Properties of Geopolymer Bricks Exposed To High Temperatures

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ABSTRACT

Green concrete are generally composed of recycling materials as full or partial substitutes for aggregate, cement, and admixture in concrete. To reduce greenhouse gas emissions, efforts are needed to develop environmentally friendly construction materials. Using fly ash based geopolymer as an alternative binder can help reduce CO_2 emission of cement. This paper presents the results of a study to compare the properties of geopolymer bricks prepared using class C fly ash. Also, utilization of cement kiln dust (by-pass) with its high alkali content in the activation of geopolymer bricks specimens to create nonconventional cementitious binders was investigated. Many different geopolymer mortar mixtures were tested. Mixtures evaluation was based upon replacing the fly ash with cement kiln dust (by-pass). The cement kiln dust (by-pass) content percentages were 50%, 75%, and 100% by weight of fly ash as a partial replacement. Geopolymer mortar specimens were prepared using different concentrations of NaOH solution of M10, and M16 and were cured at air until test date. The manufactured bricks were exposed to 300^{o}C and 600^{o}C for two hours after 28 days of curing. Tests were conducted according to both Egyptian Standard Specifications (ESS) and American Society for Testing and Materials (ASTM) in order to determine compressive strength, absorption percentage, and oven-dry weight. Also, loss in weight was performed. In this study, the Local Alkaline Activator in Egypt and Natural River sand as fine aggregate, in fly ash based-geopolymer bricks was used. This paper illustrates the development of mechanical properties. Hence it has been found that the cement kiln dust (by-pass) as geopolymer base can be used to manufacture both load-bearing and non-load-bearing units at room temperature with high molarity.

Keywords: Geopolymer; molarity; temperature; solid bricks, cement kiln dust, compressive strength, water absorption, weight.

I. INTRODUCTION

In recent years, green concrete has drawn serious attention of researchers and investigators because of a concept of "thinking environmentally friendly" [1]. The contribution of ordinary Portland cement production worldwide to greenhouse gas emissions is estimated to be approximately 1.35 billion tons annually [2]. To keep the global environment safe from the consequence of cement production, it is essential to explore alternative materials that can completely or partially eliminate the use of cement in concrete and cause no environmental destruction [3]. Geopolymers are formed when various alumina and silica containing materials react under highly alkaline conditions and forms a three dimensional network of Si–O–Al–O bonds [4]. The most commonly used raw materials in geopolymer are clay and metakaolin [5]. Cement kiln dust (by-pass) is a fine-grained, particulate material easily entrained in the combustion gases moving through the kiln. It is composed primarily of variable mixtures of calcined and uncalcined feed materials, fine cement clinker, fuel combustion by-products and condensed alkali compounds. Cement kiln dust (by-pass) generation is responsible for a significant financial loss to the cement industry in terms of the value of raw materials, processing, energy usage, dust collection and disposal. Cement manufacturing plants generate approximately 30 million tons of cement kiln dust (by-pass) worldwide per year. According to, Dyer et al., [6]and Zainab H. A., [7] the compressive strength increase in the concrete mixtures that include 10% and 20% CKD (as an addition of cement weight). A decrease in the compressive strength was noticed in the concrete mixtures that include 10% and 20% CKD (as a replacement of cement weight). A similar trend was noticed in the splitting tensile strength and the increase in splitting tensile strength was less pronounced than that in compressive strength. Khater. H.M, [8] concluded that the compressive strength increased in concrete mixtures that include 10% and 20% cement kiln dust (by-pass) as an addition of cement weight. A reduction in compressive strength was noticed in concrete mixtures that include 10% and 20% cement kiln dust (by-pass) as a replacement of cement weight. Wallah and Rangan [9] reported that geopolymer concrete specimens exhibit extremely small changes in length and also show very little increase in mass after one year in sulphate solution. In another study by Bakharev [10] the author used various concentrations of sulphate solution to immerse the geopolymer materials prepared using different types of activating solutions. This study was conducted to reveal the behavior of green geopolymer bricks incorporating various percentages of cement kiln dust (by-pass) as a partial/ full replacement and evaluate its compressive strength, water absorption, and oven-dry weight.

II. EXPERIMENTAL PROGRAM

The experimental program consists of ten different mixes; four geopolymer mixes with molarity of M10, four geopolymer mixes M16 and two mixes as control. The two controlled mixture were normal bricks mixture, one with Portland cement and the other one by Cement kiln dust (by-pass). Furthermore, the effect of the different contents of cement kiln dust (by-pass) content percentages of 50%, 75%, and 100% by weight of fly ash as a partial/full replacement for the remain eight mixtures. The mechanical properties of green bricks were studied.
Test specimens were prepared from the local materials. These include natural siliceous sand from Suez area and clean rounded fine aggregate of size of 0.15 to 5 mm that was used. The physical properties of fine aggregate are shown in Table (1). CEMI 42.5 N was used from Suez Cement Company; the physical properties of ordinary Portland cement are shown in Table (2). Sodium hydroxide in flake form was used (NaOH with 98-99% purity). The fly ash used in this research is class F fly ash according to the requirement of ASTM C618 Class F [13], its physical properties and XRF analysis are given in table (3) and table (4), respectively. Cement kiln dust (by-pass) was obtained from EL-Suez Cement Company where the percentage retained on sieve #170 was less than 9%. Accordingly the cement was expected to have particles surface area in the range of 2980 cm^2/gm. Tables (5) and (6) show the physical and chemical properties of cement kiln dust (by-pass), respectively.

Table 1: Physical properties of fine aggregate

Property	Results	Limits
Specific Weight	2.63	2.5-2.75 **
Bulk Density (t/m^3)	1.78	-----
Fineness Modulus	2.89	-----
Clay and Fine Dust Content (% By Volume)	0.85	Not more Than 3 **

** Egyptian Standard Specifications ESS 1106 [11].

Table 2: Physical properties of Ordinary Portland Cement.

Property		Results	Specifications Limits*
Compressive Strength of Standard Mortar (Mpa)	2 days	21.4	Not less than 18
	28 days	39.7	Not less than 36
Fineness in terms of S.S.A** (cm^2/gm)		3185	>2750
Setting Time (min)	Initial	75	Not less than 45
	Final	480	Not more than 600

* Egyptian Standard Specifications ESS 4756-1/2009 [12].

Table (3): Physical properties of the used fly ash

Property	Test Results
Specific surface area (cm^2/gm)	3950
Bulk density (kg/m^3)	1250
Specific gravity	2.5
Color	Light gray

Table (4): XRF Analysis of the used fly ash

Oxide	Content %	Limits % *
SiO_2	61.30	Min. 70%
Al_2O_3	29.40	
Fe_2O_3	3.27	
CaO	1.21	-----
MgO	0.75	-----
K_2O	1.20	-----
SO_3	0.003	Max. 3%
TiO_2	0.01	-----
Na_2O	0.73	Max. 1.5%
Cl	0.04	Max. 0.05%
LOI	0.67	Max. 6%

* According to ASTM C618 Class F [13].

Table (5): Physical properties of the used cement kiln dust (by-pass).

Property	Test Results
Specific surface area (cm^2/gm)	2980
Bulk density (kg/m^3)	1150
Specific gravity	2.81
color	Light gray
Physical Form	Powder

Table (6): XRF Analysis of used cement kiln dust (by-pass).

Oxide	Content %
SiO_2	16.65
Al_2O_3	4.48
Fe_2O_3	2.08
CaO	41.87
MgO	2.33
K_2O	5.20
SO_3	2.15
Na_2O	4.16
Cl	3.36
LOI	11.82

III. MIXING, MOLDING, AND CURING

Table (7), represents the mix proportions of the tested mixes by weight quantities for geopolymer bricks. The control mix design for the manufactured product was designed and tested at age 28 days (as specified by the Egyptian Standard Specification). For 28 days after casting, all specimens were sprayed twice daily. Geopolymer mixture proportions, different molarity and exposure temperatures are given in Table 7. Solid cement bricks 26x 12x 6 cm were manufactured by conventional equipment. The manufacturing process involves compaction of the mixed constituent materials in a mold followed immediately by extrusion of the pressed product so that the mold can be used repeatedly. Since the finished product is required to be self-supporting and able to withstand any movement and vibration from the moment they are extruded, very much drier, and leaner mixes are used than in the normal concrete work. The demoulding ability is an essential criterion for manufacturing solid cement bricks. The molarity contents of the solid cement bricks were adjusted to maintain an almost zero slump. Crushed stone was not washed prior to mixing. A series of tests were carried out after 28 days of curing according to ASTM C 67-03a [14] to determine compressive strength, oven dry-weight and absorption values of the brick samples. Also, the mass loss was performed before and after the specimens exposed to high temperatures. Three specimens were tested for each test. After curing for 28 days, the samples which were exposed to elevated temperatures were heated in an electric oven up to 300, and 600°C. The temperature was maintained at the respective temperature for 2 hours to achieve a thermally steady-state. Then, the furnace door was opened and the samples were allowed to cool naturally to room temperature.

Table (7): Mixture proportions, molarity and cement kiln dust

Mix No.	Molarity	cement (kg)	FA (kg)	Sand (kg)	Dolomite (kg)	cement kiln dust (by-pass) (kg)	water
1	0	250	0	1086.66	1086.66	0	125
2	0	0	0	1086.66	1086.66	250	125
3	M10	0	250	1086.66	1086.66	0	-
4	M10	0	0	1086.66	1086.66	250	-
5	M10	0	125	1029.3	1029.3	125	-
6	M10	0	187.33	1029.3	1029.3	62.6	-
7	M16	0	250	1086.66	1086.66	0	-
8	M16	0	0	1086.66	1086.66	250	-
9	M16	0	125	1029.3	1029.3	125	-
10	M16	0	187.33	1029.3	1029.3	62.6	-

IV. RESULTS AND DISCUSSION

The effects of molarity, fly ash, and cement kiln dust (by-pass) in the activation on geopolymer bricks properties due to exposure to elevated temperatures are herein presented.

Compressive Strength: The effects of the cement kiln dust (by-pass) in the activation of geopolymer bricks specimens and elevated temperatures on average product compressive strength are presented in Figure 1. The limits of both load-bearing and non-load bearing units are shown in Table 8. Ordinary Portland cement class 42.5N and cement kiln dust (by-pass was used in mixes 1 and 2 respectively. The results show that mix 1 satisfied the limit of average product compressive strength concerning load-bearing units up till 300°C tested temperature. However, at 600°C, the limit of non-load bearing units was met. Mix 2, on the other hand, satisfied the requirement of load –bearing units at room temperature only. The loss in compressive strength using cement kiln dust (by-pass) can be related to the chemical effects. Moreover, the percentage of free calcium hydroxide during the reaction of cement and cement kiln dust (by-pass) increase similarly.

In other words, both could be used as load-bearing units at room temperature. It should be noted that there are two phenomena that govern the behavior of bricks when exposed to various temperatures: firstly, the increase in the rate of cement hydration and secondly, the thermal incompatibility between the cement paste and the aggregates, the dehydration of the matrix and the thermal expansion of the aggregates give rise to internal stresses and beginning at 300°C, micro-cracks begin to pierce through the material [19, 20]. In some cases, the first factor becomes the governing factor, while in other cases; second factor becomes the overriding factor.

Mixes 3, 4, 7 and 8 produced geopolymer bricks specimens of different base and molarity. The mixes provided average compressive strength satisfied that the requirement for load-bearing units at room temperature except mix 4 which contained cement kiln dust (by-pass) base. According to these results, the compressive strength of geopolymer mixes containing sodium silicate solution of molarity 16 is higher than that of mixes of molarity 10. At room temperature only, using cement kiln dust (by-pass) as geopolymer base with high molarity satisfy the load-bearing requirements. The results of the remaining mixes containing cement kiln dust (by-pass) as partial replacement by 25% and 50% of fly ash by weight in geopolymer mixes of different molarity, showed using cement kiln dust (by-pass) with high molarity can satisfy the load-bearing requirements at room temperature.

Table (8): Strength and Absorption Requirements [15-17]

Compressive strength, min, (kg/cm^2) Average net area Average of 3 Units		Water absorption, max, (kg/cm^3) Average of 3 Units Weight classification-oven-dry weight of concrete(kg/cm^3)		
		Light weight	Medium weight	Normal weight
Loadbearing units	Non-loadbearing units			
131	41.4	Less than 1680 288	1680 288 (240)	2000 or more 208

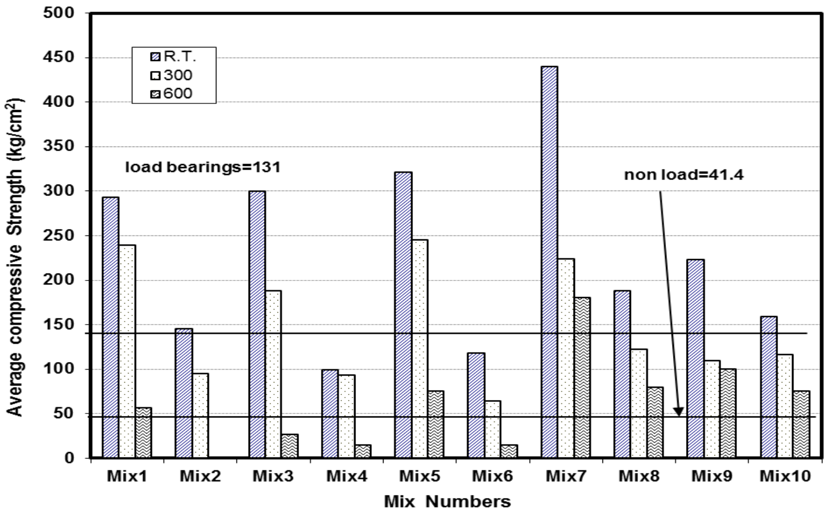

Fig. (1): Effects of geoypolymer base and elevated temperatures on compressive strength

Oven-Dry Weight and Water Absorption Percentage:

There are three classes of solid cement bricks: normal weight, medium weight and light weight according to both ESS 1292-1/2005 [16] and ASTM C90-03 [15]. The two criteria that specify the categorization of weight are water absorption and the Oven-Dry weight. The effects of the geoypolymer base at room temperature on absorption and unit weight are presented in Fig. 2 and 3, respectively. The limits of water absorption and Oven-Dry weight are given in table 8. The criterion regarding normal weight for absorption was satisfied by the ten mixes at the tested temperatures. In other words, all mixes at tested temperatures had values of water absorption less than 208 Kg/m^3. Thus, the Oven-Dry weight of the specimens becomes the decisive factor with regard to the categorization of weight. At different temperatures testeds, all mixes satisfied the criteria of normal weight, while mixes 2 and 7 met the criteria of medium weight at elevated temperatures. From the above results, it may be concluded, that irrespective of the different geoypolymer base, the weight classification generally ranged from medium to normal weight at elevated temperatures.

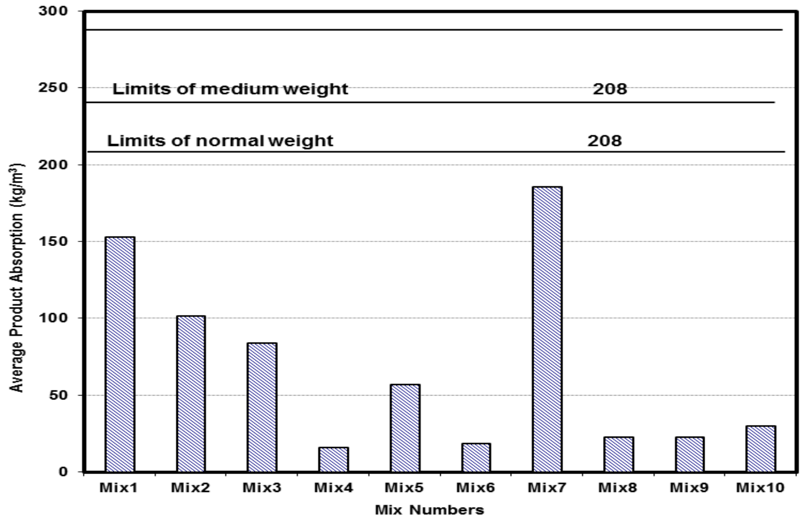

Fig. (2): Effects of geoypolymer base on water absorption

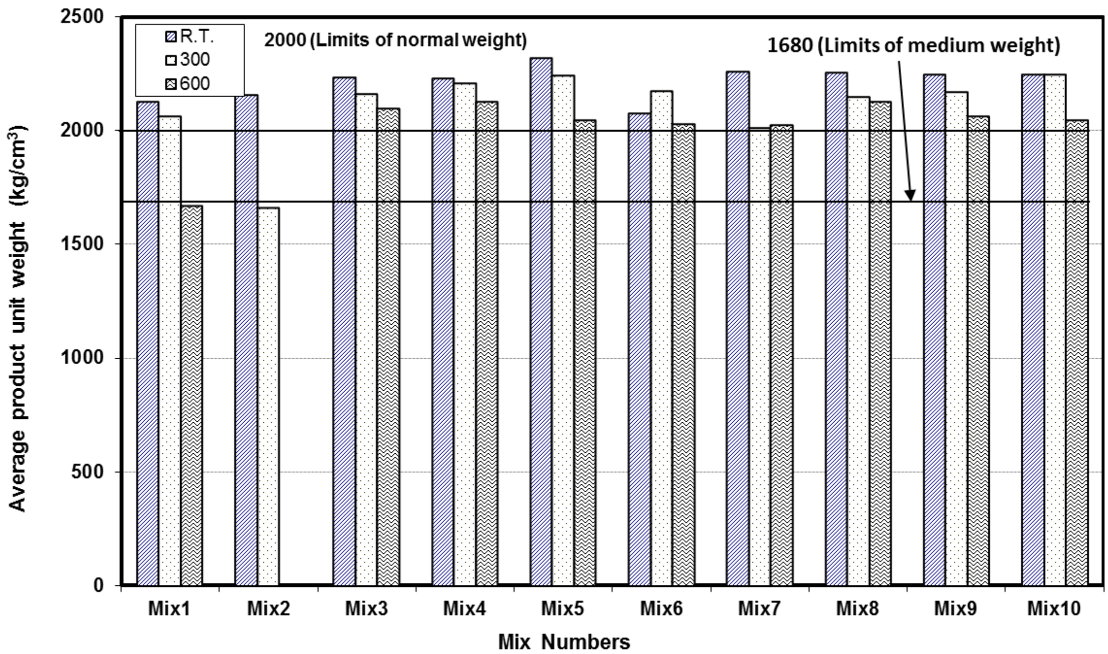

Fig. (3): Effects of geoypolymer base and elevated temperatures on unit weight

Mass Loss: The effects of cement types and elevated temperature on mass loss are shown in Fig. 4. When comparing mixes 1 and 2, at 300°C, mix2 resulted in lower mass. However, there was a pronounced increase in mass loss regarding mix 2 at temperature 600°C. from the figure it can be observed that, using cement kiln dust (by-pass) as base in geopolymer mixes increase the mass loss for this specimens. The highest mass loss was obtained for mix 2 at 300°C of 22.9%. Weight reduction occurs due to the release of bound water from the cement paste. Consequently, air voids are formed and the structural integrity of the specimens deteriorates. Thus, the reduction in weight confirms the loss of mass by the concrete material and the increase in the proportion of air voids [18].

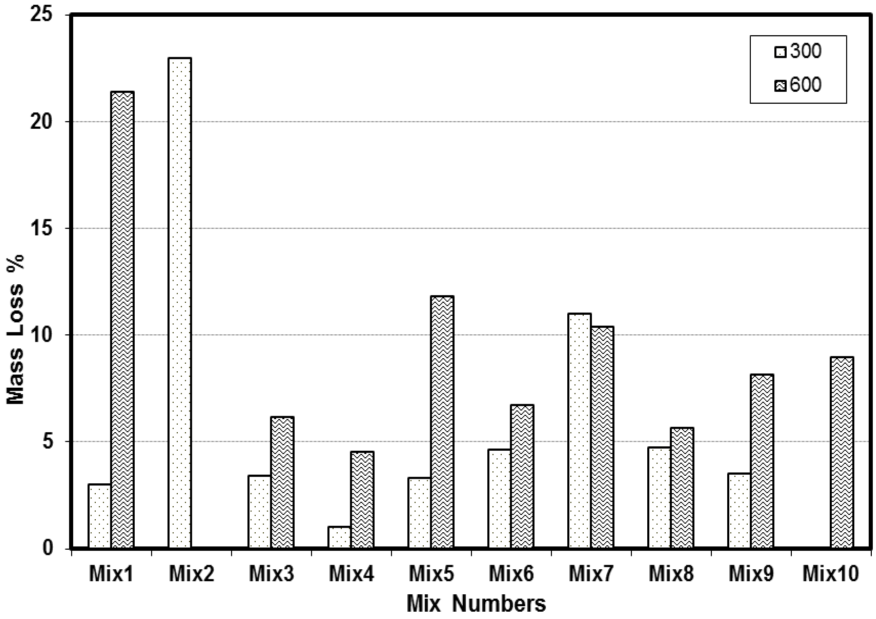

Fig. (4): Effects of geoypolymer base and elevated temperatures on mass loss

V. CONCLUSIONS

Based on the experimental results obtained from this study, the following conclusions can be drawn:

- Concerning using OPC and cement kiln dust (by-pass) can be used for load-bearing units in room temperature only.
- Using cement kiln dust (by-pass) as geopolymer base cannot be used for load-bearing units with lower molarity.
- Using cement kiln dust (by-pass) as partial replacement for geopolymer base can be used for non-load-bearing units with high molarity even when subjected to temperature up to 600°C.
- At room temperature, bricks incorporating cement kiln dust (by-pass) full or partial replacement geyopolymer base satisfied the criteria of normal weight even when subjected to temperature up to 600°C.
- Bricks incorporating cement kiln dust (by-pass) resulted in the highest mass loss.
- The tested cement kiln dust (by-pass) as geopolymer base can be used to manufacture both load-bearing and non-load-bearing units at room temperature with high molarity.

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