5,1:1) and sodium hydroxide to sodium silicate (1:2, 1:2.5, 1:3) respectively, with concentration of sodium hydroxide (Molarity) M14 and M16. The mixtures were designed to achieve an average compressive strength of 35MPa. Significant increase in strength and decrease in slump were observed in geopolymer concretes with increasing of GGBFS content and lower sodium silicate to sodium hydroxide ratio in mix.Generally, Metakaolin and slag blend has improved mechanical properties of geopolymer concrete cured at ambient condition.

Keywords: GGBS, metakaolin,Geopolymer, slump,Compressive Strength, Ambient Curing

1- Introduction

The use of environmentally friendly materials has become an urgent necessity for sustainable development. UsingPortland cement as the main component in concrete is responsible for about 6% of the CO2 emission. Recent years have develop new type of cementitious binder called geopolymeric binder.Application of geopolymer in concrete, improves the greenness of normal concrete [1].Geopolymer concrete issubstitute material for structural application. It can play a significant role in green concrete by eliminating cement and using various by-product materials such asblast furnace slag and fly ash [2]. Two main constituents of geopolymers, namely the source materials and the alkaline liquids. Source materials for geopolymers based on alumina-silicate should be rich in silicon (Si) and aluminium (Al), such as kaolinite, by-product materials such as fly ash, silica fume, slag, rice-husk ash, red mud, could be used as source materials. The alkaline liquid used in geopolymerisation is a combination of sodium hydroxide (NaOH) or potassium hydroxide (KOH) and sodium silicate or potassium silicate. [3].The geopolymerisationprocesscan be explained in three distinct reactions: (1) destruction-coagulation; (2) coagulation-condensation; and (3) condensation-crystallisation [4]. Polymerization reaction depend on many factors such as chemical composition of binder and the alkaline solution,water content and curing condition. Curing temperature has a significant impact on mechanical strength of geopolymer system. Generally, the polymerization is accelerated at higher temperature increasethan ambient [5]. Use of slag as a complete alternative to cementreduce carbon dioxide emissions. Proportions of up to 70 or even 80 % can be used with advantage in suitable situations [6]Metakaolinis having high reactivity, silica is form of a kaolite which is a clay mineral which has excellent cementitious properties. It is a clay mineral which is off white in color and has a specific gravity 2.6 g/cc [7]Geopolymer concrete has many advantages such as higher mechanical properties, higher fire resistance,chemical resistances against chlorides, acids and sulphates, low creep and shrinkage compared to conventional concrete [8–11].Most studies using heat curing for setting and hardening of fly ash geopolymer mixtures. Heat curing process requires special arrangements which not suitable for use on the site [12].GGBS blended FA based GPC mixes enhanced mechanical properties at ambient room temperatureat all ages without the need of heat curing as in the case of FA.Only based on increase in GGBS content in GPC mixes [13]. Metkaolin is a valuable admixture with excellent advantages, including porosity, high specific area, good absorbability, and strong coordinative bonds when stimulated [14–17].The cost saving due to ambient curing of geopolymer concrete, along with the reduction in the CO2 emissions and simplification of the manufacturing process for cast in-situ applications, is a major driver in the development of geopolymer concrete under ambient curing conditions [18].This study aimed to product Metkaolin, GGBS– based on geopolymer concretes suitable for ambient curing condition.Ground blast furnace slag was blend with Metkaolin to study the workability and the strength properties of geopolymer concrete.

2. Materials

Materials in this study were obtained from available local materials. sand from Atfih area,crashed stone from Suez area,sodium silicate from Miser International Silicate Company, sodium hydroxide from The Arab Alkali Company .Metakaolinfrom Normatic Building Materials Company, (GGBFS) Bought from a local dealer.

2-1 Fine Aggregates (Sand)

Testing of sand was carried out according to the Egyptian Code No. 203-2020 [19] and, ESS 1109/2002 [20].The physical propertiesand the grading of sand are given in Tables (1,2).

Table (1): Physical properties of used sand.

Property	**Results**	**Limits**
Specific Weight	2.62	2.5-2.75 *
Bulk Density (t/m^3)	1.68	-----
Fineness Modulus	2.75	-----
Clay and Fine Dust Content (% By Volume)	0.75	Not more Than 2.5*

* Egyptian Code No. 203-2020 [19]

Table (2)Fine aggregates sieve analysis

Sieve (mm)	32.0	22.4	16	11.2	8	5.6	4	2	1	0.25	0.125	0.063
Cumulative percentage passing (%)	100	100	100	100	100	100	98.57	94.08	74.06	3.47	0.00	0.00

2-2 Coarse Aggregates

Coarse aggregates used in this study were one size of coarse aggregate as 10 mm.Testing of crashed stone aggregate, was carried out according to the Egyptian Code No. 203-2020, and ESS 1109/2002 .The physical propertiesand the grading of crashed stone is given in table (3,4)

Table (3): Physical and mechanical properties of crashed stone aggregate

Property	Results	% Limits
Specific Weight	2.65	-----
Bulk Density (t/m^3)	1.56	-----
Water Absorption %	1.75	Not more than2.5**
Clay and Fine Dust Content %	1.21	Not more than2.5*
Flakiness Index %	19.5	Not more than25**
Crushing Coefficient %	21	Not more than 30%*
Elongation Index %	9.8	Not more than25**
Abrasion Index %	16.5	Not more than30**
Impact Value %	12.2	Not more than45**

*Limits of ESS 1109/2002. **Limits of ECCS 203-2020

Table (4): coarse aggregates sieve analysis

Sieve (mm)	32.0	22.4	16	11.2	8	5.6	4	2	1	0.25	0.125	0.063
Cumulative percentage passing (%)	100	100	100	95.60	48.59	10.92	0.40	0.00	0.00	0.00	0.00	0.00

2-3 Ground Granulated blast furnace slag (GGBFS)

GGBS is a by-product obtained during the manufacture of iron in the blast furnace. it is suitable for use in ready-mix concrete, in the production of large quantities of site-batched concrete and in precast product manufacturing [21]. Physical and chemical properties of GGBS and ASTM C618 [22] requirements are shown in Tables (5), (6) respectively.

Table (5): Physical properties of used slag (GGBFS).

Property	Test Results
Specific surface area (m^2/Kg)	435
Bulk density (kg/m^3)	1050
Specific gravity	2.85
color	Off white
Physical Form	Powder

Table (6): XRF Analysis for GGBFS according to the requirement of ASTM C618 Class F

Oxide	Content %	Limitation % * for fly ash
SiO_2	33.2	Min. 70%
Al_2O_3	15.2	
Fe_2O_3	1.44	
CaO	33.6	-----
MgO	5.78	-----
Na_2O	0.87	Max. 1.5%
K_2O	1.77	-----
SO_3	1.21	Max. 3%
Cl	0.04	Max. 0.05%
P2O5	0.08	
Mno	0.36	
LOI	0.32	Max. 6%
Zro2	0.07	
ZnO	0.03	
BaO	0.04	
Total	99.95	

2-4 Metakaolin

Metakaolinis a dehydroxylated form of the clay mineral kaolinite. An aluminosilicate material such as kaolinite can be dissolved in an alkali-silicate solution to form a rock hard brittle ceramic. metakaolin is often used due to increased reactivity over raw kaolinite. Metakaolin obtain from calcination or dehydroxylation of kaolin clay at 500-900 °C. [23]. Physical and chemical properties of Metakaolin (MK) in Table (7), and (8), respectively.

Table (7): Physical properties of the used metakaolin.

Property	Test Results
Specific surface area (m^2/gm)	20000
Bulk density (kg/m^3)	1065
Specific gravity	2.5
color	Off white
Physical Form	Powder

Table (8): XRF Analysis for Metakaolin according to the requirement of ASTM C618 Class F

Oxide	**Content %**	**Limitation % * for fly ash**
SiO_2	56.4	Min. 70%
Al_2O_3	33.9	
Fe_2O_3	1.66	
CaO	1.76	-----
MgO	0.36	-----
Na_2O	0.16	Max. 1.5%
K_2O	0.12	-----
SO_3	0.53	Max. 3%
TiO_2	1.51	-----
P2O5	0.08	
ZrO2	0.16	
Cr2O3	0.02	
SrO	0.02	
ZnO	0.02	
Cl	0.04	Max. 0.05%
LOI	1.55	Max. 6%

2-5 Alkaline Liquid

In this study, a combination of sodium hydroxide and sodium silicate was chosen as the alkaline liquid. Sodium based solutions were chosen because they are cheaper than Potassium based solutions. Generally, sodium hydroxide and sodium silicate are readily available in market in the form of pellets and gel (liquid)[24]

2-5-1 Sodium Silicate Solution (NS)

NS solution was at liquid gel state. It is locally available with Na2O = 14.7%, SiO2= 29.4% and water = 55.9% by mass).

2-5-2 Sodium Hydroxide (NH)

The sodium hydroxide with 97-98% purity, in flake or pellet form, is commercially available. Solids must be dissolved in water to make a solution with the required concentration. The concentration of sodium hydroxide solutionusedhad a concentration of 16 molar.

2-6 Water

Potable water was used in the mixtures to dilute the caustic soda to obtain the required concentration, and the additional water to improve the workability of the mixtures.

3- EXPERIMENTAL PROGRAM

The experimental work consists of twelve mixture, to achieve compressive strength 35MPa using Metakaolin, blast furnace slag with ratios of sodium hydroxide to sodium silicate by 1:2, 1:2.5, 1:3 respectively, with concentration of sodium hydroxide (Molarity) M14 and M16. It mains Six mixes containing metakaolin to slag with ratio (1:0.5) andSix mixes containing metakaolin to slag ratio (1:1) using ratios of sodium hydroxide to sodium silicate 1:2, 1:2.5, and 1:3 respectively. Flowchart of the experimental program are shown in figure (1).

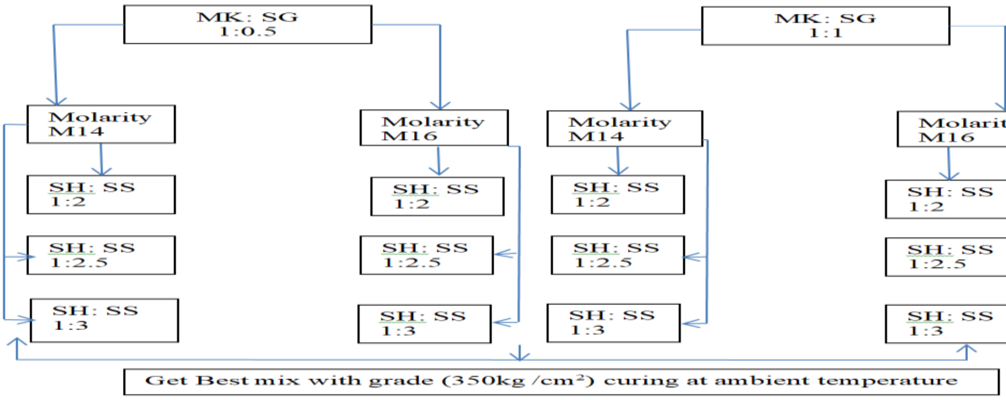

Figure (1) Flowchart of the experimental program

3-1 Mixing and casting of specimens

Geopolymer concrete specimens were prepared by mixing the dry material (slag, metakaolin coarse aggregate, and sand) in a pan mixer. Afterwards, alkaline activators (SS/SH) were added to the dry mix. Finally, water was added. . InitiallyGGBS and metakaolin and Sand were mixed in pan mixer followed by the addition of coarse aggregate, then the alkaline solution was added to the mix and mixed about 5minutes. The specimens were cast and compacted in three stages. Each stage was internally vibrated using an electric vibrator to remove air voids and to compact the fresh geopolymer concrete. The specimens kept under ambient conditions until the day of testingas shown in fig (2). Table (9) represent the mix proportions of the tested mixes by weigh quantities per 1m^3.

Fig (2) mold and vibrate cubes

Table (9) mix proportions of the tested mixes by weigh quantities per 1m^3
MK = metakaolin, M = molarity, NH = sodium hydroxide solution, NS = sodium silicate solution,

Mix No	Slag (kg)	MK (kg)	Sand (kg)	Coarse Aggregate (kg)	Alkaline Liquid (kg)		M	NS/ NH	Extra Water (kg)
					NS	NH			
1	117	233	550	1200	175	88	14	2	24
2	117	233	550	1200	188	75	14	2.5	27
3	117	233	550	1200	197	66	14	3	29
4	117	233	550	1200	175	88	16	2	26
5	117	233	550	1200	188	75	16	2.5	29
6	117	233	550	1200	197	66	16	3	32
7	175	175	550	1200	175	88	14	2	24
8	175	175	550	1200	188	75	14	2.5	27
9	175	175	550	1200	197	66	14	3	29
10	175	175	550	1200	175	88	16	2	26
11	175	175	550	1200	188	75	16	2.5	30
12	175	175	550	1200	197	66	16	3	33

4- Testing program

The testing program contain of slump, compressive, flexural, and indirect tensile strengths and Static modulus of elasticity tests.

4-1 slump test

Slump test was carried out for all mixes. The test was carried out according to the Egyptian Code No. 203-2020 [21], and ESS 1658-1989 Part 2 [25].

4-2 Compressive strength test

Compression tests were performed at 7, and 28 days on 100x100x100 mm cubes. All specimens were tested in a hydraulic testing machine with a capacity of 2000 KN and accuracy of 5 KN as shown in Fig. (2). The test was conducted as per EN 12390-3 [26].

5- Test Resultsand Discussion

The slump test was carried out to assess workability of the fresh Geopolymer concrete. The various hardened test such as unit weight, compression test, test were carried out to determine the mechanical properties of geopolymer concrete.

5-1Slump test

Slump test was carried outfor all mixes. The readings were tabulated in table10.The slump Test of concrete is one of method to calculate the workability or fluidity of concrete. Table (10) show theslump values of geopolymer concrete with NaOH concentration, M14, and M16 for all ratio between metakoline and slag (1:0.5,1:1) respectively. The slump ranged from 126 mm for M16 mix to, 140 mm for M14 mix for ratio between metakoline and slag (1:0.5) where ranged from 87 mm for M16 mix to, 98 mm for M14 mix for ratio between metakoline and slag (1:1). It can be observed that with the increase in molarity (M) the slump value decreases. It can also observed that with the increase in slag content the slump value decreases. The reason for the decreased slump of the mixtures is most likely due to the decreased mobility of irregular shaped slag particles in contrast to spherical shaped of metakolin. The Slump of geopolymer concrete is high when the proportion of SS to SH is reduced in the geopolymer concrete

5-2Compression test

The compression test was carried out for all mixes in two ages for 7 days and 28 days. The readings were tabulated in (10) respectively.Figure (3) show relationship between SH concentration and compressive strength, it appears that there is a strong relationship between SH concentration and compressive strength. The increase in the SH concentration increase the compressive strength.these due to dissolves the initial solid more and consequently increases geopolymerization reaction, which helps in achieving higher compressive strength. It is considered that geopolymer with SH concentration of M16 might have the best effect on increasing the strength. Figure (3) show also relationship between (GGBFS to metakolin ratio) and compressive strength. The higher percentage of slag in the concrete mix, the higher compressive strength . This may be attributed to the increase in the intensity of the calcium content when the amount of GGBFS was increased in the mix. The decrease in calcium content in the mix results in a delay in the polymerization reaction and the formation of an amorphously structured Ca-Al-Si gel was hindered. Hence, slag based geopolymer modified with metakolin can be considered as a suitable binder for geopolymer concrete under ambient curing conditions for reasonably high compressive strength.

Table (10): Slump testand, compressive strength results for geopolymerconcrete

Mix No	Mix ID	Slump (mm)	compressive strength (MPa)	
			7 days	28 days
1	M14- MK:SG =1:0.5, SH: SS= 1:2	140	308	343
2	M14- MK:SG =1:0.5, SH: SS= 1:2.5	138	319	363
3	M14- MK:SG =1:0.5, SH: SS= 1:3	135	333	354
4	M16- MK:SG =1:0.5, SH: SS= 1:2	132	314	347
5	M16- MK:SG =1:0.5, SH: SS= 1:2.5	128	326	369
6	M16- MK:SG =1:0.5, SH: SS= 1:3	126	339	361
7	M14- MK:SG =1:1, SH: SS= 1:2	98	345	404
8	M14- MK:SG =1:1, SH: SS= 1:2.5	96	366	456
9	M14- MK:SG =1:1, SH: SS= 1:3	94	383	448
10	M16- MK:SG =1:1, SH: SS= 1:2	92	352	462
11	M16- MK:SG =1:1, SH: SS= 1:2.5	90	379	492
12	M16- MK:SG =1:1, SH: SS= 1:3	87	396	478

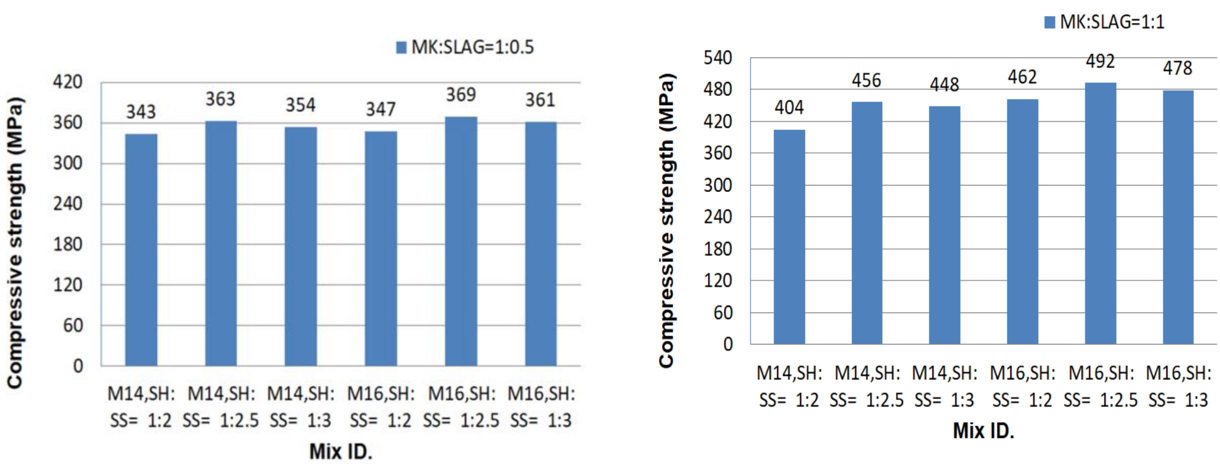

Fig. (6) Compressive strength results at (Slag: Mk=1:0.5,Slag: Mk=1:1)

6. Conclusion:

The effects of blending GGBFS with metakolin in the binder of geopolymer concrete cured at ambient temperature were studied by using an experimental work. Effects of the other mixture variables such as SS/SH ratio and SH concentration in the binder were also investigated. Workability of the fresh mixtures and development of compressive were determined.The following conclusions are drawn from the study:

1-Slump value of geopolymer concrete decreased with the increase of GGBFS content together with metakolin in the binder. This is mainly because of the accelerated reaction of the calcium and the angular shape of the slag. The addition of GGBFS enhanced setting of the concrete at ambient temperature.

2- Slump value decreased with the increasing of SH concentration.

3- The higher of slag content in the concrete mix, the higher compressive strength. This attributed to the increase in the intensity of the calcium content when the amount of GGBFS was increased in the mix. The decrease in calcium content in the mix results in a delay in the polymerization reaction.

4- The increase in SH concentration increase the compressive strength these due to dissolves the initial solid more and consequently increases geopolymerization reaction, which helps in achieving higher compressive strength.

5- Mix with blast furnace slag and metakaolin using ratio1:1 with concentration of sodium hydroxide (Molarity) M16 and ratio of sodium hydroxide to sodium

silicate 1:2.5 get best compressive strength at ambient temperature

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