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Properties of Self-Compacting Cementitious Composite Materials Containing Cement Kiln Dust Powder

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K E Y W O R D S

Self-compacting mortar,
Cement kiln dust,
Compressive strength,
Direct tensile strength,
Flexural strength.

A B S T R A C T

This paper aims to investigate the influence of utilization micro cement kiln dust as a sustainable materials additive in order to reduce the voids and micro cracks in the cementitious mortar materials which cause a drastic reduction in the load carrying capacity of the element. Its therefore very important to decrease the pores and enhance the mechanical strength of the cementitious composite materials. In this article, the properties of self-compacting mortar containing micro cement dust additive was experimentally assessed. Micro cement dust powder was added to the self-compacting mortar in (1, 2, 3, 4 and 5 %) percentage by weight of cement to be used as cementitious sustainable materials. The experimental results indicated that the modification and enhancement of the workability of fresh mixture and the mechanical strengths of self-compacting mortar were increased as micro cement dust additives increases. Also; the water absorption and total porosity were decreased with increases of micro cement dust powder.

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1. Introduction

Self-compacted concrete (SCC) is considered a promising construction materials technology that's developed and used in huge quantities almost everywhere in the world, it's predominantly depended on the main constitutes behavior as like as mortar, aggregate and aggregate – paste interface. Thus, various studies have been taken to enhance the performance of cement paste and mortar [1,2]. Mortar acts as the basically responsible part of SCC workability characteristic, thus these properties can be estimated by self-compacting mortar (SCM) [3]. SCM as modern technology products; which are utilized to rehabilitate and repair the reinforced concrete structure. Water-cementitious materials ratio and type of chemical admixture should be specified carefully in the designed mixtures to produce fresh mortar without any external compact and at the same time without any segregation and bleeding. In addition to; self-compatibility of mortar may provide largely features upon the classical mortar such as reduction of building time and enhancement filling capacity of highly congested structural members [4]. Pozzolanic materials were added to mortar and paste of cement in order to improve its mechanical and durability properties with densify microstructure. The antecedent studies explained that the silica fume was found to be actually effective to enhancing mortar and cement paste properties by increased rate of cement hydration. Furthermore, strength of the cement pasts and mortar was improved due to the decreasing of $Ca(OH)_2$(CH) crystals quantity and strengthening of aggregate cement paste interfacial zone by filling the minute pores present in it [5,6].

Through the latest decades, further material was used as replacement of cement which has pozzolanic and cementitious characteristics in concrete production. Some of these materials are industrial wastes or by-products such as fly ash, slag and silica fume [7,8]. Several investigation of the possibility of utilized of cement kiln dust (CKD) in concrete structures was clarified; Hassan et al. [9] were investigated the utilization of the CKD as a partial replacement of cement to produce a sustainable concrete, and they are notifying that the CKD could be utilized as a partial replacement of cement in concrete mixture within up to 15% percentage. Moreover, the recommendation of CKD limit was up to 5%, by weight of cement in order to prevent the corrosion of steel reinforcement process to occur due to the increasing of chloride permeability and reduction the electrical resistivity of CKD blended cement concrete. However, Najim et al. [10] demonstrated that the SCC strength can be improved with up to 20% replacement of CKD for most of the civil infrastructure applications. Thus, CKD can be effective to be used as a cement replacement material to produce a sustainable concrete. Bonder et al. [11] clarified that the CKD could be act as an activator in high volume fly ash concrete (HVFA). The initial setting and hardening rate of concrete at early stages were enhanced as compared to conventional concrete. Knowing that 50% of the concrete volume is employed within cement mortar (Lu and Wang) [12], it's significant to focus on its mechanical characteristics rather than on the other constituents in concrete. Najim et al. [13] demonstrated that the replacement of cement with CKD needed additional water to obtain a standard uniformity because of microstructure modification of the cement mortar after combined the CKD. They have notified the increasing of the porosity and reduced the compressive strength because of the reduction in C_3S and C_2S phases in self-compacting concrete (SCC).

The main objective of this studying is to investigate the influence of micro cement kiln dust powders that are used as a sustainable materials additive by weight of cement on the fresh state and hard state properties of self-compacting mortar.

2. Experimental Part

I. Materials used

Ordinary Portland cement (OPC) Type I conforms to ASTM C150 [14] was used, the physical properties and chemical components of Portland cement and micro cement kiln dust (CKD) powders are given in Tables 1 and 2 respectively. Particle size and shape of micro cement dust powder was represented in Figure 1.

Micro silica powders were used as pozzolanic admixture. It conforms to the requirement of ASTM C-1240 [15], where the specific gravity equal to 2300kg/m^3, SiO_2 more than 85%, SO_3 less than 2%, finesses larger than 15000 m^2/kg, and the strength activity index is 147%. Natural river sand was used as fine aggregate with a maximum size of 4.75mm. Specific gravity, fineness modulus, sulfate content, clays and fine material, and absorption capacity were 2.65, 2.61, 0.086 %, 2.9%, and 1.75%, respectively. The grading and the characteristics of sand conform to the ASTM C33 [16]. A polycarboxylic ether, modified high rang-water reducer admixture conforms to ASTM C-494 type F&G [17] was used, with a relative density of 1.07.

II. Mix proportion

The mainly constituents of self-compacting mortars are given in Table 3. In all mixtures, the amount of superplasticizer to binder ratio (S/b) and water to cement ratio (w/c) are 2.5 and 0.35 % respectively was sufficient use such that no segregation no bleeding was reported.

Table 1: Properties of Portland cement used

Physical properties	Results	Limits of ASTM
Specific surface (m^2/kg).	395	
Setting time (Vicat΄s method) -Initial setting (min) -Final setting (min)	 90 210	 ≥ 45 ≤ 375
Compressive strength of Mortar (MPa) 3-days 7-days	 20.3 30.1	 ≥ 12 ≥ 19
Expansion (Autoclave), Max,%	0.05	≤ 0.8
L.O.I. Max,%	2.16	3
L.S.F. %	0.88	
I.R. Max, %	0.36	0.75

Table 2: Chemical components of Portland cement and micro blast furnace slag

Components	OPC [Wt.%]	CKD [wt. %]
CaO	61.11	52.43
SiO_2	20.38	15.02
Al_2O_3	5.82	6.84
Fe_2O_3	3.28	4.9
MgO	4.27	/
MnO	/	0.07
K_2O	/	14.2
SO_3	2.12	1.3

Table 3: Mix proportion of self-compacting mortar with cement kiln dust powder additives

		Cement kg/m^3	Sand kg/m^3	Micro silica kg/m^3	W/P ratio %	S/P ratio %
Mix proportions		450	1200	150	0.35	2.5
Mix ID	Ref. mix	CKD1	CKD2	CKD3	CKD4	CKD5
CKD %	0	1	2	3	4	5

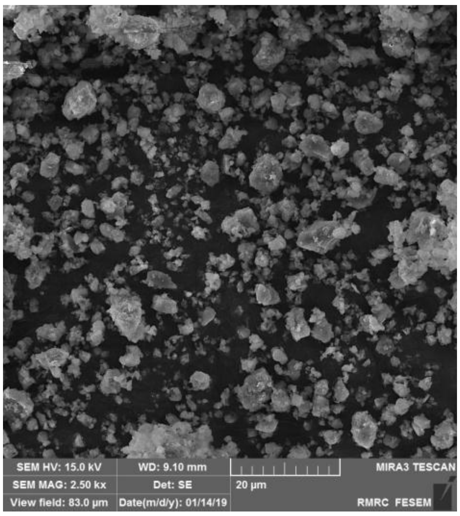

Figure 1: Particle size and shape of micro blast furnace slag

3. Tests methods

I. Fresh mortar tests

1) Mini flow test: Cone mold apparatus was used to determine the slump flow diameter of self-compacting mortar. Cone mold dimensions was 100 mm at the base, 70 mm top diameter and 60 mm is high. The cone was fixed at the centre of steel based sheet and then full of with mortar, and lifted upwards, the mortar spreads without any segregation and bleeding over the table and the subsequent

diameter of the mortar was measured in two perpendicular dimensions and the average was reported as final diameter (mm) of speared mortar. This test according to EFNARC 2005 [18], ASTM C1437 – 03 [19], and ASTM C230M-03 [20].
2) Mini V-funnel test: A suitable water/ binder ratio of the mixture was selected via v- funnel test, the apparatus v-funnel was fill up with a mortar; and then the gate was unlocked and stopwatch at the same time immediately started. The timer was paused when the light appeared immediately; looking down into the funnel from above, the flow time (in Sec.) was then recorded, according to the procedure outlined in EFNARC 2005 [18].

II. Hardened mortar tests

Three average hardened mortar specimens tested was adopted to each property; for the compressive strength according to ASTM C109/C109M-12 [21], flexural strength according to ASTM C348 [22], direct tensile strength according to ASTM C190 – 85 [23], Dry density, total absorption, and total porosity properties according to ASTM C642 – 13 [24].

4. Results and discussion

I. Fresh properties

The slump flow diameter and flowability time of self-compacting mortar results are presented in Figure 2. The results reflecting the viscosity and segregation resistance of mortar mixtures. Slump flow diameters of all mixtures were kept in the range of (260 – 285 mm) and flowability time in the range between (8.5 – 13 Sec.). Thus, fresh mixtures had some workability properties that conformed with the EFNARC [18] recommendation. Furthermore, the flowability of the self-compacting mortar was evaluated by mini v- funnel, which was based on the time of the mortar mixture required to flow through the funnel. The results showed that the increasing of micro cement dust powder percentage leads to increase of flow diameter and reduce the flow time, due to the increasing of fine constituent contents, this gives more filling ability and flowability of mortar.

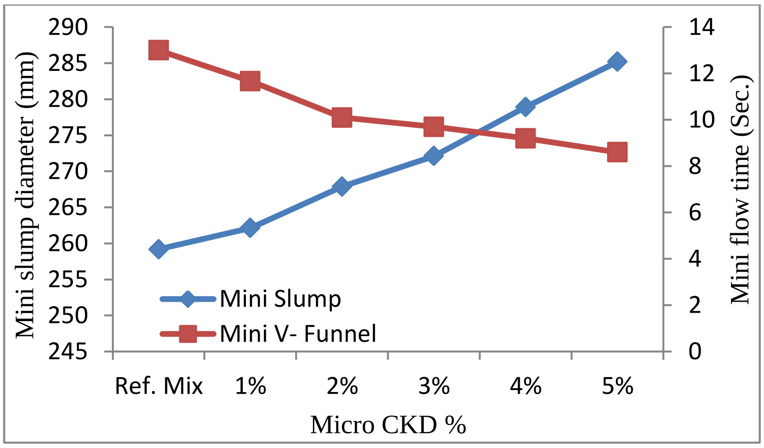

Figure 2: Slump flow diameter and flowability time of self-compacting mortar

II. Physical properties

Physical properties tests result; dry density, water absorption, and total porosity of self-compacting mortar were represented in Figures 3, 4 and 5 respectively. The dry density of hardened mortar increases with the addition of micro CKD powder and modified with curing time as compared with reference mix. Whereas water absorption and total porosity decrease as CKD powder additives increased. Generally, incorporating of CKD into cementitious binders of cement-based composites can decrease the material total porosity and refine the pore size. The pore refinement by CKD is attributed, at macro-scale, to the filling effect of CKD particles in the binder particle packing, and, at micro-scale, to the pozzolanic reaction of active silica-alumina in CKD particles.

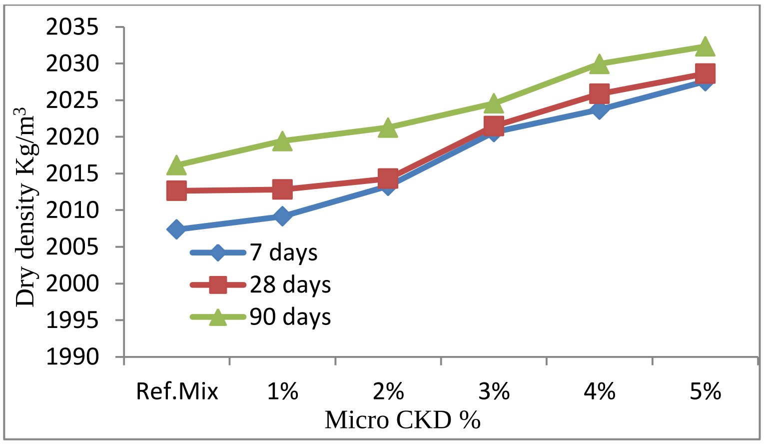

Figure 3: Dry density development of self-compacting mortar with CKD additives

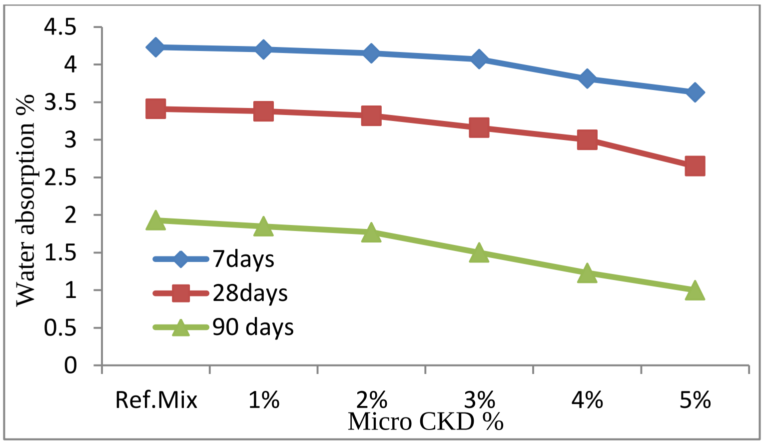

Figure 4: Water absorption development of self-compacting mortar with CKD additives

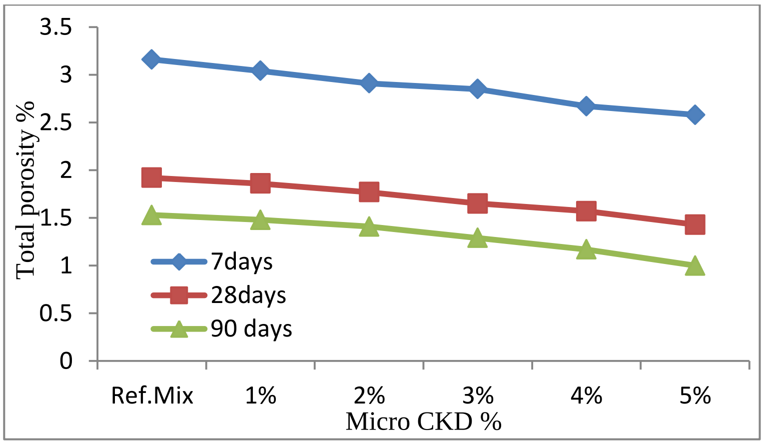

Figure 5: Total porosity development of self-compacting mortar with CKD additives.

III. Mechanical properties

The mechanical strength which include compressive strength, flexural strength and direct tensile strength of self-compacting mortar were enhanced with addition of micro CKD additives. Since the experimental results are graphically represented in Figures 6, 7 and 8 respectively. Showed that the compressive strength develops with the addition of micro CKD powder as compared with reference mortar mix. The mechanical properties improvement of the cement mortar composite due to the utilization of micro CKD powder were observed due to the high chemical reactivity of micro CKD is beneficial for creating additional nucleation places in order to formation more C-S-H phases, which have an effecting on mortar strength. In the case of micro CKD which containing mixture of CaO, SiO_2, Al_2O_3, and other oxides, the pozzolanic effect could be also considered.

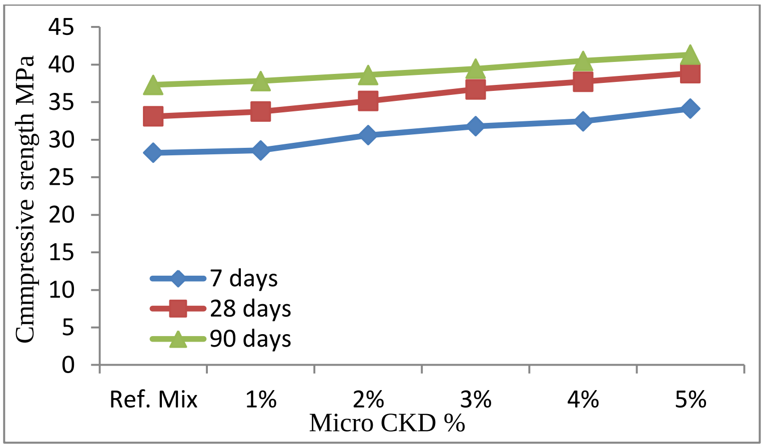

Figure 6: Compressive strength modification of self-compacting mortar with CKD additives

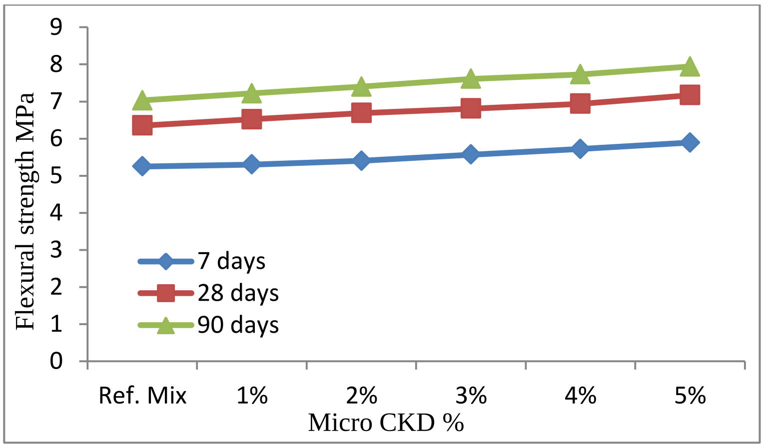

Figure 7: Flexural strength modification of self-compacting mortar with CKD additives

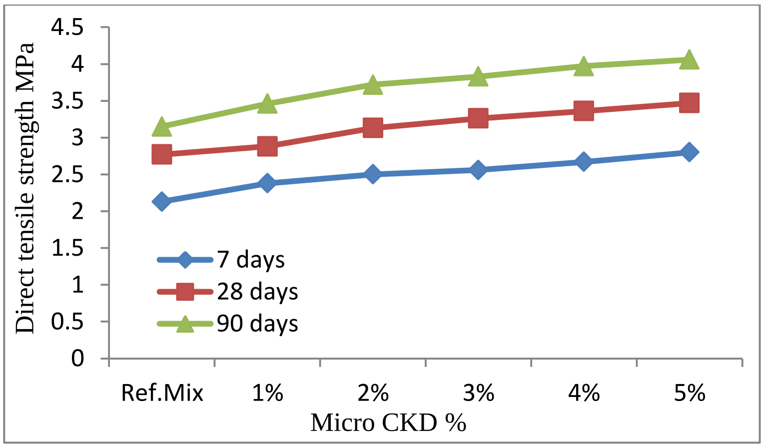

Figure 8: Direct tensile strength modification of self-compacting mortar with CKD additives

5. Conclusions

Depended on the tests results provided of this study, conclusion could be observable that:

1) The effectiveness of micro cement kiln dust powder has a cementitious and pozzolanic activity when used as an additional powder to conventional cement mortar. Consequently, the fineness affects the reactivity properties of the cement kiln dust in the cement mortar. Furthermore, the increasing of the fine materials constituents leads to better strength development.

2) The addition of micro cement kiln dust powder to mortar mixes leads to:

a- Increase the dry density by about (0.01% to 0.8%) for mortar at 28 days' age.

b- Decrease the water absorption and total porosity by about (0.8% to 22.3%) and (3.1% to 30 %) at 28 days' age respectively.
c- Increase the compressive strength, direct tensile strength, and flexural strength by about (1.9% to 18%), (2.5% to 13%), and (4% to 25%) respectively compared with conventional reference mortar at 28 days' age.

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