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A Study on the Effect the addition of thermally treated Libyan Natural Pozzolan has on the Mechanical Properties of Ordinary Portland Cement Mortar

Mohamed -A-Aboubakar[1], Eshmaiel Ganjian[1], Homayoon Pouya[1], A. Akashi[2]
[1]Department of Civil, Architecture and Building, Faculty of Engineering & Computing, Coventry University
[2] Department of Civil Engineering, Sebha University Libya

ABSTRACT

The effect of Libyan Natural Pozzolan Kaolin (clay) on the mechanical properties of Portland cement mortar was investigated in this report. The principal aim of this research is to constitute a blended cement mortar with high mechanical properties. The Libyan clay used in this study was natural Pozzolan (kaolin) from south Libya, Sebha place. The Metakaolin (MK) was prepared by thermally activating the kaolin clay for 2 hours at 800 ^{o} C.

The blended cement used in this investigation consists of ordinary Portland cement (OPC), from a company in England, and Libyan Metakaolin. The OPC was partially substituted by LMK, different percentages of the total weight of cement was added to each sample. The percentage replacement of LMK was 0, 10, 15 and 20%.

The blended cement mortar was prepared using cement - natural sand ratio of 1:3 by weight and a water-binder ratio (w/b ratio) of 0.50. The fresh mortar pastes were first cured at 90 % relative humidity for 24 hours and then cured in water for 28 days. It has been reported that by substituting 5-20% MK into the mortar mix it significantly increases the compressive strength of high performance concretes and mortars in early ages and up to 28 days [1-2].
Therefore, the present research investigates the effect of thermally treated (Natural Pozzolan) Libyan kaolin) on the mechanical properties of Portland cement mortar.

The mechanical properties investigated were; the compressive strength, tensile strength and phase composition of mortar. The results showed that after 28 days of curing with the same w/b ratio, the compressive strength and the tensile strength of the cement mortars with MK were higher than the control cement mortar.

Keywords: *Natural pozzolan, kaolin, mechanical properties calcined*

1. INTRODUCTION

It is thought that in order for Natural Pozzolan, such as calcined clays, to develop maximum pozzolanic activity they must be thermally treated and calcined at optimal temperatures of 800-850^{o}C. Even after beneficiation, it is noted that Kaolin obtained from natural sources can still be very impure; therefore, during heating it is essential to convert un reactive Kaolin to reactive MK. The specific firing characteristics of clay are governed by its mineralogical and chemical composition. Metakaolin (MK) is a valuable pozzolanic material; it is known to be an amorphous mixture of alumina and silica. It is a thermally activated alumina-silicate material that is obtained by calcining kaolin clay within a temperature range of 700-850^{o}C [3, 4, 5]. Its reactivity depends primarily on the calcinations conditions.

To obtain optimal reactivity, it is reported to use temperatures of 700-900^{o}C. When kaolin is heated at less than 700^{o}C residual kaolin is obtained, whereas at temperatures over 900^{o}C crystallization of Metakaolin occurs; which inhibits Metakaolin reactivity [6]. MK contains $SiO2$ and $Al2O3$ and is highly reactive. Due to MK being highly reactive and having high pozzolanic properties it has been studied extensively [7-8].A Laboratory furnace was used to burn the kaolin clays to 800^{o}C; which is sufficient enough to transform kaolin into Metakaolin as mentioned previously. The furnace used can burn clay up to 1200^{o}C. The kiln achieved the optimum temperature of 800^{o}C by using a heating rate of 15^{o}C/min. Calcinations took two hours; this is the optimum time, reported by workers, to transform kaolin clay into Metakaolin and obtain a high pozzolanic reactivity [9].

2. EXPERIMENTAL WORK

2.1 Kaolin

The Libyan clay (kaolin) was collected from different parts of Southern Libya, around the Sebha city regions as shown in Table 1 and Figure 1.

Most of the tests have been carried out according to procedures as per BS and ASTM, in a laboratory of concrete technology, in the Department of Civil Engineering, Coventry University.

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Table 1: Locations and Chemical Minerals of used Clays

Sample site	Location	Mineral in clay (%)
A	10 km from north ***Sebha***: 4 m from the earth surface, near a road side of Sebha_ Temenhint.	Kaolinite 95%, quartz 5%

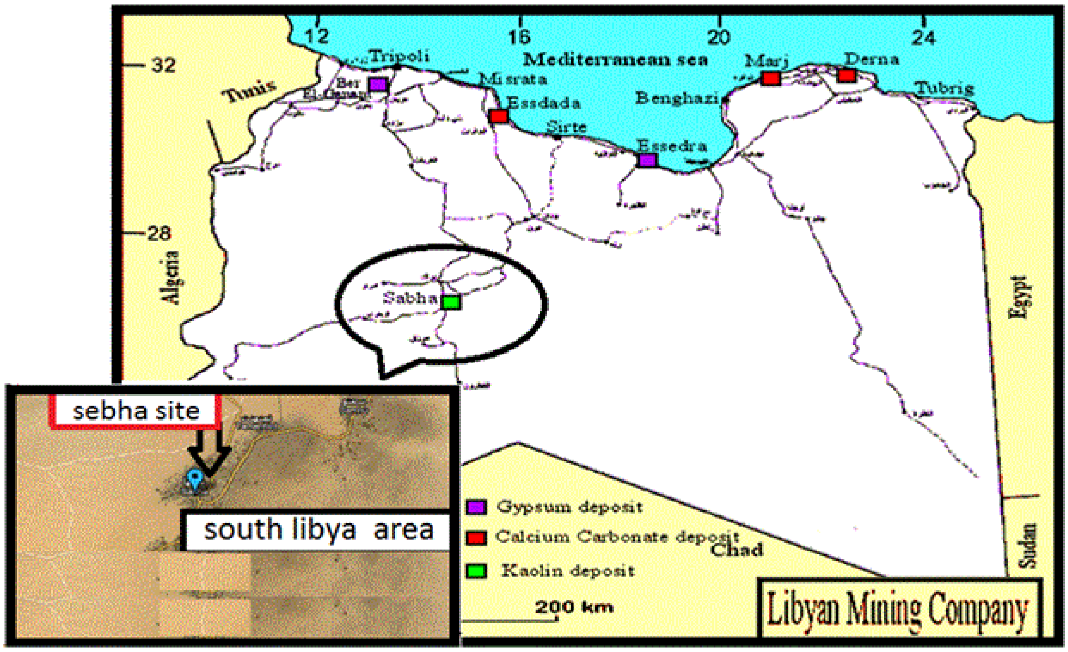

Figure 1: Map of Libya and south Libya showing the locations the kaolin clays were obtained (Sebha city)

2.2 Cement

Portland cement type I was obtained from a manufacturer in England. The type I Portland cement used in this study complies with the specifications as per the ASTM C150 and Libyan standard 340/97. Table 2 shows the chemical composition of type I cement.

Table 2: The Chemical Composition of Type I Cement

Oxide	Determined value (%)	ASTM C150-03 limits type I (%)
SO_3, max (%)	1.66	3.0
MgO, max (%)	2.01	6.0
Loss on ignition, max (%)	1.8	3.0
Insoluble residue, max (%)	0.39	0.75

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2.3 Mix Proportions

The mortar was prepared using a cement-sand ratio of 1:3 and water/binder ratio of 0.5%. The blended cement mortar was prepared using ordinary Portland cement that was partially substituted by Sebha MK, as illustrated in Table 3. Table 3 shows four different proportions of Sebha MK mixes ranging from 0% to 20% MK substitution. The samples were prepared and used in the present study.

Table 3: Mix Proportions of Blended Cement

Sample/mix	Symbol	Calcined kaolin (MK) (%)	Portland cement (%)
OPC	Control	0	100
Sebha sample (kA)	KA10	10	90
	KA15	15	85
	KA20	20	80

2.3.1 Proportion of Specimens

Three briquettes were prepared for each mix. The proportion of the mortar was carried out by using 1 part blended cement and 3 parts standard sand. For the preparation of three briquettes, the quantities of dry materials that can be mixed at one time in the batch of mortar were 700 grams. First, the blended cement was mixed well, and then it was mixed with standard sand. The percentage of water used in the mortar depends on the normal consistency of each blended cement proportion, according to ASTM C 190-85. Afterwards, the mortar was mixed and placed into moulds. KA15 moulds were kept on the base plates in the moist closet for 24 hours, next, the moulds were removed and immersed in saturated lime water storage tanks for 27 days. The operations of mixing, molding, curing and immersing were carried out in accordance with ASTM C190-85.

2.3.2 Mechanical Tests

The mechanical strength of hardened cement is an important property required for structural purposes [10]. Therefore, when the cement is used as a structural material its usefulness depends mainly on its mechanical strength in the set and hardened conditions. In normal conditions, most mortars and concretes that contain materials with pozzolanic characteristics have porosity values equal or higher than OPC concrete [11]. The strength of mortar or concrete depends mainly on the cohesion of the cement paste and on the adhesion to the aggregate itself. However, the last factor is not considered and is eliminated in tests performed on the quality of cement paste by using a standard aggregate [10]. Strength tests are not performed on neat cement pastes due to the difficulties of moulding, and testing leads to big inconsistencies in test results [10].

In order to determine the strength of cement, precise cement-sand mortar proportions are used with specific materials under strictly controlled conditions. The following strength tests were performed: direct tension, direct compression and flexure. Compressive and tensile strengths were determined according to the ASTM method.

2.3.2.1 Determination of Compressive Strength

The compressive strength of the mortar cubes after 3, 7, 28 and 90 days of mixing was determined by ELE (UK) Auto Test 3000 KN compression machine by a rate of loading of 0.9 k N/S, according to ASTM C109-03[12]. The average values of three samples are shown in Figure 3.

2.3.2.2. Determination of tensile strength:

At 28 days of being immersed in water, the briquettes were removed from the storage water for testing. Each briquette was wiped so the surface was in a dry condition. Loose sand grains or incrustations from the surface that will be in contact with the clips of the testing machine were removed before testing began.

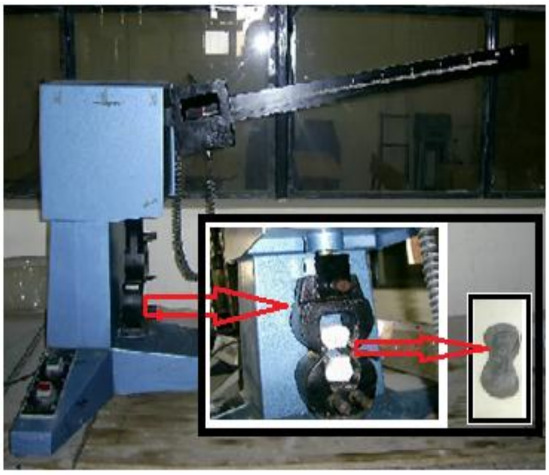

Figure 2: Tensile Test Machine

The briquette was installed in its position in the ELE (UK) 10kN Flexural/Tensile Test Machine as shown in Figure 2. The tensile strength tests were performed on mortar briquettes using a tensile testing machine according to ASTM C-307 [13].

The briquettes were carefully placed in the centre of the clips and a load of2.67 kN/min was applied continuously.

The shape of the mould and apparatus used for the test are shown in Figure 2 above. The tensile strength in kilopascals was determined from the average tensile strength test of three briquettes molded from a single batch of mortar, and the average strength was reported.

3. RESULTS AND DISCUSSION

3.1 Compressive Strength

3.1.1 Sebha Mortar Samples (KA)

The compressive strength variation at the different curing times for MK mortar is plotted and shown in Figures 3 and 4.At 3 and 7 days of curing, kA15 mortar showed slightly reduced compressive strength. However, beyond 7 days of curing, the compressive strength of kA15 mortar increases until 28 days of curing. After 28 days the curve begins to show a decreasing value of compressive strength until it reaches 90 days of curing. KA10 and kA20 mortars showed an increase in compressive strength at all curing times.

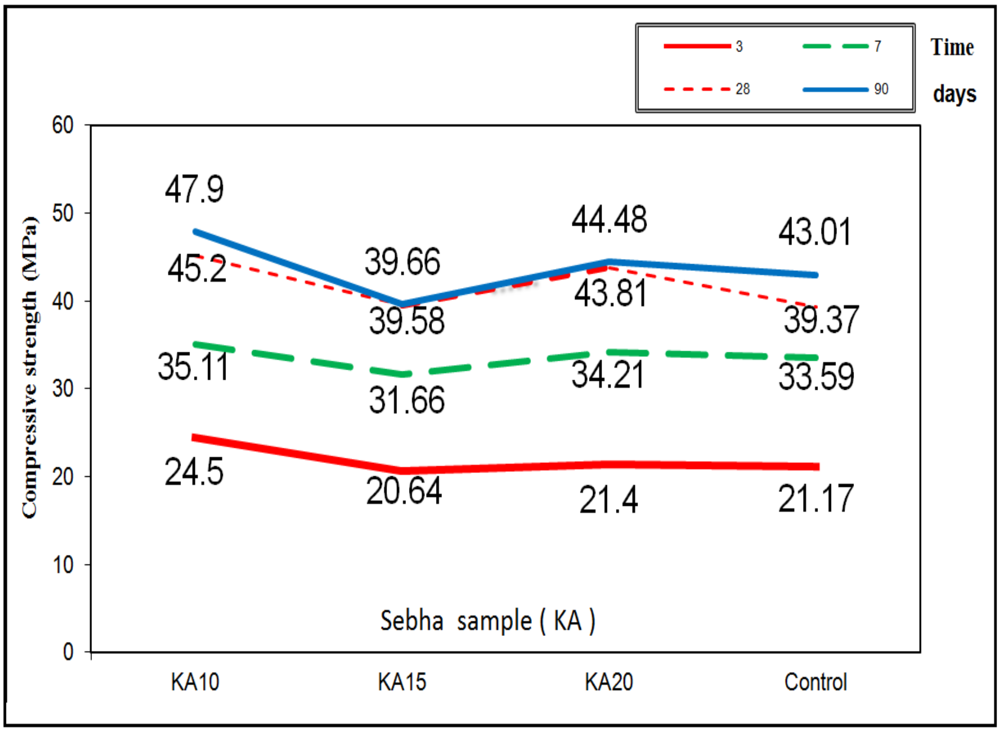

Figure 3: Compressive strength variation of (3, 7, 28, 90) days

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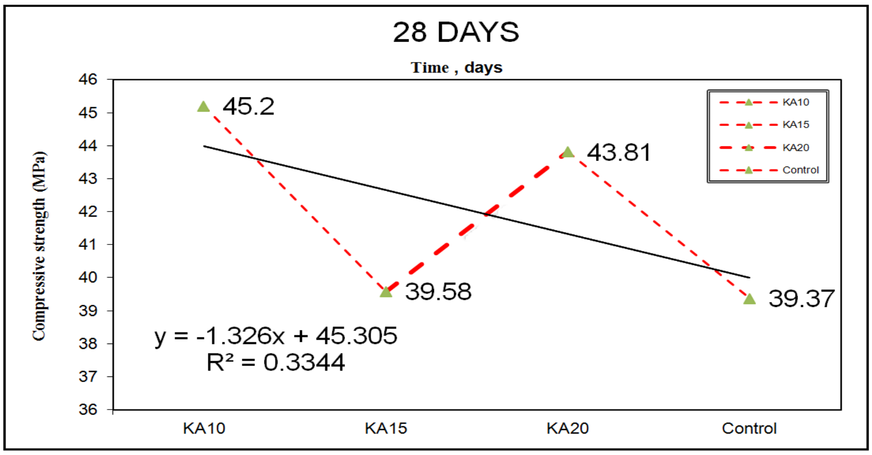

Figure 4: Compressive strength of Sebha (KA) mortar hydrated for 28 days

Figure 4 shows the variation of compressive strength for different MK ratios at 28 days. The compressive strength of the MK mortar is found to increase with decreasing MK ratio, from KA10 (10%) to KA20 (20%). The compressive strength of mortar with15% ratio of MK was 15% higher than that of the control mortar. But the compressive strength ratio from KA10 (10%) had the highest compressive strength compared to the other ratio's and the control.

The following mathematical model is used to explain the relationship between compressive strength and MK ratios:

$$y = -1.326X + 45.305$$

Where:

Y= compressive strength of mortar

X= percentage replacement of MK

The above equation showed a correlation coefficient R2= 0.3344 as shown in Figure 4. As MK belongs to mineral admixtures, it can improve the macro structural and mechanical properties of blended cement.

The improvement in the physical and chemical properties due to the addition of MK can be explained as follows:

Ultrafine particles of MK filled the voids in cement thus making the microstructure of cement paste denser.

The slow increase in compressive strength can be seen with increasing MK loading until KA10%, then as MK increases compressive strength decreases. This may be due to the MK particles agglomerating around the cement grains which leads to cement hydration being delayed.

3.2The Tensile Strength

3.2.1 Sebha Mortar Samples (KA)

The tensile strength of all KA mortar samples showed an increase and in the case of KA10, they reach a maximum. The maximum contribution of KA10 I occurs at 28 days of curing where more than 33% increment has been achieved in strength due to pozzolanic reaction. The optimum percentage of MK that results in a higher strength was found at around 10%.

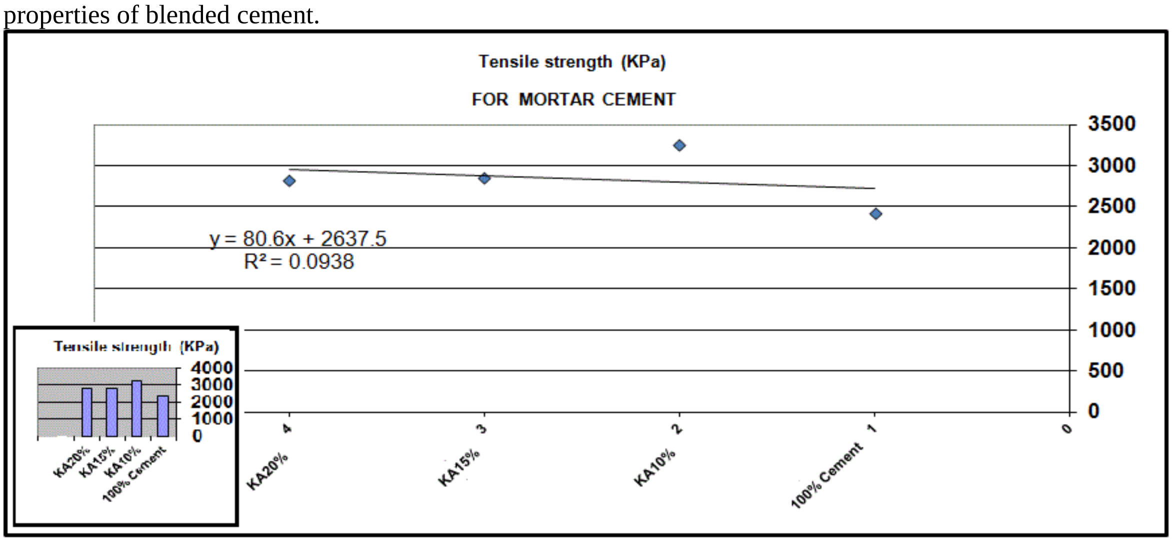

Figure 5: The tensile strength of MK mortar hydrated for 28 days

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Figure 5 shows tensile strength results of blended mortar for different NMK ratios at 28 days. It is observed that the tensile strength of NMK mortar increases as the NMK ratio increases. The pozzolanic reaction between calcium hydroxide and amorphous silica is usually slow during a prolonged period of moist curing, but it reacts rapidly in an alkaline environment; such as pore solution of fresh Portland cement mortar.

The following mathematical model shows the relationship between tensile strength and MK ratios:

$$y = 80.6\,X + 2637.5$$

Where:

y= Indirect tensile strength of mortar
X= Percentage replacement of NMK

The above equation showed a correlation coefficient of R2= 0.0938 as shown in Figure 5. The reaction of alumina-silicate elements in NMK with the lime elements of calcium oxide and hydroxide in cement leads to an increase in bond strength and solid volume. This results in the hardened cement paste having a higher tensile strength.

4. CONCLUSION

The present research work has been carried out to investigate the suitability of natural clay found in Sebha City areas/regions for making concrete and mortar as a cost effective alternative material. In this paper extensive experimental studies were carried out to investigate the mechanical strength of mortar by testing the tensile and compressive strength. The usefulness of the present findings is as follows:

- The natural clays (kaolin clays) collected from Sebha (KA) places can be used as partial replacements of OPC after calcinations and grinding.
- The use of Metakaolin material from Sebha (KA) effectively enhances the mechanical strength of mortar such as tensile and compressive strength.

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