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Research Articles

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Research Article

Mechanical properties of self-curing concrete (SCUC)

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ABSTRACT

According to lack of water, labor self curing concrete (SCUC) is necessary in construction projects. In this study, it is focuses on concrete application with new admixture to achieve SCUC. The present study involves the use of shrinkage reducing admixture polyethylene glycol (PEG 400) in concrete which helps in self curing and helps in better hydration and hence strength. The effect of admixture (PEG 400) on water retention, compressive strength, split tensile strength and modulus of rupture by varying the percentage of PEG by weight of cement from 0% to 1% were studied for M1 and M2 mixes. It was found that using PEG400 with dosage 0.3%, 0.5% gives an early strength to the concrete. It was also found that 0.5% of PEG 400 by weight of cement was the optimum for both M1 and M2 mixes.

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1. Introduction

Curing is the maintaining of a satisfactory moisture content and temperature in concrete during its early age so that desired properties (of concrete) may develop. Curing is essential in the production of concrete that will have the desired properties. The strength and durability of concrete will be fully developed only if it is cured. No action to this end is required, however, when ambient conditions of moisture, humidity, and temperature are sufficiently favorable to curing. Otherwise, specified curing measures shall be discussed (Mather, 2001).

New developments in curing of concrete are on the horizon as well. In the next century, mechanization of the placement, maintenance, and removal of curing mats and covers will advance as performance-based specifications quantify curing for acceptance and payment. In addition, effective sealants and compounds that prevent the loss of water and promote moist curing conditions will be in high demand. Self-curing concrete should become available in the future (Tikalsky et al., 2006).

1.1. Advantages of self-curing concrete

- Reduces autogenously cracking.
- Self-curing
- Reduce the permeability.
- Increases mortar strength and early age strength sufficient to withstand strain.
- Greater utilization of cement.
- Lower Maintenances.

1.2. Literature review and research objective

Junaid et al. (2015) made a comparison between the conventional cured concrete and self-curing concrete by adding admixture polyethylene glycol (PEG-4000, 1% weight of cement) in concrete which helps in self-curing and in better hydration and hence strength. The results show that the Concrete cured internally using 1% PEG-4000 attained more compressive strength than conventional cured concrete.

Indirajith et al. (2016) carried out comparative experimental tests between self-curing concrete (both external self-curing and internal self-curing) by using PEG and conventional concrete for M20, M25 and M40 grade. Self-curing concrete resulted in better hydration with time under drying condition compared to conventional concrete. Slump value increases with increase in the quantity of PEG. It was studied that the strength increases at different proportions of PEG i.e., 1% is optimum for M20 and M25 grade 0.5% for M40 grade and 0.3% for high strength self curing concrete.

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El-Dieb et al. (2012) studied the effect of using polyacrylamide (PAM) and polyethylene glycol (PEG) with a dosage of 0.02% by weight of cement as self-curing agents on the degree of hydration, water retention, permeable pores, water absorption, and microstructural characteristics of Portland cement mixes with 8% silica fume and without silica fume as cement replacement. Using PAM and PEG as self-curing agents were more effective in improving the water retention and the degree of hydration in mixes containing 8% silica fume cement replacement. The use of PAM and PEG resulted in samples with a denser microstructure, fewer and smaller crystalline hydration products, and thinner micro cracks.

Bashandy (2015) investigated the performance of ordinary concrete (OC) and self-curing concrete (SCUC) at elevated temperature from 200 ^{0}C to 600 ^{0}C , after subjected to elevated temperature, the specimens were cooled down in water or air and stored for 1 and 28 days and then mechanically tested. The test results showed that the reduction of strength of self-curing concrete increased with the exposed period and the elevated temperature. Compressive strength and tensile strength test results of SCUC always drop with elevated temperature. Air cooling is more effective compared with water cooling at high temperature.

Kumar et al. (2015) studied the effect of polyethylene glycol 200 on strength characteristics of Self-curing concrete by varying percentage from 0% to 2% by weight of cement for both M20 and M40 grades of concrete. The compressive strength increased for both PEG and PEA at 1% compared to conventional concrete for M25.

Vedhasakthi et al. (2014) investigated the strength characteristics and workability of normal and high strength concrete using polyethylene glycol (PEG) and sorbitol as self curing agents. The results show that using peg more effective than using sorbitol. There is increase in the strength of (HSSCC) high strength self curing concrete than conventionally cured high strength concrete.

Based on the above-mentioned literature review, an effort was made in the present investigation to compare the conventional cured concrete with internally cured concrete by adding water retaining admixture "polyethylene glycol" (PEG-400 0.3%, 0.5% and 1% weight of cement) which helps in self-curing and in better hydration.

2. Experimental Program

2.1. Material properties and design mix

Cement: A locally produced ordinary Portland cement complied with E.S.S.373/91 requirements was used (ECCS 373/ (1991), Specification for Ordinary Portland Cement Egyptian Standards).

Aggregates: The fine aggregate was siliceous natural sand. The coarse aggregates used was crushed dolomite of maximum nominal size 14 mm.

Fly ash: The mineral admixture used in this experimental program is fly ash under a commercial name of Supper Pozz-5 (South Africa Company for Chemical Admixtures).

Viscosity Enhancing Agent (VEA): The super-plasticizer used in this experimental program under a commercial name of Sika-Viscocrete 3425 from Sika Egypt (Sika Egypt for Construction Chemicals S. A. E. International).

Water: Ordinary potable water without acidity and alkalinity available in the laboratory was used.

Polyethylene glycol-400: PEG-400 are added at rate of 0.3%, 0.5% & 1% of cement weight.

The materials required per cubic meter of concrete is given in Table 1.

3. Experimental Setup

The experimental program investigated the strength of self curing concrete by adding poly ethylene glycol PEG400 0.3%, 0.5% and 1% by weight of cement. The experimental program was aimed to study the water retention, compressive strength, split tensile strength and modulus of rupture. To study the above properties mixes M1 and M2 were considered. The scheme of experimental program is given in Table 2.

Table 1. Materials required per cubic meter of concrete.

Specimens	MIX	Cement	Gravel	Sand	Fly ash	Superplastizer	Water	PEG %	Curing
M11		366	1128	817	19	7.7	140	-	WC
M12		366	1128	817	19	7.7	140	-	SC
M13	M1	366	1128	817	19	7.7	140	0.3	SC
M14		366	1128	817	19	7.7	140	0.5	SC
M15		366	1128	817	19	7.7	140	1.0	SC
M21		440	1220	520	-	-	154	-	WC
M22		440	1220	520	-	-	154	-	SC
M23	M2	440	1220	520	-	-	154	0.3	SC
M24		440	1220	520	-	-	154	0.5	SC
M25		440	1220	520	-	-	154	1.0	SC

Table 2. Experimental program.

Designation	Nature	M1			M2		
		Cube	Cylinder	prism	Cube	Cylinder	prism
1	Plain (water Curing)	9	9	3	9	9	3
2	Plain (Air Curing)	9	9	3	9	9	3
3	PEG 0.3%	9	9	3	9	9	3
4	PEG 0.5%	9	9	3	9	9	3
5	PEG 1%	9	9	3	9	9	3

The cube size is 100 x100 x 100 mm. The cylinder size is 100 mm in diameter and 200 mm in height. The prism size is 100 x 100 x 500 mm.

3.1. Testing

3.1.1. Water retention test

Water retention is the ability of the substance to retain water calculates according the following equation. Weight loss with age was measured to evaluate the water retention of the mix. In both mixes, the weight loss for mix without self-curing agent is more than mix including self-curing agent. This shows better water retention for self-curing mixes. The weight of cubes at different ages for M1 and M2 are shown in the Tables 3 and 4.

$$\text{Weight losses ratio } \% = (W_0 - W_1)/\, W_0 \qquad (1)$$

3.1.2. Compressive strength

The specimens were subjected to air-curing and water-curing. The cube specimens of size 100 mm X 100 mm X 100 mm were tested by compression testing machine.

$$f_c = 0.95\ P/A \quad \text{(MPa)} \qquad (2)$$

where P is the maximum load in Newton applied to the specimen and A is the cross-sectional area (mm^2).

3.1.3. Split tensile strength test

The cylinder specimens of size 150 mm diameter and 300 mm height were tested on universal testing machine and the load is applied until the failure of cylinder along the vertical diameter.

$$f_{ct} = 2P\ /\ \pi\ dl \quad \text{(MPa)} \qquad (3)$$

where P is the maximum load in Newton applied to the specimen, l is the length of the specimen (mm) and d is the cross sectional dimension of the specimen (mm).

3.1.4. Flexural strength test

It is the ability of beam to resist failure in bending. The beam specimens of size 100 mm x 100 mm x 500 mm were tested on compression testing machine. The flexural strength is expressed as modulus of rupture in N/mm^2.

$$f_b = P\,l\,/\,b\,d^2 \quad \text{(MPa)} \qquad (4)$$

where P is the maximum load in Newton applied to the specimen, l is the length of the specimen (mm), b is the breadth (mm) and d is the depth (mm) of the specimen.

Table 3. Average weight loss of cubes for Mix M1.

Designation	Curing Period (days)							Weight losses ratio
	0	3	7	10	14	20	28	
M11	0	-	0.015	-	0.024	-	0.15	-
M12	0	0.037	0.042	0.056	0.061	0.062	0.0633	1
M13	0	0.022	0.024	0.042	0.05	0.048	0.0327	0.516
M14	0	0.0245	0.0282	0.049	0.054	0.05	0.037	0.584
M15	0	0.0294	0.0314	0.052	0.057	0.056	0.0408	0.644

Table 4. Average weight loss of cubes for Mix M2.

Designation	Curing Period (days)							Weight losses ratio
	0	3	7	10	14	20	28	
M21	0	-	0.0246	-	0.028	-	0.041	-
M22	0	0.046	0.052	0.059	0.067	0.079	0.093	1
M23	0	0.023	0.026	0.029	0.034	0.041	0.051	0.5484
M24	0	0.0305	0.0334	0.036	0.042	0.049	0.06	0.6452
M25	0	0.036	0.0404	0.044	0.051	0.0607	0.068	0.73

4. Results

4.1. Water retention

From Figs. 1 and 2, it is clear that Mix M1 self-curing self compact concrete with 0.3% dosage of lower molecular weight polyethylene glycol (PEG 400) shows least weight loss compared with other dosages (0.5% and 1%). Similarly Mix 2 self-curing conventional concrete with 0.3% dosage of PEG 400 shows better water retention compared with other dosages. But when mix with lower w/c ratio together with super-plasticizer, it shows better water retention (lower value in weight loss) compared with mix with higher w/c ratio and without super-plasticizer.

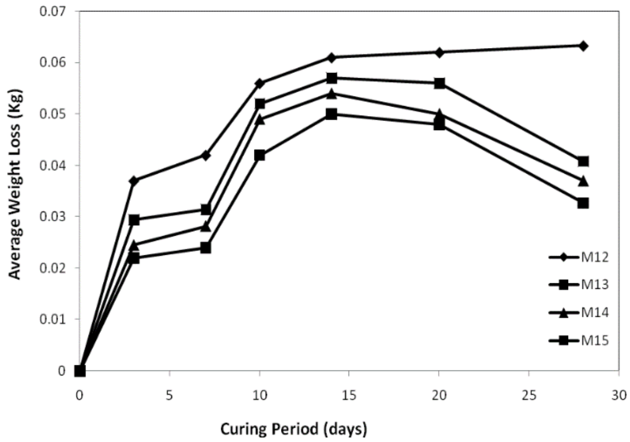

Fig. 1. The effect of polyethylene-glycol on mass loss for Mix M1.

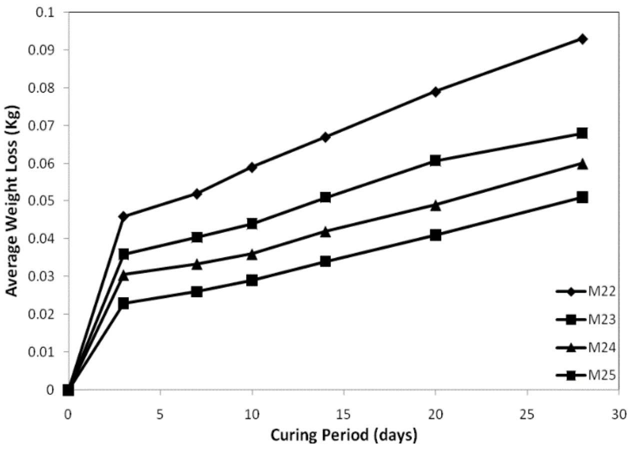

Fig. 2. The effect of polyethylene-glycol on mass loss for Mix M2.

4.2. Compressive strength

The strength parameters of mixes M1 and M2 were compared using water curing and air curing at 7 days, 14 days and 28 days. Self compact concrete cured internally using 0.3%, 0.5% and 1% PEG-400 attained more compressive strength than conventional concrete. The results of the compressive strength are represented in Tables 5 and 6. The compressive strength was found to increase up to 0.5% PEG400 and then decreased for M1 & M2. The increase in compressive strength is 17.17% at 0.5% of PEG 400 compared with plain concrete curing in air for M1, while the increase is 10.66% at 0.5% of PEG400 in case of M2. We note that the use of 0.3% and 0.5% Polyethylene-Glycol PEG400 gives an early resistance to the concrete at 7 days by 0.84% of the compressive strength of concrete in case of M1. Using the same proportions (0.3% and 0.5%) in the mixture M2 gives early resistance at 7 days by 78%, 82% respectively of the compressive strength of concrete. Fig. 3 shows comparison of compressive strength for self-curing concrete mixes and conventional concrete mixes.

Table 5. Compressive strength of Mix M1.

Designation	Days (MPa)		
	7	14	28
M11	28.6	37.27	43.3
M12	27.88	38.67	43.14
M13	34.19	38.98	40.65
M14	42.48	47.57	50.55
M15	26.13	30.99	39.34

Table 6. Compressive strength of Mix M2.

Designation	Days (MPa)		
	7	14	28
M21	23.28	29.49	33.42
M22	18.21	30.68	33.75
M23	28.52	33.84	36.3
M24	30.83	34.4	37.35
M25	17.66	26.31	28.75

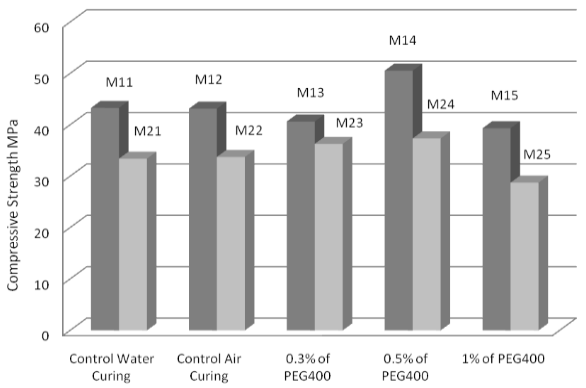

Fig. 3. Comparison of compressive strength for self-curing concrete mixes and conventional concrete mixes.

4.3. Splitting tensile strength

The results of the split tensile strength are represented in Table 7 and the graphical representations are shown in Figs. 4-6. The split tensile strength was found to increase at 0.5% PEG400 and then decreased for M1. In the case of M2 split tensile strength increased at 0.5% and then decreased. The increase in split tensile strength was 25.6% at 0.5% of PEG400 compared with plain concrete curing in air for M1, while the increase is 3.08% at 0.5% of PEG400 in case of M2.

Table 7. Splitting tensile strength of M1 & M2 self curing concrete.

Designation	Days (MPa)			Designation	Days (MPa)		
	7	14	28		7	14	28
M11	3.66	4.52	4.81	M21	3.08	3.573	4.08
M12	2.83	3.887	4.055	M22	2.66	3.44	4.084
M13	3.795	4.215	4.059	M23	3.429	3.57	3.93
M14	3.601	4.917	5.094	M24	2.81	3.76	4.21
M15	3.42	3.79	4.12	M25	2.816	2.95	3.03

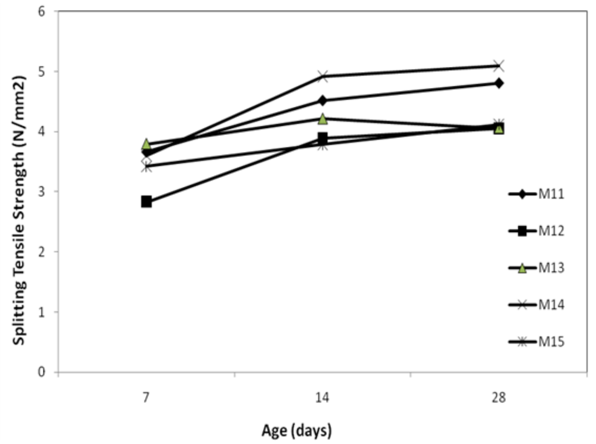

Fig. 4. The effect of polyethylene-glycol content on splitting tensile strength for Mix M1.

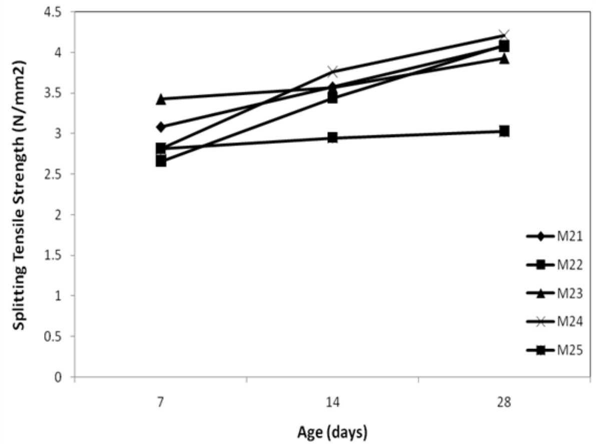

Fig. 5. The effect of polyethylene-glycol content on splitting tensile strength for Mix M2.

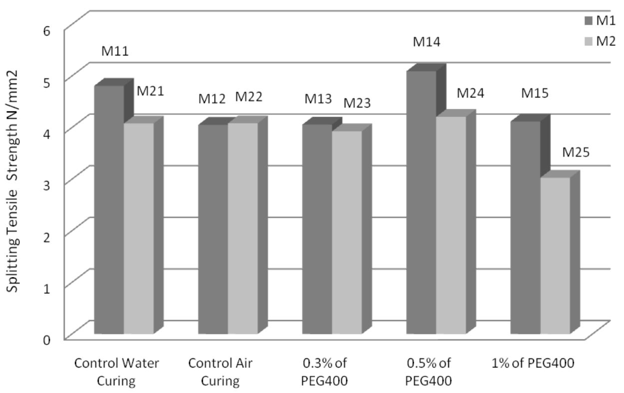

Fig. 6. Comparison of splitting tensile strength for self-curing concrete and conventional concrete mixes.

4.4. Modulus of rupture

The results of the modulus of rupture are represented in Table 8 and the variation of modulus of rupture is shown in Fig. 7. The modulus of rupture was found to decrease up to 0.5% PEG400 and then increased for M1. In the case of M2 modulus of rupture increased up to 0.5% and then decreased. The decrease in modulus of rupture was 13.5% at 0.5% of PEG 400 compared to plain concrete curing at air for M1, while the increase is 2.92% at 0.5% of PEG400 in case of M2 of concrete.

Table 8. Modulus of rupture.

No.	Designation	f_{rup} (MPa) at 28 days	
		M1	M2
1	Plain (Water Curing)	8.475	8.1
2	Plain (air Curing)	8.5	6.85
3	0.3% PEG	7.8	6.5
4	0.5% PEG	7.35	7.05
5	1% PEG	7.95	6.05

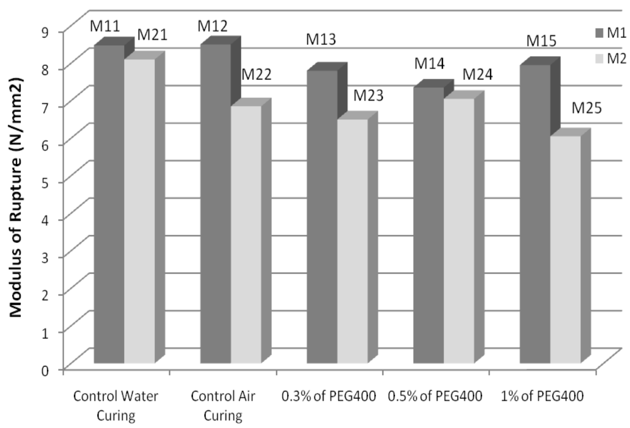

Fig. 7. Comparison of modulus of rupture for self-curing concrete and conventional concrete mixes.

5. Conclusions

- Self-Cured Concrete (SCUC) gives better strength than Conventionally Cured once till 14 days, after that for 28 days results are almost the same for both concrete.
- The optimum dosage of PEG400 self curing agents for maximum strengths (compressive, tensile and modulus of rupture) was found to be 0.5% for M1 & M2 concrete mixes.

- For Mix M1 & M2 self-curing self compact concrete with 0.3% dosage PEG 400 shows least weight loss compare to other dosages.
- Generally Water retention of concrete mixes incorporating PEG 400 is higher compared to conventional concrete mixes.
- Using PEG400 with dosage 0.3%, 0.5% gives an early strength to the concrete at 7 days by 0.80% of the compressive strength of concrete.
- Self curing concrete is the answer to many problems faced due to lack of proper curing, less labor and harsh environmental conditions in addition to hot and dry weathering conditions.

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Research Article

Steel scrap added roller compacted concrete

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ABSTRACT

The purpose of this paper is to investigate the benefits of using steel slag as an additive in Roller Compacted Concrete (RCC) which is a promising material can be used in streets, local roads, residential streets, high-volume roads, industrial access roads, airports...etc. The mechanical performances of steel scrap added reinforced cementitious composites produced with an industrial punch scrap. In specimen mixtures two types of scraps with diameters of 5 mm and 7 mm were used. The additive was mixed with 1%, 1.5% and 2% ratios by weight. Due to the results of the study, it was obtained that flexural strength properties of the specimens have increased up to 11%. In addition, freeze thaw effect of the specimens was investigated and found that 2% percent of scrap usage was given the best results.

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1. Introduction

Beside the base pavement design performance, RCC pavement has cheaper and faster producibility than conventional concrete pavements due to its properties (PCA, 2010). RCC also has a high flexural strength, high abrasion resistance and a better resistance for high temperature compared to the traditional pavements (Rao et al., 2014). RCC is produced with cementitious materials, aggregate and a low amount of water that is applied with asphalt pavers, compacted by vibratory rollers and hardens into concrete (Hossain and Ozyildirim, 2015). In RCC pavement design there is no need for forming, finishing, joint sawing or surface texturing and in a short period of time the produced road can open to traffic (PCA, 2010; Hossain and Ozyildirim, 2015). RCC is easy in transporting, laying and compacting, comparing to conventional concrete pavement production (Toplicic-Ćurcic et al., 2015). RCC also have a higher percentage of fine aggregates than conventional concrete which allows for tight packing and consolidation. RCC has been used for pavements traditionally to carry heavy vehicle loads in low-speed areas, due to its relatively coarse surface (Wu et al., 2017). RCC can be used also in ports, airports, military installations, intermodal facilities, warehouses, manufacturing facilities commercial and industrial parking lots, maintenance and storage yards, highway frontage roads and shoulders, minor arterials, local streets and roads (ACPA, 2014; FHWA, 2016).

The first RCC pavement usage in United States was at an airfield in Yakima, WA, in 1942; however, at early 1930s RCCP construction was reported in Sweden and Australia (Modarres et al., 2018; Ludwig et al., 1994). RCC pavement construction projects started to increase in number after mid-1980's (Ludwig et al., 1994).

Normally there is no need a wearing course for RCC pavements however in some cases a Hot Mix Asphalt (HMA) overlay has been added for smoothness or rehabilitation (ACI 325, 2001). The use of RCC base with a HMA overlay as a composite system gaining popularity to improve ride quality and saving money while still providing a durable pavement structure (PCA, 2009).

The Vebe test provides for determining RCC workability. RCC workability can measure by Vebe test, a simple and fast evaluation technique, according to ASTM C1170. For RCC workability the field experiences shown that generally fall between 40 and 90 sec is adequate when RCC is placed (Khayat and Libre, 2014; ASTM C1170, 1998).

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RCC pavements have performed well and meet the required properties to carry heavy loads under both freezing conditions, such as in Canada, and in hot conditions such as in the southern United States (Delatte et al., 2003).

The study notes that non–air entrained RCC pavements can provide reliable and durable performance in F-T environments as long as the mix has adequate cement content, sound aggregates, proper mixing, adequate compaction, and proper curing. Field performance studies have indicated that RCC has performed well in harsh weather conditions. Studies in the United States and Canada indicate that RCC mixtures, whether air entrained or not, have performed well for more than three decades (Harrington et al., 2010).

There are also some studies on literature on steel additives for RCC. In a study, a new mix design method for determining the optimal water content, the modified light compaction method, is proposed for steel fibre reinforced, roller-compacted, polymer modified, bonded concrete overlays (Lin et al., 2013). Moreover, in Coventry University a new steel-fibre reinforced, roller compacted, polymer modified concrete mix was investigated and the results have addressed a suitable mixture for the structural repair of concrete pavements has been developed. The developed mixture has shown exhibiting high flexural, shear and bond strengths and high resistance to reflection cracking, the mixture also demonstrated unique placeability and compaction properties (Karadelis and Lin, 2015).

2. Materials and Method

2.1. Materials

In this study, river sand and crushed rock were used as fine and coarse aggregates. Material properties of the aggregates are given in Table 1.

Table 1. Material properties of aggregates.

Material Property	Coarse Aggregates	Fine Aggregates
Specific gravity, t/m3	7.8	2.64
Fineness modulus	2.73	2.68
Silt content, %	-	0.72
Water absorption, %	0.42	0.12
Total moisture, %	0.41	0.10

Aggregates were air dried and cleaned from any organic content. Potable water was added into the RCC mixtures. Aggregate gradation curves can be found in Fig. 1.

CEM I type Portland cement complying TS EN 196 standard was used as the binder component of the RCC mixes. Chemical and physical properties of the cement are presented in Table 2.

Table 2. Chemical and physical properties of the cement.

Chemical and physical property	
Fe_2O_3, %	3.52
CaO, %	60.22
MgO, %	2.30
SO_3, %	2.61
Al_2O_3, %	4.32
Free CaO, %	1.7
Loss on ignition	2.85
Specific gravity, t/m^3	3.12
Soundness	0.5
Blaine number, cm^2/g	3618
Setting time (initial, final), min.	172, 228

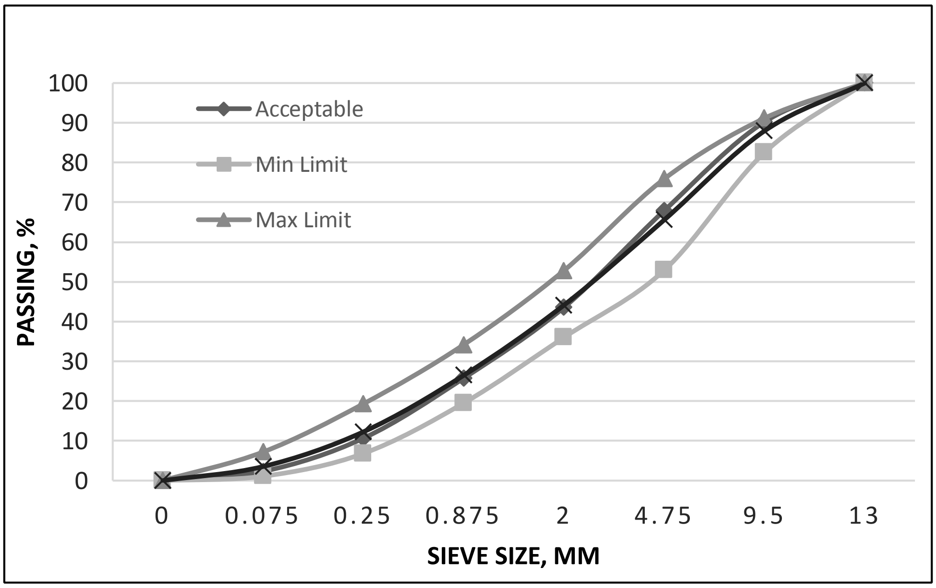

Fig. 1. Aggregate gradation curve.

AISI 304 type austenitic and stainless-steel staple scraps (5mm and 7 mm) were used in this study at 1%, 1.5% and 2% by weight. Chemical and mechanical properties of the scraps are given in Tables 3 and 4, respectively.

Table 3. Chemical properties of the scraps (AISI 304).

Material (% wt.)	AISI 304
C	0.58
Mn	1.62
Si	0.15
Cr	19.06
S	0.03
P	0.09
Ni	9.67
Balance / Fe	68.81

Table 4. Mechanical properties of the scraps (AISI 304).

Mechanical Property	
Tensile Strength (N/mm2)	505
Yield Strength (N/mm2)	215
Hardness (HRB)	70
Density (gr/cm3)	8

5 mm and 7 mm AISI 304 stainless steel pin scrap are presented in Figs. 2 and 3, respectively.

Fig. 2. 5 mm AISI 304 stainless steel pin scrap.

Fig. 3. 7 mm AISI 304 stainless steel pin scrap.

2.2. Preparation of test specimens

All RCC mixes have the same cement content as 310 kg/m3. Optimum water contents were determined according to the ASTM C1435 standard. Experimental sets and optimum water contents of the RCC mixes are given in Table 5.

Table 5. Experimental sets.

Mixture Code	W/C	Optimum water content, %	Scrap content, % wt.	Compaction ratio, %
R	0.44	5.30	0	100
S_{5-1}	0.45	5.43	1	99
$S_{5-1.5}$	0.46	5.57	1.5	100
S_{5-2}	0.47	5.67	2	99
S_{7-1}	0.48	5.45	1	100
$S_{7-1.5}$	0.50	5.60	1.5	100
S_{7-2}	0.51	5.68	2	100

Compaction process was applied to the RCC specimens with a compactor as per the requirements of the ASTM C 1435 standard. The F&T resistance of the mixes was recorded according to the ASTM C 666 standard. Compressive and flexural strength tests were applied to the specimens as per the regulations of EN 12390-3, EN 12390-5 standards. Workability of the RCC mixes was determined with the aid of Ve-Be test equipment. The mixer rate was kept constant at the rate of 350 r/min.

3. Experimental Results and Discussions

3.1. Compressive strength test results

Compressive strength test results are given in Fig. 4. Test results for 28 days vary between 39.64 MPa and 39.19 MPa. 2% punch scrap addition showed the best performance compared to the other scrap inclusions. Scrap addition slightly improved the compressive strength values. 7 mm scrap addition with the weight of 2% reflected the best performance as 39.64 MPa.

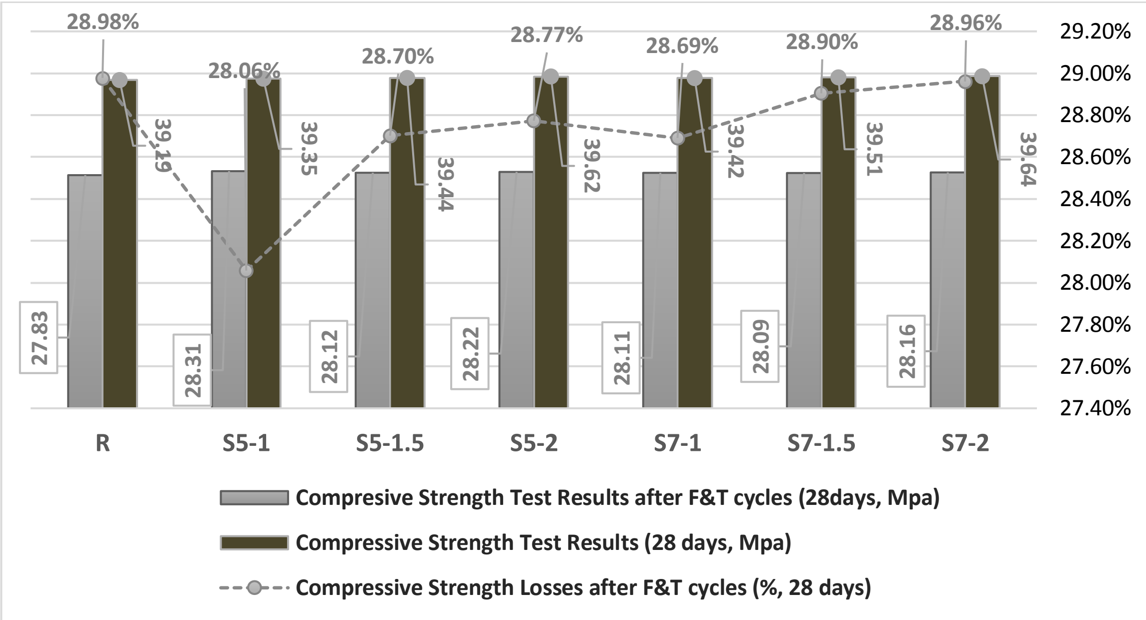

Fig. 4. Compressive strength losses after F&T cycles.

The compressive strength deformation curves of the RCC specimens are given in Fig. 5. It was observed that toughness values of the mixes slightly increased with the scrap addition.

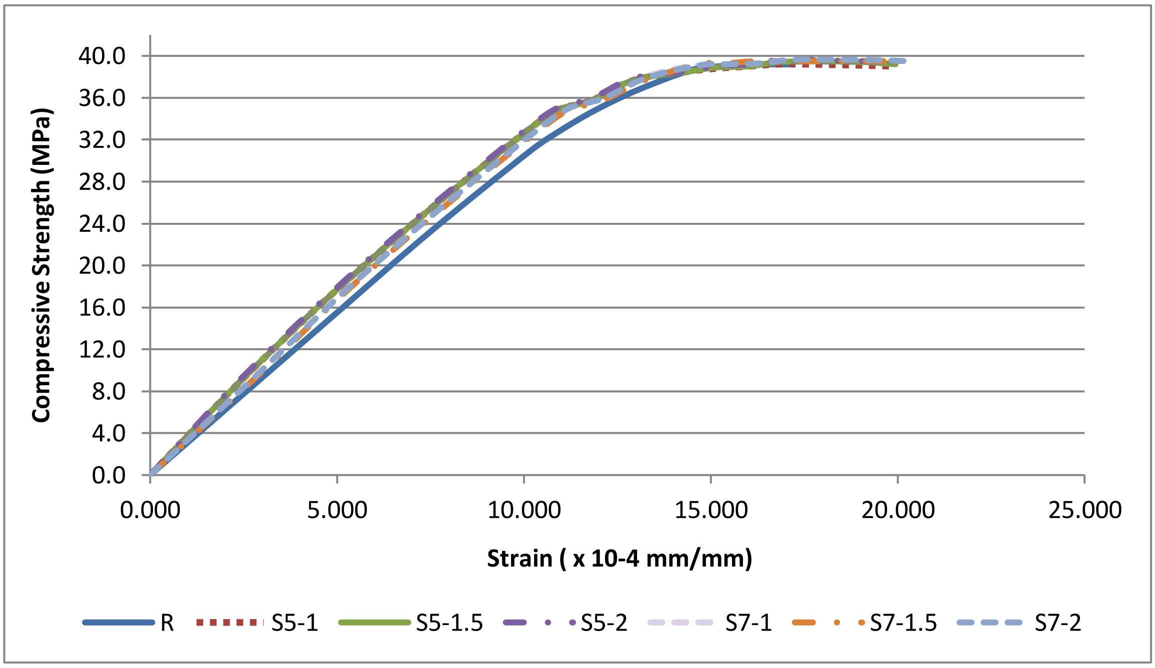

Fig. 5. Compressive strength and strain relation.

3.2. Flexural strength test results

The flexural strength test results are presented in Fig. 7. 28-days flexural strength values are increased by 10% with the 7 mm and 2% wt. Scrap addition. Scrap addition generally enhanced the flexural test results compared to the reference mix. The freeze and thaw resistance results can be found in Figs. 4 and 6 for both compressive and flexural tests. Scrap addition improved the F&T resistance of the RCC mixes

3.3. Ve-Be Results

Ve-Be test results are given in Fig. 7. Reference specimen with no scrap content showed the best performance. Obtained Ve-Be results decreased with the increasing scrap content of the RCC mixes.

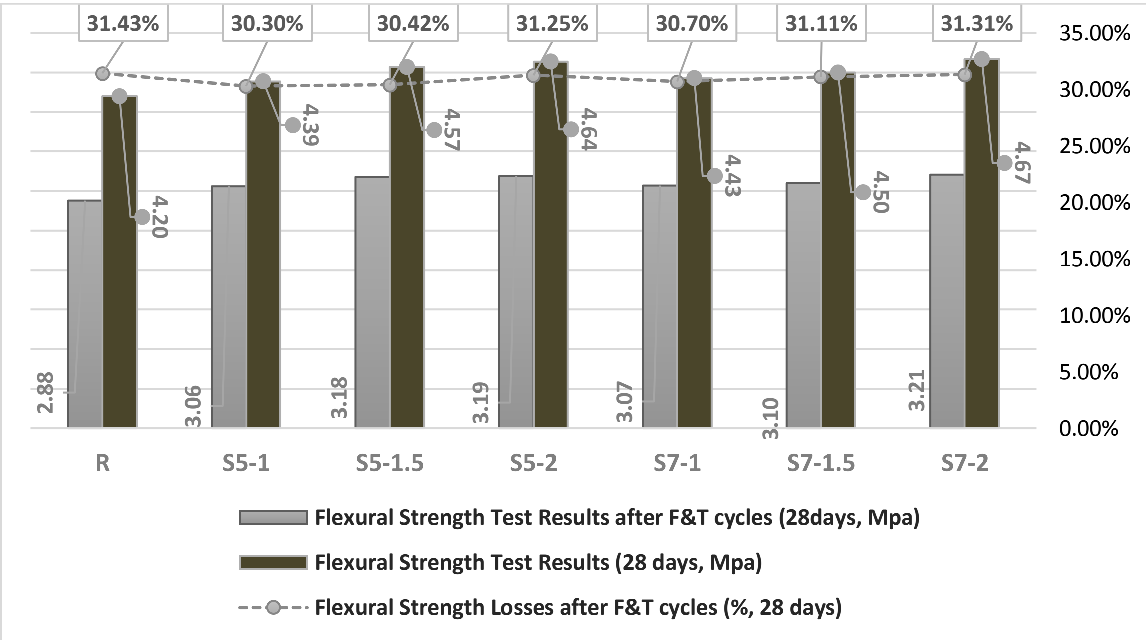

Fig. 6. Flexural strength losses after F&T cycles.

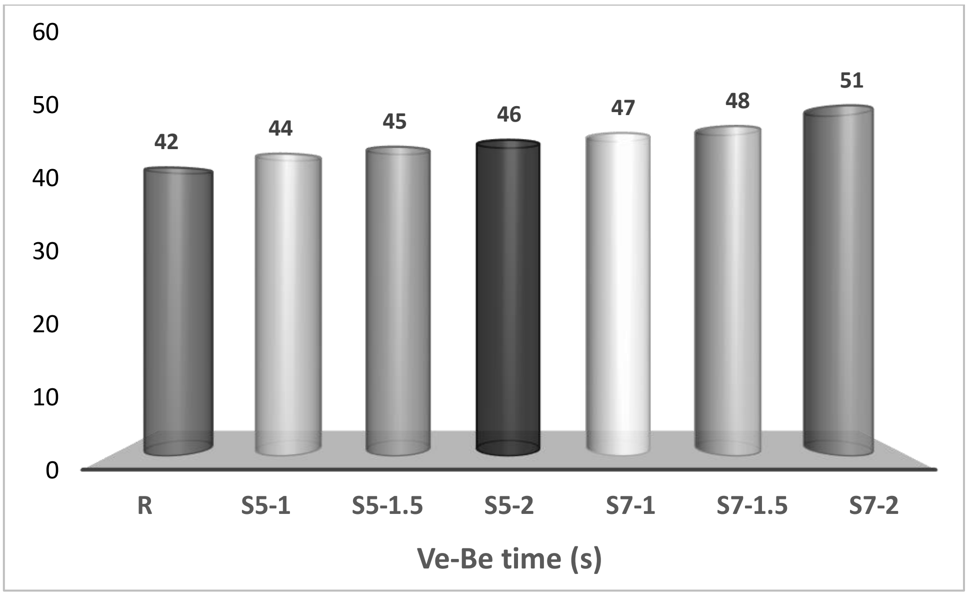

Fig. 7. Ve-Be test results.

4. Conclusions

The effect of industrial punch tool scrap on the mechanical and workability behavior of RCC mixes was studied within the scope of this research. The following findings can be concluded:

- The addition of scraps increased the water demand of the RCC mixtures. Water to cement ratio of the mixes was also increased.
- Scrap addition slightly increased the compressive strength test results. However, flexural strength performance of mixes significantly improved with the scrap addition.
- Scrap with 7mm diameter showed the best performance for all mechanical test compared to the reference and the mixes including 5 mm diameter scrap.
- Scrap addition slightly improved the F&T resistance of the RCC mixes.

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Research Article

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

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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

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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.

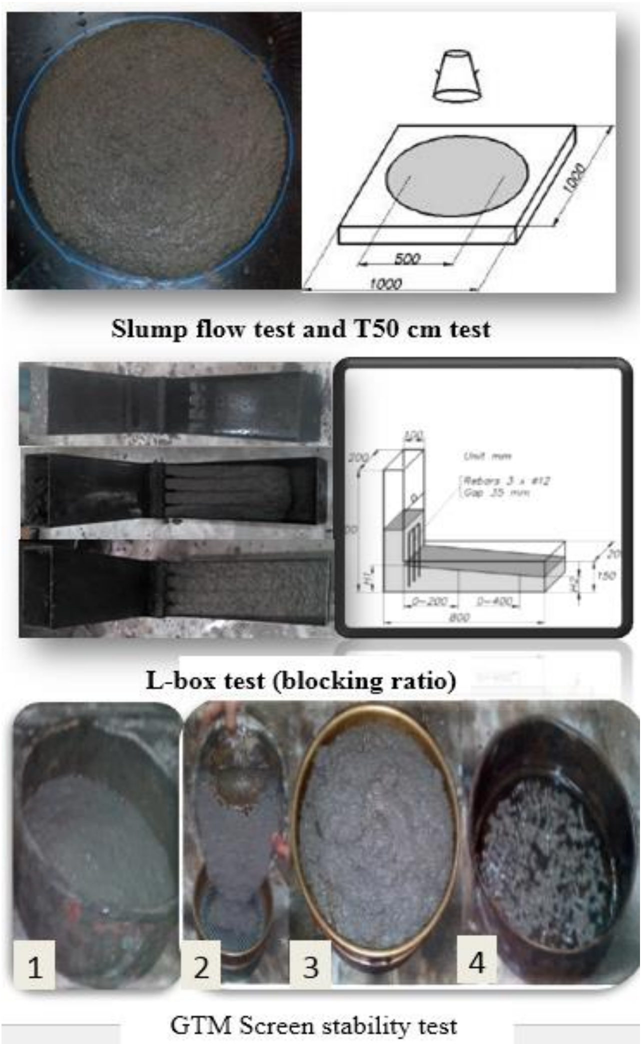

Fig. 2. Fresh properties test.

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%.

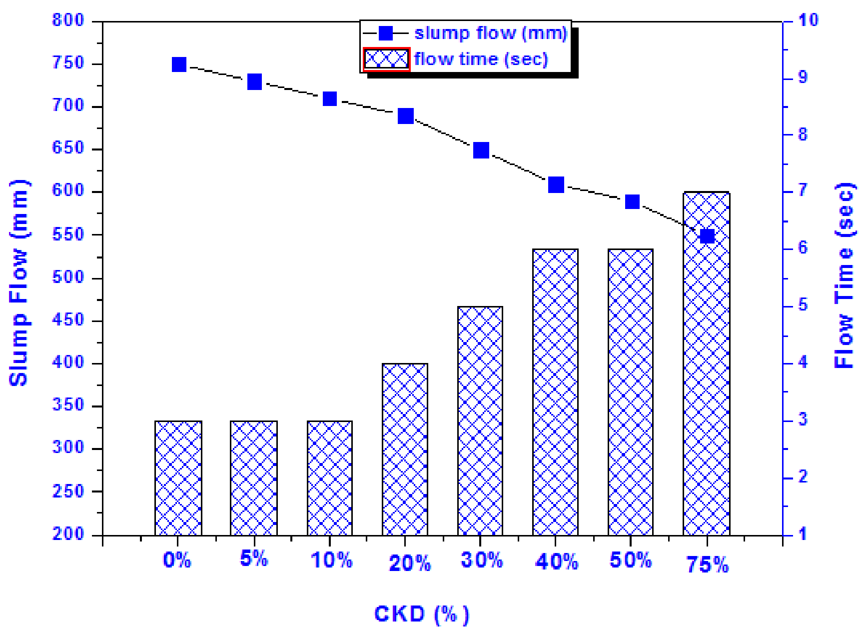

Fig. 3. Relation between slump flow and CKD (%).

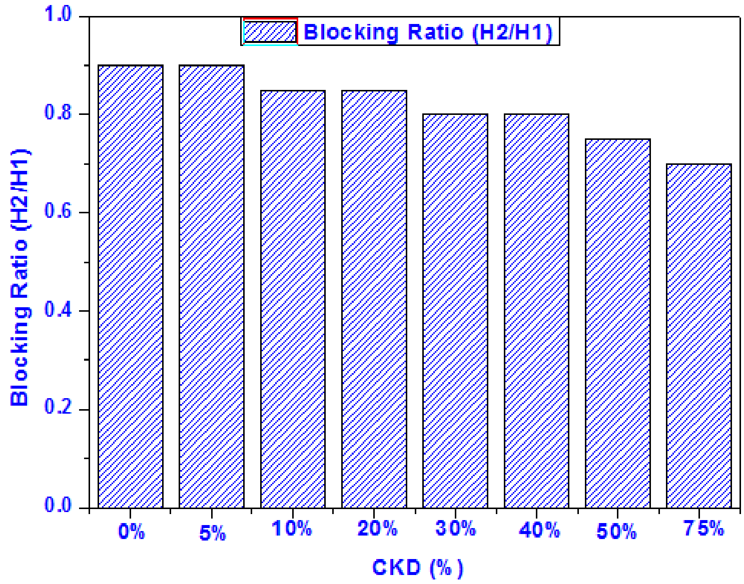

Fig. 4. Relation between blocking ratio and CKD (%).

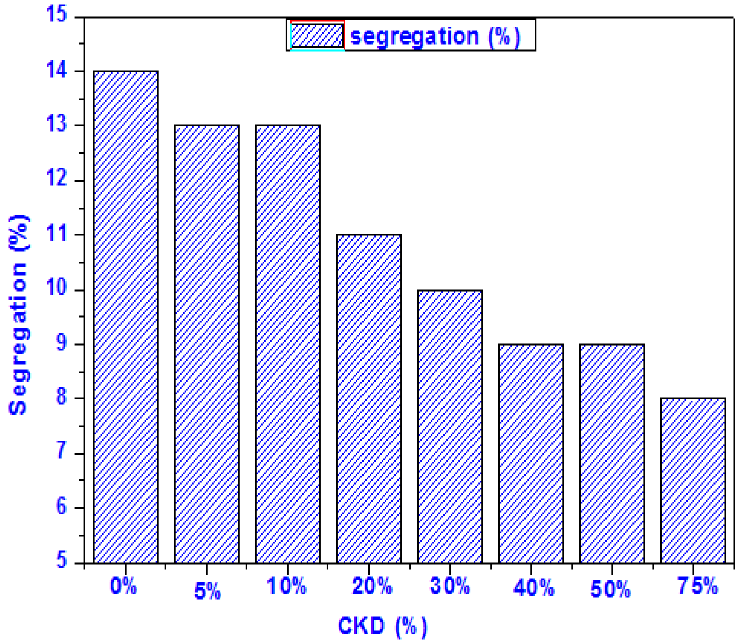

Fig. 5. Relation between segregation ratio and CKD.

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

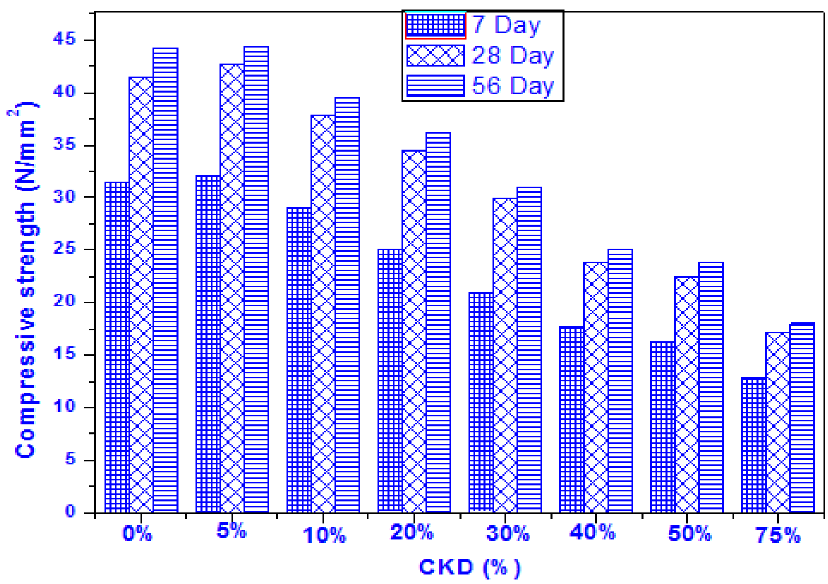

Fig. 6. Relationship between compressive strength and CKD (%).

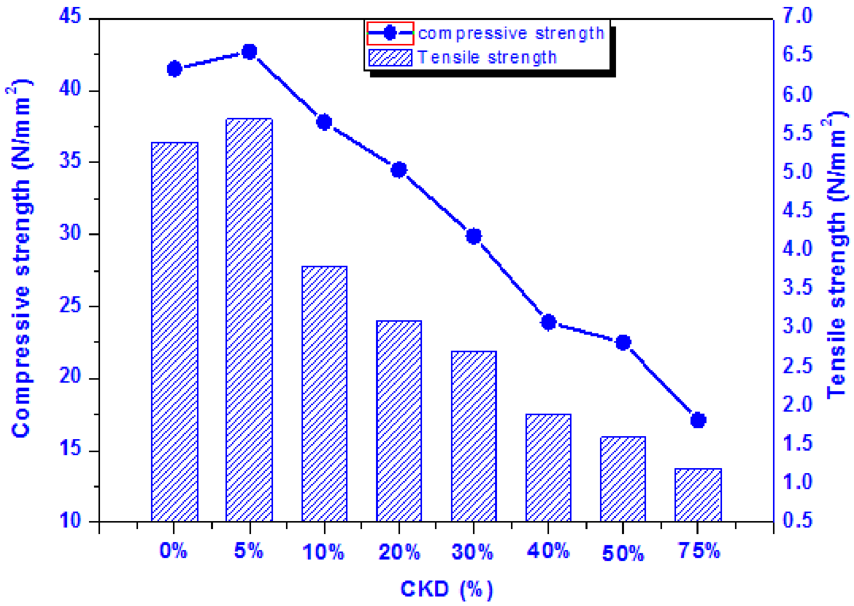

Fig. 7. Relationship between compressive, tensile strength and CKD (%).

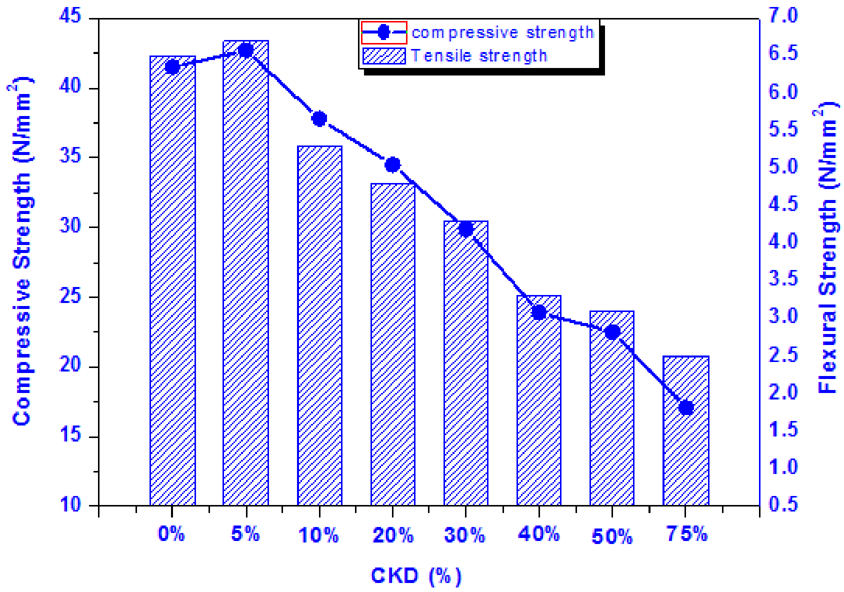

Fig. 8. Relationship between compressive, flexural strength and CKD (%).

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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