Utilization of Cement Kiln Dust in Concrete Manufacturing

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ABSTRACT

The present study aims to assess the properties of concrete containing cement kiln dust (CKD). Concrete specimens were prepared with 0% CKD, (10% and 20% CKD) as a replacement of cement weight, (10% and 20% CKD) as an addition of cement weight and 20% CKD as an addition of cement weight with super plasticizers. Ordinary Portland cement (O.P.C.) (ASTM C 150 Type I) and sulphate resisting Portland cement (S.R.P.C.) (ASTM C 150 Type V) were used throughout this investigation. The properties of concrete specimens were evaluated by measuring workability (using slump test), compressive strength, splitting tensile strength and absorption. The results of slump test showed that the using of CKD in concrete mixtures increases the water demand for a constant consistency. The compressive strength increased in the concrete mixtures including 10% and 20% CKD (as an addition of cement weight). A decrease in the compressive strength was noted in the concrete mixtures including 10% and 20% CKD (as a replacement of cement weight). A similar trend was noted in the splitting tensile strength and the increase in splitting tensile strength was less pronounced than that in compressive strength. The absorption percent increased when CKD was used in concrete mixtures. The using of super plasticizers enhanced workability, compressive strength, splitting tensile strength and absorption of the concrete for the two types of cement. The ordinary Portland cement concrete mixtures and the sulphate resisting Portland cement concrete mixtures including CKD had almost the same behaviors.

KEYWORDS: Cement kiln dust (CKD), Portland cement, Mechanical properties of concrete, Absorption of concrete, Workability, Super plasticizers.

INTRODUCTION

A large quantity of dust, commonly known as cement kiln dust (CKD), is produced during the production of Portland cement. The bulk of this dust, mostly with high alkali contents, filled land with a significant financial loss to the local cement industry in terms of the value of raw materials, processing, energy consumption during preprocessing, dust collection and disposal (Daous, 2004). With modern manufacturing techniques, it is technically possible to introduce most of the CKD back into the clinker-making process. However, it is not done due to the high alkali content in the CKD. Most international specifications restrict the alkali content in cement to less than 0.6% equivalent of Na_2O to avoid the possibility of alkali-aggregate reaction. Recently, there has been a trend of utilizing CKD in soil stabilization, treatment of sewage,… etc. Also, attempts were made at utilizing it in cement products. Most of the studies conducted so far have been restricted to assessing the properties of cement mortars (Maslehuddin et al., 2009).

Wang et al. (2002) investigated the characteristics of a binder system containing cement kiln dust CKD,

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blast-furnace slag and O.P.C. The system consists of 0 to 50% CKD and 0 to 75% slag replacement for O.P.C., with a total amount of supplementary cementitious materials equal to or less than 75%. The study evaluated the heat of hydration, rheological behavior and flexural and compressive strengths of pastes and mortars made with these binders. It also examined the effects of binder proportions on concrete properties. Tests demonstrated that properly designed O.P.C.-CKD-slag binders display properties comparable to pure O.P.C. or an O.P.C.-CKD blend. A CKD-slag specimen made without Portland cement also displayed satisfactory compressive and flexural strengths. This indicated that alkalis released from CKD may activate slag hydration.

Daous (2004) reported results of an investigation into the usage of CKD and fly ash in concrete. Test results showed that satisfactory mechanical strength (a minimum of 94% of compressive strength of ordinary Portland cement) could still be achieved in blends utilizing 90% cement and not more than 4% fly ash. Adequate mechanical strengths (a minimum of 80% of compressive strength of Portland cement) were achieved in blends utilizing as little as 70% cement when only kiln dust was blended.

Maslehuddin et al. (2009) evaluated the properties of cement kiln dust (CKD) blended cement concretes. The percentages of CKD were 0%, 5%, 10% and 15%, replacing cement ASTM C 150 Type I and Type V. The results showed that the compressive strength of concrete specimens decreased with the quantity of CKD. However, there was no significant difference in the compressive strength of 0 and 5% CKD cement concretes. A similar trend was noted in the drying shrinkage strain. The chloride permeability increased and the electrical resistivity decreased due to the incorporation of CKD. The performance of concrete with 5%, CKD was almost similar to that of concrete without CKD. Therefore, they suggested to limit the amount of CKD in concrete to 5%, since the chloride permeability and electrical resistivity data indicated that the chances of reinforcement corrosion would increase with 10% and 15% CKD.

Al-Mabrook (2010) studied the ability of using CKD in mortar and hollow cement bricks. The percentages of CKD were 10%, 20%, 30%, 40% and 50% replacing cement. The best results of compressive strength were in mixtures containing 30% CKD. The absorption percents were within the limit of standard specifications for all mixtures. By using the chemical analysis of samples taken from all mixtures, it was concluded that: (a) there was an increase in C_3S with the increase of CKD in mixtures, and that led to an increase in compressive strength at early ages. (b) there was a decrease in C_2S associated with the increase in C_3S.

Rahman et al. (2011) investigated the possibility of using CKD in the manufacturing of bricks. 12 different types of mortar bricks were investigated. Half of these mixes were prepared with crushed aggregates of limestone origin (Designated as Type-N). The other half were prepared with a mixture of light-weight aggregate of pozzolanic origin (from Western Saudi Arabia) and limestone aggregate (Designated as Type-P). In each of the two groups of specimens, the only variable was the content of CKD addition to each mixture. Six CKD additions were used in each group 0%, 10%, 20%, 30%, 40% and 50% by weight of cement. For Type-N blocks, the strength of the block increases from 52% to 82% at various percentages of CKD added. For Type-P blocks, the strength of the block increases from 38% to about 147% at various percentages of CKD added. The optimum dosage of CKD addition is 20% for both types of blocks (type N and type P). However, the improvement seemed to be higher when light-weight pozzolanic aggregate was used. For this type of aggregate, the increase in strength of the blocks was about 1.5 times when 20% CKD was added to the mix. At 30% CKD, a 75% increase in strength was observed. From these results, it could be concluded that CKD may be used in the future for replacing cement in the blocks without sacrificing the strength of the blocks.

This study was conducted to reveal the behavior of concrete incorporating from various percentages of CKD and evaluate its workability, compressive strength, splitting tensile strength and absorption.

Table 1. Grading of sand and the requirements of IQS No.45 : 1984, zone 3

Sieve size (mm)	Percent passing	IQS No.45 : 1984, zone 3
10	100	100
4.75	98.7	90-100
2.36	90.75	85-100
0.15	81.86	75-100
0.6	65.18	60-75
0.3	20.7	12-40
0.15	4.6	10-0

Table 2. Properties of sand

Property	Test results	IQS 45:1984 limits
specific gravity	2.65	-
absorption	1.2	-
sulfate content (SO_3)	0.32	≤ 0.5
clay	2.1	≤ 3.0

Table 3. Grading of coarse aggregate

Sieve size (mm)	Percent passing	IQS No.45 : 1984 limits
37.5	100	100
20	100	95-100
10	58	30-60
5	8	0-10

Table 4. Properties of coarse aggregate

Property	Test results	IQS 45:1984 limits
specific gravity	2.6	-
absorption	0.8	-
sulfate content (SO_3)	0.07	≤ 0.1
clay	0.5	≤ 1.0

EXPERIMENTAL PROGRAM

MATERIALS

Cement: Ordinary Portland Cement (O.P.C.) (ASTM C 150 Type I) and sulphate Resisting Portland Cement (S.R.P.C.) (ASTM C 150 Type V) were used throughout this study, and they were accomplished according to the Iraqi standard specification *(IQS No.5: 1984)*.

Fine Aggregate: Natural sand, from Al-Najaf sea region, was used as a fine aggregate. Its grading conformed to the Iraqi specification *(IQS No.45 : 1984, zone 3)* as shown in Table (1). The properties of the sand are listed in Table (2).

Coarse Aggregate: Crushed gravel with a maximum size of 20 mm was used in this investigation. Table (3) shows the grading of coarse aggregate which complied with the Iraqi specification No.45:1984. The properties of the coarse aggregate are illustrated in Table (4).

Cement Kiln Dust (CKD): Cement kiln dust produced in New Kufa Cement Plant as waste material was used in this study. It was passed through a sieve of size (0.15 mm). The chemical properties of CKD are reported in Table (5).

Water: Tab water was used for both mixing and curing of concrete.

Super plasticizers: Two types of super plasticizers (high-range water reducing) were used throughout this study. The first type is called Glenium 51. It has accelerating effects on concrete. The second type is called (Flocrete W52) which reduces the permeability of concrete. The two types of super plasticizers comply with ASTM C 494. The typical properties of super plasticizers are shown in Table (6).

Table 5. Chemical properties of CKD

Composition	SiO_3	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	K_2O	Na_2O	L.O.I.	chlorides
Percent	15.46	3.41	3.05	43.4	2.98	6.34	2.44	1.42	28.86	0.92

Table 6. The typical properties of super plasticizers*

Property	**Glenium 51**	**Flocrete W52**
Form	Viscous liquid	Viscous liquid
Color	Light brown	Dark brown
Relative density	1.1@20˚C	1.15 @25˚C
pH	6.6	6.9
Viscosity	+128/-30 cps@20˚C	-
Transport	Not classified as dangerous	Not classified as dangerous
Labeling	No hazard label required	No hazard label required

* From the catalog of manufacture.

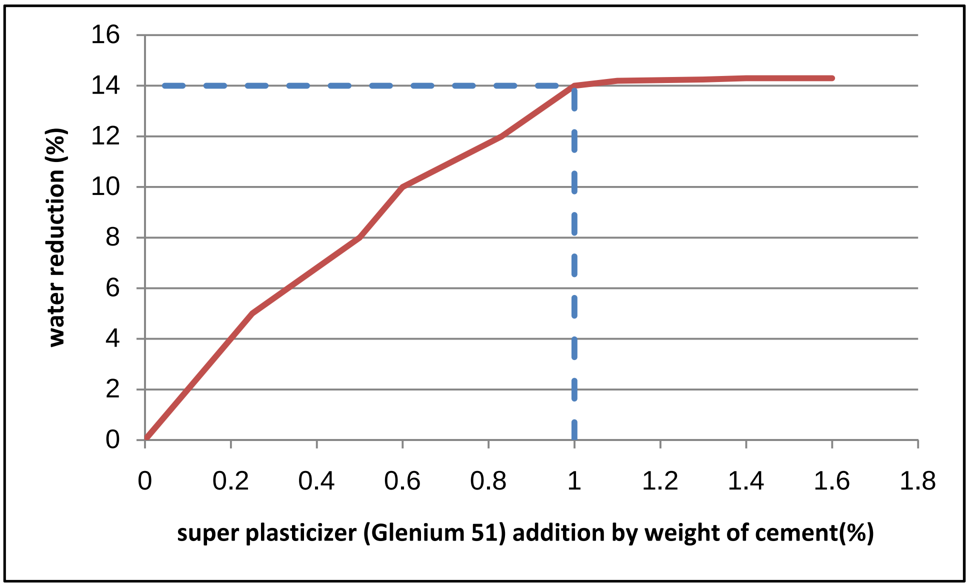

Figure 1: Water reduction for super plasticizer Glenium 51 mixtures

Super plasticizer – cement compatibility: In order to assess the super plasticizer – cement compatibility, the percentage of water reduction for the super plasticizer mixtures having the same workability, using slump method **(ASTM C 143-89, 1989)** was determined. Figures (1) and (2), obtained by experimental work, show the amount of super plasticizers by weight of cement and the percentages of water reduction.

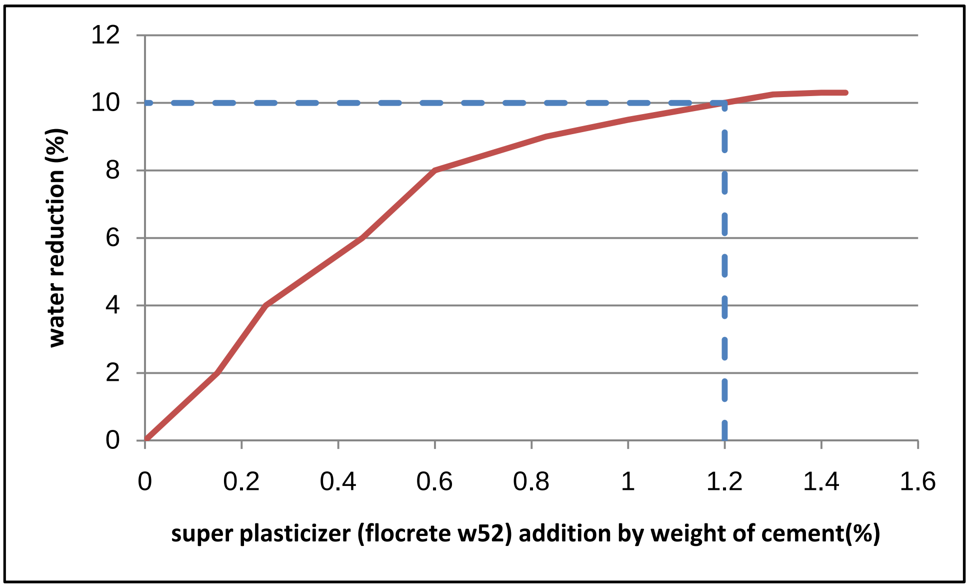

Figure 2: Water reduction for super plasticizer flocrete W52 mixtures

Mix Design: The concrete mixtures were designed according to British mix design method (B.S. 5328, Part 2:1991). The target compressive strength was 30 MPa at an age of 28 days. CKD was added to concrete mixtures as a percent of cement content. A total of fourteen concrete mixtures were prepared. The details of the concrete mixtures were as follows:

1. The first mixture was a reference mixture (without CKD or super plasticizer).
2. In the second and third mixtures, CKD was used with 10% and 20%, respectively, as a replacement of cement weight.
3. In the fourth and fifth mixtures, CKD was used with 10% and 20%, respectively, as an addition of cement weight.
4. In the sixth and seventh mixtures, CKD was used with 20% as an addition of cement weight with super plasticizers (Glenium 51) and (Flocrete W52), respectively.
5. In the first seven concrete mixtures, ordinary Portland cement was used. In the other seven concrete mixtures, sulphate resisting Portland cement was used with CKD proportions and super plasticizers remaining similar to those in ordinary Portland cement.

The mixture proportions are shown in Table (7).

Table 7. Properties of mixtures used

No.	w/c	Water kg/m^3	Cement kg/m^3	CKD kg/m^3	Super plasticizer %	Fine aggregate kg/m^3	Coarse aggregate kg/m^3	Slump mm
M1	0.47	190	405	---	---	505	1365	60
M2	0.47	190	364.5	40.5	---	505	1365	55
M3	0.47	190	324	81	---	505	1365	47
M4	0.43	190	405	40.5	---	505	1365	40
M5	0.39	190	405	81	---	505	1365	32
M6	0.34	163	405	81	Glenium 51 (1)	505	1365	110
M7	0.35	171	405	81	Flocrete W52 (1.2)	505	1365	110

TEST PROCEDURES

Slump test: Slump test of each concrete batch was conducted immediately after mixing by using slump method (ASTM C 143-89, 1989).

Compressive strength: The compressive strength test was determined according to (B.S. 1881-part 116-1989). 100 mm cubes were tested using a standard testing machine with a capacity of 2000 kN at a loading rate of 15 MPa per minute. The average of three cubes was adopted at each test. The test was conducted at ages of 7 and 28 days .

Splitting tensile strength: The splitting tensile strength test was conducted according to (ASTM C496 -86 -1989). Cylinders of (100×200) mm were used and load was applied continuously up to failure using a standard testing EIE–machine of 2000 kN capacity. The average splitting tensile strength of three cylinders was recorded at ages of 7 and 28 days for all concrete mixtures. Splitting tensile strength can be calculated by using the following equation:

$$f_t = \frac{2P}{\pi DL} \qquad \text{...(1)}$$

where:

f_t =Splitting tensile strength (MPa);
P=Applied load in (N);
D=Diameter of cylinder (mm);
L=Length of cylinder (mm).

Absorption: The absorption test was conducted according to (ASTM C140). The test procedure involves drying a specimen to a constant weight at 105˚C, weighing it, immersing it in water for 48 hours and weighing it again. The increase in weight as a percentage of the original weight is expressed as its absorption (in percent). The average absorption of three test samples was recorded at an age of 28 days.

RESULTS AND DISCUSSIONS

Slump test

Slump test was used to measure workability of the mixtures. The results of this test are shown in Table (7) and Fig. (3). In general, the results showed that CKD increases the water demand for a constant consistency. From the results of slump test, it is clear that the slump of concrete mixtures containing 20% CKD (as an addition of cement weight), (i.e., M5) was less than those of other mixtures. This reduction in slump may be attributed to high content of fine materials and high surface area. To obtain a desirable workability, high-range water-reducing admixtures were used.

Compressive strength

The compressive strength test results are abstracted in Table (8). The compressive strength development in O.P.C. concrete specimens prepared with and without CKD is depicted in Fig. (4). The compressive strength increased with age in all concrete mixtures. However, a decrease in the compressive strength was noted in concrete mixtures including 10% and 20% CKD (as a replacement of cement weight) over the control mixture without CKD (i.e., M2 and M3 compared with M1). It is commonly accepted because of the low hydraulic property of CKD (Shoaib et al., 2000).

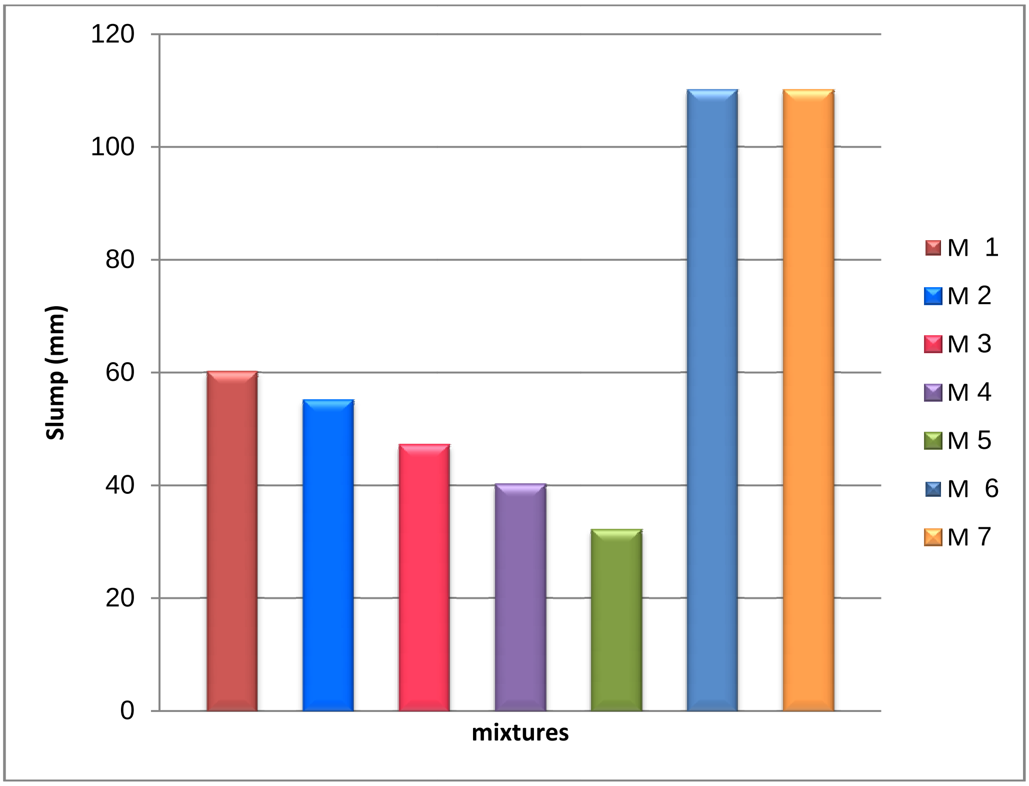

Figure 3: Slump test results of concrete mixtures

Table 8. The compressive strength test results

Mixture symbol	Cement type	Compressive strength (MPa), 7 days	Compressive strength (MPa), 28 days
M1	O.P.C.	20.26	31.33
	S.R.P.C.	23.12	34.03
M2	O.P.C.	6.00	10.86
	S.R.P.C.	7.50	12.32
M3	O.P.C.	10.92	19.71
	S.R.P.C.	12.03	20.22
M4	O.P.C.	23.36	39.88
	S.R.P.C.	27.06	45.82
M5	O.P.C.	28.19	35.12
	S.R.P.C.	31.11	40.32
M6	O.P.C.	32.03	44.85
	S.R.P.C.	35.04	48.95
M7	O.P.C.	30.16	41.68
	S.R.P.C.	33.62	45.83

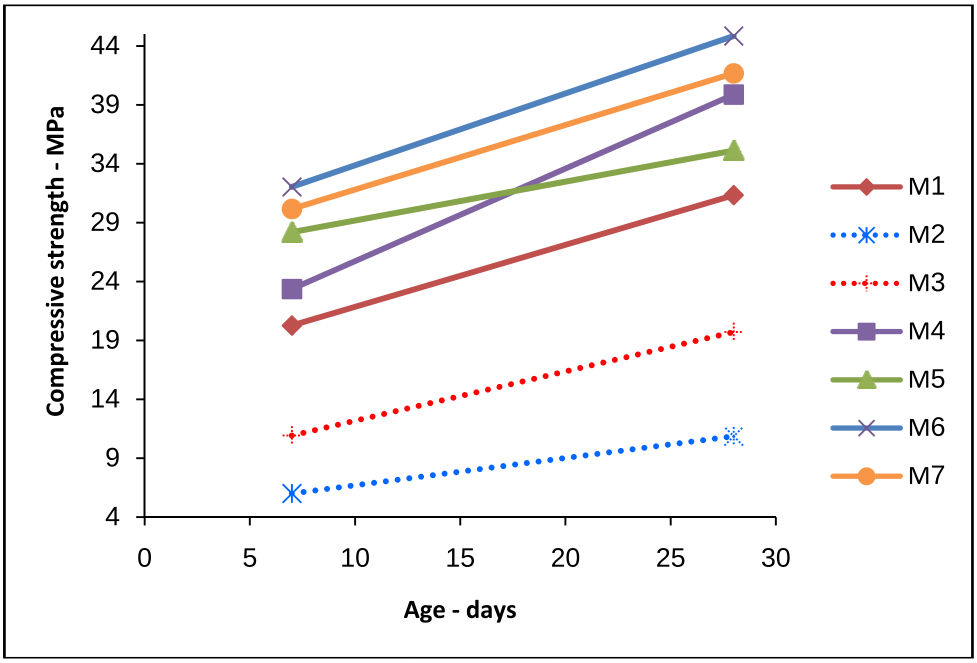

Figure 4: Development of compressive strength of concrete cubes using ordinary Portland cement

The compressive strength increased at ages of 7 and 28 days in concrete mixtures containing 10% and 20% CKD (as an addition of cement weight) over the control mixture without CKD (i.e., M4 and M5 compared with M1). At the age of 7 days, the compressive strength of concrete mixtures M4 and M5 was about 3.1 MPa and 7.93 MPa more than M1, respectively. At the age of 28 days, the compressive strength of concrete mixtures M4 and M5 was about 8.55 MPa and 3.79MPa more than M1, respectively. These results indicate that the maximum increase in compressive strength at the age of 7 days occurred in concrete mixture M5; while at the age of 28 days, the maximum increase in compressive strength occurred in concrete mixture M4. The increase in compressive strength may be attributed to an appropriate alkalinity in the Portland cement-CKD system, which increases the dissolution of silicate species and formation of C-S-H in the system (Shoaib et al., 2000).

The compressive strength of concrete mixture M6 (containing 20% CKD as an addition of cement weight and super plasticizer Glenium 51 with accelerating effects on concrete) was about 11.77 MPa and 13.52 MPa more than the control mixture M1 at ages of 7 and 28 days, respectively. The compressive strength of concrete mixture M7 (containing 20% CKD as an addition of cement weight and super plasticizer Flocrete W52 which reduces the permeability of concrete) was about 9.9 MPa and 10.35 MPa more than the control mixture M1 at ages of 7 and 28 days, respectively.

The compressive strength development in S.R.P.C. concrete specimens is depicted in Fig. (5). The compressive strength of concrete mixtures M1 and M2 was almost similar to that of the analogous O.P.C. concrete mixtures after 7 and 28 days. At the age of 7 days, the compressive strength of concrete mixtures M4 and M5 was about 3.94 MPa and 7.99 MPa more than M1, respectively. At the age of 28 days, the compressive strength of concrete mixtures M4 and M5 was about 11.85 MPa and 6.29 MPa, more than M1, respectively.

The compressive strength of concrete mixture M6 was about 11.91 MPa and 14.92 MPa more than the control mixture M1at ages of 7 and 28 days, respectively. The compressive strength of concrete mixture M7 was about 10.5 MPa and 11.8 MPa more than the control mixture M1 at ages of 7 and 28 days, respectively. However, the difference in the strength of concrete mixtures M7 and M4 at the age of 28 days was not that significant. The above results indicate that the O.P.C. concrete mixtures and the S.R.P.C. concrete mixtures including CKD had almost the same behaviors. The using of super plasticizers enhanced the compressive strength of the concrete mixtures (containing 20% CKD as an addition of cement weight) of the two types of cements.

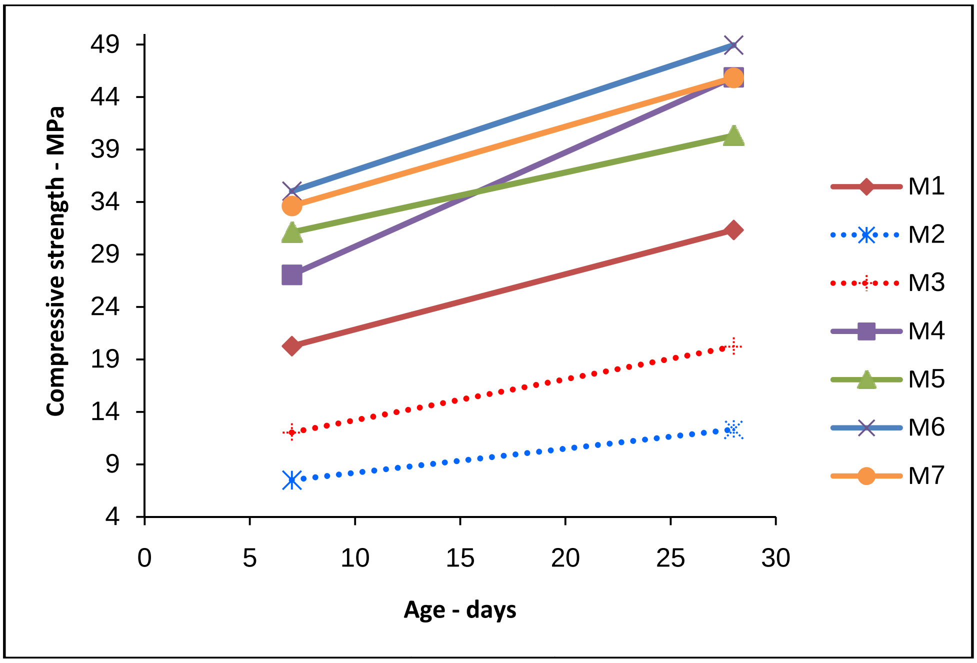

Figure 5: Development of compressive strength of concrete cubes using sulphate resisting Portland cement

Splitting tensile strength

The effect of CKD percent on splitting tensile strength for all concrete mixtures is summarized in Table (9) and represented in Figures (8) and (9) for O.P.C. concrete specimens and S.R.P.C. concrete specimens, respectively. It is clear that the splitting tensile strength and the compressive strength had the same trend. The splitting tensile strength increased with age in all concrete mixtures, and a decrease in it was noted in concrete mixtures including 10% and 20% CKD (as a replacement of cement weight) over the control mixture without CKD (i.e., M2 and M3 compared with M1) for both types of mixtures, O.P.C. concrete and S.R.P.C. concrete. At the age of 7 days, the splitting tensile strength of concrete mixture M4 was about 0.13 MPa and 0.19 MPa more than M1, for O.P.C. concrete mixture and S.R.P.C. concrete mixture, respectively. At the age of 28 days, the splitting tensile strength of concrete mixture M4 was about 0.40 MPa and 0.43 MPa more than M1, for O.P.C. concrete mixture and S.R.P.C. concrete mixture, respectively. However, the difference in the strength of concrete mixture M4 for the two types of cement at the age of 7 days was not that significant. The same thing was noted at the age of 28 days.

The splitting tensile strength of concrete mixture M5 was about 0.17 MPa and 0.23 MPa more than the control mixture M1 at the age of 7 days, for O.P.C. concrete mixture and S.R.P.C. concrete mixture, respectively; while the splitting tensile strength of concrete mixture M5 was about 0.48 MPa and 0.41 MPa more than the control mixture M1 at the age of 28 days, for the O.P.C. concrete mixture and the S.R.P.C. concrete mixture, respectively. It is obvious that the difference in the strength of concrete mixtures M5 for the two types of cement was almost similar to that of the parallel M4 mixtures after 7 and 28 days. However, the difference in the strength of concrete mixtures M4 and M5 at the age of 28 days was not that weighty, for both types of cement. The splitting tensile strength of concrete mixture M6 (containing 20% CKD as an addition of cement weight and super plasticizer Glenium 51 which has accelerating effects on concrete) was about 0.67 MPa and 0.64 MPa more than the control mixture M1 at the age of 7 days, for O.P.C. concrete mixture and S.R.P.C. concrete mixture, respectively; while the splitting tensile strength of concrete mixture M6 was about 0.86 MPa and 0.93 MPa more than the control mixture M1 at the age of 28 days, for O.P.C. concrete mixture and S.R.P.C. concrete mixture, respectively.

Table 9. The splitting tensile strength test results

Mixture symbol	Cement type	Splitting strength (MPa), 7 days	Splitting strength (MPa), 28 days
M1	O.P.C.	1.26	2.1
	S.R.P.C.	1.86	2.89
M2	O.P.C.	0.31	0.73
	S.R.P.C.	0.52	0.80
M3	O.P.C.	0.90	1.40
	S.R.P.C.	1.40	2.00
M4	O.P.C.	1.39	2.50
	S.R.P.C.	2.06	3.32
M5	O.P.C.	1.43	2.58
	S.R.P.C.	2.10	3.30
M6	O.P.C.	1.93	2.96
	S.R.P.C.	2.51	3.82
M7	O.P.C.	1.71	2.77
	S.R.P.C.	2.30	3.57

Table 10. The absorption test results

Mixture symbol	Cement type	Absorption percent (%), 28 days
M1	O.P.C.	4.42
	S.R.P.C.	4.00
M2	O.P.C.	5.15
	S.R.P.C.	4.82
M3	O.P.C.	6.58
	S.R.P.C.	5.73
M4	O.P.C.	4.70
	S.R.P.C.	4.35
M5	O.P.C.	4.82
	S.R.P.C.	4.52
M6	O.P.C.	4.45
	S.R.P.C.	4.32
M7	O.P.C.	3.60
	S.R.P.C.	3.45

Figure 6: The cube and the mold of the compressive strength test

Figure 7: The compressive strength test

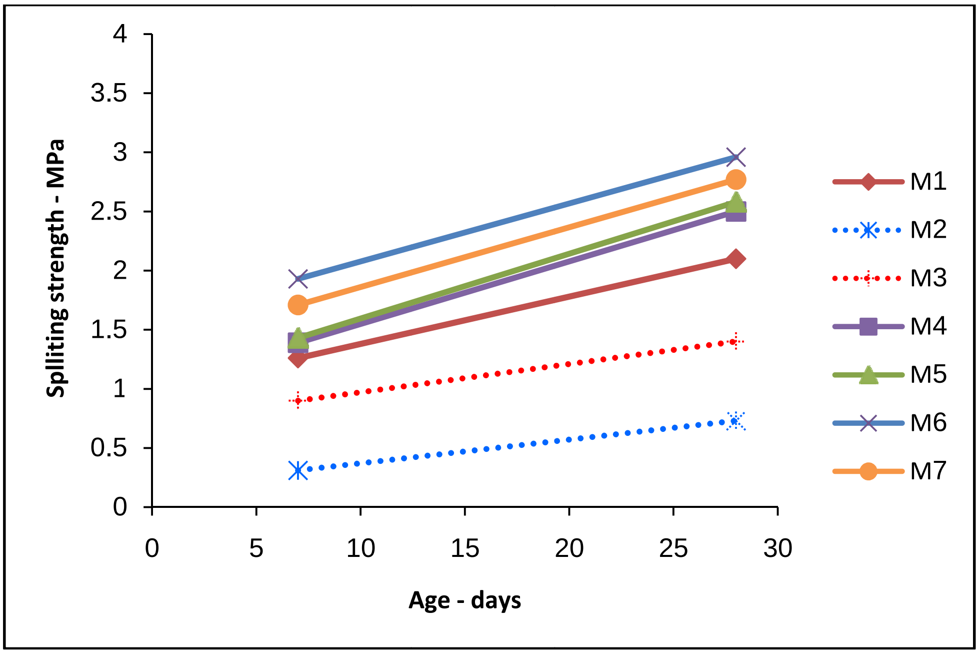

Figure 8: Development of splitting tensile strength of concrete cylinders using ordinary Portland cement

The splitting tensile strength of concrete mixture M7 (containing 20% CKD as an addition of cement weight and super plasticizer Flocrete W52 which reduces the permeability of concrete) was about 0.45 MPa and 0.43 MPa more than the control mixture M1 at the age of 7 days, for O.P.C. concrete mixture and S.R.P.C. concrete mixture, respectively; while the splitting tensile strength of concrete mixture M7 was about 0.67 MPa and 0.68 MPa more than the control mixture M1 at the age of 28 days, for O.P.C. concrete mixture and S.R.P.C. concrete mixture, respectively. It is evident that the behavior of M6 and M7 was similar to that of M4 and M5, for both types of cement. The above results show that the difference in the strength of all concrete mixtures was not that significant and the increase in the splitting tensile strength is less pronounced than that in the compressive strength.

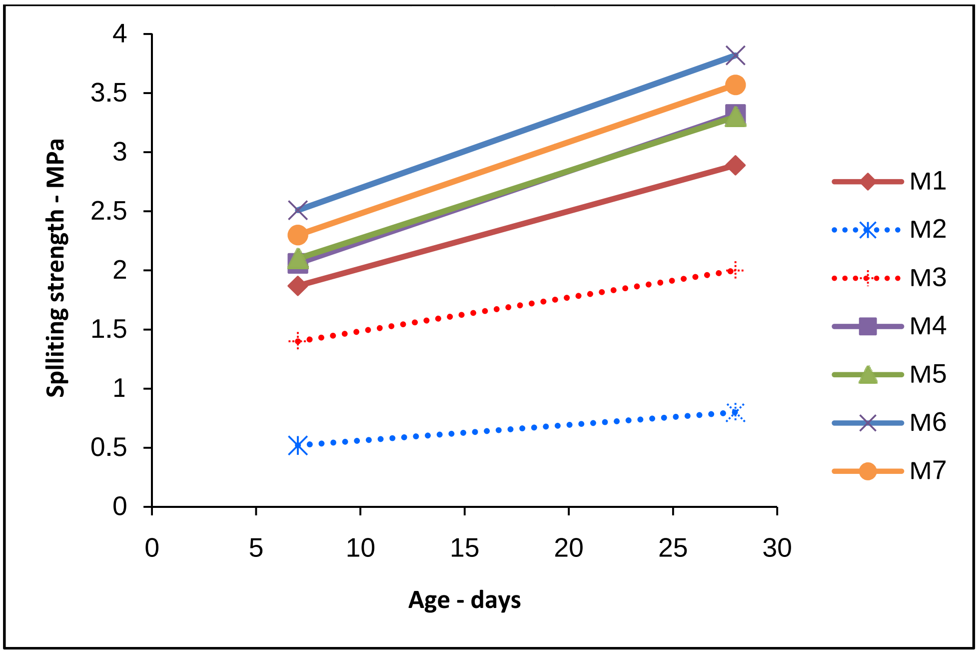

Figure 9: Development of splitting tensile strength of concrete cylinders using sulphate resisting Portland cement

Figure 10: The cylinder and the mold of the splitting tensile strength test

Figure 11: The splitting tensile strength test

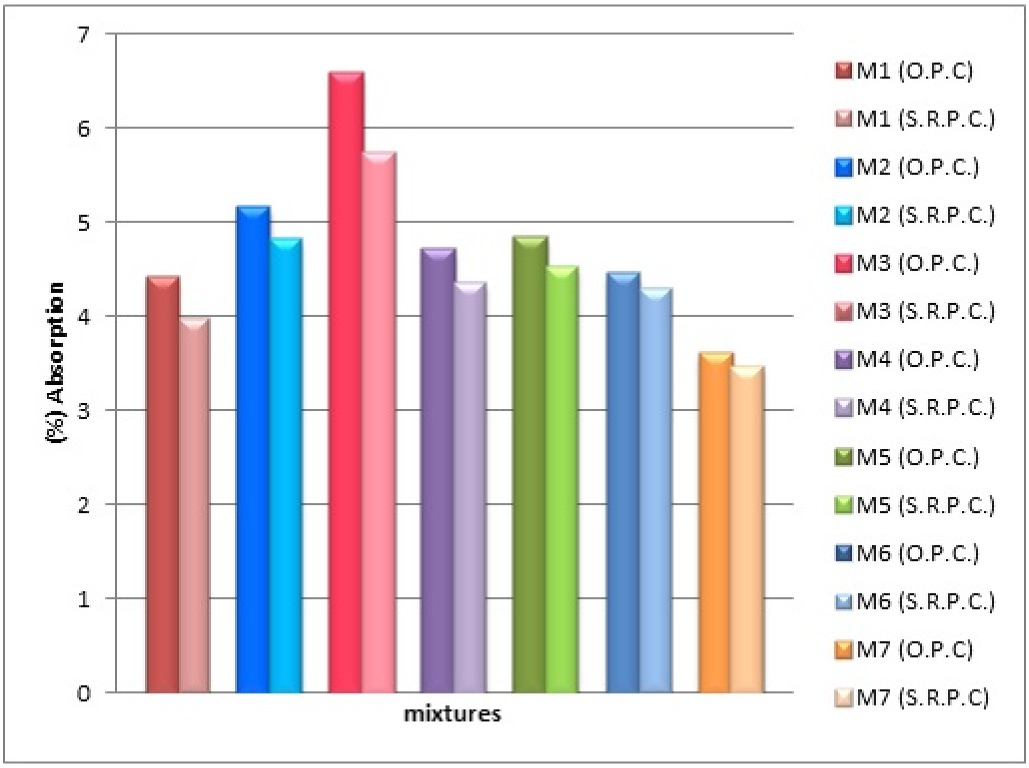

Figure 12: Absorption test results of concrete mixtures

Figure 13: The specimens inside the drying oven

Figure 14: Determination of the specimen weight

Absorption

The absorption test results (at the age of 28 days) are illustrated in Table (10) and plotted in Fig.(12). It is obvious that the absorption percent increased when CKD was used in concrete mixtures from M2 to M6 (i.e., in all the concrete mixtures except M7) for both types of mixtures, O.P.C. concrete and S.R.P.C. concrete. The maximum increase occurred in mixture M3 (i.e., the concrete mixture including 20% CKD as a replacement of cement weight). It was about 2.16 and 1.73 more than the control mixture M1, for O.P.C. concrete mixture and S.R.P.C. concrete mixture, respectively. The absorption percent of concrete mixture M2, the concrete mixture including 10% CKD as a replacement of cement weight, was about 0.73 and 0.82 more than the control mixture M1 for both types of mixtures, O.P.C. concrete and S.R.P.C. concrete, respectively; while it was- for the two types of mixtures –about 0.28, 0.35, 0.41 and 0.52 more than the control mixture M1 in concrete mixtures containing 10% and 20% CKD (as an addition of cement weight), respectively (i.e., M4 and M5 compared with M1 for O.P.C. concrete mixture and S.R.P.C. concrete mixture, respectively). The increase in the absorption percent may be attributed to the fact that CKD is a fine material and more absorbing.

The absorption percent of concrete mixture M6 (containing 20% CKD as an addition of cement weight and super plasticizer Glenium 51 which has accelerating effects on concrete) was about 0.03 and 0.32 more than the control mixture M1, for O.P.C. concrete mixture and S.R.P.C. concrete mixture, respectively. In concrete mixture M7 (containing 20% CKD as an addition of cement weight and super plasticizer Flocrete W52 which reduces the permeability of concrete), the absorption percent decreased and it was about 0.82 and 0.55 less than the control mixture M1, for O.P.C. concrete mixture and S.R.P.C. concrete mixture, respectively. It is clear that the use of super plasticizers improved the absorption percent of the concrete mixtures (containing 20% CKD as an addition of cement weight) of the two types of cements.

CONCLUSIONS

1. The workability of both O.P.C. and S.R.P.C. concretes decreased with increasing quantity of CKD. The slump of concrete mixtures containing 20% CKD (as an addition of cement weight) was less than for other mixtures.
2. The compressive strength increased in concrete mixtures including 10% and 20% CKD as an addition of cement weight. A reduction in compressive strength was noted in concrete mixtures including 10% and 20% CKD as a replacement of cement weight.
3. The splitting tensile strength and the compressive strength had the same tendency. The difference in the splitting tensile strength of all concrete mixtures was not that significant and the increase in splitting tensile strength is less pronounced than that in compressive strength.
4. The absorption percent increased when CKD was used in concrete.
5. The using of super plasticizers enhanced the properties of concrete including CKD.
6. O.P.C. concrete mixtures and S.R.P.C. concrete mixtures including CKD had almost the same manners.

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