Improving the mechanical properties of novel paste using nano Cement Kiln Dust

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Abstract

The cement kiln dust (CKD) is a by-product of cement manufacturing which pollutes the environment. This study aims to investigate the mechanical properties of a useful paste manufacturing from harmful nano CKD. The tensile strength, modulus of elasticity, elongation, resilience, and specific weight of the novel paste were examined. It was found that tensile strength and elongation of 90 nm CKD were 5.4 MPa and 3.04% respectively. The best sample for tests of elasticity factor and stiffness was 80 nm CKD, where the modulus of elasticity and hardness were 4.17 MPa and 71.5 HB respectively. In terms of the results of the specific weight, the sample with 90 nm CKD was the best, where the yield stress and specific weight were 70.1 MPa and 1.33 N/mm^3 respectively.

Keywords: Nano-Cement Kiln Dust, Nano filters, Cement, Environment, Tensile strength.

1. Introduction

The production of cement in the world has grown every year because the demand for cement is increasing. The cement production factories in the world emit approximately 7% of CO_2, where 8 – 20% of harmful cement kiln dust (CKD), which is a by-product produced during the cement production in a rotary kiln [1]. Air pollution is the most critical and most dangerous type of pollution because it is related to human life and should be good air quality [2]. Furthermore, air pollution can occur when the physical and chemical specifications of the air components are changed because of the presence of one or more pollutants in the outside environment such as dust, vapour, gas, fog, odours, and smoke [3]. Thus, it is necessary to remove the CKD and recycle it to produce a new useful material. The main sources of dust emissions in cement industries are kiln systems, clinker coolers and cement mills.

Also, fugitive dust released from handling and storage of materials and the dust generated from crushing and grinding of raw materials in cement factories can be significant. Various precipitators were used in the past for these three sources of dust emission but nowadays only electrostatic precipitators (Eps) or fabric filters are installed [2-4].

In recent years, some studies have been conducted to reduce air pollution caused by the cement production factories by recycling the cement kiln dust (CKD). CKD material at present has occupied great importance in the field of study and research because of its unique properties such as its high elasticity and its ability to undergo a series of stresses without the occurrence of permanent deformation and this makes it ideal for many applications. Generally, CKD is an alkaline material and should be removed from cement. When mixing CKD with water, it was reported that the pH was more than 12 [5]. Yaseri et al. [6] mentioned that the smaller CKDs, the higher alkalinity. A combination of CKD, silica fume and rice husk ash (RHA) was used to produce a geopolymer paste [6]. Subsequently, mixing CKD and feldspar to make pozzolanic materials and geopolymer with different reactivity and whiteness was reposted [7, 8]. Moreover, fly ash mixed with CKD and water to replace 20% of cement was revealed to have a good mechanical behaviour of concrete [9]. A review of using CKD in published studies was conducted [10, 11]. It was reported that CKD enhanced the mechanical properties of cement paste, mortar, and concrete. In addition to that, the CKD is used as a soil stabilizer and in asphalt concrete [10]. Adding CKD also improved the mechanical properties of geopolymer bricks [12]. Seo et al. [13] mixed CKD with distilled water and organic acid to be used in different applications as a raw cement material.

The use of CKD to produce cementitious materials has been reported in many studies. The combined CKD with fly ash was investigated to bind aggregates and find the best strength of mixture depending on the amount of 20% CKD and 10% fly ash [14, 15]. On the other hand, Mohammadinia et al. [16] found that the optimum combination was 50:50 of CKD and fly ash after assessing the resilient modulus and obtaining the optimum confining and deviatoric stresses of these composite materials. Subsequently, nano CKD was utilized to strengthen the cement and it was found that nano CKD improved the compressive strength of cement mortar and reactive burnt kaolin [17, 18]. It was observed that the mechanical performance of combined CKD, iron slag with nano-silica was stable during compressive loading [19]. Najim et al. [20] investigated the mechanical properties and dynamic damping of CKD to be used as replacement bonding materials and they found that the mechanical strength and dynamic modulus of elasticity of the materials decreased with the increase of CKD percentage. Furthermore, Sulaymon et al. [21] also found that the CKD barrier related to its thickness and the percentage of CKD. However, investigating the mechanical performance of paste made of nano cement kiln dust, water and linseed oil is still lacking and needs more information to understand its mechanical behaviour.

In the present study, several experimental tests were conducted to evaluate the mechanical properties of novel paste made of combined nano cement kiln dust, starch, water, and linseed oil by adding different weights of CKD and water with homogeneous proportions. The specimen preparation and the devices used in this study were explained. The procedure of experimental work was also clarified. The mechanical performance of this paste is analyzed.

2. Specimens and Experimental setup

Cement kiln dust (CKD) is calcium-rich and known as a volatile substance with a small granular size resulting from the accidental combustion inside kiln precipitators in cement plants and thermal power plants. CKD is initially molten particles that solidify later into a spherical shape and most of these particles contain gas bubbles in their centres. The chemical composition of CKD is listed in Table 1[22]. The dust emission from the furnaces is shown in Fig. 1.

Table 1. The chemical composition of cement dust [22]

Components	SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_3	Na_2O	K_2O	MgO	Cl	L.O.I
Ratio%	12.27	2.27	3.70	45.28	2.59	0.31	5.68	1.49	8.06	17.38

Fig. 1. Dust from precipitants of the kilns.

Electrostatic precipitators (EPs) generate electrostatic fields across the path of particulate matter in the air stream. The particles become negatively charged and migrate towards positively charged collection plates. The collection plates are rapped or vibrated periodically, dislodging the material so that it falls below into collection hoppers. EPs rapping cycles must be optimized to minimize particulate entrainment and thereby minimize the potential to affect plume visibility. EPs are characterized by their ability to operate under conditions of high temperatures (up to approximately 400 ºC) and high humidity. Factors affecting the efficiency of EPs are flue gas flow rate, the strength of the electric field, particulate loading rate, SO_2 concentration, moisture content, shape, and area of the electrodes. The performance of EPs can be impaired by a build-up of material forming an insulating layer on the collection plates and so reducing the electric field. This can happen if there are high chlorine and Sulphur inputs to the kiln process, forming alkali metal chlorides and sulphates. The alkali metal chlorides form very fine dust (0.1-1 µm) and have high specific dust resistivity between 1012-1013 Ω·cm, forming insulating layers on the electrodes and leading to some problems in dust removal. This has been observed and studied particularly in the iron and steel industry. However, such problems of high dust resistances can be solved by water injection.

2.1. CKD separation process

The precipitant dust produced from the rotary kilns (CKD) was placed in a Spanish device (Marz – AII) and heated to a temperature of 38 ℃. The purpose of this heating process is to dry the cement kiln dust before the material separation process is carried out. Then, to separate nano dust from other macro materials. A vacuum device was used with different nanoscale filters up to 90 nm holes and placed in a rotating Chinese salved-run device that contains excitation fans and a draft tube. This process was repeated several times to ensure the isolation of the nano dust from other materials.

2.2. Smoothness test

The smoothness of the materials was examined using a Danish smoothness tester from Fl.S company as shown in Fig. 2. Table 2 presents the dimensions of the materials with the clarification of the smoothness coefficient for each dimension. sieves and filters were used with holes diameter of 180 μm, 80 nm and 90 nm as listed in Table 2.

2.3. Mixing process

The brand of a special kneader used in this study to mix the cement kiln dust with Reverse Osmosis (RO) water and linseed oil. This device is made in Italy and is called Comerio Ercole Busto Avsizo. The rolling system of this device contains two cylinders with a diameter of 150 mm and a length of 300 mm. Dust precipitators were passed between these two cylinders several times, reducing the space between the two cylinders every time. During this mixing process, additional CKD and water with different amounts were added to the paste with continuous mixing when adding each substance to find the optimum paste with excellent strength to be used in prosthetics or construction applications. After completing the base paste, the starch substance was added, after which the cement kiln dust was added in different amounts. Then water and linseed oil were added with continuous mixing bypassing the paste between the two cylinders several times to obtain a homogeneous paste and professionally mix the gradients of the paste. After that, the paste was left to cool at room temperature to prepare it to prepare samples. Depending on the amount of CKD and water added to the paste, three groups of specimens are investigated as listed in Table 3.

Fig. 2. Smoothness measuring device

Table 2. Smoothness test	
CKD dimension	Smoothness (g/cm^2)
180 µm	3250
80 nm	3360
90 nm	4900

2.4. Vibration detection device

After the mixing process of the paste, the mixture was poured inside a container of a mechanical vibration device (Fleden – key Company) shown in Fig. 3 to get rid of the air bubbles in the paste. These bubbles might weaken the strength of the paste and cause cracks to spread from the location of bubbles when conducting mechanical tests. The paste with the iron mould presented in Fig. 3 was prepared in a horizontal position. After that, the paste was placed in the vibrating device with a starting speed of 6 rpm at a time of 5 mins, then the speed was increased to 15 rpm for the same time of 5 mins. Subsequently, the speed of the device was increased up to 35 rpm, then the device was stopped. After finishing the vibrating process, the paste was pressed by a hydraulic press machine under a pressure of 5 MPa and a temperature of 200 ºC for 15 min to accomplish the vulcanization process. Then, the mixture was poured inside other moulds with different dimensions and moved to another location for continuity of the material for drying and testing. After that, specimens were removed from the mould and left for 24 hr. Fig. 4 shows paste inside mould and final specimens after drying.

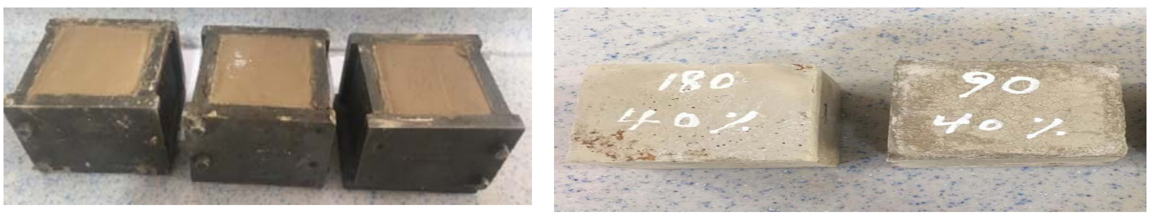
Table 3. The detail of Specimens tested in this study

Group No.	Sample No.	RO Water (ml)	CKD weight (g)
S_1	S_{11}	20	10
	S_{12}	40	20
	S_{13}	60	30
	S_{14}	80	40
	S_{15}	100	50
S_2	S_{21}	20	10
	S_{22}	40	20
	S_{23}	60	30
	S_{24}	80	40
	S_{25}	100	50
S_3	S_{31}	20	10
	S_{32}	40	20
	S_{33}	60	30
	S_{34}	80	40

S_{35}	100	50

(a) (b)

Fig. 3. (a) Mixing device of CKD and RO water; (b) vibration detecting device.



(a) (b)

Fig. 4. (a) Specimens after mixing inside the moulds; (b) specimens after drying.

Several experimental tests were conducted on three different groups of specimens S1, S2 and S3 (Table 3) to assess the mechanical performance of the paste. The specimens were cut into specific dimensions with length, width and thickness of 200 mm, 180 mm, and 6.5 mm respectively. Tensile strength test samples, elastic modulus, and elongation were prepared using a rectangular parallelepiped mould consisting of two parts. The first part has length, width and thickness of 395 mm, 160 mm, and 2.5 mm respectively and contains two sections. The dimensions of one section are 150 mm, 150 mm, and 2.5 mm for length, width, and thickness respectively. The second part represents the top cover and has dimensions of 395 mm, 160 mm, and 10 mm. The detail and results of these tests are discussed in the next section. Four standard test samples (Dumbbell Specimen) were cut from the paste. The sample dimensions are 115 mm in length, 25 mm in width.

3. Results and discussion

To understand the mechanical properties of CKD dough, many tests were conducted, and the results were analyzed in this section.

3.1. Tensile strength, elastic modulus, and elongation test

The effect of CKD additive on the properties of the paste made of CKD, RO water and linseed oil on the tensile strength of paste was investigated. The values of the tensile strength, elongation and elastic modulus of three groups of specimens were tested to start with the gradual rise and then drop with the increase in the adding amount of CKD. When the amount of CKD added to the paste reached 40 g, the highest tensile strength of specimen group S3 was 5.4 MPa for 90 nm CKD (Fig. 5) with a corresponding elongation of 3.04% (Fig. 6). It is obvious from Figs. 5 and 6 that the tensile strength of tested specimens' groups S1 and S2 is approximately similar. The reason for this is due to a large number of interconnections between the crystal chains and the additive as indicated by the vulcanization curve. It might be that the nanoparticles of CKD filled the gaps (pores) in the paste and stacked particles together as can be seen from the microscopic photograph in Fig. 7. Thus, the rise in the curve is due to an increase in the number of cross-linked correlates within the material CKD because of the small granular size that increases the surface area of diffusion. However, it was found that the optimum amount of CKD was 40 g to satisfy a high tensile strength and explain that the material reaches the critical point of failure.

It is also noted from Fig. 6 that the trend of elongation-CKD additive curves was dropped after adding the CKD amount of 40 g and after this amount, the paste started to fail after a well resist to collapse. As the increase of the elastic modulus values after adding the CKD amount of 40 g to 50 g can indicate the strong drop in elongation. The highest modulus of elasticity was 4.17 MPa for the 80 nm CKD specimens (S2). The inverse proportion to the paste on the elastic modulus caused a clear increase in the elastic modulus and a slight decrease in tensile strength as shown in Fig. 8.

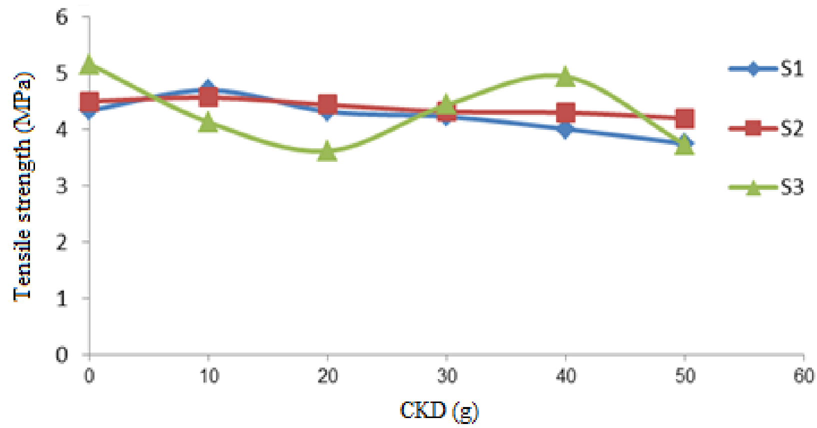


Fig. 5. Effect of adding CKD on tensile strength of the pastes.

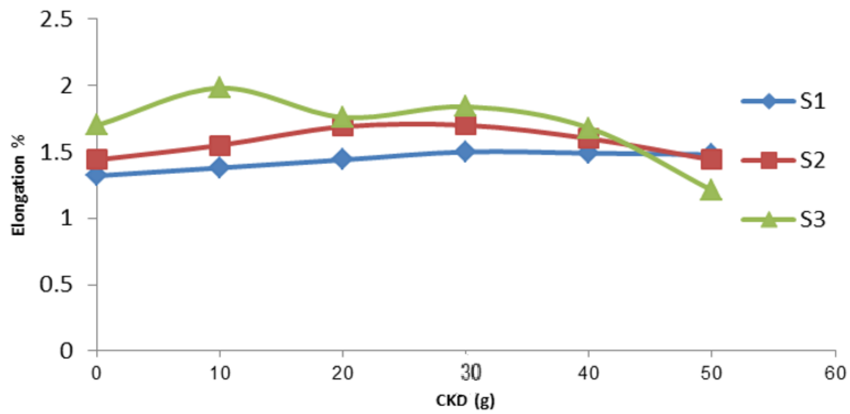


Fig. 6. Effect of adding CKD on elongation of the pastes.

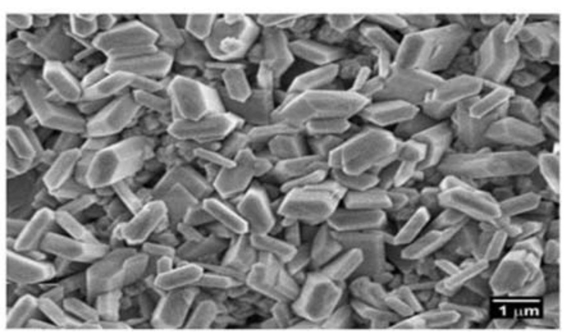


Fig. 7. A microscopic photograph of the paste with 40 g CKD

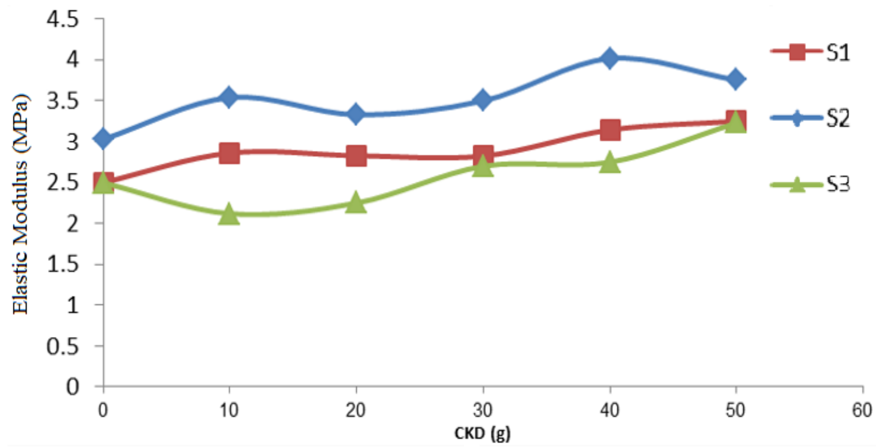


Fig. 8. Effect of adding CKD on the elastic modulus of the pastes.

3.2. Resilience

Figure 9 shows the effect of cement kiln dust additive (CKD) on the rebounding property of the pastes of specimens' groups S1, S2 and S3. The ratio of resilience is ranging between 55% and 65% for all groups of specimens tested. The reason for this is that the cement kiln dust increases the number of cross-linkages inside the material and stacks the particles of the pastes.

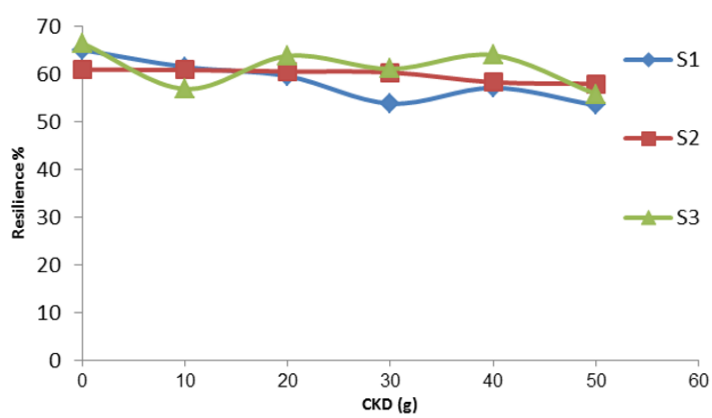


Fig. 9. Effect of CKD additive on the resilience of the pastes.

3.3. Hardness

Hardness test is an essential test to investigate the rigidity of the paste. Fig. 10 illustrates the hardness curves with different amounts of CKD additive for three different tested specimens' groups. The measured Brinell hardness number (HB) of the surface of the paste for the specimens' group S3 increases gradually and uniformly with the increase in the amount of additive CKD. The largest hardness of 90 nm CKD specimens (S3) was 71.5 HB. This may occur due to the CKD having a small granular size that increases the surface area of diffusion. This is also the reason for the increase in the bonding of particles of the paste materials. The stacking of nanoparticles of the additive inside the prepared paste caused to increase the resistance to the applied external forces, which raises the hardness of the surface of the material

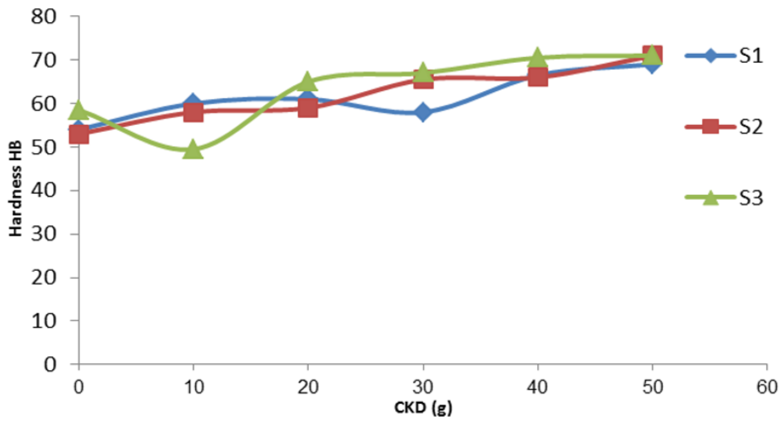


Fig. 10. Effect of CKD additive on the hardness of pastes.

3.4. Specific weight

Figure 11 shows a gradual increase of the specific weight of the group of specimens S3 with an increase of CKD weight. It was observed that the maximum specific weight of S3 specimens with 90 nm CKD was 1.33 N/mm^3. This occurred due to the small granular size of cement kiln dust as it filled the gaps (pores) that formed inside the prepared paste and reduce the spacing between particles.

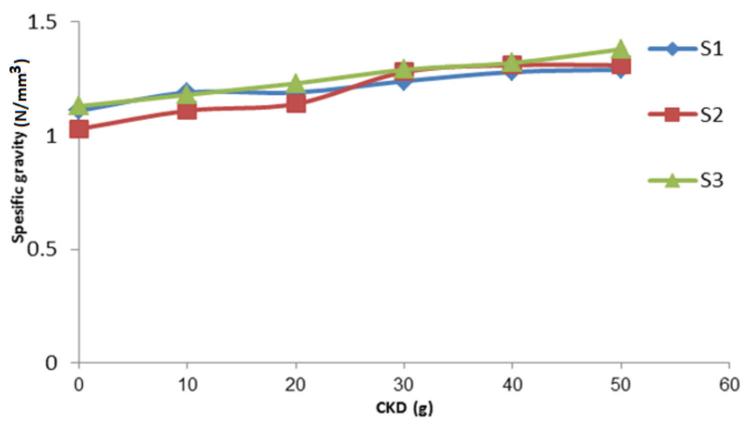


Fig. 11. Effect of CKD additive on the specific weight of the pastes.

3.5. X-ray fluorescence test

Figure 12 presents the X-ray inspection Germany device that was used to inspect the phases of components of CKD paste.

Specimens were placed in the form of a circular disk and the device was locked to examine the phases of the structures. The measured components of the suggested paste in this study are listed in Table 4. To compare the chemical composition of CKD listed in Table 1 with measured components of the novel paste listed in Table 4, it was observed that CKD is calcium-rich material with a ratio of 45.28%, while this ratio is reduced with the novel paste suggested in this study to be only 0.06% of the total components that make this paste.

Fig. 12. X-ray fluorescence device

Table 4. The measured chemical composition of the suggested paste

Compound	SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_3	Na_2O	K_2O	MgO	L.O.I
XRF (measured)%	49.9	41.09	1.45	0.06	0.007	0.07	1.05	0.15	1.54

4. Conclusions

A harmful by-product of cement kiln dust (CKD) from cement factories is converted into a useful paste when mixing CKD, RO water and linseed oil. This paste could be used in prosthetics applications or putty for glass windows. The mechanical properties of this paste with adding different amounts of CKD were investigated and analyzed. It was observed that adding cement kiln dust up to 40 g increases tensile strength, modulus of elasticity and elongation of the paste. The values of the return curve of group S3 show a uniform gradual increase in the values of the measured hardness number of the paste surface and the specific weight with an increase in the amount of the CKD additive

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References

[1] Kaliyavaradhan, SK, Ling, T-C & Mo, KH 2020, 'Valorization of waste powders from cement-concrete life cycle: A pathway to circular future', *Journal of Cleaner Production*, vol. 268, p. 122358.

[2] Turan, A, Hinchberger, SD & El Naggar, MH 2009, 'Mechanical Characterization of an Artificial Clay', *Journal of Geotechnical and Geoenvironmental Engineering*, vol. 135, no. 2, pp. 280-290.

[3] Mitchell, BS 2003, An Introduction to Materials Engineering and Science: For Chemical and Materials Engineers, John Wiley & Sons, Inc.

[4] Arkin, Y & Michaeli, L 1989, 'Strength and consistency of artificial clay — carbonate mixtures: Simulation of natural sediments', *Engineering Geology*, vol. 26, no. 3, pp. 201-213.

[5] Kunal, Siddique, R & Rajor, A 2014, 'Strength and microstructure analysis of bacterial treated cement kiln dust mortar', *Construction and Building Materials*, vol. 63, pp. 49-55.

[6] Yaseri, S, Masoomi Verki, V & Mahdikhani, M 2019, 'Utilization of high volume cement kiln dust and rice husk ash in the production of sustainable geopolymer', *Journal of Cleaner Production*, vol. 230, pp. 592-602.

[7] Abdel-Gawwad, HA, Heikal, M, Mohammed, MS, El-Aleem, SA, Hassan, HS, García, SRV & Alomayri, T 2019, 'Sustainable disposal of cement kiln dust in the production of cementitious materials', *Journal of Cleaner Production*, vol. 232, pp. 1218-1229.

[8] Abdel-Gawwad, HA & Khalil, KA 2018, 'Application of thermal treatment on cement kiln dust and feldspar to create one-part geopolymer cement', *Construction and Building Materials*, vol. 187, pp. 231-237.

[9] Bagheri, SM, Koushkbaghi, M, Mohseni, E, Koushkbaghi, S & Tahmouresi, B 2020, 'Evaluation of environment and economy viable recycling cement kiln dust for use in green concrete', *Journal of Building Engineering*, vol. 32, p. 101809.

[10] Siddique, R 2006, 'Utilization of cement kiln dust (CKD) in cement mortar and concrete—an overview', *Resources*,

demolition aggregates', *Construction and Building Materials*, vol. 186, pp. 71-78.

[17] Alnahhal, W, Taha, R, Al-Nasseri, H & Nishad, S 2018, 'Effect of Using Cement Kiln Dust as a Nano-Material on the Strength of Cement Mortars', *KSCE Journal of Civil Engineering*, vol. 22, no. 4, pp. 1361-1368.

[18] Abo-El-Enein, SA, Heikal, M, Amin, MS & Negm, HH 2013, 'Reactivity of dealuminated kaolin and burnt kaolin using cement kiln dust or hydrated lime as activators', *Construction and Building Materials*, vol. 47, pp. 1451-1460.

[19] Saleh, HM, El-Saied, FA, Salaheldin, TA & Hezo, AA 2019, 'Influence of severe climatic variability on the structural, mechanical and chemical stability of cement kiln dust-slag-nanosilica composite used for radwaste solidification', *Construction and Building Materials*, vol. 218, pp. 556-567.

[20] Najim, KB, Al-Jumaily, I & Atea, AM 2016, 'Characterization of sustainable high performance/self-compacting concrete produced using CKD as a cement replacement material', *Construction and Building Materials*, vol. 103, pp. 123-129.

[21] Sulaymon, AH, Faisal, AAH & Khaliefa, QM 2015, 'Cement kiln dust (CKD)-filter sand permeable reactive barrier for the removal of Cu(II) and Zn(II) from simulated acidic groundwater',

Conservation and Recycling, vol. 48, no. 4, pp. 315-338.

[11] Kunal, Siddique, R & Rajor, A 2012, 'Use of cement kiln dust in cement concrete and its leachate characteristics', *Resources, Conservation and Recycling*, vol. 61, pp. 59-68.

[12] Ahmari, S & Zhang, L 2013, 'Utilization of cement kiln dust (CKD) to enhance mine tailings-based geopolymer bricks', *Construction and Building Materials*, vol. 40, pp. 1002-1011.

[13] Seo, M, Lee, S-Y, Lee, C & Cho, S-S 2019, 'Recycling of Cement Kiln Dust as a Raw Material for Cement', *Environments*, vol. 6, no. 10, p. 113.

[14] Arulrajah, A, Mohammadinia, A, D'Amico, A & Horpibulsuk, S 2017, 'Cement kiln dust and fly ash blends as an alternative binder for the stabilization of demolition aggregates', *Construction and Building Materials*, vol. 145, pp. 218-225.

[15] Ghavami, S & Rajabi, M 2021, 'Investigating the Influence of the Combination of Cement Kiln Dust and Fly Ash on Compaction and Strength Characteristics of High-Plasticity Clays', *Journal of Civil Engineering and Materials Application*, vol. 5, no. 1, pp. 9-16.

[16] Mohammadinia, A, Arulrajah, A, D'Amico, A & Horpibulsuk, S 2018, 'Alkali-activation of fly ash and cement kiln dust mixtures for stabilization of

Cement Kiln Dust (CKD) with Silica Fume (SF) as a Partial Replacement of Cement in Concrete Production', *Journal of Minerals and Materials Characterization and Engineering*, vol. 7, pp. 137-149. *Journal of Hazardous Materials*, vol. 297, pp. 160-172.

[22] Arafa Elsayed Elhelloty, Mohammed Taha Nooman, Rafik Khairy Abdelwahab & Abdullah, AI 2019, 'Utilization of