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PHYSICO-MECHANICAL AND CHEMICAL CHARACTERISATION OF CEMENT KILN DUST AS COMPARED TO NORMAL SET PORTLAND CEMENT AS A MINERAL FILLER IN RECYCLED ASPHALT

USMAN K. R.*[1], AHMAD Z.[2], MUSA R.[3], ZAILANI J.[4], ABDULKADIR M. S.[5], USMAN S.[6], SHARIFF F. U.[7]

[1,2,3,4]Department of Civil Engineering Technology, Nuhu Bamalli Polytechnic Zaria. [5]Department of Mechanical Engineering Technology, Nuhu Bamalli Polytechnic Zaria. [6]Department of Computer Science Technology, Nuhu Bamalli Polytechnic Zaria. [7]Training Department, National Water Resource Institute Kaduna, Kaduna State.

ABSTRACT

Cement is a major construction material globally and its consumption geometrically increases especially in Nigeria with its use for road construction. Consequently, increased production to meet this demand comes with attendant environmental concerns of greenhouse emission and by-product safe disposal. Cement kiln dust

Introduction

Sustainable construction practices requires the minimization of the use of non-renewable resources whilst maintaining an environmentally-healthy production (Usman et al., 2021). Against this backdrop asphalt production utilises by-products or waste materials and cold mixing technologies for its production to curb green-house gas (GHG) emission and uphold sustainable practice (Al-Busaltan et al., 2012; Peploe & Zealand, 2006). Cement is a major

(CKD) as the by-product of cement poses risks both to the soil and humans if disposed in landfills, hence, some part is reinjected back into the kiln. Nonetheless, larger part is disposed as waste. Sustainable construction practices seek to reduce waste and most importantly reduce the use of non-renewable resources - cement raw material inclusive. Utilising a by-product for asphalt production will entail reducing the use of cement and invariably reduce the cost of asphalt. Thus, the study assessed the desirability of CKD as compared to normal setting cement for inclusion in asphalt production. The CKD and the cement were tested for chemical, physical and mechanical properties by X-ray fluorescence (XRF), X-ray Diffraction (XRD), toxicity characteristics leaching procedure (TCLP), specific gravity and Blaine fineness tests. Result suggest that CKD has desirable characteristics for use as filler in asphalt in place of cement.

Keywords: Cement Kiln Dust (CKD), Physico-mechanical, Recycled Asphalt, Natural aggregate

construction material whose consumption increases geometrically in Africa; thus, production is beeped up to meet demand. The emissions from cement production alone account to significant percentage to the total greenhouse emissions (Ali et al., 2014). About 10 - 20% of any batch of cement produced in a plant is waste in form of cement kiln dust (CKD). CKD's fine particles travels up to 10km from th cement plant in air and its cancerous, can Therefore, replacing cement with sustainable by-products for asphalt manufacture is key to minimising cement demand which in turn reduces global warming (Inyim et al., 2016). Numerous waste and by-products were tried for use in asphalt mixtures to improve its mechanical properties whilst addressing environmental challenges, but the key challenge remains the physico-chemical or mechanical suitability of such by-products in asphalt (Jamshidi et al., 2017; Peploe & Zealand, 2006). Some criteria for the selection of suitable by-product for construction purposes base on structural performance, energy consumption, GHG emission, aesthetic features, 4R policies, and socioeconomic concerns were proposed. The combined influence of blast furnace slag (GFS) and fly ash proves to enhance sulphate resistance of asphalt pavement and improves the long-term structural performance of the pavement (Jamshidi et al., 2017).

By-products incorporated in asphalt must possess the needed chemical, mechanical, morphological and physical properties to blend well with the bitumen and most importantly enhance its mechanical properties. All bituminous mixtures irrespective of the type of asphalt should possess the required stability against rutting, adequate compatibility among constituent materials and cohesion against stripping, and the required stiffness against flowing and segregation. Recently, researchers sought to improve the aforesaid qualities in asphalt with the introduction of waste slags, fibres, glass, polymers, epoxy resins, biomass ash etc, in asphalt mixtures. Varying degree of success were attained and complementary results achieved by adding these materials in asphalt. Steel slag was found to significantly improve the Marshall stability of asphalt mix by up to 35% improvement when utilised as fine aggregate replacement (Kandhal & Hoffman, 1997). Nickel slag on the other hand served well as both fine and coarse aggregate (Wang et al., 2011). Blast furnace and CKD were blended to form an eco-friendly cement which has even better cementitious properties than ordinary Portland cement (Rahman, 2016; Shen et al., 2006).

Recently, the use of cement kiln dust as a replacement for cement in concrete has gained wide popularity for its suitability and cost-effectiveness. However, the use of CKD for asphalt production is needs to be justified in terms of CKD's characteristics and compatibility attributes. This study aimed to evaluate the physico-chemical and mechanical attributes of CKD in comparison to ordinary setting cement for recycled asphalt production. Result of the study is compared to established standard limits for ordinary setting cement (Sultan et al., 2018).

MATERIALS AND TEST METHODS

Material

Cement

Normal setting Portland cement by Dangote Industry usually referred to as Ordinary Portland Cement (OPC) was utilised for this study. The Nigerian construction industry utilises this cement more than similar brands for regular construction works. The OPC was emptied from the sack and stored in air-tight containers to assure its pristineness.

Cement Kiln Dust (CKD)

Cement kiln dust (CKD) or flue dust as its popularly referred to was obtained from Dangote Cement factory in Obajana. Table 1 presents the physical attributes of the constituent materials including an evaluation of the key similarities between the cement and the CKD. Generally, it was reported that the cementitious compounds in CKD accounts to about one third (1/3) to that in a standard cement (Modarres et al., 2015).

Table 1. Physical Properties of CKD and Cement

Physical Properties	CKD	OPC	Remark
Colour (appearance)	Whitish grey	Dark grey	The CKD looks like gypsum
Specific gravity	2.95	3.11	The specific gravity is similar
Blaine Fineness (B.F) (cm^3/g)	7399	4100	CKD has higher B.F
Soundness (mm)	1.6	1.0	OPC is better than CKD
Percent passing sieve 10 µm (%)	36	23	CKD is finer than OPC
Loss on ignition (LOI) at 1000 °C (%)	6.6	10.8	

Table 1 indicated that CKD has lower LOI than OPC perhaps due to the fact that CKD has undergone the production process and has lower 'volatile' constituents that may lead to loss of weight. Moreover, the fineness of CKD may be more desirable than OPC in asphalt for the specific high surface which result in greater reactivity. The CKD use din this study is unusually whitish to light-grey as compared to the OPC. This could not be far fetched from the fact that the clinker has been subjected to a higher temperature, especially when the coarse CKD is reinjected back into the production line.

Test Methods

The study will be conducted almost entirely in the laboratory and the field. The research is phased into three (3) stages viz; material collection and characterisation, then physical, mechanical, and chemical testing are conducted under controlled environment.

Specific gravity test

The specific gravity is conducted according to ASTM C 188 (ASTM, 2011) which measures the density of a standard hydraulic cement. The methods which use the Le Chatelier flask, indirectly measure the specific gravity of the cement by determining and calculating from laboratory test, the density of the cement and CKD alike. The specific gravity of the cement is mathematically computed by dividing the density of the cement to that of distilled water at 4 ^{o}C.

Gradation test (Sieve analysis)

A dry sieve analysis under ASTM C136/C136M-14 standard procedures was employed and subsequently employed the 90 and 75 µm sieve sizes due to the mixture's fineness (ASTM C136, 2010). The method invariably measures the fineness of cement and CKD as well. The cement and CKD samples were dried to ensure moisture traces is expelled and then sieved through 600 µm to 75 µm set of sieves stacked in reducing aperture sizes from top to bottom. The sieves were shook using a mechanical shaker and manually to ensure completeness of the sieving.

Toxicity characteristics leaching procedure (TCLP)

This test was introduced by the United States environmental protection agency (US EPA) 1311 (1999). Trace toxic elements often contaminates waste and industrial by-products and if used for construction may leach into the soil thereby polluting groundwater or cause serious illnesses like cancer if airborne. Possible heavy metals targeted to be detected include Barium (Ba), Lead (Pb), Arsenic (As), Selenium (Se), Silver (Ag), Cadmium (Cd), Copper (Cu), Chromium (Cr) and Zinc (Zn). Distilled water was used to prepare the test specimens in the ratio 1:20 then centrifuged at 30 – 40 rpm for 24 hours. The filtrate was subjected to inductively coupled plasma mass spectrometry (ICP–MS) to detect the heavy metals.

X-ray fluorescence (XRF)

The extent of chemical composition in a crystalline sample is best determined by the XRF test. XRF works on the principle that unpaired electrons in the outer atomic orbitals detaches and replaced by another from sub-orbital lower energy levels creating fluorescence effect with a consequent energy differential. The energy is captured, recorded and matched with a library of stored similar fluorescence in the XRF machine which affirms the type of chemical compound so detected with reasonable accuracy.

X-ray Diffraction (XRD)

This test was employed in this study to determine the crystallinity of CKD and cement. spent garnet at atomic and elemental levels was evaluated using X-ray diffraction. Copper (Cu) Kα radiation source was used in an X-ray diffractometer set at 0.02° scanning at 0.5°/min within the range of 2θ from 0° to 100°.

RESULTS

Physico-mechanical properties of CKD and Cement

The CKD is largely light whitish-grey while the cement is dark-grey when pristine but turns darker when exposed to moisture. The CKD has higher specific surface area with smooth-textured grains similar to the cement. The particle size distribution of cement and CKD are presented in Fig. 1. The physical properties of the constituent material in this study are highlighted in Table 1 while the chemical composition is presented in

Table 2. The chemical composition of the two materials indicated similarity in the percentages of the active cementing ingredients.

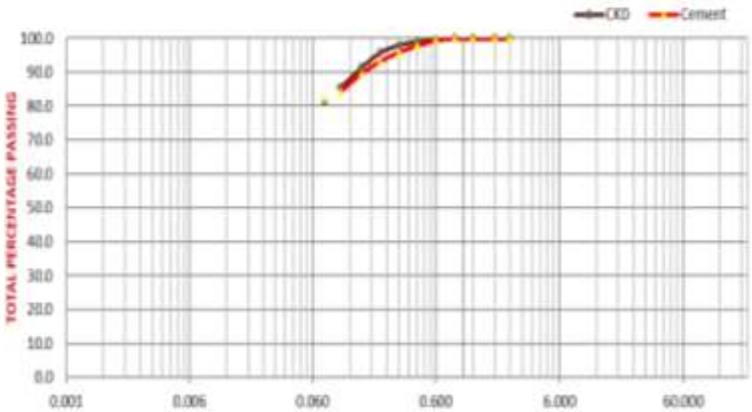

Fig. 1. Gradation for CKD and Cement

Table 2. Chemical properties of CKD and Cement

Compound (%)	CKD	OPC	ASTM C150 Requirement for Type II & Type IIA cements (max. %)	REMARK
Fe_2O_3	2.72	3.28	6	The value for CKD is well below that of OPC
Al_2O_3	3.89	5.11	6	
SiO_2	14.88	20.66	N.A	Higher temperatures of
CaO	63.81	63.43	N.A	CKD has higher CaO thus, higher reactivity
MgO	1.34	1.98	6	
K_2O	1.02	0.49	-	
Na_2O	0.20	0.37	-	

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Ti_2O	0.36	0.29	-	The higher TiO may be due to contamination
SO_3	3.49	3.64	-	
LOI	29.48	3.10	-	
Others	0.54	1.66	-	

It can be seen that from Fig. 1 that both CKD and cement 100% passed through the 2.36 mm up to 825 μm sieves. While the CKD has a percentage retained on the pan of 7.29 g, the cement has 12.89 g on the pan. The result signifies that cement is finer than the CKD. Nonetheless, it is interesting to note that from the laboratory data both CKD and cement records highest retained weights on the 150 μm sieve.
Importantly, each material satisfies the fineness modulus requirement for hydraulic cements of minimum percentage retained of 10 % on the 90 μm sieve.
The morphology or rather crystallinity of the CKD and Cement samples present similar peaks as seen in Fig. 2. The crystalline latices of the active ingredients in cementitious materials notably tricalcium silicate, dicalcium silicate, and tetra calcium Alumno-ferrite within 30 – 40 degrees were detected. Moreover, CKD has more peaks within the said range signifying better bond.

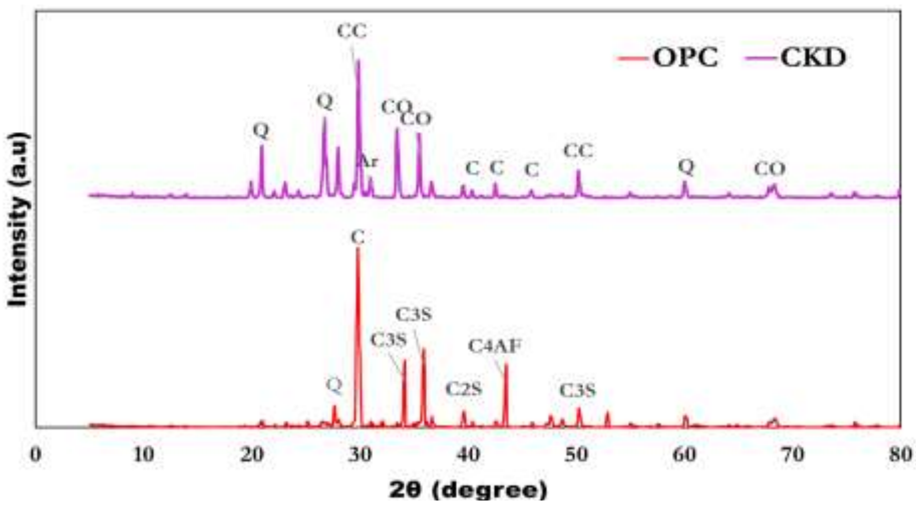

Fig. 2. XRD pattern of CKD and Cement

Chemical properties of CKD and Cement

X-Ray fluorescence (XRF) and TCLP constitutes the chemical composition and extent of contamination respectively. The various percentages of the constituent compounds present in CKD and Cement is presented in Table 2. Moreover, the test which determines the suitability/safety or otherwise of a material to be used for construction is the TCLP test. The test result is presented in Table 3

Table 3. Result of Heavy metal concentration test

Heavy Metal Concentration (mg/L)	CKD	TCLP Standard Levels	REMARK
Ni	0.001	2.00	
Cr	0.000842	5.00	
Pb	0.000014	0.005	
Cu	11.00	25.00	Cu is high though well below limit
Ar	0.02	5.00	
Ba	15.00	100.00	
Zn	17.80	250.00	
Sr	-	-	
Th	7	-	
Cd	0.00021	1.00	
Co	-	8.00	Cobalt is not detected in the CKD sample

The CKD sample exhibited that it is free from contamination by heavy toxic metals as indicated in Table 3. The result in Table 3 shows that Zinc (Zn), Barium (Ba) and Copper (Cu) represents the elements with the highest concentration. Despite having the highest concentration, yet they are well below the maximum set limits. Thus, CKD is safe to be employed for construction purposes including asphalt production and pavement construction.

DISCUSSION

The CKD has comparable chemical, physical and mechanical properties to that of cement in most ramifications. More so, the TCLP test proven that CKD is safe to be used for construction purposes with the obtained limits well below the set limits. by X-ray fluorescence (XRF), X-ray Diffraction (XRD), toxicity characteristics leaching procedure (TCLP), specific gravity and Blaine fineness tests. Result suggest that CKD has desirable characteristics for use as filler in asphalt in place of cement.
From the gradation result presented in Fig. 1., CKD has met the fineness modulus test requirement of cement of having a minimum percentage of 10% passing the 90 µm test sieve. The high specific surface area of CKD as revealed by the Blaine fineness test and presented in Table 1 which nearly doubles that of cement and a lower loss on Ignition than cement suggests that CKD can adequately serve as a filler in asphalt. The function of a filler in asphalt is to increase stiffness, reduce voids and prevent asphalt bleeding in asphalt.

CONCLUSION

Assessment of the obtained results indicated that the tested CKD is free from toxic heavy metal substances, it has the requisite specific gravity, fineness and desired chemical composition needed to serve as a filler in asphalt. Furthermore, the OPC cement has high crystallinity, specific gravity and active chemical constituents which satisfies the ASTM C150 requirement for Type II & Type IIA cements necessary for strong bond in asphalt. It is therefore concluded that the CKD from Obajana cement factory can satisfactorily be incorporated in asphalt production.

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