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Research Article

Fresh and hardened properties of self-compacting concrete containing cement kiln dust

Ibrahim Saad Agwa *, Omar Mohamed Omar Ibrahim

Civil Construction and Architectural Department, Suez University, Suez, Egypt

ABSTRACT

There are many wastes form the cement industry among them cement kiln dust (CKD). This residue is obtained after the process of burning the raw materials of cement in the rotary kiln where it is suctioned by fans during the clinker exit of the rotary kiln. Cement dust is a major environmental and economic problem in terms of high quality air pollution ranging from (20-100) microns and the proportions of chlorides, sulphates, alkali and lime living in a way that threatens the general health of human, as well as water pollution if the waste is discharged by rivers and waterways. This investigation's main objective is to present the potential of using CKD as a cement replacement in self-compacting concrete (SCC). Eight mixes incorporating CKD with partial cement replacement of 0%, 5%, 10%, 20%, 30%, 40%, 50% and 75% in addition to control mix were investigated. The properties of all mixture were determined. Based on the experimental program results, it was found that SCC mixture incorporating 5% to 10% of CKD was almost similar to that of control mixture. The workability of SCC concrete decreased as CKD replacement increased. This established benefits of substituting cement by CKD to make SCC.

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1. Introduction

Portland cement production, a blend of lime-stone, shale, sand and clay are composite in determine ratios and mixing together as a dry mix or a water mix (Najim et al., 2014). CKD, is produced in great amount during the manufacture of Portland cement, Maslehuddin et al., 2008). One of the recently used by-products in controlled low-strength material is CKD that improves flowability and reduces bleeding and segregation. Generally, the CKD compositions are similar to that of cement since they contain alumina, sulfates, alkalis, calcium oxide and silica. However, sulfates and alkalis amounts are substantially higher in CKD than cement (Kunal et al., 2012). Generally 98–100% of all ash created through cement manufacture is captured by Filters for air purification (Lachemi et al., 2010). Cement manufacture negative influence the environment not only by consumption the raw materials but also by the production of by product as CKD and releasing CO_2 (Abukhashaba et al. 2014). Self-Consolidating-Concrete, including the CKD, may offer various environmental, economic and technical advantages (Abukhashaba et al., 2014). CKD can be utilized successfully as an activator for industrial wastes such as copper slag, ground granulated blast furnace slag, etc. (Siddique, 2014). The initial and final setting times of CKD cement mixtures are decreased slightly but they are well within the ASTM C 150 requirements, the shrinkage of CKD-cement mortar increases with the increase of CKD quantity (Abukhashaba et al., 2014). The compressive strength is best described by the water-to-cementitious materials, w/c ratio and the porosity relationship. When fully compacted, the concrete strength was taken to be inversely proportional to the w/cm ratio (Neville, 1996). It was stated that at similar w/cm ratios, the compressive strength of SCC was comparable or higher than normally vibrated concrete (NVC) (Turcry et al., 2002). The literature review indicates that there are studies on the SCC with different admixtures as powder content and comprehensive studies on properties of SCC

* *Corresponding author*. Tel.: +20-10-2824-2681 ; E-mail address: ibrahim.agwa@suezuniv.edu.eg (I. S. Agwa)
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with different percentages of MK and CKD. The addition of 10 percent MK and CKD in SCC mixes will increase the SCC ability like filling, passing and flowing ability and segregation (%). It also can be seen that compressive strength, flexural strength, and split strength are most for 10 percent replacement as compared to 20 percent and 30 percent (Mehetre et al., 2014). SCC mixes incorporating with CKD as a filler and addition of CKD as a partial cement replacement create use of SCC whenever economic, environmental and simple handiness considerations predominant, whereas not voluminous apprehension. Properties of the fresh and hardened state were studied. The SCC mixes with the addition of two hundredth CKD gave an optimum strength for M30 grade (Madandoust and Mousavi, 2012). However, in the literature, it has been reported different aspects of normal concrete incorporating CKD, but the CKD performance in SCC is not well documented. So, this study is to characterize the fresh and hardened properties of SCC incorporating CKD. For this purpose, several tests concerning slump flow, T_{500}, blocking ratio, and segregation ratio were performed to assess the workability of the matrix. In addition, hardened properties of SCC, and drying shrinkage.

2. Materials

The materials used in the empirical work were selected from local Egyptian sources. (CEMI 42.5 N) was used. Local silica fume was used. HRWR (high range water reducer) was used to enhance workability and viscosity of the concrete mixes. Clean natural sand was used. Dolomite aggregates was used in this investigation from (Attaka Quarries, EL Suez area). Fig. 1 shows CKD obtained from EL-Suez Cement Company. Lime-stone powder was obtained from local crusher in Suez, Egypt. The properties of used materials as shown in Table 1.

Fig. 1. Cement kiln dust used.

3. Methods

The mix proportion of concretes is explained in Table 2. It consists of eight SCC mixes having by CKD as a replacement to cement of ($M_{0\%}$, $M_{5\%}$, $M_{10\%}$, $M_{20\%}$, $M_{30\%}$, $M_{40\%}$, $M_{50\%}$ and $M_{75\%}$) were tested. Concrete mixture incorporating CKD replacements (0%, 5%, 10%, 20%, 25%, 50% and 75%) from 350 kg/m^3 cement weight. All concrete mix incorporating SF and LSP of 15% by weight of cement. Fig. 2 shows the fresh properties test of SCC that were measured in terms of slump flow, T500, blocking ratio (BR) and segregation ratio, according to Egyptian Standard Specification (2007). The hardened properties of SCC measured in terms of compressive strength for all mixes at seven, twenty eight and fifty six days, as well as the following properties were measured for all mixes; splitting tensile at twenty eight days, flexural strengths at twenty eight days, and drying shrinkage according to Egyptian Code (2009).

Table 1. Chemical materials used.

	Results by wt. (%)		
Chemicals	Cement	Silica fume	Cement-Kiln-Dust
SiO_2	21.2	96.7	17.80
Fe_2O_3	3.00	1.45	2.90
Al_2O_3	6.10	1.10	6.59
CaO	62	1.23	42.96
MgO	4	0.2	2.56
SO_3	2.9	0.25	6.12
Na_2O	0.4	0.45	2.39
K_2O	0.3	1.22	3.18
Cr_2O_3	-	-	0.775
Cl	-	-	7.61
LOI	-	-	7.30

Table 2. Concrete mix proportions.

Mix ID	Cement (Kg)	CKD (%)	SF (%)	LSP (%)	FA	CA	SP (%)	W/P (%)
M0	350	0	15	15	1	1.5	1.5	0.5
M5%	332.5	5	15	15	1	1.5	1.5	0.5
M10%	315	10	15	15	1	1.5	1.5	0.5
M20%	280	20	15	15	1	1.5	1.5	0.5
M30%	245	30	15	15	1	1.5	1.5	0.5
M40%	210	40	15	15	1	1.5	1.5	0.5
M50%	175	50	15	15	1	1.5	1.5	0.5
M75%	87.5	75	15	15	1	1.5	1.5	0.5

where;

CKD : Cement kiln dust SF : Silica fume
LSP : Lime stone powder FA : Fine aggregates
CA : Cores aggregates SP : Superplasticizers
W/P : Water/pander ratio

4. Results and Discussion

4.1. Fresh properties of SCC

The test results properties of SCC (slump flow, flow time (T500), BR (H2/H1) and segregation ration) are presented in Table 3.

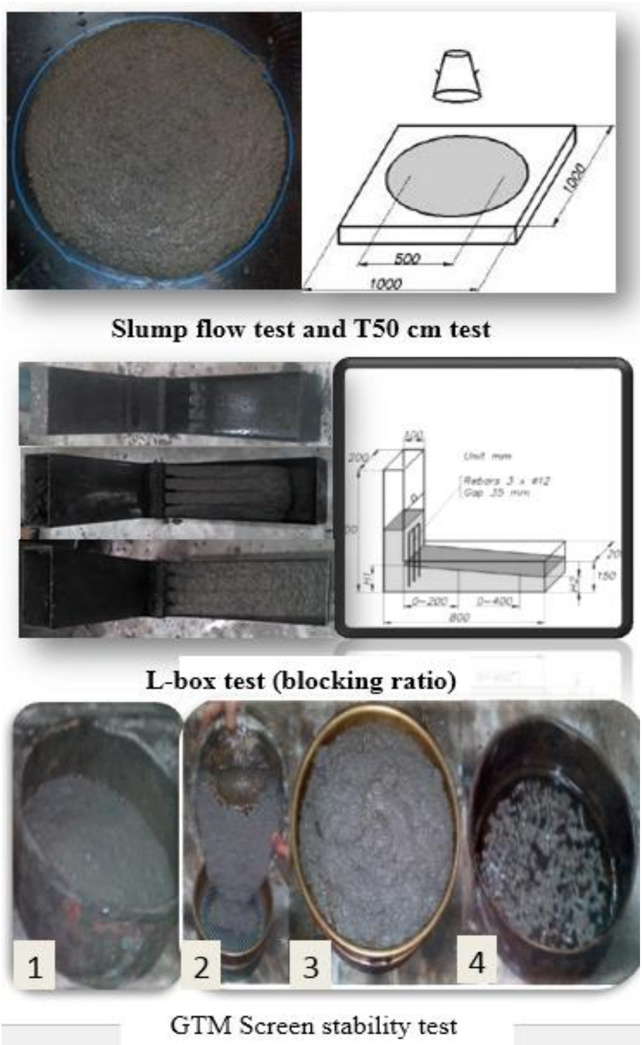

Fig. 2. Fresh properties test.

Table 3. Fresh concrete properties.

Mix	Slump Flow (mm)	Flow time (T500)	Blocking Ratio (H2/H1)	Segregation (%)
M0	750	3	0.9	14
M5%	730	3	0.9	13
M10%	710	3	0.85	13
M20%	690	4	0.85	11
M30%	650	5	0.8	10
M40%	610	6	0.8	9
M50%	590	6	0.75	9
M75%	550	7	0.7	8

The slump flow, flow time (T500) and segregation ratio were used to measure the slump flow and viscosity of the SCC mixes. Furthermore, L-box used for measuring the SCC passing ability.

The slump flow of SCC with various CKD contents are given in Table 3 and Fig. 3, the slump flow for various concrete mixes were measured in the ranged from 550 – 750 mm. The mixes flowability was lower with the increased ratio of CKD, as shown in Table 3 and Fig. 3, the slump flow of M0% was measured to be 750 mm while it could be decreased to 650 mm when CKD increased to 30%. This can be explained by the higher surface area of the CKD particles compared with cement. Fig. 4 shows the SCC mixes blocking ratio ranged from 0.9 to 0.7 for all different concrete mixes. Fig. 5 shows the results from the segregation (%) test and are presented in Table 3. segregation (%) of SCC containing CKD changed from 14 to 8%.

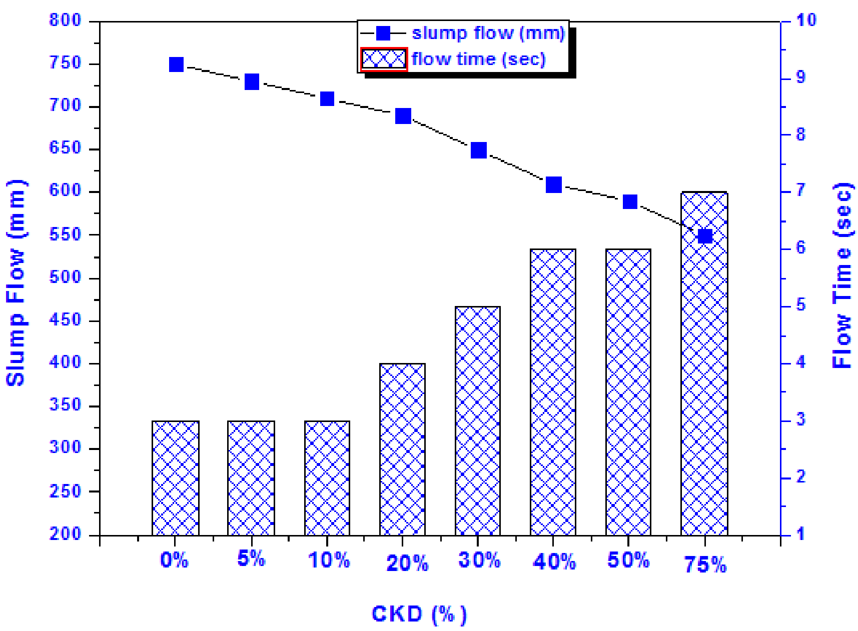

Fig. 3. Relation between slump flow and CKD (%).

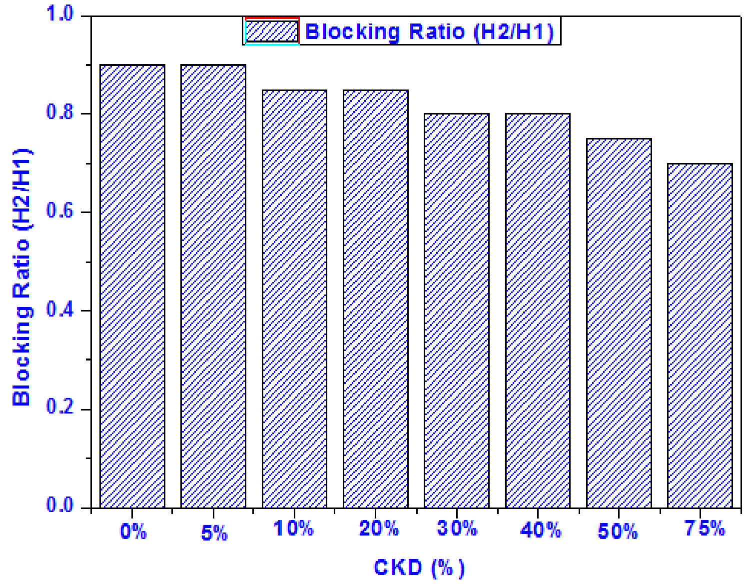

Fig. 4. Relation between blocking ratio and CKD (%).

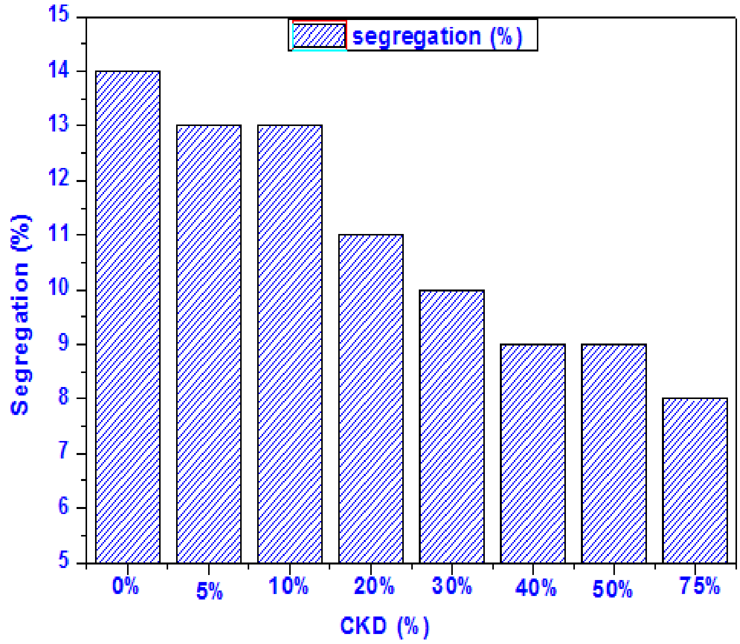

Fig. 5. Relation between segregation ratio and CKD.

4.2. Hardened properties of SCC

The test results of hardened properties of SCC are presented in Table 4. Compressive strength test results of SCC with different replacement percentages are presented in Fig. 6 for $M_{0\%}$, $M_{5\%}$, $M_{10\%}$, $M_{20\%}$, $M_{30\%}$, $M_{40\%}$, $M_{50\%}$ and $M_{75\%}$, respectively. The compressive strength is increased slightly with the increase of CKD content till up to $M_{5\%}$. The compressive strength significantly dropped above this percentage. The decrease in the compressive strength is due to the cement content reduction and the free lime content increase in CKD. The large amount of calcium hydroxide has weakened the hardened SCC matrix. The porosity also increased, because of the high chloride 7.61%, and sulfate 6.12%, content in the CKD. The crystallization of hydration products is enhanced by formation of these products leading to the opening of the pore system. The CKD replacement by up to M5% in OPC can be utilized in the SCC. Using CKD with level $M_{10\%}$, $M_{20\%}$, $M_{30\%}$, $M_{40\%}$, $M_{50\%}$ and $M_{75\%}$ has decreased the compressive strength of SCC by about 7.9%, 20.6%, 33.3%, 43.8%, 48.5% and 59.3%, respectively at 7 days when compared to control mix. There is a reduction in compressive strength of about 8.9%, 16.8%, 27.9%, 42.4%, 45.7% and 58.7% at 28 days, at the replacement level of $M_{5\%}$, $M_{10\%}$, $M_{20\%}$, $M_{30\%}$, $M_{40\%}$, $M_{50\%}$ and $M_{75\%}$, respectively, when compared to the control mix. The loss in the compressive strength at a replacement level of $M_{5\%}$, $M_{10\%}$, $M_{20\%}$, $M_{30\%}$, $M_{40\%}$, $M_{50\%}$ and $M_{75\%}$ can be related to the chemical effects of CKD. Moreover, the percentage of free calcium hydroxide during the reaction of cement increases, when CKD increases similarly. It was shown by the previous studies.

The effect of using CKD, $M_{0\%}$, $M_{5\%}$, $M_{10\%}$, $M_{20\%}$, $M_{30\%}$, $M_{40\%}$, $M_{50\%}$ and $M_{75\%}$ replacement of cement at the ages of 28 days on tensile strength are presented. However, due to the increase in the amount of replacement CKD as presented in Fig. 7, the tensile strength decreases. This is due to the increase of cement dust percentage that doesn't provide good bond between aggregates and cement mortar-like free OPC hydration phases. Thus, the concrete sample shows a lower bond between the aggregates particles and that lowers tensile strength. For example, the increase in CKD replacement of cement of $M_{5\%}$, $M_{10\%}$, $M_{20\%}$, $M_{30\%}$, $M_{40\%}$, $M_{50\%}$ and $M_{75\%}$, the tensile strength were 5.7, 3.8, 3.1, 2.7, 1.9, 1.6 and 1.2 N/mm^2 respectively.

Flexural strength effect of using CKD, $M_{0\%}$, $M_{5\%}$, $M_{10\%}$, $M_{20\%}$, $M_{30\%}$, $M_{40\%}$, $M_{50\%}$ and $M_{75\%}$ replacement of cement at the ages of 28 days are presented in Fig. 8. The results indicated that the control mix M0% gave flexural strengths in the range of 6.5 N/mm^2. Fig. 8 shows a progressive reduction in flexural strengths with the increase in CKD percentage replacement. This reduction could be illustrated by the decrease in the OPC content, due the CKD replacement that led to reducing C_3S and C_2S (they are mainly responsible for the strength). The effect of the variations of replacement of CKD on the flexural strength of SCC is illustrated in Fig. 8. For instance, as a result of changing CKD from 0.0% to 75%, the 28–day flexural strength changed from 6.5 N/mm2 to 2.5 N/mm^2 respectively.

Table 4. Hardened concrete properties.

Mix	Compressive Strength (N/mm^2)			Tensile strength (N/mm^2)	Flexure strength (N/mm^2)
	7 (days)	28 (days)	56 (days)	28 (days)	28 (days)
M0	31.5	41.3	44.2	5.4	6.5
M5%	32.1	42.7	44.4	5.7	6.7
M10%	29	37.8	39.5	3.8	5.3
M20%	25	34.5	36.2	3.1	4.8
M30%	21	29.9	31	2.7	4.3
M40%	17.7	23.3	25	1.9	3.3
M50%	16.2	22.5	23.8	1.6	3.1
M75%	12.8	17.1	18	1.2	2.5

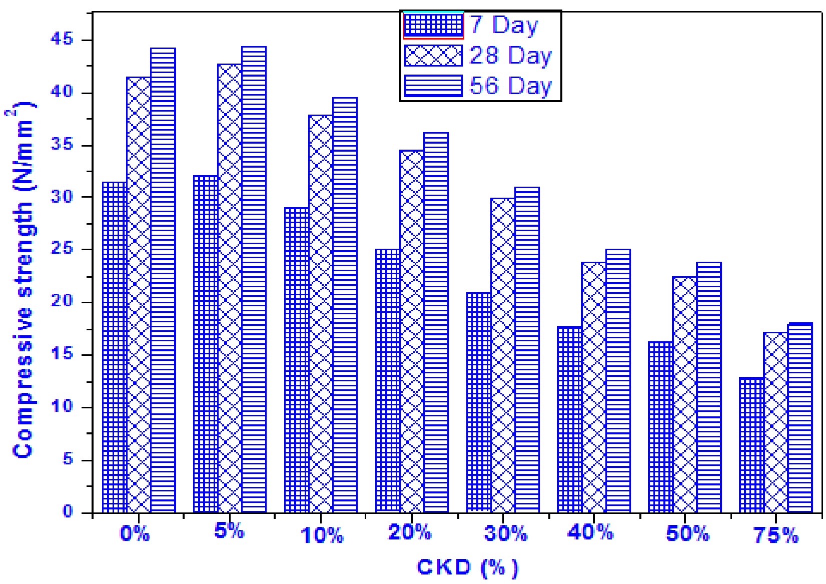

Fig. 6. Relationship between compressive strength and CKD (%).

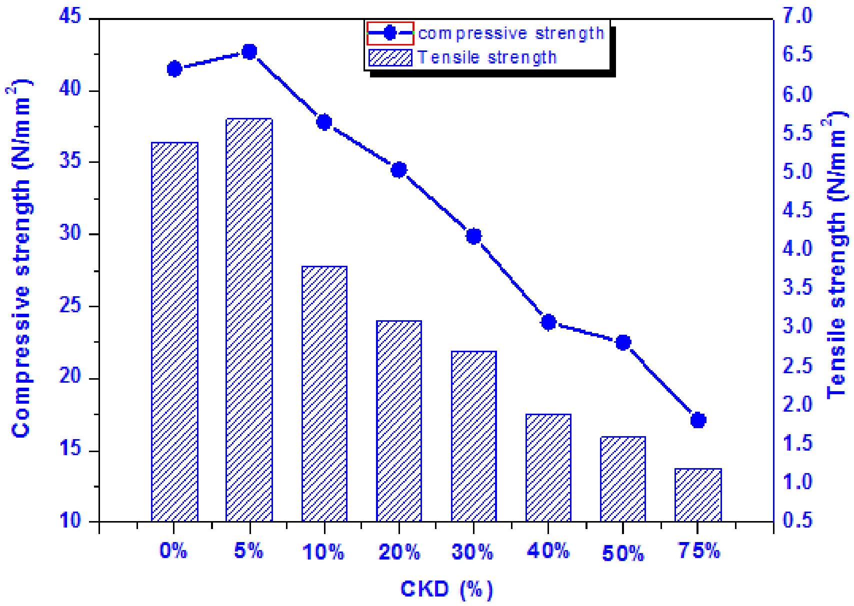

Fig. 7. Relationship between compressive, tensile strength and CKD (%).

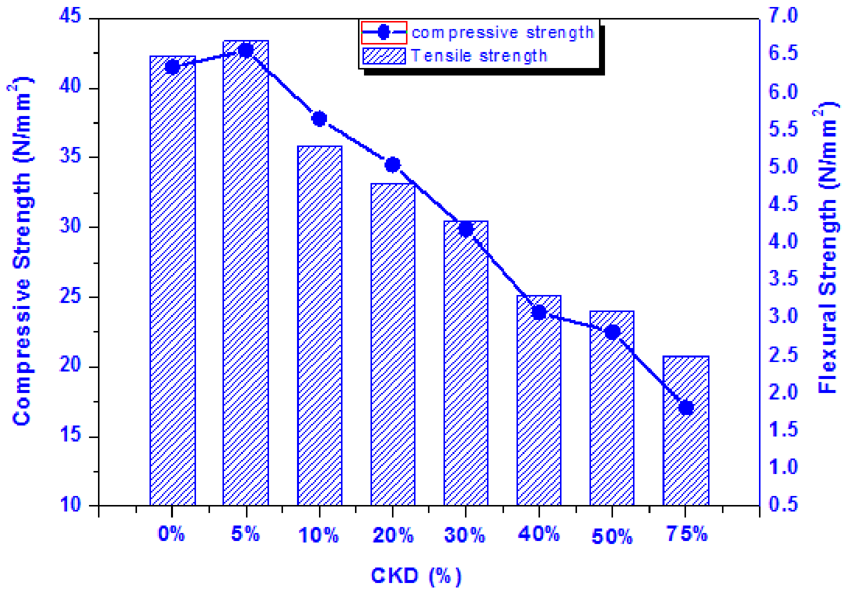

Fig. 8. Relationship between compressive, flexural strength and CKD (%).

4.3. Drying shrinkage

The test data plotted for mixtures M0%, M5%, M10%, $M_{20\%}$, $M_{30\%}$, $M_{40\%}$, $M_{50\%}$ and $M_{75\%}$ in Fig. 9 shows that the drying shrinkage strains slightly fluctuated over the measurement time. There was an increase in the shrinkage strain with time and quantity of CKD in the mixtures. The highest shrinkage strain was mostly in the concrete specimens with 75% CKD followed with a decrease in drying shrinkage at decreased in CKD content by that in the concrete specimens with 50%, 40%, 30%, 20, 10% and 5% CKD. However, the shrinkage strain of 5% CKD concrete specimens was marginally more than that of concrete specimens without CKD. This could be related to the moisture movement from the environment to the concrete or vice versa that leads to reversible shrinkage or swell in the concrete.

5. Conclusions

From the test results discussion and analysis obtained from this research, the later conclusions can be extracted:

- SCC containing CKD with slump flow values between 550 and 750 mm can be produced by adjusting the high range water reducer dosage. Partially replacement of cement by CKD causes a decrease in the slump flow retention of the SCC mixtures.
- Although the passing ability of SCC mixes reduced by CKD inclusion, As a result of changing CKD from 0.0 to 75% replacement of cement, the blocking ratio changed from 0.9 to 0.7%, respectively.
- Concrete mixtures with 5% of CKD can achieve almost similar compressive strength, flexural and tensile strengths as that of control mixture.

- Compressive strength reduced with CKD incorporation considerably which is illustrated by the increase in the porosity as well as decrease in C_3S and C_2S contents , using CKD as a partial replacement with a percentage up to 40% from cement weight decreases compressive strength about 43 % as that of the control mixture.
- The increase in shrinkage of CKD-cement mortar happens with the increase in the CKD quantity.

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