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Investigation of adding cement kiln dust (CKD) in ordinary and lightweight concrete

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Abstract. Cement kiln dust (CKD) is one of the most important waste materials in the cement industry. The large amount of this material, has encouraged researchers to propose new ways to recycle and reuse it. In this paper, effects of adding cement kiln dust to the ordinary Portland cement, on the physical and mechanical properties of ordinary and lightweight concrete were investigated. Results showed that concrete containing CKD, presents lower workability and modulus of elasticity; however, improvements in strength was observed by adding particular amounts of CKD. Eventually, it was found that adding 10% of cement weight CKD is the appropriate percentage for utilizing in manufacturing ordinary and lightweight concrete.

Keywords: cement kiln dust; concrete; mechanical properties; compressive properties; lightweight concrete

1. Introduction

Developments in technologies and construction industries have always been accompanied with the amount and the type of the waste material produced. This has led to the crisis of managing these wastes. Most of the waste materials are non-disposal and remain in the environment for a long time. This has encouraged many researchers around the world to find new ways to recycle and reuse them. Generally, utilizing waste products in concrete receives a high interest due to the long usable lifespan of concrete and it appears that the incorporation of waste materials in concrete is a safely way of disposing them (Sharma and Bansal 2016).

In the cement industry as well as other industries, management of the waste materials is a matter of concern. Large quantities of cement kiln dust (CKD) are produced during the manufacturing of cement clinker by the dry process. “The bulk of this dust, containing high alkali contents, is land filled with a significant financial loss to the local cement plant in terms of the value of raw materials, processing, and energy consumption during pyro processing, dust collection, and disposal” (Daous 2004). These factors have made CKD one of the most important by-products in the cement industry.

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Therefore, alternative applications of CKD, including industrial applications are sought and reported in the literature. A general review of these methods is provided (Bhatty 1995, Siddique 2006, Siddique and Rajor 2012, Taha *et al.* 2004). Utilization of cement kiln dust in soil stabilization, waste treatment, and cement replacement has been investigated in several research (Anwar Hossain 2011, Baghdadi *et al.* 1995, Bassani *et al.* 2016). Furthermore, due to the absorptivity of CKD, it is commonly used for treatment and solidification of different waste materials such as wastewater sludge, sewage and oil sludge (Morgan *et al.* 1984).

Several research have investigated the characteristics of blended cement containing CKD. Maslehuddin *et al*. (2008) reported that cements blended with CKD had reductions in initial and final setting times and workability. Furthermore, the compressive strength and drying shrinkage of CKD cements increased compared to Type I cement. It was demonstrated that utilizing up to 10% CKD as partial replacement of cement, does not have negative effects on the properties of the resulting cement. Bhatty (1984), Bhatty and Muhammad (1985) investigated the addition of slag and fly-ash to improve the properties of blended cements containing CKD. Addition of slag lowered workability but improved blends' strength due to activating the high lime content of CKD and addition of fly-ash reduced the alkali contents and increased the strength of the blended cement.

A great piece of work has considered the effects of CKD on the properties of concrete and mortar mixtures. The effects of using CKD as a cost effective additive in blended cement, mortar and concrete, was investigated by (Wang and Ramakrishnan 1990). Properties of mortar, fresh and hardened concrete, including shrinkage, creep and durability were determined. The test results showed that replacing 5% of the cement weight with CKD, slightly increases shrinkage and creep and imposes greater setting time compared to the control concrete, but does not adversely affect other properties of mortar or concrete.

Najim *et al*. (2014) studied the feasibility of using CKD as a cement replacement in concrete mortar production. For this purpose, specimens containing various CKD contents, in addition to a reference mortar were manufactured and chemical and some physical properties were evaluated. Results showed that there is an increase in mortar porosity with CKD replacement and this was in parallel decrease in mortar strength.

Udoeyo and Hyee (2002) investigated the effects of CKD as a substitution of ordinary cement, on the strength of ordinary concrete. Specimens containing 20%, 40%, 60% and 80% substitution of cement with CKD and a control specimen were prepared. Results indicated that the strength of concrete containing CKD, including compressive, splitting tensile and flexural strength decreased with respect to the conventional concrete. Minimum reduction was reported at 20% substitution. Moreover, it was reported that the initial and final setting times were increased with the amount of CKD content.

Al-Harthy *et al*. (2003) investigated the effects of CKD on concrete and mortar mixtures in different ratios as a substitution. It was concluded that in lower ratios of substituting cement with CKD, no negative effect on strength is observed; however, a decrease in strength is expected as the quantity of CKD increases.

Maslehuddin *et al*. (2009) evaluated the properties of CKD blended cement concrete. The mechanical properties of CKD concrete specimens were evaluated by determining compressive strength and drying shrinkage. Results showed that the compressive strength of concrete specimens decreased with the quantity of CKD. Additionally, in order to avoid reinforcement corrosion, it was suggested to limit the amount of CKD replacement to 5%.

Abdulabbas (2013) investigated the utilization of CKD in concrete manufacturing. For this

Table 1 Chemical properties of cement

Component	Portland cement type Π	
	Test result	ISIRI 389 Iranian standard
SiO_2	21.9	>20
Al_2O_3	4.86	<6
Fe_2O_3	3.3	<6
CaO	65	-
MgO	1.15	<5
SO_3	2.10	<3
K_2O	0.56	-
Na_2O	0.36	-
Free CaO	-	-
Blaine (cm^2/g)	3050	-

purpose, concrete specimens were prepared with different CKD ratios in two cases, one as a replacement of cement weight and the other as an addition. Results indicated that workability was decreased. The compressive and splitting tensile strength increased in the concrete mixtures including 10% and 20% CKD as an addition of cement weight. In contrast, reduction in the mechanical properties was noticed in the concrete mixtures including 10% and 20% CKD as a replacement of cement weight.

In this paper, with a more comprehensive approach, the effects of adding cement kiln dust (CKD) to the Portland cement, on the mechanical and physical properties of ordinary and lightweight concrete were investigated. Furthermore, by considering specimens with different CKD contents, this study aimed at determining the appropriate amount of CKD for utilizing in manufacturing ordinary and lightweight concrete. In order to have comparable results with similar studies Abdulabbas (2013), specimens containing 10%, 20%, and 30% CKD as an addition of cement weight and a reference concrete in each case were prepared. Properties of fresh concrete were investigated by conducting slump test. Effects of adding CKD on the mechanical properties were studied through an experimental program in which, compressive, splitting tensile, modulus of rupture and modulus of elasticity of the specimens were measured. Additionally, flexural strength of concrete beam specimen was determined by using the universal test machine. Eventually, based on the experimental results, the appropriate percentage of CKD for utilizing in ordinary and lightweight concrete was determined.

2. Materials and experimental program

2.1 Cement

Cement used in this investigation is Portland cement type II, which is produced in Mazandaran Cement Factory located in north of Iran. Its density is 3.14 g/cm^3 and the specific surface area (Blaine surface) is 3050 cm^2/g. The chemical composition and the limitations provided by the Iranian standard (ISIRI 389) are given in Table 1.

Table 2 Physical characteristics of the fine (sand) and coarse (gravel) aggregates

Aggregate	Gravel	Sand
Specific gravity (g/cm^3)	2.51	2.75
Unit weight (Kg/m^3)	1581.3	1728.9
Moisture content (%)	0.2	0.4
Moisture of saturated surface dry (%)	0.5	0.7
Fineness modulus (F.M)	-	2.88
Sand Equivalent Value (S.E) (%)	-	86

Table 3 Sieve analysis results for LECA

Sieve size (mm)	Passing percentage (%)	ASTM limits (%)
12.5	100	100
9.5	83	80-100
4.75	19.5	5-40
2.63	5	0-20
1.19	2.1	0-10

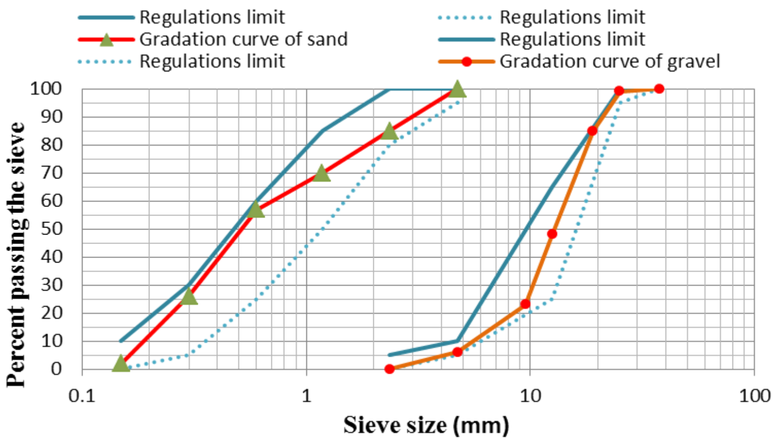

Fig. 1 Gradation curve of fine and coarse Aggregates with ASTM C33 standard limits

2.2 Aggregates

In order to manufacture concrete specimens, an amount of coarse and fine aggregates with specific gravity in saturated surface dry (SSD) state of 2.51 g/cm^3 and 2.75 g/cm^3 were used which were determined according to (ASTM C127-15 2015) and (ASTM C128-15 2015). The chemical and physical characteristics of aggregates are given in Table 2, while Fig. 1 shows the gradation results according to (ASTM C33/C33M-16 2016). Furthermore, the sand equivalent value was determined in accordance with (ASTM D2419-02 2002) and as it can be observed its value satisfies the standard limits for concrete manufacturing. For lightweight concrete, light expanded clay aggregate (LECA) produced in LECA factory (Saveh, Iran) with dry compacted density of 740 kg/m^3, was used. The sieve analysis was conducted for LECA aggregates, according to

Table 4 Chemical analysis results (Documentary of mazandaran cement plant lab results)

Component	Comp. (%)
SiO_2	11.48
Al_2O_3	2.83
Fe_2O_3	1.99
CaO	43.3
MgO	0.68
SO_3	-
K_2O	0.44
Na_2O	0.22
Cl	-
LOI	38.3
Total	99.24

Table 5 Gradation of CKD

Size (mm)	0.075	0.05	0.04	0.03	0.02	0.01	0.005
Passing (%)	100	72	58	48	35	18	11

(ASTM C330/C330M-14 2014) and the results are presented in Table 3.

2.3 Cement kiln dust (CKD)

Cement kiln dust (CKD) is produced during the process of cement production in kilns. These particles are industrial waste in factories. However, in recent years, with the change of European standards it has been used as a percentage of the raw materials in clinker production. CKD used in this investigation was prepared from Mazandaran Cement Factory. The results of the chemical analysis and gradation of CKD are presented in Table 4 and Table 5, respectively. As it can be observed, the main differences between CKD and the ordinary cement are related to lime content and Loss on Ignition (LOI) value.

2.4 Concrete mix design

The mixture proportions of concrete components were determined according to (ACI Committee 211 1991) and (ACI Committee 211 1998) for ordinary concrete (OC) and lightweight concrete (LWC), respectively. The mix design of the control concrete, ordinary CKD concrete (OCC), and lightweight CKD concrete (LWCC) containing different CKD percentages are given in Table 6. It should be noted that for lightweight concrete, Metakaolin has been included in the mix design, since it is highly effective in enhancing the compressive strength and durability (Kim *et al.* 2012).

In order to mix the substances together, the following procedure is adopted. First, the gravel is poured in the mixer. It should be noted that for a proper mixture, cement and CKD were mixed manually in a separate container and then they were added to the mixture. Afterwards, Metakaolin (if included) was added and eventually, sand was poured in. The required water and high range

Table 6 Concrete mix designs for ordinary and lightweight concrete

Component	Content (kg/m^3)							
	0% CKD		10% CKD		20% CKD		30% CKD	
	OC	LWC	OCC	LWCC	OCC	LWCC	OCC	LWCC
Cement	448	400	448	400	448	400	448	400
Water	215	148	236.5	162.8	258	177.6	279.5	192.4
Gravel	821	-	821	-	821	-	821	-
Sand	831	700	831	700	831	700	831	700
CKD	-	-	44.8	40	89.6	80	134.4	120
LECA	-	428	-	428	-	428	-	428
HRWR (L/m^3)	-	3.2	-	3.52	-	3.84	-	4.16
Metakaolin	-	120	-	120	-	120	-	120

water reducer (HRWR) (if included) were added during the mixing process. It is noticeable that the materials mix duration was increased with the amount of CKD.

As given in Table 6, control samples with a w/c ratio of 0.48 and 0.37 and the cement content of 448 kg/m^3 and 400 kg/m^3 were designed to achieve 35 MPa and 21 MPa average 28-day compressive strength of a standard cylindrical specimen for ordinary and lightweight concrete, respectively. The physical and mechanical properties of the concrete samples containing 10%, 20%, and 30% of cement weight CKD were compared with the aforementioned control samples.
( )

2.5 Methods

In this section, a summary of samples preparation and test procedures is provided. After the mixing process is completed, the mixture is poured in the desired mold and is compacted by means of a standard rod. All samples were extruded after one day and they were cured at the temperature of 30℃ in a water tank according to (ASTM C192/C192M-16 2016). In order to evaluate the fresh concrete properties, slump test based on (ASTM C143/C143M-15a 2015) was conducted. This test is introduced to measure the mixture consistency in the fresh mode and could be considered as a criterion for the concrete flow and workability. This test was developed in the USA and due to its simplicity, it is widely used in construction sites all over the world.

In order to evaluate the strength of the hardened concrete, compressive and splitting tensile strength tests are defined for the cylindrical samples according to (ASTM C39/C39M-16 2016) and (ASTM C496/C496M-11 2004). In the compressive strength test, concrete samples are axially loaded in compression by means of an automatic hydraulic jack, with a specified pace of loading, until they reach their ultimate strength. The compressive strength is calculated by dividing the maximum load to its cross-section area.

The splitting tensile strength test is conducted on standard cylindrical samples with the dimensions of 15 cm×30 cm. In this test, the specimen is horizontally placed in a special ring and the force is applied along the cylinder’s vertical axis constantly, until the fracture happens (ASTM C496/C496M-11 2004).

In order to evaluate the modulus of elasticity, cylindrical samples were cast and tested according to (ASTM C469/C469M-14 2014). For this purpose, each sample is placed in a special ring including a dial gauge and the load and the deformation are measured until the load reaches

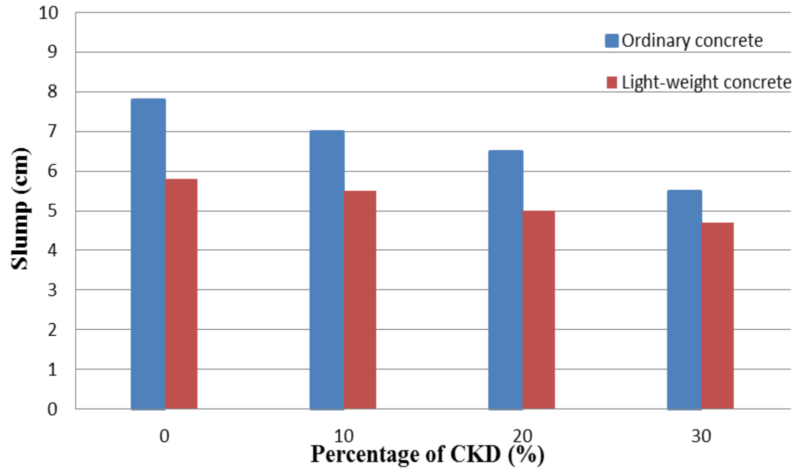

Fig. 2 Slump of concrete mixtures for various amounts of CKD

40% of its maximum.

Moreover, to measure the flexural strength, beam specimens with the dimensions of 50×10×10 cm^3 were made and tested based on (ASTM C293/C293M-16 2016) by the means of a universal flexural machine. In this test, the sample is placed on two supports near the two ends within a distance of 30 cm and the load is applied at the center of the sample until collapse occurs.

Furthermore, in order to measure the flexural tensile strength, i.e., the modulus of rupture, third-point loading flexural test was conducted on beam samples according to (ASTM C78/C78M-16 2016) after 28 days. For this purpose, the prismatic specimen is placed on the special flexural test machine in order to simulate the condition of a simply supported beam with middle span loading. In this test, two roller supports with the distance of 40 cm (beam span length) are placed under the sample and the load is applied on the top, through two jaws within 100 mm distance.

3. Results and discussion

3.1 Fresh concrete properties

The workability of concrete is defined in terms of simplicity of transportation, casting, compacting and surface finishing without detachment. The workability measuring or concrete consistency is called slump, which is necessary for design and its value depends on construction requirements, including the size of concrete blocks, the amount of reinforcements and the available compaction equipment. In order to evaluate the fresh concrete properties, samples were prepared in the temperature of 30℃ and the relative humidity of 76%. Fig. 2, shows the concrete mixtures' slump with respect to the CKD percentage. It can be observed that due to the high absorption capacity of CKD, as the amount of CKD increases, the required water increases; hence, slump tends to decrease. In addition, since the lightweight concrete is designed for a lower water to binder ratio, it demonstrates lower slump in comparison with the ordinary concrete. In addition, another reason may have something to do with the absorptivity of Metakaolin which is used in the lightweight concrete.

Table 7 Compressive strength of cube specimens at age of 28 days (MPa) for ordinary and lightweight concrete

Property	0% CKD		10% CKD		20% CKD		30% CKD	
	OC	LWC	OCC	LWCC	OCC	LWCC	OCC	LWCC
Cube average	40.55	27.88	47.08	29.53	48.81	27.86	45.26	26.76
Equiv. cylindrical average	32.45	25.09	37.67	26.58	39.05	25.07	36.21	24.08
COV (%)	0.9	4.3	0.17	3.5	1.24	5.42	4.11	5.36

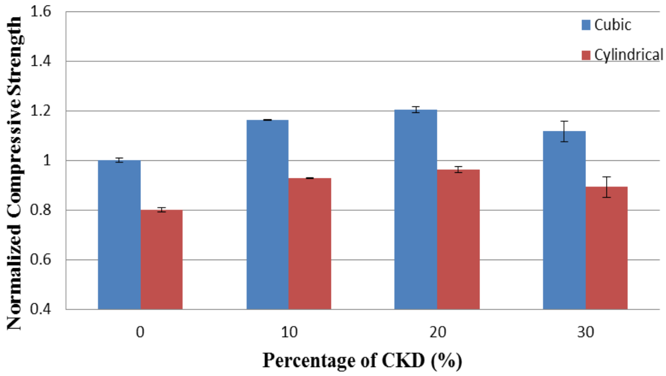

Fig. 3 Normalized compressive strength of cube and equivalent cylindrical specimens at age of 28 days for ordinary concrete

3.2 Compressive strength

In order to investigate the effects of adding CKD on the compressive strength, cubic samples with the side length of 10 cm and 10%, 20%, and 30% CKD content, in addition to a reference sample were manufactured. It is noticeable that a number of 3 cubic specimens were prepared in each case and their average compressive strength, the coefficient of variations (COV), and the equivalent cylindrical compressive strength at the age of 28 days; equal to 80% and 90% of the compressive strength of cubic samples for ordinary and lightweight concrete (Reynolds *et al.* 2007), respectively, are given in Table 7.

In the following sections, all mechanical properties are normalized by the average value of the corresponding property of the control concrete. In Fig. 3 and Fig. 4, the normalized compressive strength is illustrated for ordinary and lightweight concrete, respectively.

As shown in Fig. 3, by adding CKD, compressive strength of ordinary concrete has generally increased which has an increasing trend at first, but it decreases after a while. For instance, adding 20% and 30% of cement weight CKD to the ordinary concrete, leads to 20.3% and 11.6% increase in strength compared to the control sample, respectively. The reason of this behavior is probably due to the fact that adding CKD increases the amount of binder in the concrete and produces an increment of strength. Another reason may be attributed to an appropriate alkalinity that increases the dissolution of silicate species and the formation of C-S-H in concrete (Batis *et al.* 1996). In addition, adding particular amounts of CKD, fills concrete inner void space which results in a less

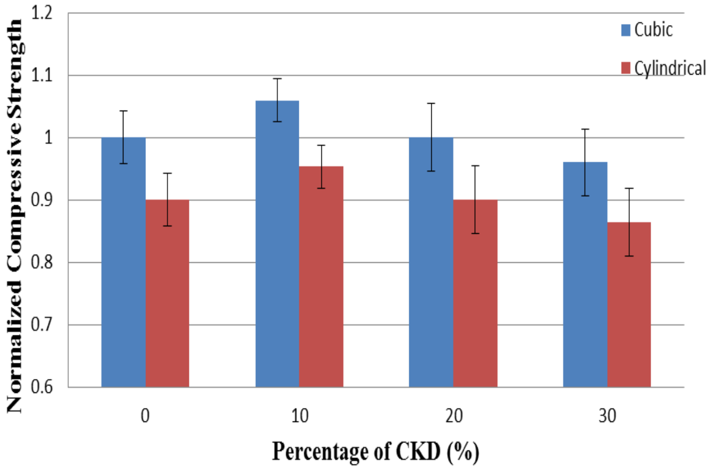

Fig. 4 Normalized compressive strength of cube and equivalent cylindrical specimens at age of 28 days for lightweight concrete

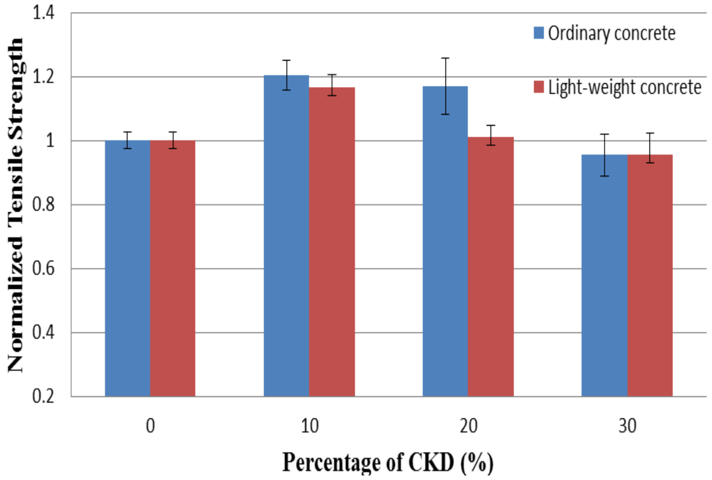

Fig. 5 Normalized splitting tensile strength of concrete specimens for various CKD percentage

porous structure. Conversely, when CKD percentage increases, it acts as a barrier and prevents the cement paste from adhering to the natural aggregates. As a result, the friction and the interlocking decrease and as a result, the compressive strength decreases gradually. For lightweight concrete, adding 10% CKD leads to 5.9% increase in strength; however, at 20% and 30% CKD, no significant influence on the strength is observed. This may be due to the inherent weakness of the aggregates utilized in the lightweight concrete, which controls the strength of the specimen.

3.3 Splitting tensile strength

The splitting tensile test was conducted on cylindrical samples with dimensions of 15 cm×30 cm at the age of 28 days. The splitting tensile strength is calculated as follows (ASTM C496/C496M-11 2004)

Table 8 Splitting tensile strength of ordinary and lightweight concrete at the age of 28 days (MPa)

Property	0% CKD		10% CKD		20% CKD		30% CKD	
	OC	LWC	OCC	LWCC	OCC	LWCC	OCC	LWCC
Average	3.28	2.66	3.95	3.11	3.83	2.69	3.13	2.54
COV (%)	2.60	2.55	4.60	3.75	8.78	3.74	6.61	6.67

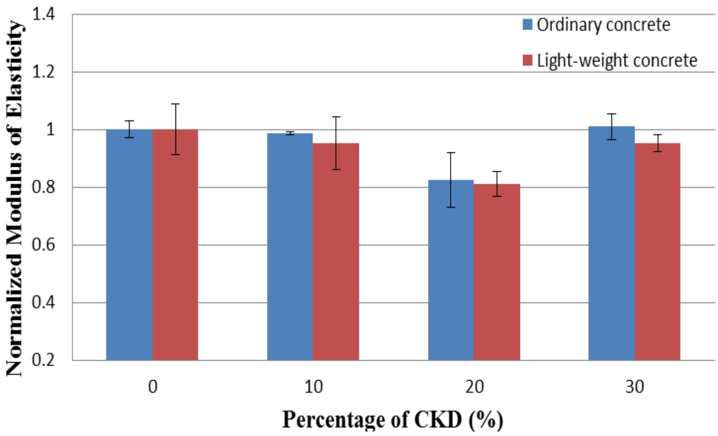

Fig. 6 Modulus of elasticity of concrete specimens with respect to the CKD percentage

$$T = 2P/\pi ld \quad (1)$$

In Eq. (1), T is the splitting tensile strength, P refers to the maximum applied load indicated by the testing machine, l and d denote the specimen’s length and diameter. In Fig. 5 and Table 8, the effects of adding CKD on the normalized tensile strength are presented.

As shown in Fig. 5, in low percentages of CKD, tensile strength has generally increased. It can be observed that at first it has an increasing trend, but it decreases after a while. For instance, by adding 10% CKD, 20% and 16.9% increase in tensile strength has occurred in ordinary and lightweight concrete, respectively. Conversely, adding 30% CKD led to 5% and 4.5% reduction compared to the control sample. The increase in the tensile strength could be due to the less porous structure in the concrete containing CKD and the increase in binder content. On the other hand, in high percentages of CKD, it has a negative influence on the strength which can be due to the less cohesion between CKD and the aggregates in comparison with cement.

3.4 Modulus of elasticity

In this section, the effects of adding CKD on the modulus of elasticity of ordinary and lightweight concrete are investigated. The modulus of elasticity is given by (ASTM C469/C469M-14 2014)

$$E = (S_2 - S_1)/(\varepsilon_2 - 0.000050) \quad (2)$$

In Eq. (2), E is the modulus of elasticity, S_1 denotes the stress corresponding to ε_1 (longitudinal strain of 50 millionths), S_2 represents the stress corresponding to 40% of the ultimate load and ε_2

Table 9 Modulus of elasticity of the ordinary and lightweight concrete (MPa)

Property	0% CKD		10% CKD		20% CKD		30% CKD	
	OC	LWC	OCC	LWCC	OCC	LWCC	OCC	LWCC
Average	30612	18740	30170	17838	25245	15207	30901	17836
COV (%)	3.05	8.76	0.54	9.14	9.53	4.33	4.37	2.96

refers to the longitudinal strain corresponding to S_2.

Fig. 6, shows the normalized static modulus of elasticity for cylindrical specimens, with respect to the amount of CKD, while Table 9 shows the numeric values and the corresponding coefficient of variation of the samples. As it is observed, adding CKD does not have a significant influence on the modulus of elasticity; however, by adding 20% CKD a reduction is observed. This may be due to the fact that in this particular percentage of adding CKD, the cement matrix is affected which results in development of matrix cracking; hence, reduction in the modulus of elasticity is observed.

3.5 Flexural strength

In order to evaluate the flexural tensile strength, i.e., the modulus of rupture, flexural test with third-point loading was conducted on a number of 3 beam specimens with the dimensions of $50\times10\times10$ cm^3. The modulus of rupture is determined by Eq. (3) (ASTM C78/C78M-16 2016)

$$R = \frac{PL}{bd^2} \tag{3}$$

Where, R is the modulus of rupture, P represents the maximum applied load indicated by the testing machine, L refers to the span length, b and d denote the width and depth of the specimen, respectively. Fig. 7 shows the effects of CKD on normalized modulus of rupture. As it can be observed, similar to the splitting tensile test on cylindrical samples, adding low amounts of CKD improves the tensile strength and hence, the modulus of rupture increases.

As shown in Table 10, when the amount of CKD increases, the modulus of rupture shows an increasing trend at first, but it drops after a while. For instance, adding 10% of cement weight CKD leads to 25% and 4.4% increase in strength for ordinary and lightweight concrete, respectively. However, at 30%, 8.9% and 12% reduction is observed, respectively, compared to the control samples.

Similar to the results obtained in sections 0 and 0, it is observed that for the lightweight concrete there is no significant difference between the strength of specimen containing 20% and 30% CKD and it is relatively lower than the control sample strength. This behavior appears to be related to the characteristics of the aggregates used in manufacturing this type of concrete. LECA aggregates have a spherical shape which results in low interlocking. This naturally reduces the strength and as shown in Fig. 7, in high percentages, the effect of CKD is not significant. It appears that aggregates dominated the strength of the specimen and CKD enfolds the aggregates which results in the reduction of strength with respect to the control specimen.

Furthermore, flexural strength was determined using center point loading by means of a universal test machine and the normalized quantities are shown in Fig. 8. It can be observed from the data presented in Table 11 that adding CKD has generally enhanced the flexural strength of

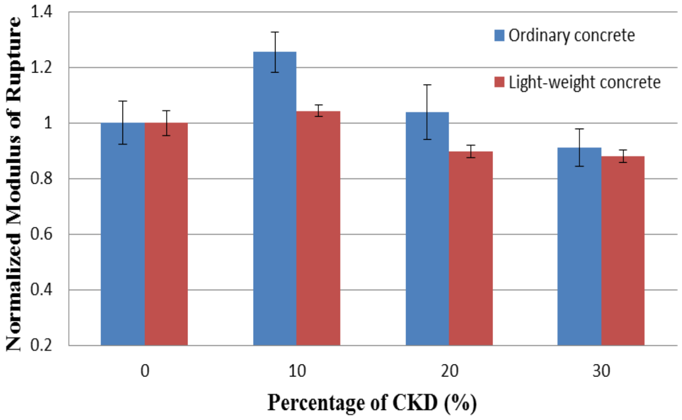

Fig. 7 Normalized modulus of rupture of concrete specimens at 28 days with various CKD percentage

Table 12 Modulus of rupture of beam specimens for ordinary and lightweight concrete (MPa)

Property	0% CKD		10% CKD		20% CKD		30% CKD	
	OC	LWC	OCC	LWCC	OCC	LWCC	OCC	LWCC
Average	4.14	5.50	5.2	5.74	4.3	4.93	3.77	4.84
COV (%)	7.73	4.47	7.33	2.22	9.86	2.29	6.67	2.22

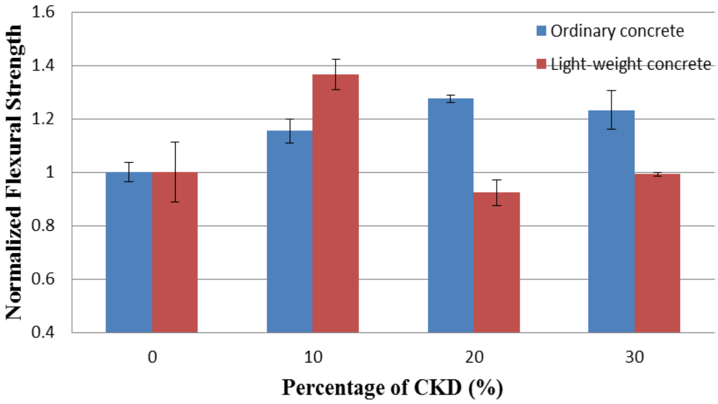

Fig. 8 Normalized flexural strength of CKD concrete specimens for prismatic beams (10 cm×10 cm×50 cm)

ordinary concrete specimens. For example, by adding 10% and 20% of cement weight CKD, flexural strength has increased by 15.3% and 27.4%, respectively. On the other hand, lightweight concrete demonstrated similar trend as in preceding sections, in which, adding low percentages of CKD increases the strength. For instance, adding 10% CKD increases the flexural strength by 36.6% compared to the control sample. Also, negligible changes in strength is observed in lightweight concrete with 20% CKD (LWCC-20) and 30% CKD (LWCC-30), which can be explained as discussed in section 0.

4. Summary and concluding remarks

Table 13 Flexural strength of beam specimens for ordinary and lightweight concrete (MPa)

Property	0% CKD		10% CKD		20% CKD		30% CKD	
	OC	LWC	OCC	LWCC	OCC	LWCC	OCC	LWCC
Average	6.71	3.35	7.74	4.58	8.56	3.1	8.27	3.32
COV (%)	3.5	11.16	4.35	5.69	1.42	4.7	7.18	0.65

In this study, the feasibility of using CKD in ordinary and lightweight concrete as a partial addition of cement weight was investigated. Experiments were conducted and physical and mechanical properties of concrete containing CKD were evaluated. The following conclusions were drawn.

1. With constant water to binder ratio, as the amount of CKD content increased, the workability of fresh concrete was reduced.
2. The compressive strength of ordinary concrete specimens containing CKD, was generally increased. For example, in OCC-20 and OCC-30, 20.3% and 11.6% increase in strength was observed with respect to the control sample, respectively. For lightweight concrete, adding 10% CKD led to 5.9% increase in compressive strength, while by adding 20% and 30% CKD a slight decrease was observed.
3. The ordinary CKD concrete showed higher splitting tensile strength and modulus of rupture compared to the reference concrete which both of them had similar trends. In fact, by adding 10% of cement weight CKD, 20% and 25% increase in splitting tensile strength and modulus of rupture was observed, respectively. In lightweight concrete, LWCC-10, showed improvements in tensile strength, while in LWCC-20 and LWCC-30 a slight reduction in tensile strength occurred.
4. Results of flexural test indicated that by adding CKD, flexural strength can be enhanced, effectively. As a matter of fact, in ordinary concrete, by adding 10% and 20% of cement weight CKD, flexural strength increased by 15.3% and 27.4%, respectively. Also, in LWCC-10, 36.6% increase in flexural strength was observed compared to the control sample, while low sensitivity to higher percentages of CKD was observed.
5. Based on the experiments results, adding 10% of cement weight CKD was determined as the appropriate percentage of CKD for utilizing in manufacturing ordinary and lightweight concrete.

Eventually, it can be concluded that CKD can be reused as binder in concrete technology. There would be improvements in physical and mechanical properties of concrete and also it can be an environmental solution for this kind of waste material, since it reduces the amount of CKD to be landfilled.

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