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EFFECT OF EXPOSURE TO ELEVATED TEMPERATURES ON GEOPOLYMER CONCRETE PROPERTIES

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الملخص

ظهرت في الفترة الأخيرة مشكلة التخلص السلبي من المخالفات الصناعية و التي تنتج بكميات هائلة يومياً وذلك يمثل خطورة على البيئة و الصحة العامة ولهذا إن التفكير في إجراء تلك الدراسة لبحث إمكانية إستخدام بعض أنواع المخلفات الصناعية كبدائل لمواد الربط التقليدية مثل الأسمنت وذلك لحماية البيئة من تراكم المخلفات من ناحية وتوفير إستخدام الأسمنت من ناحية أخرى . حيث تتكون الخرسانة الجيوبليمرية من المكونات التقليدية للخرسانة العادية مستبدلا فيها الاسمنت (المادة الرابطة) بمواد جيوبلميرية (خبث الافران المطحون - رماد متطاير- ميتاكاولين). البرنامج العملي تم عمل خمسة خلطات بإستخدام خبث الحديد بمحتوى 450 كجم/م3و خلطة تحكم من خبث الحديد فقط بمولارية (12) مولر. خلطتان تم أحلال (10% - 20%) ميتاكاولين بمولارية (12) مولر. خلطتان تم أحلال (10% - 20%) رماد متطاير بمولارية (12) مولر. ثم تم مقارنة بين نتائج اختبار مقاومة الضغط ومعاير المرونة عند عمر 28 يوم في حالة عدم التعرض لدرجات حرارة عالية وفي حالة تعرضها لدرجات الحرارة العالية لفترات زمنية مختلفة.

ABSTRACT

The problem of passive disposal of industrial waste, which is produced in large quantities daily ,has emerged in the recent period and this is why thinking about conducting .This study to examine the possibility of using some industrial waste as an alternative to traditional bonding materials such as cement in order to protect the environment from the accumulation of waste on the one hand and to provide the use of cement on the other hand. , where concrete consist of traditional components of normal concrete replacing cement with geopolymer marital (ground granulated blast furnace slag, fly ash and metakolin). The practical program: five mixtures were made using granulated blast furnace slag contents (450) Kg/m^3, granulated blast furnace slag only control mixes with molarities (12 %) molar, two mixes (10 % - 20 %) metakolin were replaced by (12) molar and two mixes (10 % - 20 %) fly ash were replaced by (12) molar. Then comparison was made between the results of the compressive strength and modulus of elasticity at the age 28 days in the case of not being exposed to elevated temperatures and in the case of being exposed to elevated temperatures for different time periods.

KEYWORDS: Geopolymer concrete, Ground granulated blast furnace slag (GGBFS), Flay ash (F.A), Metakolin (M.K), Molarty(M)

1. INTRODUCTION

Geopolymer concrete can be considered as sustainable concrete. Replacing cement by Aluminosilicate source materials like ground granulated blast furnace slag, fly ash, metakaolin and rice husk ash eliminate the CO2 emissions and energy consumption of cement industry. Producing geopolymer concrete is not a complicated process, it follows the same procedure of producing cement concrete but with one added step. The source material needs to be activated with highly alkaline solutions just like Sodium or Potassium Hydroxide and Sodium or Potassium Silicate. Mechanical, physical and micro structure of geopolymer concrete is affected by the source material composition, alkali content and liquid/solid ratio [1]. Geopolymer concrete could have comparable flexural and tensile strength of ordinary cement concrete while the modulus of elasticity of fly ash and GGBS geopolymer concrete under compression is about 12–19% less than the modulus of elasticity of OPC with a similar compressive strength [2,3]. Established relationship between different mechanical properties as strength and modulus of elasticity of ordinary cement concrete may not realistic if used in geopolymer concrete [4]. Increasing amount of GGBS in blended geopolymer concrete increases the compressive strength due to formation of calcium silicate hydrate C-S-H while it could be harmful at elevated temperature due to decomposition [5]. Structural stability at elevated temperature of geopolymer concrete depends on its source materials and the inclusion of aggregates [6]. Heating fly ash based geopolymer concrete to 100-350^{o}C leads to 15-25% loss in strength and heating up to 400-600^{o}C results in compressive strength degradation of 38-58% relative to strength at ambient temperature [7, 8]. On the contrary other studies found that fly ash based geopolymer concrete underwent slight and significant increase in strength when exposed to elevated temperatures of 200-400^{o}C while it lost its strength at 800^{o}C [4]. Geopolymer concrete with blended ashes from agro-industrial wastes exhibited better structural stability than ordinary cement concrete after exposure to elevated temperature of 200-800^{o}C due to stable cross linked aluminosilicate polymer structure [9]. Diversity of geopolymer concrete constituents leads to a high uncertainty of expected properties of geopolymer concrete. Thus, it is important to make extensive experimental programs to well define the characteristics of the produced geopolymer concrete before using in structural elements.

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 28 days, of geopolymer specimens and static modulus of elasticity. standard cubes 150 x 150 x 150 mm for compressive strength 28 days, cylinders of 150 mm diameter and 300 mm length were cast.

2.1 MATERIALS

GGBFS is an industrial by-product resulting from rapid water cooling of molten steel. This material is available in Iron and Steel Factory, Helwan city. It has favorable properties for cement industry, as it is relatively inexpensive, highly resistant to chemical attack and maintains excellent thermal properties. The physical properties and XRF analysis of used GGBFS was showed in Table (1) and Table (2) respectively. The major components of the utilized slag were Silicon Dioxide (SiO_2), Carbon Oxide (CaO), Magnesium Oxide (MgO), Aluminum Oxide (Al_2O_3), Barium Oxide (BaO) and Manganese Oxide (MnO)

Table (1): Physical properties for the used GGBFS

Fineness (µm)	**84.7**
Specific weight	**3.1**
Color	**Black yellow**

Table (2): Chemical Composition of GGBS

Oxide	Content%
SiO_2	35.08
TiO_2	0.59
Al_2O_3	9.32
Fe_2O_3	0.63
MnO	4.56
BaO	2.79
MgO	6.02
CaO	35.97
Na_2O	0.95
K_2O	0.57
P_2O_5	0.05
SO_3	3.15
Cl	0.05

Fly Ash The used of fly ash (FA) is by-product material rich in silicon and aluminum, such as low-calcium fly ash according to the ASTM C 618 Class F. In the present experimental work, low-calcium (Class F).). The chemical composition of the fly ash, as determined by x-ray fluorescence (XRF) analysis is given in Table (3).

Table (3): XRF analysis for the used fly ash

Oxide	Content %	Limitation % *
SiO2	61.3	Min. 70%
AL2O3	29.4	
Fe2o3	3.27	
CaO	1.21	--------
MgO	0.75	--------
K2O	1.20	--------
SO3	0.003	Max. 3%
TiO2	0.01	--------
Na2O	0.73	Max. 1.5%
CL	0.04	Max. 0.05%
L.O.T	0.67	Max. 6%

Metakaolin Heating up of clay with kaolinite Al2O3.2SiO2.2H2O as the basic mineral component to the temperature of 500 °C – 600 °C causes loss of structural water with the result of deformation of crystalline structure of kaolinite and formation of an unhydrated reactive form so called metakaolinite. Physical and chemical properties of Metakaolin (MK) in Table (4), and Table (5).

Table (4): Physical properties of the used Metakaolin.

Property	Test Results
Specific surface area (cm^2/gm)	3950
Bulk density (kg/m^3)	1250
Specific gravity	2.5
Color	Off white, Gray to Buff
Physical Form	Powder

Table (5): XRF Analysis for the used Metakaolin.

Oxide	Content %	Limitation % * for fly ash
SiO_2	58.3	Min. 70%
AL_2O_3	37.3	
Fe_2o_3	0.09	
CaO	0.41	--------
MgO	0.29	--------
K_2O	0.05	--------
SO_3	0.001	Max. 3%
TiO_2	1.51	--------
Na_2O	0.04	Max. 1.5%
CL	0.04	Max. 0.05%
L.O.T	0.42	Max. 6%

2.2 CONCRETE MIXES

Table (6), Geopolymer concrete mixture proportions

Mix No.	Alumina Silicate Source (Kg/m^3)	Fine Aggregate (Kg/m^3)	Coarse Aggregate (Kg/m3)	NaoH Solution (Kg/m^3)	Na_2Sio_3 Solution (Kg/m^3)	Extra Water (Kg/m^3)
1	450 (Slag Only , 12 M)	643	964.5	57.9 (19.1 S-38.8 W)	144.6	68.7
2	450 (10% M.K , 12 M)	643	964.5	57.9 (19.1 S-38.8 W)	144.6	68.7
3	450 (10% Fly ash , 12 M)	643	964.5	57.9 (19.1 S-38.8 W)	144.6	68.7
4	450 (20% M.K , 12 M)	643	964.5	57.9 (19.1 S-38.8 W)	144.6	68.7
5	450 (20% Fly ash , 12 M)	643	964.5	57.9 (19.1 S-38.8 W)	144.6	68.7

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 [5].

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

c) Show cubes in electric Furnace

Figure (1), Mixing , compaction of geopolymer concrete and Show cubes in electric Furnace

2.4 SPECIMENTS CURING

The system of curing for cubes which were remolded after 24 hours from casting. After casting, specimens were left to harden for 24 hours. After removing specimens form molds, they are transferred to the steam curing tank. Steam curing interval was used; three days.

as shown in figure (2).

Figure (2), The steam curing tank

2.5 CONCRETE TESTS

Compressive strength, and Modulus of Elasticity test were conducted on specimens as shown in figure (3). Compressive strength tests were conducted according to standard specification BS EN 12390-3:2009 [6]. Modulus of Elasticity test were conducted according to standard specification ASTM C78/C78M-18[7].

a) Compressive strength test **b) Modulus of Elasticity test**

Figure (3) Tests of specimens

3. RESULTS

3.1 Elevated temperature effect on compressive strength.

Elevated temperature effect on compressive strength. At age of 28days, specimens of sets mix 1, 2,3,4, and mix 5 of each group were heated in an electric furnace. The maximum temperature of the furnace was 1000^0C and the increment rate of heating was 10^0C/min. Specimens of each mix were then kept at the target temperature of (700:800) ^{0}C for the specified durations of 1, 2 and 3 hrs. Specimens were allowed to cool inside the furnace for about 2 hr., then were taken out the furnace and allowed to cool naturally to the lab temperature before testing. Table (7) shows the elevated temperature effect on compressive strength for mix1,2,3,4, and mix5. The mix 1 (100% slag- 12M) as shown in table (7), at air cooled regime heating to for 1,2 and 3 hours led to compressive strength decreases about 31,6%, 57.98% and 69.73% respectively. The mix 2 (10% M.K – 12M) as shown in table (7), at air cooled regime heating to for 1,2 and 3 hours led to compressive strength decreases about 30.86%, 52.38% and 65.94% respectively. The mix 3 (10% F.A – 12M) as shown in tabe (7), at air cooled regime heating to for 1,2 and 3 hours led to compressive strength decreases about 29.86%, 51.43% and 66.33% respectively. The mix 4 (20% M.K – 12M) as shown in table (7), at air cooled regime heating to for 1,2 and 3 hours led to compressive strength decreases about 25.77%, 35.89% and 62.12% respectively. The mix 5 (20% F.A – 12M) as shown in table (7), at air cooled regime heating to for 1,2 and 3 hours led to compressive strength decreases about 24.1%, 26.67% and 51.63% respectively. the exposure samples to elevated temperature at (700:800) ^{0}C decreased the compressive of all geopolymer mixes regardless the cooling regime, but use of (20% F.A-12 M) as a replacement to slag in geopolymer concrete was better than the use of slag only, (10% M.K), (10% F.A), and (20%M. K). The performance of samples subject to 1hours of heating in compressive strength is better than the samples subject to 2hour and 3 hour of heating. In general, the observed drops in the compressive strengths for the studied geopolymer concrete specimens were more pronounced and as the elevated temperatures increased as the drop in compressive strength increased especially for 3 hours' exposure period. Moreover, the other mechanical properties quantities dropped as the temperature degree increased and showed similar trends happened in compressive strength. Sometimes, the observed reductions in these quantities were dramatic. This means that as the elevated temperature increased as the damage in the mechanical properties increased especially in geopolymer concrete mixes which suffered if exposed to elevated temperatures [8].

Table (7), The elevated temperature effect on compressive strength

Mix .NO	Compressive Strength (MPa)			
	Ambient	(700:800) ^{0}C		
		1 hour	2 hour	3 hour
Mix 1	28.88	19.744	12.134	9.03
Mix 2	29.26	20.231	19.33	9.965
Mix 3	30.79	21.596	14.954	10.367
Mix 4	32.35	24.011	20.739	12.255
Mix 5	40.83	31.05	29.941	19.749

3.2 Elevated temperature effect on Static modulus of elasticity

Table (8) shows the elevated temperature effect on Static modulus of elasticity for mix5, 4, and mix5. The mix 1 (100% slag- 12M) as shown in table (8), at air cooled regime heating to for 1,2 and 3 hours led to Static modulus of elasticity decreases about 28.1%, 37.48% and 60.01% respectively. The mix 4 (20% M.K – 12M) as shown in table (8), at air cooled regime heating to for 1,2 and 3 hours led to Static modulus of elasticity decreases about 25.66%, 35.88% and 62.10% respectively. The mix 5 (20% F.A – 12M) as shown in table (8), at air cooled regime heating to for 1,2 and 3 hours led to compressive strength decreases about 23.8%, 27.09% and 51.62 % respectively. the exposure samples to elevated temperature at (700:800) ^{0}C decreased the modulus of elasticity of all geopolymer mixes regardless the cooling regime, but use of (20% F.A-12 M) as a replacement to slag in geopolymer concrete was better than the use of slag only, (20%M. K). The performance of samples subject to 1hours of heating in modulus of elasticity is better than the samples subject to 2hour and 3 hour of heating [8].

Table (8): The elevated temperature effect on Static modulus of elasticity (MPa)

Mix name	Static modulus of elasticity (MPa)			
	Ambient	1 hour (700:800) ^{0}C	2 hour (700:800) ^{0}C	3 hour (700:800) ^{0}C
100% Slag (12M)	7932	5711	4959	3172
20% M.K (12M)	10370	7709	6649	3930
20% F.A (12M)	18450	14040	13452	8926

6. CONCLUSIONS

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

1. Compressive strength increased with the increase age.
2. The exposure samples to elevated temperature at (700:800) ^{0}C decreased the compressive of all geopolymer mixes regardless the cooling regime The increase in molarity of NaOH from 10 M to 12 M gradually increases the compressive strength of geopolymer concrete.
3. In the case of mixtures exposure to elevated temperature at (700:800) ^{0}C use of (20% F.A-12 M) as a replacement to slag in geopolymer concrete was better than the use of slag only, (10% M.K), (10% F.A), and (20%M. K).
4. The performance of mixtures exposure to 1hours of heating in compressive strength is better than the samples subject to 2hour and 3 hour of heating.
5. The exposure mixtures to elevated temperature at (700:800) ^{0}C decreased the modulus of elasticity of all geopolymer mixes regardless the cooling regime
6. In the case of mixtures exposure to elevated temperature at (700:800) ^{0}C use of (20% F.A-12 M) as a replacement to slag in geopolymer concrete was better than the use of slag only, (20%M. K) in modulus of elasticity.

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