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Refractory and Mechanical Properties of Dealuminated Kaoline-Based Geopolymer Concrete

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Abstract: ***This study has been performed to evaluate the performance of the industrial by-product dealuminated kaolin (DK) as geopolymer paste in production a refractory concrete. The paper study the thermal and mechanical properties of concrete mixtures containing crushed refractory brick as combined aggregate and geopolymer paste produced from the blend of 10%, 20% and 30% of DK, ordinary Portland cement (OPC), solution of sodium hydroxide and sodium silicate as alkaline activator. These concrete mixtures were tested for workability, shrinkage at 400,800 and 1200 °C, thermal shock resistance at temperature of 950 °C, Cold crushing strength, tensile strength, and elastic modulus. The results of these mixtures compared with the results of concrete mixtures containing 100% OPC and 100% aluminous cement (AC) .The results show that the thermal and mechanical properties of geopolymer concrete produced by dealuminated kaolin (DK) are enhanced. Also, it is found that mixture contains 20% of DK appears to be the optimal geopolymer concrete mixture.***

Keywords: ***Dealuminated kaolin, Geopolymer, Refractory Concrete, industrial by-product, Thermal Properties, Strength.***

I. INTRODUCTION

Geopolymer concrete is a concrete composite of aggregate and geopolymer paste. This geopolymer paste produced by a polymeric reaction based on a source of silica and alumina like fly ash ,rice husk ash, steel slag or kaolin activated by alkaline solution [1].Geopolymer concrete can be used to produce pre-cast concrete, structural elements, concrete pavements, and concrete used to resist heat and aggressive environments [2,3]. Dealuminated kaolin (DK) is an industrial by-product material formed during production of alum and considers an environmental Pollutant, this paper study utilization of dealuminated kaolin (DK) as a source of silica and alumina to produce refractory geopolymer concrete. In heating equipment, such as water boilers, boiler utilizers, etc., the operating temperature usually does not exceed 600–1000 ºC. Therefore, the lining of these elements is made of refractory concretes containing calcium aluminate cement (40% Al_2O_3).

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One of the possible ways to reduce the cost of the above-mentioned refractory concrete is the replacement of the alumina cement with Portland cement (PC), which is approximately by four times cheaper than the alumina cement. Refractory concretes with PC and dispersive additives have been widely used in various countries from 1950 to 1980. Concretes were made with fireclay, expanded clay, vermiculite, perlite and other fillers.

The main disadvantages of these concretes are the higher decrease of compressive strength after exposed to temperature ranging between 600 and 800 °C, low operating temperature [4], and Probability of exploding during first heating [5]. Moreover, thermal shock resistance of these concretes is very low, it often reaches only 5–12 cycles of heating and cooling in water. The effect of aggregate type and composition of binder on the properties of concrete exposed to temperatures have been widely studied. However, studies about the dealuminated kaolin effects on the behavior of concrete exposed to elevated temperatures still need further researching. The objective of this investigation is to study the production of refractory concrete using geopolymer paste composed of dealuminated and crushed refractory brick aggregates.

II. MATERIAL PROPERTIES

Detailed information about the available materials and their characteristics are given in this section.

- *Aggregate*: As shown in Fig.1 crushed refractory brick that comply with the requirements of ASTM C 33/C33-M [6] was used in all mixtures as a combined aggregate (i.e. coarse and fine). Grading and physical properties of aggregates are shown in Table I respectively.
- *Cement*: Ordinary Portland cement (OPC) CEMI-42.5N that meets the ASTM C150/C150-M requirements [7] was used.
- *Aluminous Cement (AC):*Cement containing 42% alumina supplied by Lafarge was used.
- *Dealuminated kaolin (DK)*: A by-product formed during manufacture of alum in The Egyptian Aluminum Sulphate Company. The chemical composition of ordinary Portland cement, aluminous cement, and dealuminated kaolin shown in Table II.

-*Super plasticizer:* Sikament-163M high range water reducer (HRWR) complies with ASTM C494 type F [8] was used as a super plasticizer additive with percentage of 2% of cement weight.

- *Alkaline Activator:* A combination of sodium silicate solution and sodium hydroxide solution with ratio of (2.5:1) was used as alkaline activator [9].
- *Water:* Potable tap water that meets the ASTM C1602/C1602M-18 requirements [10] has been used.

Fig. 1. Crushed Refractory Brick

Table-I: The grain size distribution of Aggregate

Sieve size (mm)	9.5	4.75	2.36	1.18	0.6	0.3	0.15	0.075
Passing %	100	84.55	47.55	14.75	6.15	3.5	3.2	0

Table-II: Composition of cements and dealuminated kaolin

Components	Percentage by weight %		
	OPC	AC	DK
SiO2	21.36	5	83.00
Al2O3	5.57	42	9.00
Fe2O3	4.35	16	0.50
CaO	62.50	37	0.08
Na2O	0.24	-	3.40
others	5.98	-	4.02

Table-III: Physical Properties of Aggregate

Physical Property	Value
Specific Gravity of oven dry	2.75
Dry rodded weight (kg / m^3)	2048
Absorption by weight %	3

III. MIX PROPORTION

The mix proportions were calculated according to Procedures outlined in the guide for refractory concrete ACI 547R-79 [11], mix proportions of concrete mixtures given in Table IV.

Table-IV: Mix Proportions of Concrete Mixtures kg/m^3

Mix Code	Crushed R.Brick	PC	AC	DK	Water
C1	1857	400	-	-	140
C2	1857	-	400	-	140
D10	1857	360	-	40	140
D20	1857	320	-	80	140
D30	1857	280	-	120	140

IV. EXPERIMENTAL INVESTIGATION &RESULTS

Mixing was carried out in a revolving mixer of pan drum type. Then concrete was cast into three sizes steel moulds immediately after mixing. For cold crushing compressive strength; cylinders of size 300 × 150 mm were formed and cured in clean water until tested in according with ASTM C39-15 [12].To determine the shrinkage percentage, dried specimens of 100x100x100 mm were kept for two hours exposed to temperature of 400, 800 and 1200 ºC in an electric furnace and cooled, and then the shrinkage of samples was measured. Cylindrical specimens of 300 × 150 mm were used for split tensile and elastic modulus after cured in clean water for 28 days in according ASTM C496/C496M-04 [13] and ASTM C469 [14] respectively. Thermal shock resistance of the concrete mixtures was determined for 70×70×70 mm samples according to the provisions of standard GOST 20910-90 [15], with the heating cycles 950 °C for 40 minutes and cooling in water for 5 minutes and in air for10 miniuts,this process was repeated until the samples break or lose 20 % of their mass.

V. RESULT AND DISCUSSION

A. *Workability*

Fig.2 shows the results of the slump values of concrete mixtures. It indicates that use of dealuminated kaolin (DK) as cement replacement with percentages of 10%, 20%, and 30%, results in lower slump values than that of concrete mixtures containing ordinary Portland cement only or aluminous cement only. Moreover the results show that the minimum observed slump value was 60 mm for mixtures (DK30), Mehta et al. [16] stated that concretes with at least slump value of 50 mm could attain a suitable workability. Also, the results indicate that the slump value of concrete mixture contains 30% DK was lower than slump of (PC) mix by 22% and less than the slump value of (AC) mixture by 19%.This behavior may be because the particles of DK are fine more than OPC and AC particles, consequently DK consume more water in hydration process. Also the enhancement of the reaction between the fine silica present in DK and free lime produces more (C3S) which subsequently hydrates thus contributing to decreased flowability [17].

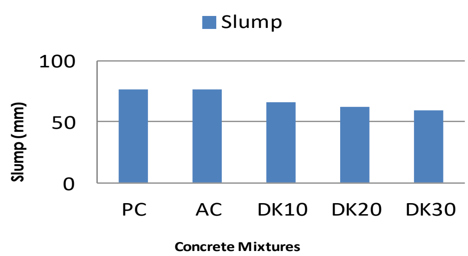

Fig.2. Slump Values of Concrete Mixtures

B. *Shrinkage*

Fig.3 shows the results of concrete mixtures shrinkage percentages after exposed to temperatures of 400,800 and 1200 °C. The results show that the concrete mixture *PC* have the maximum shrinkage (0.8%) that occurs at temperature of 1200 °C .Also, the shrinkages of Concrete mixture contains 100% *OPC* were higher than the shrinkage of concretes containing AC or DK at all temperatures (i.e.400,800 and 1200 °C).

The observed shrinkage values of concrete mixtures containing 10,20 and 30% *DK* were less than 0.49% and as the percentage of *DK* increase the shrinkage percentage decrease. This behavior of *DK* concrete mixtures due to the use of *DK* result in smaller pore size,
smaller the pore size is the greater the difficulty in removing the capillary water consequently, shrinkages of these mixtures were less [18].

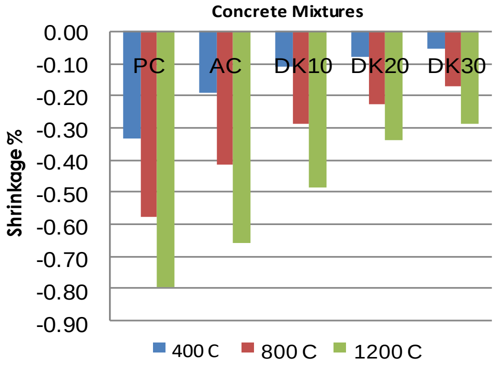

Fig.3. Shrinkage % of Concrete Mixtures

C. *Thermal Shock*

Results showed in Fig.4 illustrate the thermal shock cycles of concrete mixtures. These results indicate that the concrete mixture contains *OPC (PC)* has thermal shock resistance of one cycle while the thermal shock resistance of concrete mixture contains alumina cement increased up to 7 cycle. Also, the results clarify that the thermal shock resistance of concretes containing *DK* are 9 times higher than that of concrete mixtures containing *OPC* at least while the thermal shock resistance of concrete mixture containing *AC* less than that of (DK10) with 28.6% .In general, as the *DK* content increase the thermal shock resistance increase where it reach 15 cycle in case of 30% DK. This behavior is due to the reaction between the fine silica present in *DK* with calcium hydroxide Ca $(OH)_2$ which produced from the cement hydration and considers the main reason of volumetric changes and deterioration of concrete when exposed to elevated temperature [19].

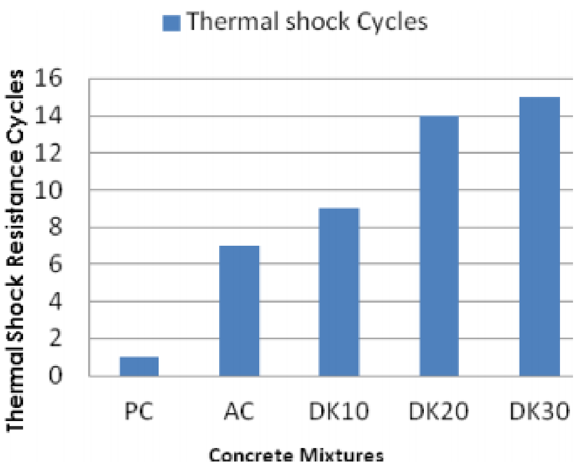

Fig.4. Thermal shock Recycle Number of Concrete Mixtures

D. *Compressive Strength*

The test results in Fig. 5 show the cold crushing strength for concrete mixtures after 7 and 28 days. It was found that use of 10 %, 20%, and 30% of *DK* results in increase in cold crushing strength than that of concrete mixtures containing 100% *OPC* with percentage of 6, 14 and 11% respectively and more than the cold crushing strength of concrete mixture containing 100% *AC* with percentage of 11, 19 and 16% for strength after 7 days and 12, 21 and 15% for strength after 28 days. It is believed that this behavior occur because *DK* react with the calcium hydroxide to produce bonding gel of calcium silicate ($C_3S_2.xH_2O$) and any further amount of *DK* will act as inert filler [17].

The results in Fig.5 also show that the cold crushing strengths of concrete mixture contains *AC* are less than that of concrete mixture contains 100% *OPC* with percentage of 4% and 6% for strength after 7 and 28 days respectively. This decrease may be due to use super plasticizer with alumina cement as stated by Naus [20].

The experimental results shown in Fig.6 clarify the residual compressive strength of concrete mixtures after exposed to temperature of 1200 °C for two hours. These results indicate the concrete mixture containing 100% *OPC* loses 87% of its compressive strength by temperature, while the concrete mixture containing 100% *AC* loses 74% of its strength. Also these results show that concretes containing 10, 20 and 30% of *DK* have residual compressive strength of 28.4, 28.5 and 28.6 % this mean that these mixtures lost 71.6, 71.5 and 71.6 % of their compressive strength respectively.

Topcu et al. [21] stated that the cement matrix loses its binding property due to water evaporation in C–S–H structure. Also, when specimens are heated above 800 °C and then cooled, the unbound CaO rehydrates, this cause concrete deteriorate as well as decreasing its strength.

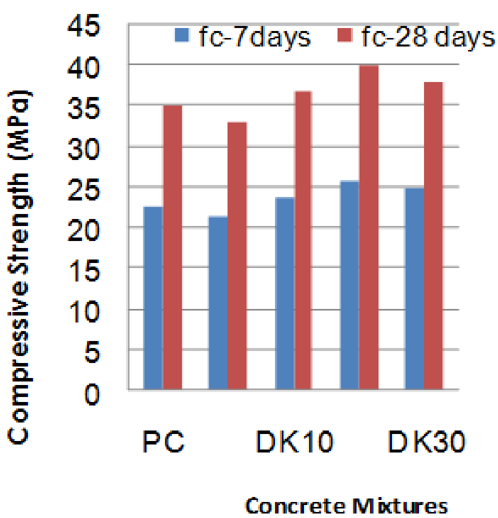

Fig.5. Cold Crushing Strength of Concrete Mixtures

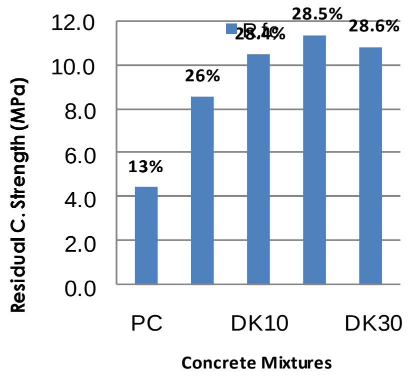

Fig.6. Residual Compressive Strength

E. *Tensile Strength*

The experimental results shown in Fig. 7 indicate that the splitting tensile strength of concrete mixtures after 7and 28 days. It can be seen that use 10 %, 20%, and 30% of *DK* results in increase in tensile strength up to 6, 14, and 11% after 7 days and 5%, 16%, and 4% after 28 days, i.e. using *DK* increase the tensile strength compared to the tensile strengths of concrete mixture containing 100% *OPC* or concrete mixture containing 100% *AC*. Furthermore, concrete containing 20% *DK* gives higher tensile strength than concrete mixtures containing 10% and 30% *DK* with percentages of 8% and 3% after 7days and 11% and 12% after 28 days respectively. Also, Fig.7 illustrate that the tensile strengths of concrete mixture containing aluminous cement *AC* were less than that of concrete mixture contains 100% *OPC* with percentage of 4.25% and 6.28% for tensile strength after 7 and 28 days respectively.

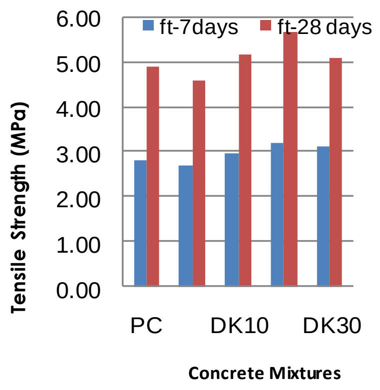

Fig.7. Tensile Strength after 7 and 28 days

F. *Modulus of Elasticity*

Test results illustrate in Fig. 8 show the modulus of elasticity of concrete mixtures after 28 days. These results indicate that use of 100% *AC* results in elastic modulus decrease with percentage of 2.9% compared to elastic modulus of concrete mixture containing 100 % *OPC*.Also, the results indicate that the concrete mixtures containing 10%, 20% and 30% of *DK* have elastic modulus higher than that of concrete mixture contains100% *OPC* with percentages of 1.7%, 6.86% and 0.82% respectively. While the replacing of cement by 10 %, 15%, and 20% SF results in increase in elastic modulus up to 6.6%, Moreover, the maximum value of elastic modulus was 32.7 GPa which obtained by replacing 20% of *OPC* with *DK*.

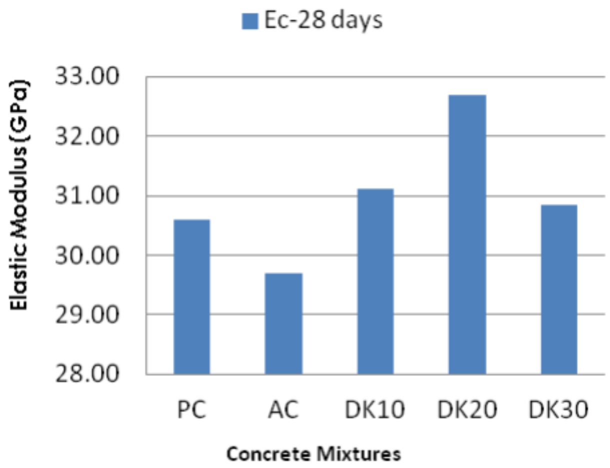

Fig.8. Elastic Modulus of Concrete Mixtures after 28 days

VI. CONCLUSION

Based on the above results obtained by conducting the experimental study, the following conclusions can be summarized:

- The industrial by-product dealuminated kaolin *(DK)* can be used to produce geopolymer concrete applicable in refractory purpose.
- Generally, dealuminated kaolin *DK* has a positive effect on the thermal and mechanical properties of concrete.
- Concrete mixture containing 20% *DK* has the optimal thermal and mechanical properties followed by concrete mixture containing 10% *DK*.
- Concrete mixtures containing *DK* have cold crushing strength, tensile strength, and elastic modulus higher than that of concrete mixtures containing *OPC* or *AC* only.
- The thermal shock resistance increase as the level of *DK* increase, while the shrinkage percentage decreases.
- Concrete mixtures containing dealuminated kaolin *DK* have slump values less than that of concrete mixtures containing 100% *OPC* or 100% *AC*.
- The dealuminated Kaolin (*DK*) is a valuable material to use with combined aggregate of crushed refractory brick in production of refractory concrete.

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