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Utilization of Normal and Treated Cement Kiln Dust as Cement Replacement Materials in Concrete

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ABSTRACT

Cement Kiln Dust (CKD) is a by-product generated throughout the production of Ordinary Portland Cement (OPC). It is normally emitted to the atmosphere or converted into liquid and subsequently drained out as effluents to landfills and wastage areas. It impacted human health and the environment negatively. However, it can be utilized in concrete as raw cement replacement materials due to its engineering properties which work as an alternative binder of OPC in addition to that it has benefits in creating economic and environmental advantages. This study aimed to modify CKD and investigate the chemical composition of normal-CKD and modified -CKD accordingly. The term modified noted that CKD has gone through a process of modification using heating process. The reactivity property of CKD was investigated using pH analysis. Then, mix proportions of different percentage of normal-CKD and modified -CKD were developed to study the addition effects on the compressive and flexural strength for different curing period. The trend of strength development over the addition of CKD was also analyzed. OPC was replaced by CKD at 0% and successively increased by 10% to 100% through binder weight (OPC). A fixed amount of water to binder (W/B) with a ratio of 0.45 was used for all hybrids. The mixes were formed into the specimen and tested for compressive strength and flexural strength at 7, 14 and 28 curing days. The medium particle size of CKD used was less than 10µm. The results of compressive and flexural strength showed that modified-CKD resulted in better properties and 10% replacement showed the maximum values of compressive and flexural strength as a result considered best percentage replacement in agreement with its noteworthy results.

Keywords: Chemical compositions, CKD, compressive strength, flexural strength, reactivity

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INTRODUCTION

The accelerated growth of construction industries has been associated with the high demand of natural materials used in all activities which correlated with the depletion of natural resource and subsequently triggered the environmental pollution which turned out to be unsuitable for a living (Rahman et al., 2011). Cement is the main material used in the built environment. It is available in nature as limestones and then subjected production process to produce OPC in mines and factories (Khanna, 2009). It is the main material that provides bonds between concrete ingredients. It has been revealed that the worldwide production of cement in 2014 was 4.18 billion metrics tons of that 83.2 million metric tons were produced in USA (Statista, 2016). These quantities reflect the huge number of by-products generated annually from the production of cement; among the several types of by-products is CKD which is produced as dust or slurry (Konsta-Gdoutos et al., 2003; Al-Harthy et al., 2003). It is the most challenge in terms of tangible hazard for the environmental health (Taubert, 2008; Khanna, 2009). In the USA, about 1,403,062 metric tons of CKD have emitted annually to the atmosphere (Daous, 2004; Taubert, 2008).In response to the global interest for the nature conservation which has increased since the 1990s, researchers have focused on the reuse of CKD encompassing its engineering properties and content of chemical compositions as well as its physical microstructures. CKD is a material that has uniform size and in the form of fine powdery (Siddique, 2008). It comes in the form of dust or slurry and its size is normally between 20 µm and 20nm (Lee et al., 2007).

Table 1 presents the chronological study from literature which focuses on the use of normal CKD in concrete and other applications but there is no study that investigates the possibility of treating and modifying the property of CKD and utilizing that as cement replacement materials.

CKD can be used in other engineering applications for example as soil stabilization agent, and cracking filler (Siddique, 2008). A study by Baghdadi (1990) has successfully utilized CKD to stabilize clay soil. The stabilized clay has shown a considerable decreasing in plasticity index and an increase in the compression strength. The maximum strength was recorded after 28 days ($8.8x10^3$ kPa). The study indicated that CKD has high potential to improve the maximum dry density and reduced the optimum moisture content of kaolinite clay. Therefore, it can be used in modifications of soil property. To support that, Miller, & Azad (2000) studied the influence on stabilization with CKD and it was found that adding CKD to soil had increased the UCS. Furthermore, Peethamparan et al (2008) investigated the influence of adding CKD to the physical and chemical properties of soil. It was found CKD paste gave an early indication of its suitability to be as a soil stabilization agent.

It has been demonstrated that CKD has high ability to interact with concrete's elementary materials such as OPC, water, and aggregate (Khanna, 2009). The reactivity is very important to improve the bonds among concrete ingredients. Rahman et al. (2011)

Table 1
Chronological study on the utilization of CKD in concrete

Study	Replacement Percentage	Maximum compressive strength achieved	References
The study focused on the effect of normal CKD on mortar and concrete blend	5, 10, 15, 20, 25, 30%	Compression strength was recorded to be 55,53,51,44, 42 and 41Mpa respectively after 28 days	Al-Harthy et al., 2003
Normal dust CKD was used for concrete strengthening	5 and 10%	The maximum compressive strength was recorded in 28 curing days to be 34.79 and 36.89MPa respectively	Maslehuddin et al., 2008
Normal CKD was used as partial cement replacement materials	5 –15%,	Compressive strength was approximately 51 and 42MPa respectively	Khanna, 2009
In this study the additives have less significant impact of compressive strength	10, 30 and 50%	compressive strength were 28, 25, 22 MPa respectively	Mohammad & Hilal, 2010
Silica fume was mixed with normal CKD	10%, 60% and 100 %).	18MPa ,17.4MPa	Wahab, 2013
Super plasticizer added with normal CKD in normal concrete	0% CKD, (10% and 20% CKD)	Achieved 31.33MPa ,10.86MPa and 19.71MPa	Abdulabbas, 2013
In this study, combination of normal CKD and Rice Husk Ash were incorporated and was found that, combining two of these wastes as replacement of cement led to enhanced or acceptable properties.	0%, 10%, 20%, 30%, 40% and 50%.	Compressive strengths of 29 N/mm2 and 28N/mm2 were obtained at 10% and 20% of replacement of cement respectively	Afolayan et al., 2015

indicated that the addition 34% of CKD to concrete had increased the pH to more than 10, which led to the increase of the solidification and strength of concrete.

Recent studies have further used CKD in different applications. Beltagui et al. (2018) had investigated the feasibility of incorporating different by-products and the study found that KD content possible to achieve the required strength was 90% CKD blended with 10% cement. Another study by Sharma & Goyal (2018) investigated the possibility of incorporating CKD with OPC to improve carbonation process and it was found that the finer particle size of CKD particles and presence of alkali in CKD further promoted the carbonation reaction.

It was emphasized by Taubert (2008) that CKD was a particulate mixture of partially calcined and unreacted raw feed, clinker dust and ash, enriched with alkali sulfates, halides, and other volatiles. In spite of these claims, this study introduced a new technique to modify the chemical and physical property of CKD. Hence, it is suggested in this study to modify its characteristics using specific temperature regime to remove excessive materials. Based on the past technical report developed by US army (1994), it is shown that for the material to be reactive pH scale has to be about 12.4. Even with all the studies discussed, the application of normal and modified –CKD in concrete and its impact on the primary properties has yet to be investigated in depth. Therefore, the current study focused on the potential of unmodified and modified CKD by micronization process as cement replacement materials in concrete which emphasized the novelty of this work. The term micronization in this study is meant by the process of altering the shape, size, and removal of excessive materials of CKD by implying certain temperature regime.

MATERIALS AND METHODS

This study mainly consists of three phases. The first phases discussed on the literature analysis on the utilization of CKD in previous studies. Then, the second phases involved the preliminary inspections and preparation of study materials and the preparation of specimens. The third phase presented the characterization of specimens for both compressive and flexural strength and analysis of the results and findings conclusions. Figure 1 illustrates the flowchart and experimental setup of this research (Gamil & Bakar, 2016).

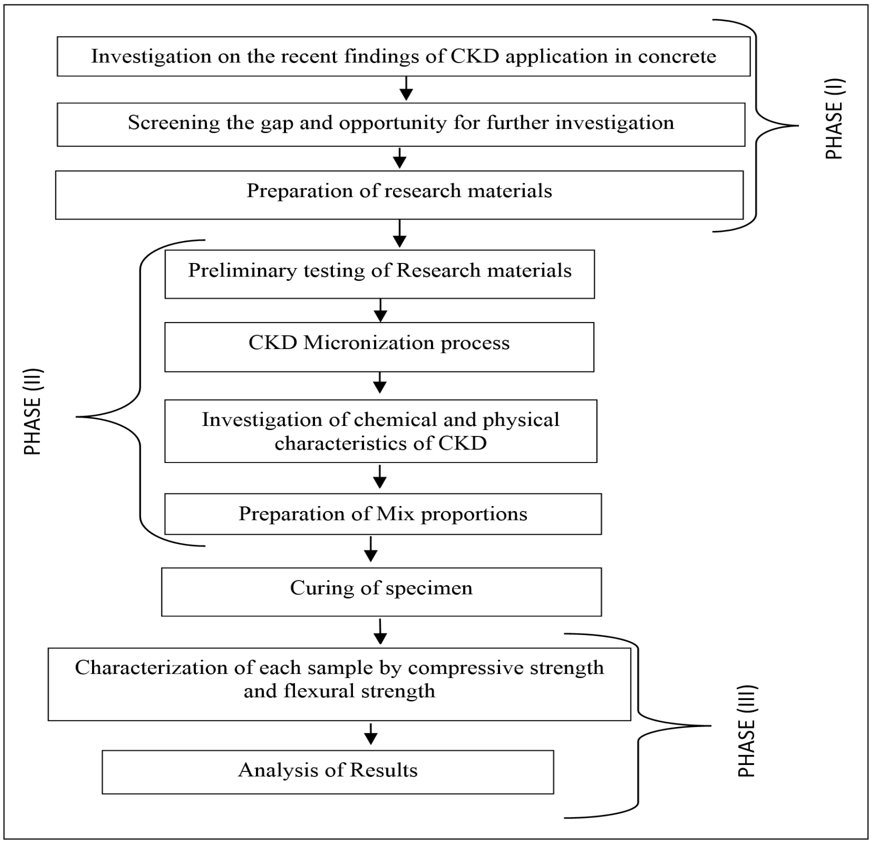


Figure 1. Flowchart of the experimental setups

OPC type 1 (ASTM, 2016) with a specific gravity of 3.04 .CKD samples were collected in bulk from cement factory located in Negeri Sembilan, Malaysia. The factory is considered as one of the main sources of cement provision in Malaysia. CKD was then crushed using crusher and then sieved to produce Nano-particles passing 10µm and stored at room temperature to maintain its moisture content at a constant temperature. Sand (fine aggregate) was collected from the commercial sector in Malaysia with a specific gravity of 2.63. The coarse aggregate was sieved and the particles less than 20 mm were used with a specific gravity of 2.61. The coarse aggregate was sieved as it is part of the technical requirements.

Specimen Preparation

The Specimen Preparation in the current work consists of a collection of samples, pretreatment and primary testing of raw materials. Factorial Complete Randomized Design (CRD) (10*2*1) in triplicate was used to study the effectiveness of CKD. The experimental work was designed as follow; ten (10) replacement percentage (10-100 %) was added to concrete, two (2) modified and unmodified-CKD, one (1) control (without CKD) making a total of three (3) groups. CRD is essentially a statistical concept which is used to run random factors.

Preparation of Modified -CKD

Heating is a method to achieve higher pozzolanic reactivity (Matias et al., 2014). In order to produce modified -CKD, the raw CKD was dried in a furnace. The temperature of the furnace was set at 550ºC for one hour to reduce the diameter of CKD particles and remove excessive and unwanted particles which might be in the form organic materials or any other unfavorable materials. The specified temperature regime was adopted from a study by Budak et al. (2010) whereby it was proven that thermally modified dust had higher potential in improving the pozzolanic reactivity and the suggested range of temperature was between 500ºC and 700ºC to improve performance and the samples modified with this temperature gains higher compressive strength in comparison with other samples. In another literature by Lee et al. (2007), the treatment process for Rice Husk Ash (RHA) by interfering temperature regime was at its best to be 500°C to create amorphous biomass silica used in concrete. Another study by Gamil et al. (2018), implied modification of Palm Oil Fuel Ash (POFA) by treating using heating process for an hour under the set of temperature regime of 500ºC. The process of treating CKD was adopted from the before mentioned studies.

Experimental Procedures

Twenty-one samples of concrete mixtures were blended separately for each curing day and mechanical property (compressive and flexural) with different replacement (10-100%) of CKD (normal and modified) of the amount of OPC and then the mixture sample was incubated at laboratory temperature for 28 days and then examined for compressive strength. The control sample was conducted without CKD addition. The same proportions were used to develop prisms to examine flexural strength. Table 2 shows the mix proportions and their significant factors.

Table 2
Experimental design and mix proportions with important factors

	Considered Factors			
	Symbols	Replaced percentage of OPC (%)	Water-cement ratio	Curing time (Days)
Control	M0	0	0.45	7, 14, 28
Normal-CKD	M1-M10	(10-100)	0.45	7, 14, 28
Modified-CKD	M11-M20	(10-100)	0.45	7, 14, 28

M*: Mix

The chemical compositions of CKD and OPC were determined using X-ray Fluorescence (XRF) according to the method described by ASTM (2014). In brief: XRF basically carried out according to the standard in which the sample of CKD was formed as pallet then incubated for overnight then analyzed for chemical compositions.

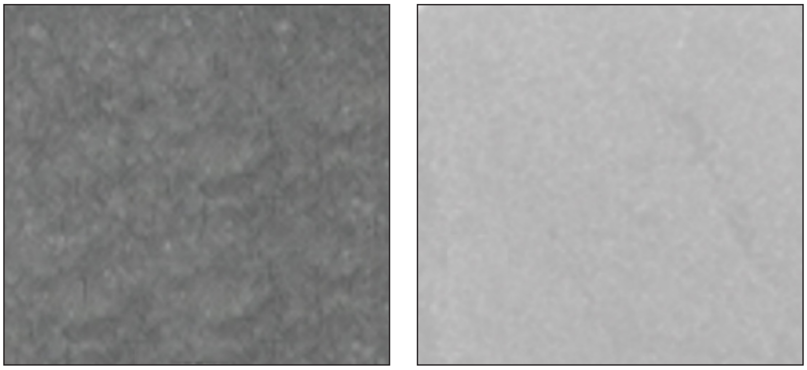
pH values of the mixture and control were recorded at the incubation periods to determine the acidity, alkalinity, and reactivity of the concrete based on ASTM (2001). For this purpose, pH meter was calibrated before each measurement according to the manufacturer's guidelines to produce precise results. The sample was in the form of slurry concrete and pH meter was utilized to determine each value. The method used to record pH was that in each percentage replacement the recorder was placed and recorded at different locations of the specimen. In this study only up to 50% was recorded because the main purpose was to prove the reactivity of CKD and that was demonstrated in figure 3.

The compressive strength of each concrete mixture was measured to investigate the compressive strength increment and decrement with the variations of additives percentages of CKD over different curing time. A fixed size of (100*100*100) mm for each sample was used to determine the compressive strength according to BS 1881-part 116-1989 (British Standard, 1881). The universal testing machine was used to carry out compressive strength. The loading rate of the universal testing machine was 15 MPa per minute. Flexural strength (modulus of rupture) of each concrete sample was conducted using concrete beam mold sample with size (100*100*500) mm in the form of prisms which was prepared prior to the test. This particular mold size was chosen because the size of aggregate is less than 20 mm. Three-point loading was used to carry out the tests in accordance with ASTM (1967) and ASTM (2002) (2012).

RESULTS AND ANALYSIS

Physical and Chemical Properties of Normal -CKD and Modified -CKD

CKD is fine materials which it can naturally exist as either in dust or slurry form if it is transmitted into a liquid state. In this study, fine powder CKD was used, the color was found to be grey to black for normal- CKD. However, modified- CKD turned out to be light grey due to the removal of excessive constituents. Figure 2 shows the physical differences between both types. The color of normal-CKD changed from blackish to light brownish which showed the effect of heating on the physical properties. It is clear that the size distribution of CKD depends on many factors which include the type of stones, method of processing, and CKD collection process (Khanna, 2009). The nominal size of CKD used in this study is less than 10µm and Specific Gravity (SG) for both normal and modified -CKD was in the range of 2.64–2.75. It is important to study the chemical compositions of CKD for both normal and modified types.



(a) (b)

Figure 2. A) Normal-CKD; B) Modified-CKD

Table 3 shows the comparison of the chemical composition of normal-CKD, modified -CKD, and OPC. Generally, CKD exhibit noticeable alkalinity in the form of lime (CaO) which initially carries 44.05% in normal-CKD and 44.3% in modified-CKD. This, therefore increase the possibility of higher reactivity, In addition, the amount of K_2O and Na_2O in CKD is relatively higher as compared to OPC. It is also shown that CKD has slightly higher percentage of Silica which illustrates that CKD can be utilized to replace OPC in reasonable percentage. The primary constituents of CKD are calcium carbonate and silicon dioxide which has an approximately similar percentage as OPC It also has high alkalinity in term of chloride and sulfate which helps to make the hybrid more reactive with other concrete materials.

Table 3
Chemical composition of OPC, normal CKD and modified- CKD

Chemical composition mass (%)	OPC	normal-CKD	Modified-CKD
Silicon dioxide (SiO_2)	21.6	17.3	17.83
Aluminum trioxide (Al_2O_3)	6.2	3.81	3.91
Ferric Oxide (Fe_2O_3)	3.13	2.99	3.04
Calcium oxide (CaO)	62.7	44.05	44.3
Magnesium Oxide (MgO)	1.48	2.00	2.04
Potassium oxide (K_2O)	1.01	2.18	2.71
Sulfur oxide (SO_3)	2.73	3.02	3.76
Phosphorus oxide (P_2O_2)	0.21	1.22	2.05
TiO_2	0.1	0.25	0.31

Effect of CKD Addition on pH

In this section, an investigation of the effects of adding OPC, modified-CKD, and normal-CKD to the mix and its reactivity was based on the measurement of pH values. The reason of performing pH analysis is to examine the alkalinity of CKD in order to check its reactivity with other concrete materials.

Figure 3 illustrates the value of pH scale and the amount of percentage of the components added to the mix. It is shown that, for OPC graph, pH value tends to increase with the percentage addition because OPC contains higher alkalinity and high precipitation of silica and lime, therefore, the hybrid becomes more reactive to bind the concrete ingredient. However, for CKD it is obvious that modified-CKD is more reactive than normal-CKD due to the removal of unwanted and excessive constituents.

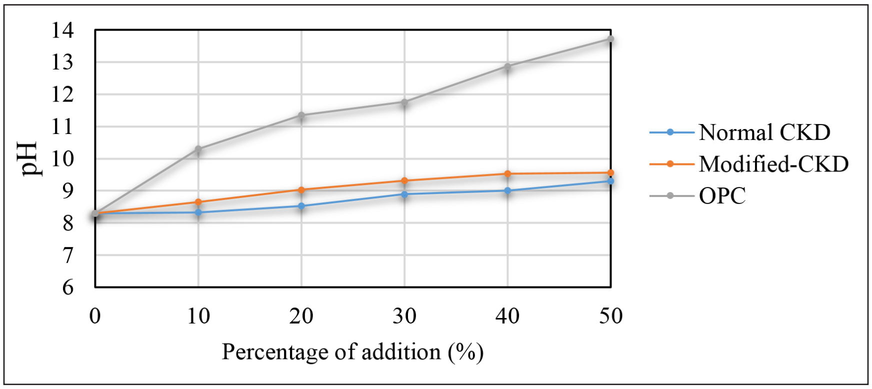


Figure 3. pH of normal CKD, modified-CKD and OPC

Compressive Strength and Flexural Strength

In this part, results of compressive and flexural strength for normal and modified -CKD for different curing period and different mix proportions are discussed.

Variations of Normal -CKD Percentages

This subsection introduces the results of using normal-CKD to replace OPC and strength developments were recorded over the curing days.

Figure 4 illustrates the compressive and flexural strength for variations percentages of normal-CKD for 7 days. From the figure, there is linear declination of compressive and flexural strength with the increment of normal-CKD. The maximum compressive and flexural strength exhibits at 10% addition which are 26.91MPa and 4.32MPa respectively. There is a considerable drop of compressive and flexural strength when the addition of 20%, however, it gradually decreases after the amount of CKD approaches 50%.

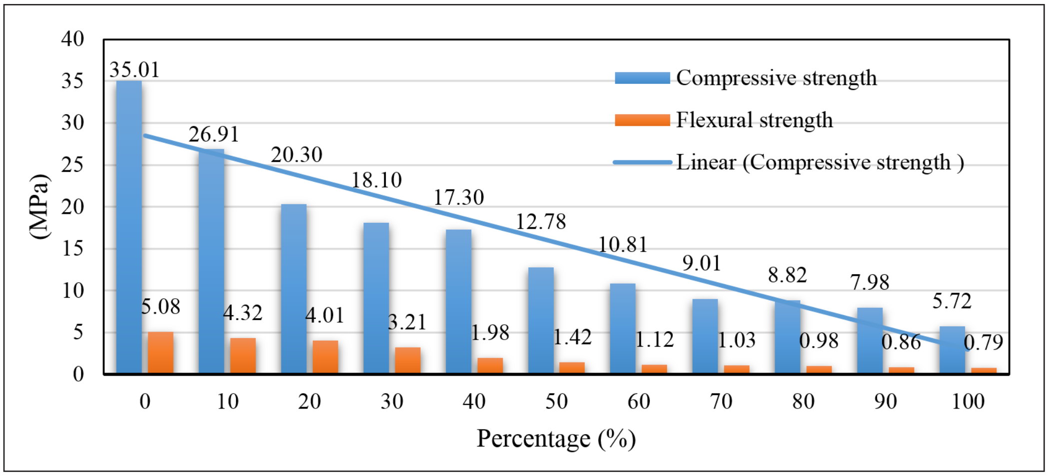


Figure 4. Variation of normal-CKD for 7 days curing

Figure 5 shows the results of compressive and flexural strength for 14 days curing. It is shown that samples with 10% replacement exhibit high compressive and flexural strength then the declination occur with the increment of CKD addition. Yet, in 14 days curing these is noticeable improvement of the strength due to late carbonation process between binder and other concrete materials.

Figure 6 illustrates the compressive strength and flexural strength and the variations percentages of normal-CKD for 28 days. For 10% the strength has considerably improved and reached 35.31MPa which is considered acceptable to be used as cement replacement material, soil stabilization and other related construction work (Siddique, 2008).

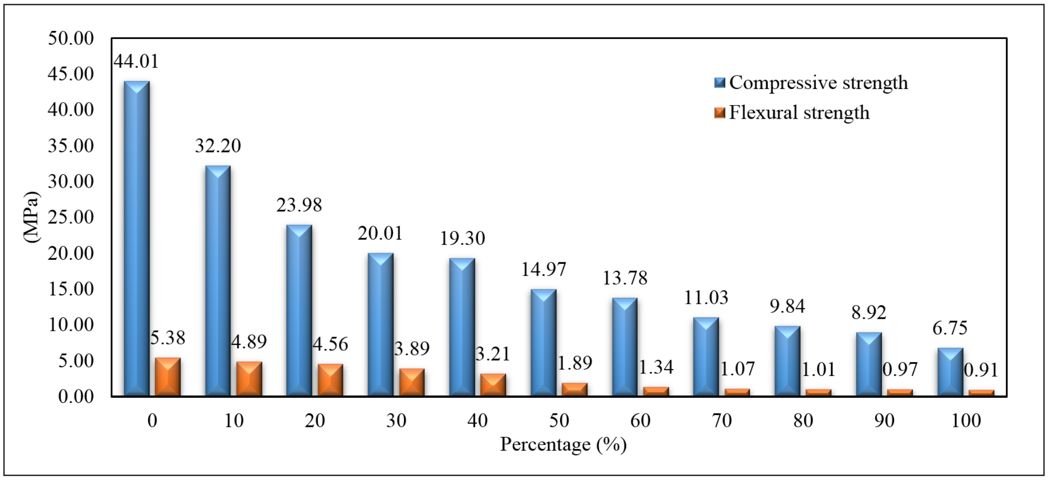


Figure 5. Variation of normal-CKD for 14 days curing

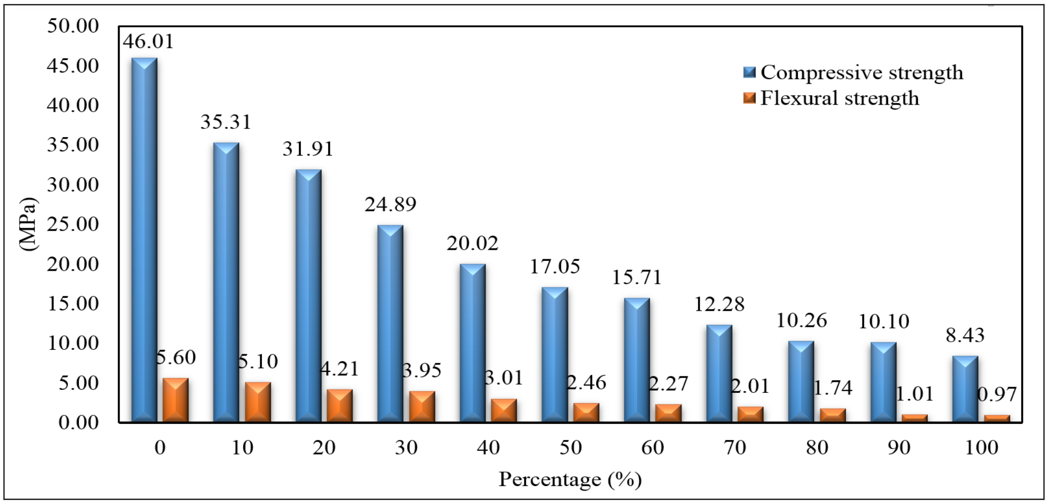


Figure 6. Variation of normal-CKD for 28 days curing

Variations of Modified -CKD Percentages

This section introduces the results of using modified-CKD with various percentages.

Figure 7 shows the compressive strength and flexural strength and the variations percentages of modified -CKD for 7 days. For 10% the strength has considerably resulted in a better outcome for compressive and flexural strength which are 35.01Mpa and 5.08Mpa respectively.

Figure 8 indicates the compressive strength and flexural strength and the variations percentages of modified -CKD for 14 days. It is shown the strength increases in comparison with normal CKD. For specimen with 10% replacement, the value increases to 44.01MPa and 5.38MPa respectively.

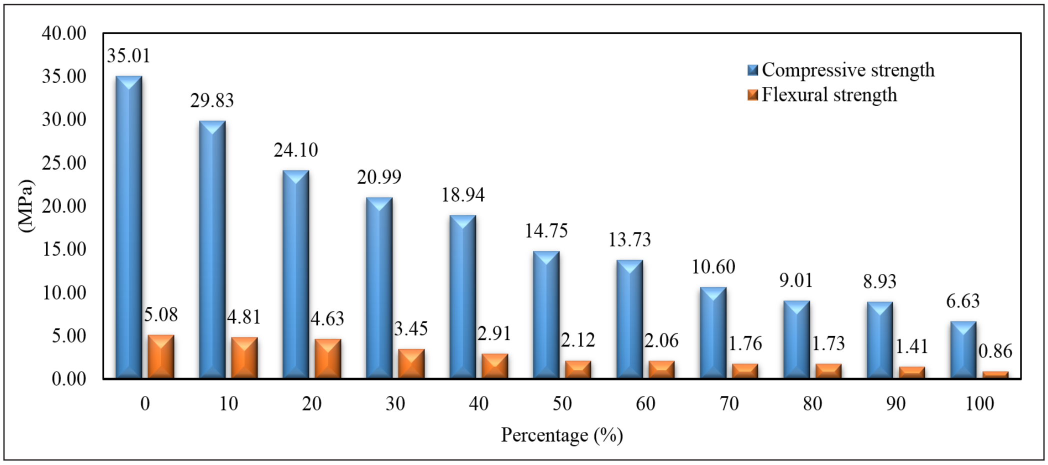


Figure 7. Variation of Modified-CKD for 7 days curing

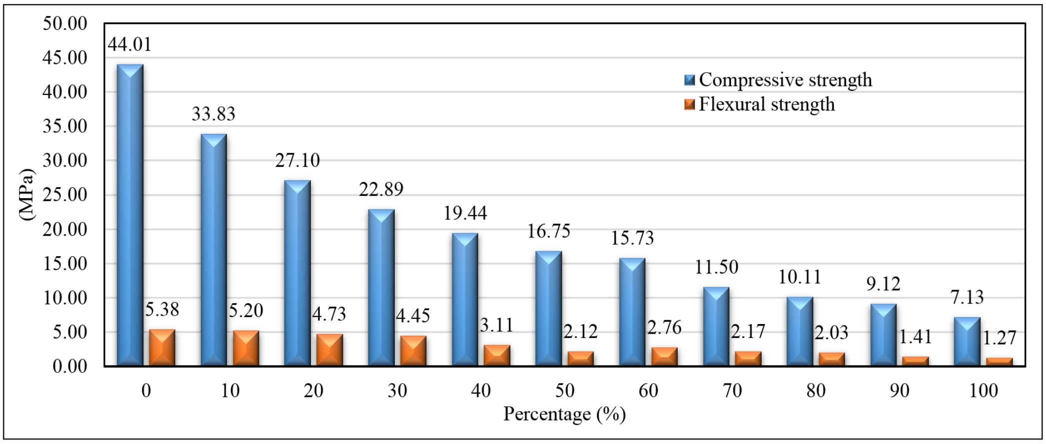


Figure 8. Variation of modified-CKD for 14 days curing

Figure 9 illustrates the compressive strength and flexural strength and the variations percentages of modified -CKD for 28 days. It is shown the strength increased in comparison with normal CKD. There is a noticeable increment of strength in comparison with unmodified -CKD. In 28 days, the peak value reached 39.11MPa which are considered crucial to prove that CKD can be used as a partial replacement material in concrete (Siddique, 2009).

Figures 10 and 11 show the compressive and flexural strength for 10% CKD addition for both modified and unmodified materials. There is an increment of both compressive and flexural strength is proportional to curing period. Therefore, it is evident that 10% is an acceptable ratio to be used. This also proves that producing high flexural and compressive strength is very essential in concrete.

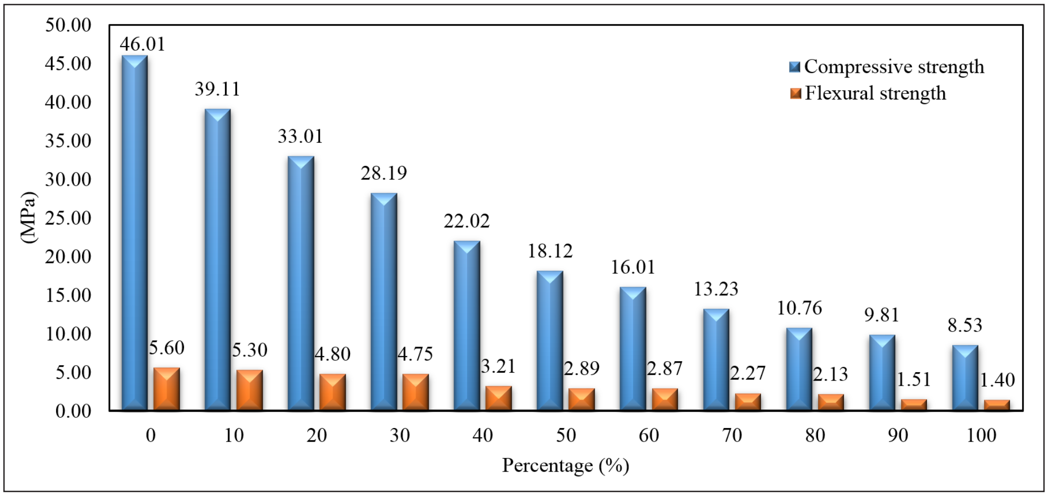


Figure 9. Variation of modified-CKD for 28 days curing

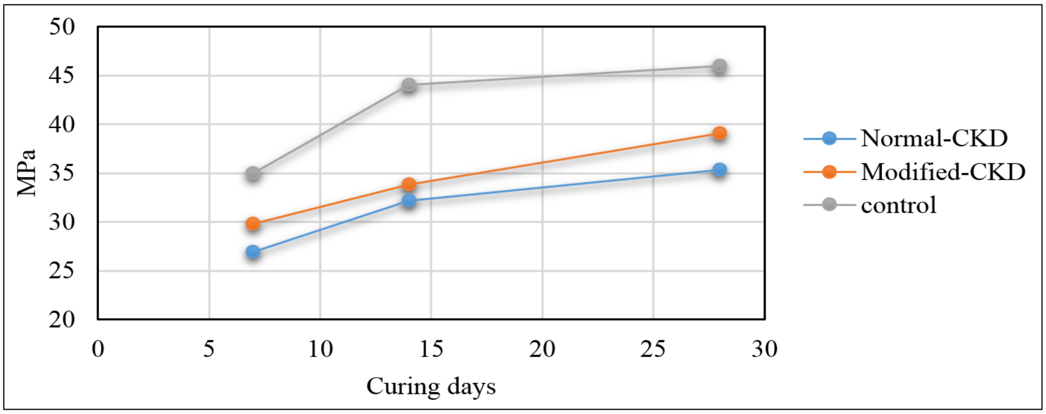


Figure 10. Compressive strength trends for 10% addition

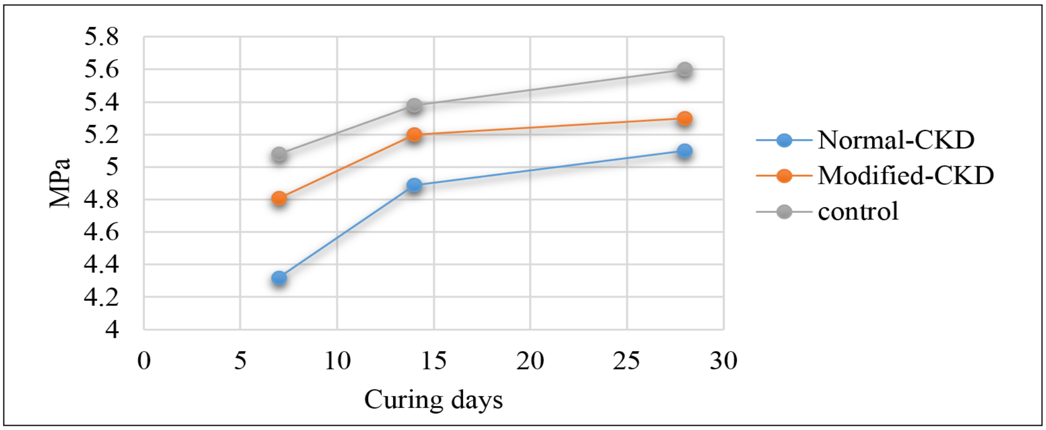


Figure 11. Flexural strength trends for 10% addition

The reason that control mix has higher flexural and compressive strength because there was no CKD added to the mix. The purpose is to filter in which percentage of addition CKD could give a best of compressive and flexural strength.

In comparison with previous findings listed in Table 1, modified-CKD in this study achieved at 10% replacement in 28 days curing a value of 39.11Mpa compressive strength which is higher comparing to a study by Maslehuddin et al. (2008) whereby compressive strength was recorded at 10% and 28 days curing were recorded as 36.89Mpa and a study by Mohammad and Hilal (2010) achieved 28Mpa at 28 curing days. The reason beyond that, this study modified the CKD by removing access carbon contents and this could be justified due to the different sources of raw OPC.

CONCLUSION

With vivid evident, CKD is a useful by-product materials which derived from the production of OPC. It has a very significant influence on the primary property of concrete. It displayed high reactivity due to the fact that it contains high amount of silica CaO. Therefore, it is concluded that CKD can be used as cement replacement which helps to generate income from secondary materials. It is also emphasized that treating CKD by removing excessive and unwanted materials can improve its chemical and physical properties. From the results, it was proven that 10% replacement of OPC by CKD has achieved 39.11Mpa compressive strength. This was also proven by Al-Rezaiqi et al. (2018) which found that replacing CKD more than 20% of OPC had negligible effect of concrete strength. Irrevocably, with its proven properties, there is a possibility for CKD to be used in construction works, for example, as filler in embankments and modification additive for soft soil and other construction solutions. This study also concluded, CKD can be modified by the interference of heating process to remove excessive materials and resulted in better property.

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