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Impact of Substitute Portland Cement with CKD on the Mechanical and Durability Characteristics of Cement Mortar

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Abstract. Cement mortar is a binding material that is made of cement, sand and water. In general, mixes of mortar are made of raw materials. However, using raw materials in producing mortar leads to many environmental and economic issues. One of the most common solutions to reduce these issues is replacing raw materials by waste and/or by-product materials; especially replacing cement. The aim of this research is to explore the characteristics of mortar mixes after partially replacing Ordinary Portland Cement (OPC) by Cement Kiln Dust (CKD) at three percentages (10%, 20% and 30%) in terms of initial and final setting time, compressive strength and Ultrasonic Pulse Velocity (UPV). The control mortar specimen (mortar containing OPC only) results were adopted for comparison with results of mortar mixes that incorporated CKD. Results showed that increment in CKD replacement percentages led to a decrement in the compressive strength and UPV and an increment in the setting time.

1. Introduction

Mortar is made of raw materials of (cement, sand and water). It has a flowable and workable behaviour, so it could be utilised in binding, plastering and pointing [1]. There are a lot of issues related to use the raw materials in mortar production. The issues are environmental and economical. The environmental issues are mainly represented by pollution and landslide, while the economic issues are represented by raised production and maintenance cost.

Cement production release carbon dioxide (CO_2) to the environment [2–11]. The quantity of the released carbon dioxide from producing 1 tonne of Portland cement is estimated to be 1 tonne. This amount of carbon dioxide represents about 7% of global production [12–21]. The limestone calcination contributes to about a little over half of the CO_2 quantity, while the used fuel to raise the temperature of the cement kiln to the required level contributes around third of the CO_2 quantity.

Operations of grinding and transportation add about 10% to the CO_2 quantity [22]. Therefore, carbon dioxide emissions must be reduced to maintain the environment [23].

In addition, there is a gap between the continuous increase in the human population and the limited available raw materials. Therefore, new materials that have an acceptable strength and low cost should be founded. Researchers have suggested that raw materials could be replaced by waste materials to solve the limited raw materials sources issue.

Cement kiln dust (CKD) is a waste material that is produced throughout the cement industrialised. It is a fine powdery material and its appearance is similar to that of Portland cement [24]. The annual production of CKD in the United States is estimated to be 15 million tonnes [25]. Although CKD could be reciprocated in the process of making cement to minimize its quantity, this way was considered not feasible. Therefore, CKD should be recycled/reused in the industry for the purpose of sustainable development. The reported researches on the usage of CKD as a cement substitute material, however, are incomplete and later age inquiries (more than one year) have not been considered.

The feasibility of utilizing (CKD) as a mixed cement material to research the impact of this partly substitution on the most significant characteristics of cement paste , mortar and concrete is investigated by Hassan, et al., [26]. The cement substitution amounts with the same volume of dust (CKD) have been (5%, 10%, 15%, 20%, 25%, 30%) by weight. For contrast, a standard concrete, mortar and cement paste mix were produced as well. The initial setting time of every cement paste and the concrete and mortars strengths of tensile and compressive were included in the measured products. Water curing has been utilized on both samples and the strength tests were conducted at (3, 7, 28) days. Experimental data findings show that (CKD) could be utilized as a partly cement substance effectively. With the growth in (CKD) content attributable to the large level of alkalis and lime in (CKD), the initial setting period of the cement paste is shortened. In general, with the increase of (CKD) material, the compressive intensity was seen to decrease. Compared to the reference blends, the (10) percent replacement standard provided the strongest performance for the compressive strengths of concretes and mortars at all levels, and this replacement level also had a major impact on the tensile strengths of concretes and mortars at an early era. It has been observed that the greater mortars tensile strength was retained at (7 , 28) days by (15) percent (CKD) substitution, while a (25) percent (CKD) had the same impact at (3 days and 28 days). However, the goal of this analysis is to experimentally explore the impact on the initial and final setting period, compressive intensity and Ultrasonic Pulse Velocity (UPV) characteristics of substitute Ordinary Portland Cement (OPC) with CKD. OPC was substituted with up to 30 percent wt. of CKD for this reason.

2. Materials and methodology

2.1 Testing Materials

2.1.1 Sand. Building sand passing from sieve size 3.35 mm has been utilised in this research.

2.1.2 Cementitious materials

2.1.2.1 Cement.

The utilised cement in this research was ordinary Portland cement kind CEM-II / A / LL 32.5-N. Its supplier was CEMEX Quality Department, Warwickshire, UK. Table 1 presents the chemical properties of cement. This cement complies with BS EN 197-1 [27].

2.1.2.2 Cement kiln dust (CKD).

CKD utilized in this research was supplied by Department of Quality CEMEX, Warwickshire, UK. Its chemical properties were tabled in Table 1.

Table 1: Chemical investigation for OPC and CKD.

Detail	**OPC**	**CKD**
CaO %	65.21	57.23
Al_2O_3 %	1.70	4.2
Fe_2O_3 %	1.64	3.8
SiO_2 %	24.56	16.52
MgO %	1.30	0.8
Na_2O %	1.34	0.23
K_2O %	0.82	6.72
SO_3 %	2.62	4.31
pH	12.73	12.75

2.2 Mixing Proportions

OPC was replaced by CKD with different percentages (10, 20 and 30) percentage. Table 2 presents the mix proportions and designations for samples of mortar. The proportion of sand to binder (S/B) and water to binder (W/B) have been, 2.5 and 0.4 [20], respectively.

Table 2. Mixing Design

Mix	OPC%	CKD%	W/B	S/B
M3	70	30	0.4	2.5
M2	80	20	0.4	2.5
M1	90	10	0.4	2.5
Control	100	0	0.4	2.5

2.3 Testing Program

2.3.1 Final and Initial setting time.

The apparatus of Vicat has been utilized to measure the final and initial setting time according to BS EN 196–3 [28].

2.3.2 Compressive strength test.

The test of compressive strength was performed depending on BS EN 196-1 [29]. The curing of specimens were done the labin the laboratory, and the curing conditions were 20 ± 2° C. Curing period was 1, 2, 3, 7, 14, 21, 28, 56, 90 and 550 days. Two samples with of 40x40x160 mm dimensions were prepared for each mixing ratio at curing period. 3 points loading has been utilized to breakdown every prism sample into 2 halves, and the final compressive strength magnitudes have been represented by the average of four parts.

2.3.3 UPV test.

The UPV test was performed for all mixing mortar ratios. The test was conducted according to BS EN1881-203 [30]. Cubic moulds (100 x 100 x100 mm) were used to conduct this test. Three samples were produced for each mixing ratios and for each curing period and they were tested after 1, 2, 3, 7, 14, 21, 28, 56, 90 and 550 curing days.

3. Results and discussion

3.1 Setting time

Consequences of the final and initial setting time of the four mortar mixes (control, M1, M2 and M3) are demonstrated in Table 3. The final and initial setting time expand with increasing replacement percentage of OPC by CKD. The final and initial setting times of mortar mixes (M1, M2 and M3) were greater than that of control mortar mix.

Table 3. Results of the initial and final setting time.

Mix	Initial (min)	Final (min)
Control	270	290
M1	295	330
M2	300	345
M3	315	355

3.2 Compressive strength

The mortars Compressive strength consequences made of various percentages of (CKD and OPC) at various curing periods are obtainable in Figure 1.

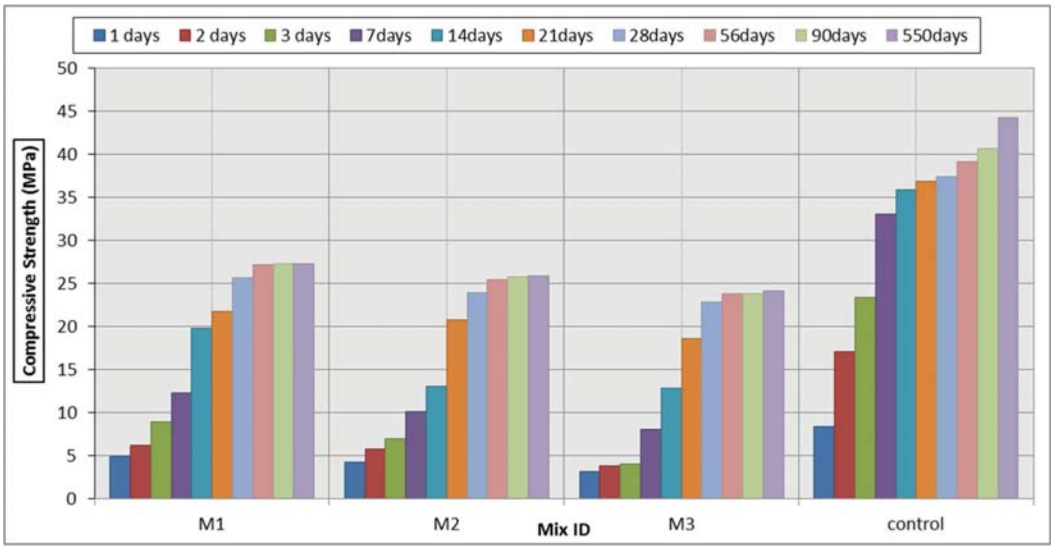

Figure 1. The observation of Compressive strength test

The control mix produced the maximum compressive strength of all other mixtures at all curing periods. However, the best compressive strength outcomes relative to other mixtures (M2 and M3) were obtained by replacing OPC with 10 percent CKD (M1). At the early curing period of 1 day, the mortar mix (M1) also reached 58 percent compressive power of the control mix and 62 percent at the

late curing period of 550 days. Although the compressive intensity of mixtures (M2 and M3) decreased relative to mixtures (M1), the growing substitution proportion of CKD in the mixture decreased. In contrast with the control mix at 1 day, the compressive intensity ratios of the mixtures (M2) and (M3) were 50 percent and 38 percent and 59 percent and 54 percent respectively at 550 days. The compressive power improved with the rising healing ages for all four mortar blends. Substitution of 30 percent of OPC with CKD (M3) cause in a substantial decrease in compressive intensity at all healing ages relative to the control mortar combination.
The cement clinker substitution, that is ultimately responsible for developing strength, may be due to this decline in compressive strength. In addition, owing to the vast number of alkalis in CKD, a kind of crystallization of hydration products is likely to occur. This could contribute to an open pore structure in the hardened samples that decreases the compressive strength of the samples. [31]. These results agreed with Bhatty [32–34] who found that setting time, strength and workability decreased when cement was replaced by CKD alone.

3.3 UPV

The UPV test results of mortar mixes (control, M1, M2 and M3) at 1, 2, 3,7, 14, 21, 28, 56, 90 and 550 days of curing are demonstrated in Figure 2.

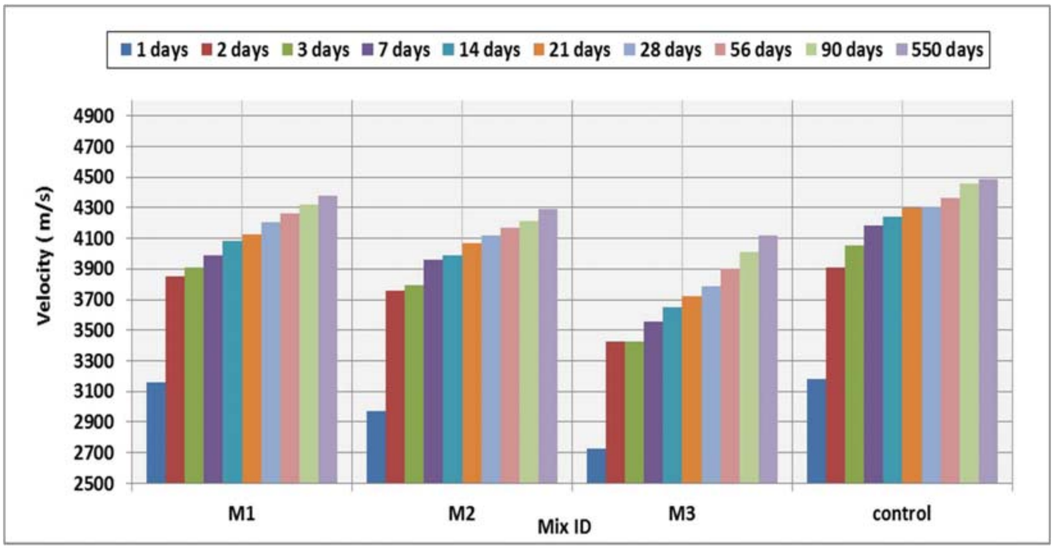

Figure 2. The observation of UPV test

Figure 2 demonstrates that the UPV values of mixtures (M3, M2, M1 and control) improved with increasing the duration of curing. However, increasing the replacement percentage of OPC with CKD resulted in a reduction of the UPV values.

4. Conclusion

Depending on the previous consequences and discussion, the following findings were observed:

1. Controlling mixture gained the best compressive strength at different curing period comparison with other mixtures.
2. The compressive strength of sample M1 is greater comparison with of M2 and M3 as it contains less CKD.
3. Increasing the percentage of substitution CKD in mixture led to decrease the compressive strength.
4. Controlling mixture gained the highest results in UPV test at all curing periods.

5. The mortar mix M1 achieved the highest UPV results in comparison with M2 and M3.
6. The UPV increased with increasing of curing ages, but is deceased with increasing of replacement percentage.

Authors recommended using other waste or by-products materials [35] including silica fume, stainless steel powder, fly ash, crude oil wastes, ground granulated blast furnace slag, agricultural waste [36–56], industrial wastes [57,58], municipal solid wastes [59] as well as water and wastewater planes waste [60–63] to enhance the resulting mortar (or concrete). Application of such materials in reinforced concrete beams is also recommended [64].

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