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Behavior of RPC based Alkali Activated Material Compared with Conventional RPC

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Abstract: ***Reactive Powder Concrete (RPC) is a type of high strength concrete that is characterized by its excellent engineering properties. Inclusion of high silica fume contents and high cement demand are the most essential parameters in the development of RPC. Silica fume is a highly cost and unavailable material in many countries. Cement industry is not a sustainable eco-friendly process. High heat of hydration and many shrinkage cracks are also the most shortcomings obtained from cement utilization. Therefore, it's urgently required to replace the utilization of silica fume and cement with partially or totally environmental friendly materials in the production of RPC. Metakaoline (MK) is a low cost, available and high pozzolanic material that can substitute silica fume in concrete. Alkali Activated Materials (AAM) binders are new technology that can totally replace the cement in concrete. The main objective of this study is to evaluate the performance of RPC based cement developed by MK and the performance of RPC based AAM under different curing conditions. Slag and MK are the used AAM in this research which are eco-friendly, sustainable and quite available materials in Egypt. The engineering properties like compressive strength and sorptivity are studied to investigate the behavior of RPC. It was concluded that thermal curing has shown a good impact in the performance of all RPC mixes. MK has shown satisfied results in the behavior of RPC based AAM under thermal curing. Slag shows better mechanical and durability properties that resemble the behavior of the conventional RPC based cement.***

Keywords : Reactive Powder Concrete, Alkali Activated Materials, GGBS, Metakaoline, Silica Fume, Curing Regimes, Compressive strength, Sorptivity.

I. INTRODUCTION

Reactive Powder Concrete (RPC) is considered a promising type of high strength concrete that has been increasingly used in the construction industry[1]–[6]. It attains its good reputation due to the outstanding mechanical and durability properties.

RPC possess an extremely compacted microstructure due to the excellent particle packing of its fine constituents[3]–[5]. Some of the important aspects that have been taken into account in the development of RPC are the inclusion of very fine pozzolanic silica fume (SF) and the high cement demand.

SF is a necessary consistent in RPC as it is a silica base product that forms calcium silicate hydrate when reacts with calcium hydroxide [3], [7], [8]. Unfortunately, SF is a high priced and unavailable material in Egypt. So there is a need to seek for an available and low cost alternative for SF in RPC.

The high cement content in RPC may adversely affect the behavior of concrete through increasing the heat of hydration and the existence of many shrinkage cracks[9]–[11]. Moreover, the manufacturing process of the cement has many bad impacts to the environment. The high dosage emissions of greenhouse gases like CO_2 and nitrous oxide arising from the cement industry are considered the worst pollutant in the surrounding atmosphere[12]–[14] Furthermore, cement production is a non-sustainable and energy consumer process[15], [16]. Nowadays, green and sustainable buildings have become a basic principle in construction industry[14], [15], [17]. Recent researchers investigate the feasibility of utilizing Alkali Activated binders in concrete as an available, sustainable and alternative material for cement. Alkali Activated Materials (AAM) concrete is developed by combing the alumiosilicate silicate source with an alkaline activator solution. Ground Granulated Blast Furnace Slag (GGBFS)[18]–[21], fly ash [18], [20], [22], [23]and Metakaoline (MK)[24], [25] are the most popular aluminosilicate source used in the development of AAM concrete. Nowadays there are many researches that pay attention for the utilization of MK in concrete for its low cost, availability, sustainability and high pozzolanic activity[26]–[29]. In Egypt, MK is widely available and can be obtained from the de-hydroxylation of the kaolinite clay[30]. Therefore, is required to investigate the behavior of RPC when MK is used as an available alternative for SF in conventional RPC based cement and when MK is used as cement replacement in RPC based AAM.

Concrete curing is an important key parameter that governs the behavior of both RPC and AAM concrete. Steam curing provides high temperature treatment together with supplying moisture medium until the full hydration of cement is carried out during curing[31]. Its well known that applying the appropriate temperature levels in steam curing will significantly increase the homogeneity of hydration products, improve the microstructure and enhance the engineering properties of RPC[31], [32].

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Increase in temperature above a certain limit may cause deterioration of concrete[33], [34]. Under ambient temperature treatment, AAM concrete specimens will last for a time in order to reach the desired mechanical strength[35], [36]. While hot air curing leads to early strength gain in AAM concrete[37]–[41].

This is revealed to the activation of the dissolution and geopolymerization process for the formed aluminosilicate gel under heat curing[41], [42]. It is worth mentioning that AAM will show weak polymerization process if cured by conventional water curing. This is due to the absorbed water which will dilute the alkaline solution[42].

In order to assist the wide spread of RPC in Egypt, it is urgently required to develop RPC based AAM and hence seek for an environmental eco-friendly and available materials as MK to achieve an appropriate mix design. However, there is a knowledge gap in the study of the behavior of using MK in RPC based cement and in RPC based AAM.

In order to fill this gap, the current work is carried out where MK is used as a total replacement of the reactive pozzolanic silica fume in the conventional RPC and also as a total replacement of slag in the RPC based AAM. An experimental program is carried out, and hence a comparison between conventional steam cured RPC and hot air cured RPC based AAM is executed to investigate the engineering properties under high temperature curing conditions through the compressive strength and the sorptivity tests.

II. EXPERIMENTAL PROGRAM

A. Materials

Ordinary Portland Cement used was (CEM I) of grade 42.5 N which satisfies the ASTM C150 [43]. The raw MK used has been obtained from the de-hydroxylation of the kaolinite clay. The used ground granulated blast furnace slag (GGBFS) was grounded to the micro-size. Silica fume used in the experimental programe, was in compliance with ASTM C 1240[44]. Its particle size reaches 0.1µm. The chemical and the physical properties of the utilized binders are shown in Table 1 and Table 2 respectively.

Fine aggregate is quartz sand with specific gravity of 2.58, particle size varied from 150 µm to 600 µm, and fineness modulus of 2.25. Quartz powder with specific gravity 2.65, particle size varied from 10µm to 45µm, and fineness modulus of 2.8 is used as a micro filler to enhance the particle packing of the microstructure. Polycarboxylate superplasticizers according to ASTM C494 types G and F [45] was used to improve the workability of the mixtures. For the alkaline solution, sodium hydroxide (NaOH) prepared with molarity reaches 12 Moles and then the sodium silicate (Na2SiO3) was mixed together one hour before the pouring. The ratio of sodium silicate solution to sodium hydroxide solution is (Na2SiO3) /(NaOH) =2.5 by mass. The ratio of alkaline solution to the AAM equals to 0.4 by mass. The chemical composition of NaOH and Na2SiO3 are given in Tables 3 and 4 respectively.

B. Mixing and Curing Conditions

This work deals with 6 different RPC mixes. Mixes were designed to study the effect of totally replacing SF by MK in the conventional RPC based cement mix. The other mixes were designed to study the effect of totally replacing the cement by Alkali Activated Slag (AAS) and Alkali Activated Metakoline (AAMK) in the RPC. In the conventional RPC based cement, all the dry constituents were mixed for about 2 min. Superplastizers and water were then added. The entire matrix was mixed for around 4 minutes until the desired consistency was obtained. In RPC based AAM, the aluminosilicate source, SF, quartz sand and quartz powder were dry mixed together for 2 min. The alkaline solution was prepared 1 hour before mixing with aluminosilicate source and then added to the dry components together with the additional water and superplasticizers. A vibrating table was utilized for compaction after pouring the mix in steel moulds. RPC based cement is cured by both conventional water curing and steam curing, while RPC based AAM is cured by air curing and hot air curing.

The water cured specimen was subjected to 20oC water till testing day, while steaming was at 90oC for 24 hours then continuing the curing in normal water at 20oC till the testing day. Hot air curing is carried out by applying the oven temperature to 180 ^{o}C for 3 hours.

C. Mix Design Proportions

The main objective of this study was to investigate the mechanical and durability properties of conventional RPC and RPC based AAM using the locally available materials in Egypt.

Table 1: The chemical analysis of the Cement, MK, GGBFS and SF:

Element	SiO_2	Fe_2O_3	AL_2O_3	CaO	MgO	N_2O	SO_3	CL	L.O.I.
Cement Content %	20.8	4	4.28	62.6	1.4	0.4	2.54	-	1.9
Metakaoline Content %	53.5	0.86	43.4	0.01	0.17	-	0.02	-	1.9
GGBFS Content %	39.8	1.2	11.2	34.4	7.6	0.2	0.46	0.0125	1.2
Silica Fume Content %	92.26	1.97	0.89	0.49	0.96	0.42	0.33	0.09	2.3

Table 2 : The Physical Properties of the Cement, MK, GGBFS and SF:

Physical property	Cement	Metakoline	GGBFS	Silica fume
Specific Gravity	3.15	2.4	2.9	2.10
Specific Surface area(m^2/g)	0.360	15	0.46	20
Color	Grey	Pale Yellow	Off White	Dark Grey

Table 3: The chemical composition of Sodium Hydroxide (NaOH).

Element	Na_2O	H_2O
Content%	25	75

Table 4: The chemical composition of used Sodium Silicate (S.S)

Element	Na_2O	SiO_3	H_2O
Content%	12.0	31.0	57.0

D. Test Procedure

Compressive strength

According to ASTM C109[46], compressive strength test was performed for the cubic specimens with size 50×50×50 mm to investigate the effect of replacing SF with MK in the conventional RPC based cement and to investigate the behaviour of RPC based AAM.

Sportivity Test

Cylindrical specimen of 100 mm diameter and 50 mm height were prepared to identify the durability property of the designed mixes. The test represents the water absorption and transmission in the specimen through the presented capillary pores. The sorptivity test followed the ASTM C1585–04 [47].

III. RESULTS AND DISCUSSION

Compressive strength

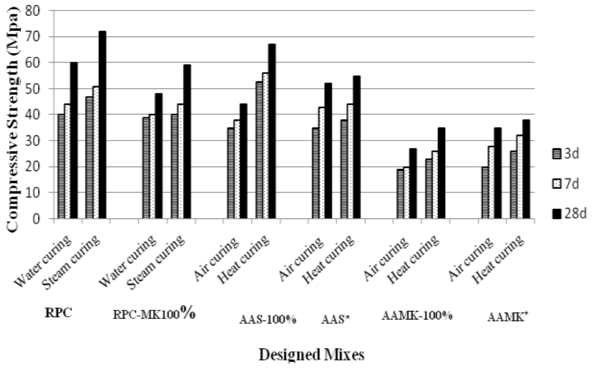

Fig. 1. Compressive strength of RPC based cement and RPC based AAM under different curing conditions

Compressive strength test results for RPC based cement and RPC based AAM under different curing techniques for 3, 7 and 28 days are illustrated in figure 1.

In the shown figure it was observed that steam curing has appeared significant enhancement by 20% more than conventional water curing in the RPC based cement due to the high percentages of pozzolanic SF. The effect of hydrothermal treatment will motivate the continuous hydration development of the unhydrated cementitious particles and increase the reactivity of the pozzolanic materials leading to the refining of the microstructure and the formation of crystalline calcium silicate phases (C-S-H phases) as recorded in previous studies[48]. The same trend can be observed in the RPC-MK100% mixture.

When comparing conventional RPC with RPC-MK100% based cement, it was noticed when replacing SF with MK that there was a reduction at age of 28 days by 20% and 18% in the strength value under water and steam curing respectively. This may be attributed to the presence of large amounts of hydrogarnet (katoite) and α-C2SH in the components of MK. These composites can cause the reduction in strength. This finding matches with many past literatures[7]. Even though MK reduces the strength, its result under steam curing resembles the behavior of conventional RPC based cement under water curing. So in order to achieve better strength results when utilizing MK in RPC based cement, steam curing treatment would take place. So MK provides an appropriate source of pozzolanics in the development of RPC based cement. Although the calcuim aluminim silicate binding gel formed from AAM reactions shows more efficiency performance than the cement hydration gel, RPC based cement exhibits high compressive strength than RPC based AAM. This is attributed to the additional water used to enhance the flow ability and the workability of the fresh mix that leads to weaken the geopolymerization process[21], [49]. Even though superplasticiser is used to achieve the desired workability, there is still an urgent demand to use additional water in concrete mixture specially in hot climate[50]. In the RPC based AAS mix, the heat curing shows 52% better strength results than air curing at age of 28 days. This is due to the heat treatment which accelerates the geopolymerization and dissolution process and contributes in the formation of extra more alumnio silicate gel.

The same trend can be achieved in the rest RPC base AAM specimens. When substituting the slag with MK in the RPC based AAM, it was observed that slag has achieved better strength than MK. This owing to the extremely higher percentage of calcium content in the slag than in the MK. Calcium content plays an important role in the polymerization process through the formation of Ca-Al-Si gel. [20], [21], [51]. In AAS* mix the SF was replaced by slag. This replacement did not appear any improvement in the strength. This reflects the benefit of the tiny SF particles in the particle packing of the microstructure where they act as filler material on which results in a compact and dense microstructure and in turn increase the strength. On the contrary, in the AAMK* the substitution of SF by MK in the RPC based AAMK has shown an increase the strength. Therefore, SF in the RPC based AAMK did not show the required filling effect as observed in RPC based AAS.

Water Sorpotivity

Sorptivity describes the durability of concrete, where the lower the sorptivity the higher the packing and the compaction of the microstructure. Figure 2 shows the water absorption rate of the RPC based cement when substituting SF with MK. It was observed that incorporating MK in RPC mixes causes an increase in the absorption rate more than incorporating SF. Owing to its high pozzolanic reactivity, MK possess calcium hydroxide and so causes the refining of pore size as well as porosity. Steam curing improves the absorption rate more than water curing.

This improvement can be due to the pozzolanic reaction of SF and MK which is thermally been activated under steam treatment forming extra C-S-H gel in the matrix and therefore controls the water movement and filling the micro pores. The continuous hydration in steam curing, decreases the pore diameter and hence porosity of all mixes.

In figure 3, the water absorption rate of RPC based AAS and RPC based AAMK are shown under air and heat curing. It is obvious that all the mixes which are thermally cured show less absorption rate when compared to those cured by air due to gepolymerization process. Figure 4 shows the sorptivity results for RPC based cement and RPC based AAM as expressed in terms of initial water absorption (mm/s1/2). Generally, the figure proved that conventional RPC based cement has a lower sorptivity values than RPC based AAM. The difference between them is mostly due to the presented voids in the matrix, which is revealed to the additional water added for workability and flow ability aspects. Broadly, all test results from sorptivity are agreeable and aligned with the achieved strength results indicating that thermal curing attains lower sorptivity than conventional curing.

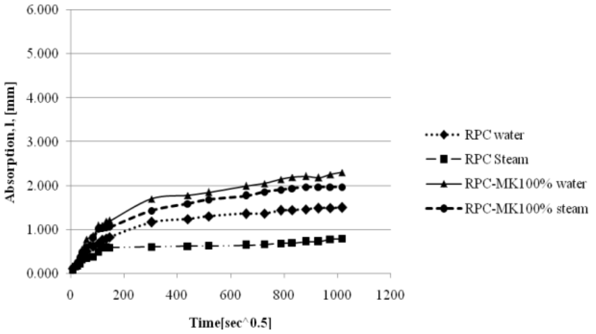

Fig. 2. Water Absorption of RPC based cement under different curing conditions

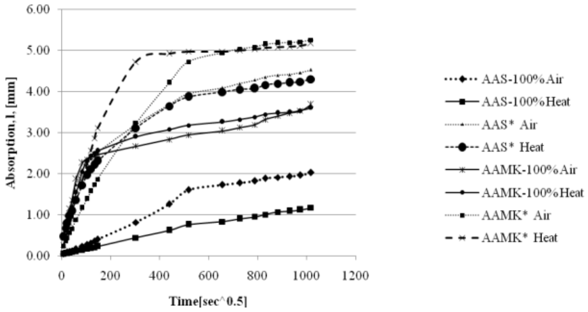

Fig. 3. Water Absorption of RPC based AAM under different curing conditions

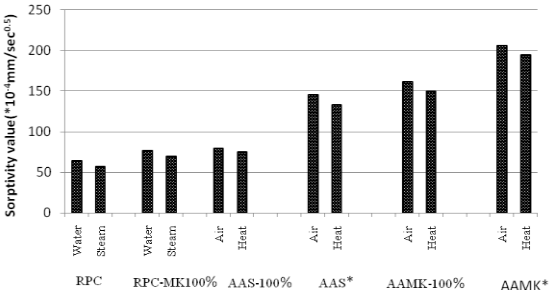

Fig. 4. Sorptivity values of RPC based cement and RPC based AAM under different curing conditions

Table 5 : The mix design proportions in (kg) per 1 m^3:

Mix Name	Cement	GGBFS	MK	Silica Fume	Quartz Sand	Quartz Powder	NaOH solution	Soduim Silicates	Water	Superplasticizers
Control RPC	750	-	-	235	885	220	-	-	200	45
RPC-MK100 %	750	-	235	-	885	220	-	-	200	45
AAS-100%	-	750	-	235	885	220	85.7	214.3	150	45
AAMK-100%	-	-	750	235	885	220	85.7	214.3	150	45
AAS*	-	985	-	-	885	220	85.7	214.3	150	45
AAMK*	-	-	985	-	885	220	85.7	214.3	150	45

IV. CONCLUSION

1- The incorporation of metakaolin in RPC based cement will show satisfied results in strength gain for steam-cured concrete. So the present study reveals the feasibility of using the available high reactive metakaolin for optimizing the production cost of RPC and reducing energy consumption.

2- Steam curing has shown better results more than conventional water curing in the RPC based cement due to the refining of the microstructure and the formation of crystalline calcium silicate. While in RPC based AAM, heat curing shows a significant improvement in the compressive strength test than air curing. This is due to the acceleration of the geopolymerization process under high temperature curing.

3- Thermal curing will convert the paste from porous matrix to a more tightly packed matrix in RPC based cement and RPC base AAM. 4- RPC based cement shows high compressive strength than RPC based AAM due to the additional water used for workability of the fresh matrix that weaken the geopolymerization process.

This additional water will effectively decrease the sorptivity results.

5- RPC based AAS shows better mechanical and durability properties that resemble the behavior of the conventional RPC based cement.

6- Incorporation of silica fume in RPC based AAS has achieved low sorptivity results indicating to a high compacted and dense matrix. However, in RPC based AAMK, the silica fume did not increase the packing density of the matrix.

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