

Thermal Treatment Influence of Metakaolin on the Concrete Properties

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Abstract

The research seeks to study the thermal treatment influence of Metakaolin (M.K.) on concrete properties by different degrees of thermal treatment. The different degrees of thermal treatment are 0, 300, 500, 700, and 900 °C of Kaolin and select the optimum treatment degree to be more activated. In addition, the research included studying the effect of the M.K. on concrete properties. The M.K. added by weight of cement in percentages of 5%, 10%, 15%, and 20%. The results viewing adding the M.K. to the concrete significantly affects concrete properties compared with the control mix. Additionally, the thermal degree of 700 °C and 5% M.K. content progressed the compressive and splitting tensile strength. At the same time, the highest density was recorded at thermal degree 700 °C and 15% M.K. content. Also, the water absorption was reduced at thermal degree 700 °C and 20% M.K. content.

Keywords: Metakaolin; Pozzolanic Reaction; Thermal Treatment; Compressive Strength; Splitting Tensile Strength; Water Absorption.

1. INTRODUCTION

The demand and need for high-performance concrete increased greatly in the past thirty years. Supplementary cementitious materials (SCM) such as fly ash, silica fume, metakaolin and furnace slag have been used as cement substitute materials because they can significantly improve the strength of concrete. [1,2]. Therefore, high-performance concrete can be produced with a lower w/b ratio by incorporating these auxiliary materials. Among these options adding fly ash has proven to be the most economical, although adding fly ash may slow the hardening of concrete. However, when high strength is required, it is more useful to use silica powder [3,4]. When designed with a very low water/binder ratio, the presence of silica fume explains the mechanical properties of high-strength concrete. Silica fume provides good particle accumulation, and due to its strong pozzolanic properties, it also increases the resistance of concrete to aggressive environments [5]. Although initially considered industrial waste, silica powder has now become an excellent product, and the construction industry constantly demands it.

Metakaolin (M.K.) is a pozzolanic material produced by calcination that can replace silica powder. M.K. is a product that has been treated with kaolin minerals [6,7]. Therefore, the use of metakaolin proved economical compared with silica fume. In the past, researchers showed great interest in M.K. because of its characteristics of both volcanic ash and micro fillers [8]. It has also been successfully used to develop the strength of concrete through mathematical modelling [9].

(Ramezaniapour and Jovein) [10] studied the effect of M.K. content on the strength and durability of concrete, where the M.K. content was 0%, 10%, 12.5% and 15% by cement mass. The results showed a significantly enhancing compressive strength and improving the durability of concretes by rising M.K. content. (Dinakar et al.) [11] studied the effect of M.K. on the properties and durability of high-strength concrete, where the M.K. content was 5%, 10%, and 15%. The results exhibit 10% M.K. having the best enhancement and effect on the properties of concrete.

This study aims to study the effect of using commercially available locally calcined Kaolin on the development of strength and water absorption of concrete design. In addition, the best substitute in terms of strength and durability can be determined by changing the degree of thermal treatment to prepare the metakaolin and the amount of M.K. as a partial cement substitute.

2. Materials and experimental work

2.1. Materials

Iraqi ordinary Portland cement manufactured by Tasloga (Aljesr) cement factory was used according to Iraqi Specification No.5/1984. [12]. AL-Ekadir/Iraq sand was used as fine aggregate; the sand falls within zone three according to the requirement of Iraqi Specification No. 45/1984 [13]. Coarse aggregate used gravel was obtained from the AL-Nebai region in Iraq and graded according to Iraqi Specification No. 45/1984 [13]. This research used ordinary tap water to mix and cure the specimens. Kaolin is taken from the Dwekhla region in Iraq and used in this research. Table 1 shows the composition of cement. Tables 2 and 3 show the Grading of Fine Aggregate and coarse aggregate, respectively.

Table 1: Chemical composition of cement

Abbreviation of Oxide	% by weight	Limits of Iraqi Specification
SiO ₂	21.95	-
CaO	63.32	-
MgO	1.48	≤5.0
Fe ₂ O ₃	4.66	-
Al ₂ O ₃	3.76	-
SO ₃	1.78	≤ 2.8
Loss on Ignition	0.83	≤ 4.0
Insoluble residue	0.77	≤1.5
Lime saturation factor	0.96	0.66-1.02

Table 2: Grading of sand

Sieve Size (mm)	% Passing	% Passing Limits of Iraqi Specification
4.75	95	90-100
2.36	90	85-100
1.18	85	75-100
0.60	70	60-79
0.30	25	12-40
0.15	5	0-10

Table 3: Grading of coarse aggregate

Sieve size (mm)	Selected % passing	% Passing Limits of Iraqi Specification
12.5	95	90-100
9.5	70	40-80
4.75	15	0-20
2.36	5	0-10

2.2 Experimental work

2.2.1 Preparation of Metakaolin (M.K.)

The powder of Kaolin has been burned in a range of temperatures at 0, 300, 500, 700, and 900 °C were observed during the heat treatment, and there is a certain change in kaolin colour. Where at 300°C to 700°C, the colour became light orange. While at 900°C, it is white to be nailed. This is due to changes in metaphase during the burning of Kaolin and the amount of water lost in each temperature stage. Figure 1 shows the SEM of M.K.

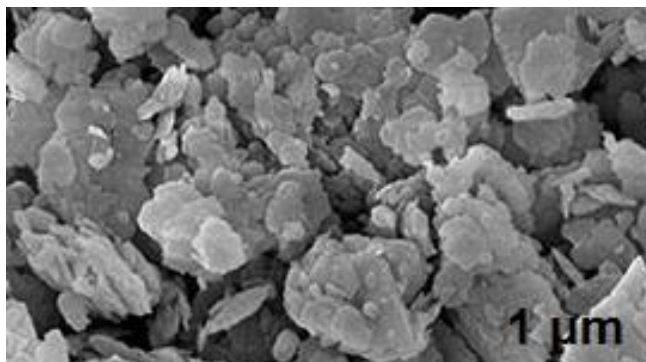


Figure 1: SEM of MK

2.2.2 Preparation of concrete specimen

The concrete mixture ratio was 1:2:4 by weight. The water/cement ratio was 0.4. The M.K. content was 5%, 10%, 15%, and 20% for each temperature step (0, 300, 500, 700, and 900 °C) as a replacement for the cement weight. After mixing, the mixture was placed in a cylinder mould according to ASTM C39 [14] and ASTM C496 [15] for compressive strength and splitting tensile strength tests, respectively. Immersed the samples in water for 28 days to complete the hydration according to ASTM C192 [16]. After that, the samples were ready to test.

3. Results and discussion

The density of the mixes increased gradually by increasing the content of M.K. from 5% to 15% and then decreased by 20%. Besides, mixes of 300° C give the least density when compared with other mixes in that the lattice structure is still held water in the crystal structure, and the dehydration process does not begin. Therefore there is no interaction between Pozzolan between M.K. and cement because it was not active in the reaction. For samples containing (MK500°C, MK700°C, and MK900°C), the density increased due to the reaction of (M.K.) with cement, which led to densification. [17]. M.K. is a Pozzolan material that behaves to agglomerate and may lead to changes in the properties of concretes [18]. However, the M.K. concrete sample shows an aggregate matrix interface much denser than the control concrete sample and other samples with 15% M.K. at 700 C. The interfacial zone between the matrix and aggregate is connected by crystals (Portlandite) vertical to the surface of aggregates

[19, 20]. The reaction between M.K. and C.H. provides a dense and impenetrable pore. This can be achieved through particle accumulation micro filling and the chemical reaction of M.K. with calcium hydroxide released from cement hydrates, the hydration of C3S to form additional strong calcium silicate hydrates that provide higher strength cement set Glue CSH. The CSH produces other cementitious compounds such as hydrogarnet or hydrogrossular phase. The tensile strength increase is almost similar to the trend of compressive strength; Metakaolin particles increase the accumulation of solid materials by filling the space between cement particles, thereby increasing the bonding strength and resulting in a significant increase in the tensile and compressive strength.

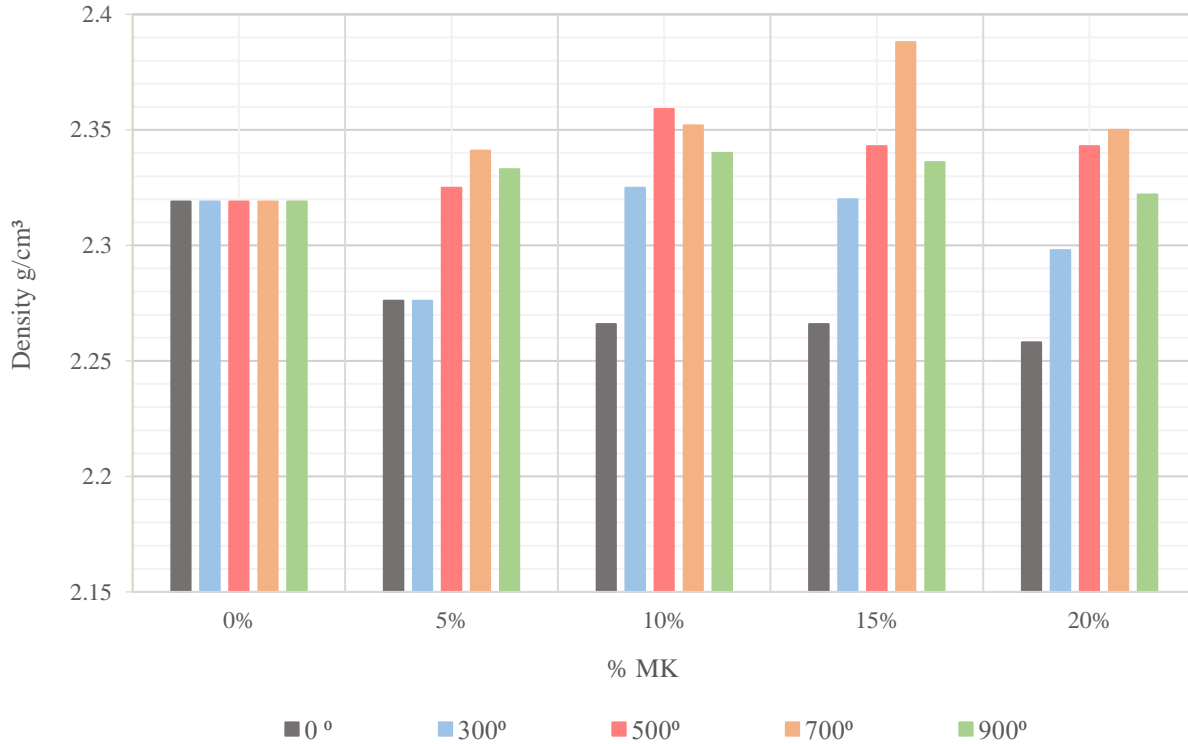


Figure 2. Effect of M.K. on density

The water absorption decrease by increasing the M.K. additives. This is due to the M.K. acting as a filling material to fill the concrete body's pores, thus decreasing the amount of water absorption. Figure 3. [21]

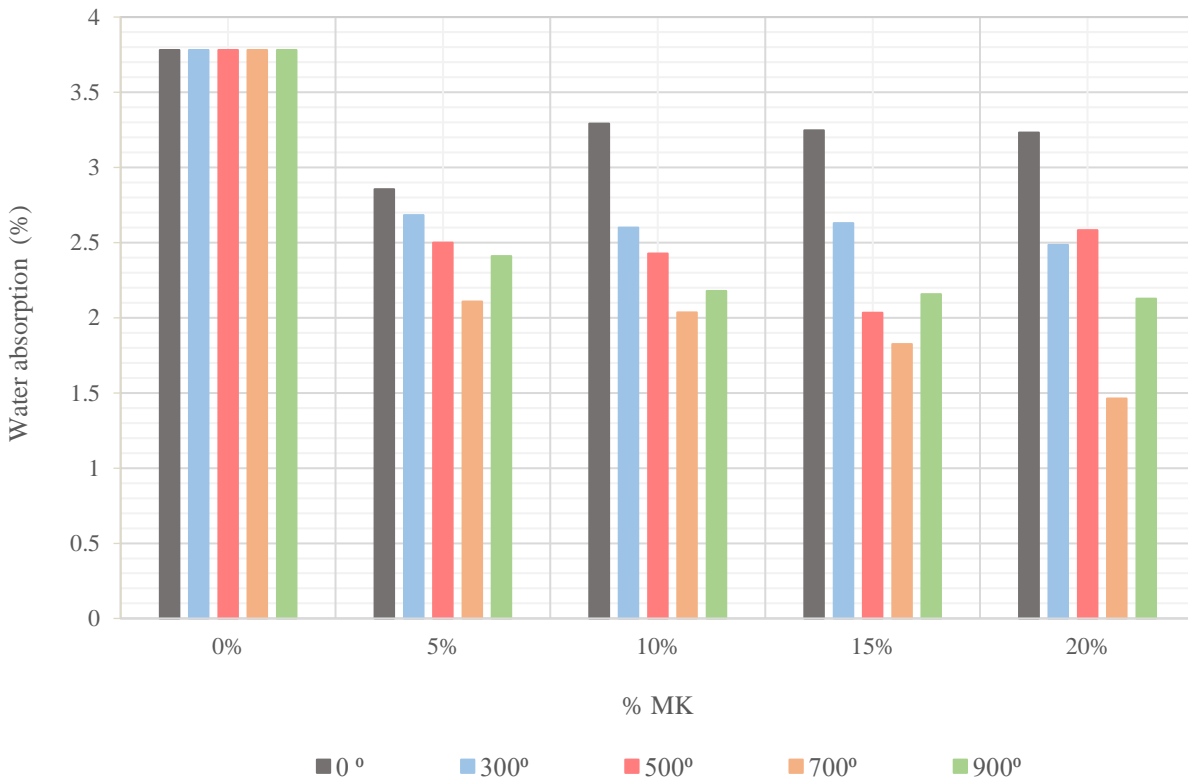


Figure 3. Effect of M.K. on water absorption

Figure 4 shows the increasing compressive strength of the concrete; the highest increase was in the mix containing M.K. 700° C and at a ratio of 5 % compared with the control and other mixes. As the number of additions is 5%, 10%, 15%, and 20%, noted that the significant percentage is 5% M.K. content, for all samples in general, because through these ratios of M.K. enough to appear the pozzolan interaction in the concrete mix. Thus, at a 20% decrease in strength, the reason for this is a large amount of M.K. excess that leads to weakness in the concrete. Figure 5. exhibits the splitting tensile strength of concrete. It noted that by increasing the ratio of M.K., the splitting tensile strength increased, with the highest value recorded at 700° C and 5% M.K. content.

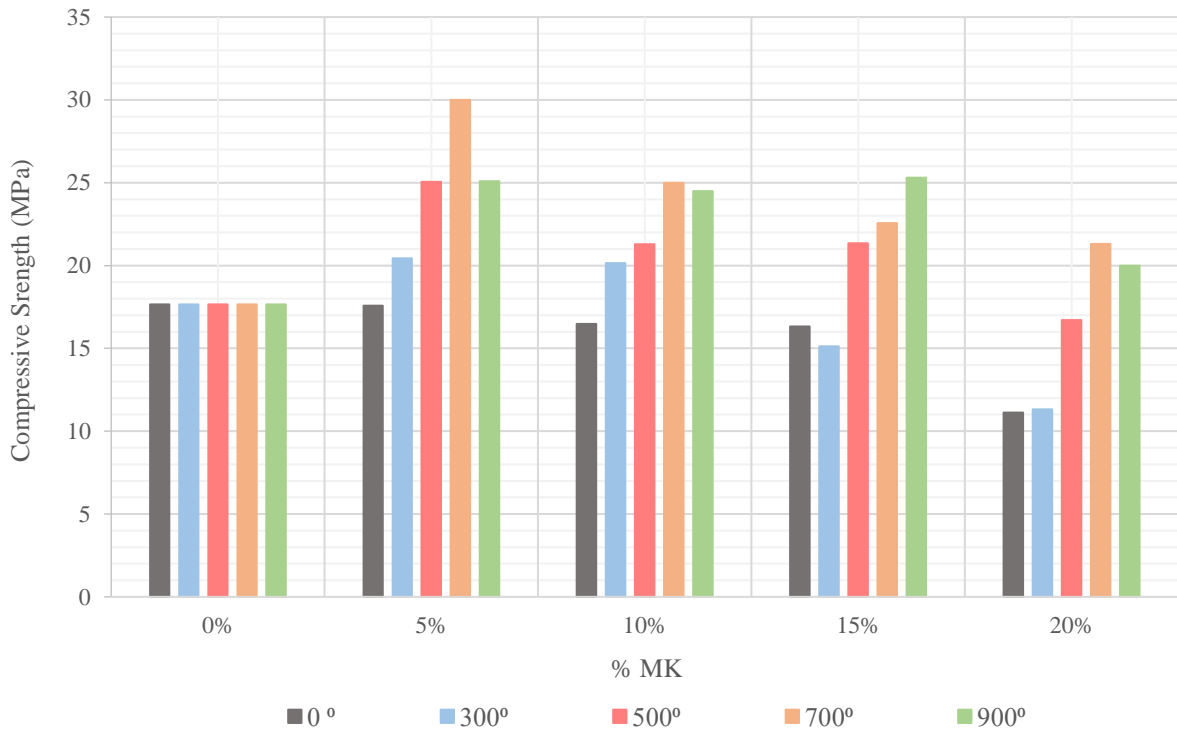


Figure 4. Effect of M.K. on compressive strength

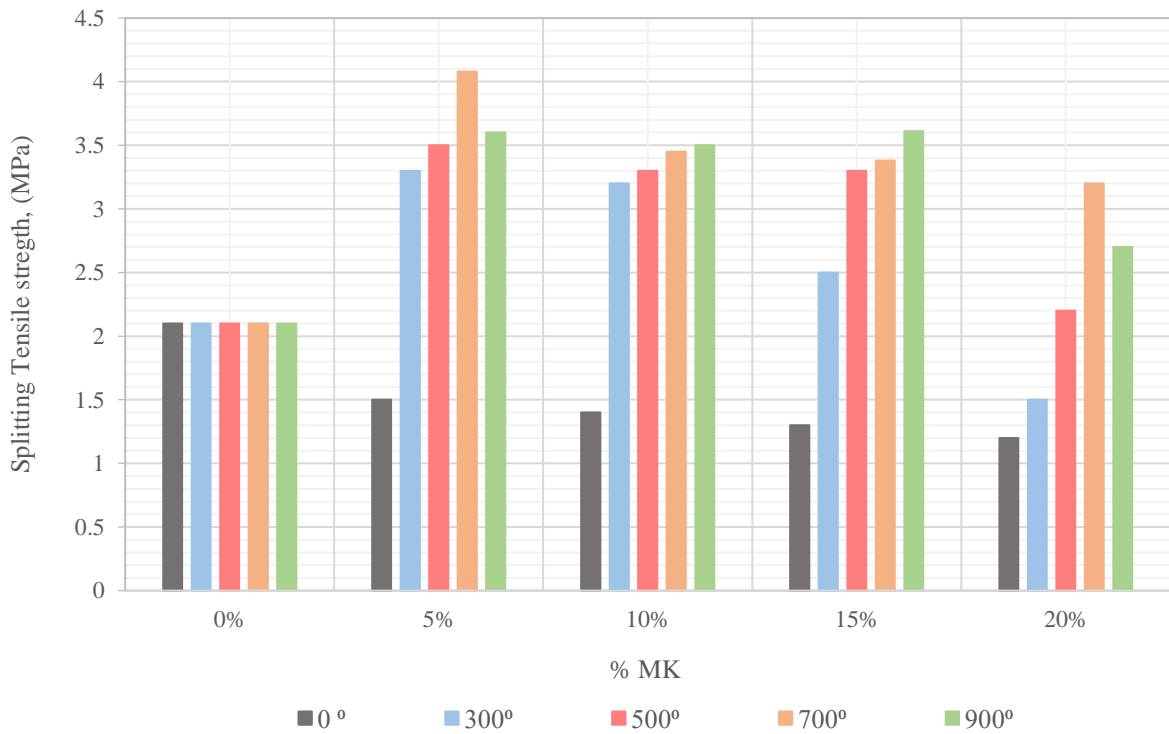


Figure 5. Effect of M.K. on tensile strength

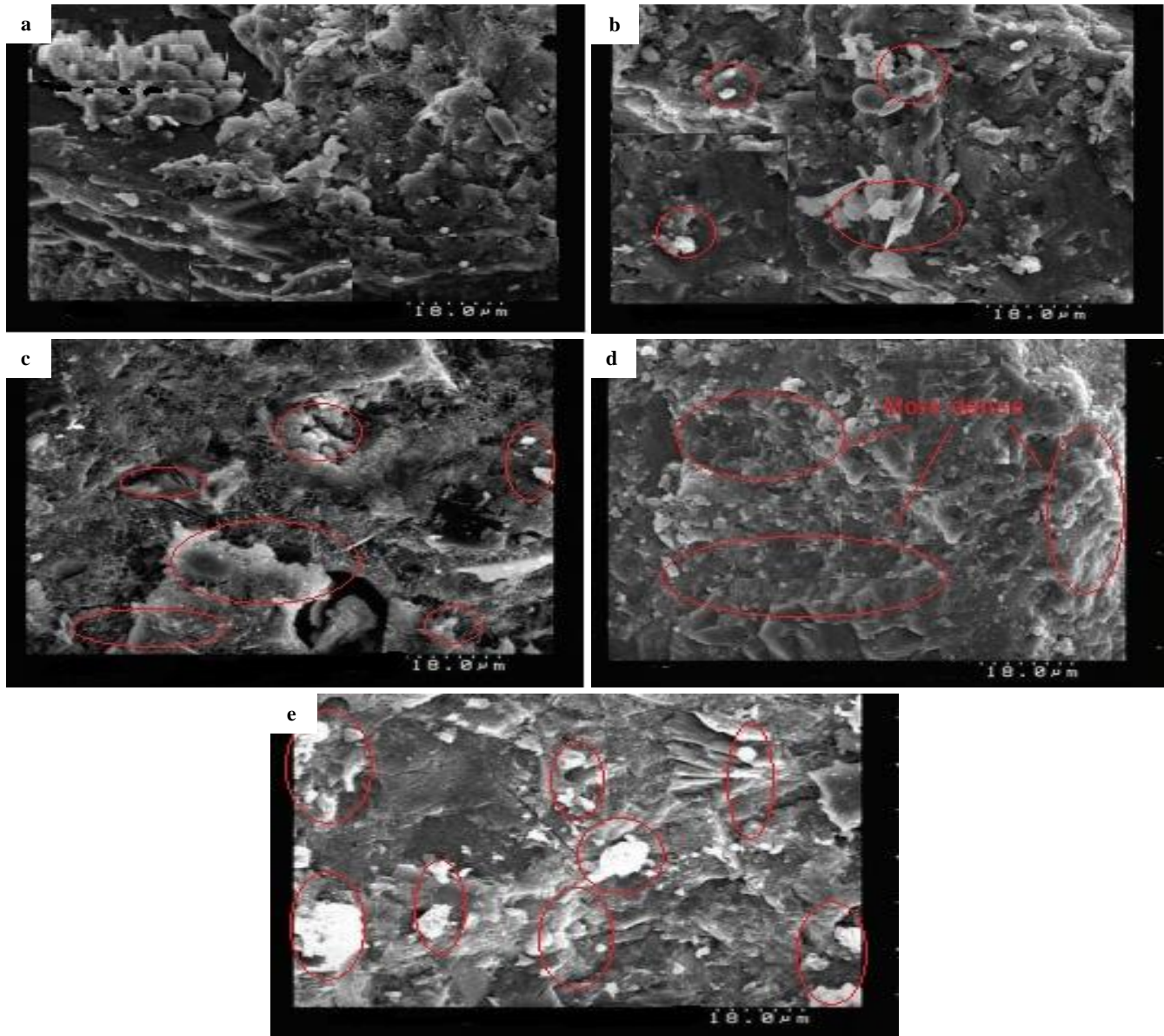


Figure 6. SEM of samples contain, a: 0 % of MK, b: 5 % of MK, c: 10 % of MK, d: 15 % of MK, e: 20 % of MK.

To determine the accuracy of concrete (Compressive and Tensile) strength results of each ratio of concrete batch. Used standard deviation represents the deviation of a set different from the mean value of results. The mean value is calculated by adding the data values and dividing by the variable's number. Eq. (3.1) to get the mean value and Eq. (3.2) to get the standard deviation:

$$\mu = \frac{X_1+X_2+X_{..}+X_n}{n} \quad (3.1)$$

$$\sigma = \sqrt{\frac{\sum(x-\mu)^2}{(n-1)}} \quad (3.2)$$

Where: -

σ = Standard Deviation

μ = (Mean value) Average Strength of Concrete

n = Number of Samples

x = load value of concrete in N/mm²

Table 3. Mean value and standard deviation of samples results

	Degrees in thermal treatment	M.K. ratio					Mean value	standard deviation
		0 %	5 %	10 %	15 %	20 %		
Density of concrete	0 °	2.319	2.319	2.319	2.319	2.319	2.319	0
	300 °	2.276	2.276	2.325	2.341	2.333	2.3102	0.0317
	500 °	2.266	2.325	2.359	2.352	2.34	2.3284	0.0371
	700 °	2.266	2.32	2.343	2.388	2.336	2.3306	0.0440
	900 °	2.258	2.298	2.343	2.35	2.322	2.3142	0.0373
Absorption of concrete	0 °	3.78	3.78	3.78	3.78	3.78	3.78	0
	300 °	2.856	2.682	2.5	2.107	2.411	2.5112	0.283
	500 °	3.291	2.6	2.427	2.036	2.179	2.5066	0.489
	700 °	3.246	2.63	2.034	1.826	2.157	2.3786	0.567
	900 °	3.231	2.484	2.582	1.463	2.128	2.3776	0.648
Compressive strength	0 °	17.663	17.663	17.663	17.663	17.663	17.663	0
	300 °	17.587	20.44	25.06	30	25.1	23.6374	4.782
	500 °	16.484	20.156	21.289	25	24.5	21.4858	3.473
	700 °	16.317	15.126	21.349	22.567	25.3	20.1318	4.293
	900 °	11.116	11.328	16.7	21.3	20	16.0888	4.749
Tensile strength	0 °	2.1	2.1	2.1	2.1	2.1	2.1	0
	300 °	1.5	3.3	3.5	4.08	3.6	3.196	0.990
	500 °	1.4	3.2	3.3	3.45	3.5	2.97	0.885
	700 °	1.3	2.5	3.3	3.38	3.61	2.818	0.946
	900 °	1.2	1.5	2.2	3.2	2.7	2.16	0.826

From Table 3. Note that the average mean value of results is homogeneous relative to the sample result; the lower the standard deviation, the closer data points tend to be to the mean (or expected value), μ . If the value exceeds the calculation range, it may be necessary to make the re-production process to ensure quality control.

4. Conclusion

- M.K. powder increases the compressive, splitting tensile strengths while a decrease in water absorption.
- The optimum heat treatment for preparing M.K. at 700 ° C.
- The best replacement of M.K. percentages after 28-day curing to get maximum compressive and tensile strength was 5 % M.K. at 700 ° C.
- M.K. content 20% replacement at 700 ° C gives minimum water absorption.
- The mean value and standard deviation of sample results, which got a homogeneous number, showed good results by adding M.K. to the properties of concrete.
- SEM images show that by increasing the M.K. ratio, the structure is denser than the control sample.

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