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Physico-mechanical and durability characteristics of concrete paving blocks incorporating cement kiln dust

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HIGHLIGHTS

- Environmental-friendly interlocking paving blocks could be produced with CKD.
- The addition of CKD is better than being used as a partial replacement of cement.
- 60% CKD blocks could be used in medium traffic applications.
- CKD adversely affects the properties of paving blocks exposed to hydrochloric acid.
- 40–60% CKD blocks are not recommended for exposure to high concentrations of HCl.

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ABSTRACT

This research aims at evaluating the physico-mechanical and durability-related properties of concrete paving blocks containing cement kiln dust (CKD) used as a partial replacement or as an addition to cement. Results indicated that up to 40% CKD could be used for producing environmental-friendly paving blocks for heavy traffic applications, while 60% CKD blocks are suitable for areas subjected to medium traffic applications such as in city streets. Furthermore, 40–60% CKD blocks are not recommended for use in applications where it will be subjected to high concentration of hydrochloric acid such as in industrial floors because of their inferior long-term performance.

1. Introduction

Paving block pavement is made up of precisely dimensioned, individual unreinforced precast cement concrete blocks that fit closely together to form the surface course of pavement [1,21]. It is adopted where the conventional types of pavement construction are not feasible or desirable due to operational or environmental constraints [47]. Paving blocks are produced in different colors, shapes and sizes and could be placed in a variety of patterns to suit the imagination of landscape architects and nature's essence [21,29].

Concrete block pavements have been widely used since World War II [40]. Today, it has become an attractive engineering and economical alternative to both flexible and rigid pavements because of its ease and fast placement, maintenance and removal, resistance to movement and breakage, durability and aesthetically pleasing surfaces. These features result in longer pavement life with reduced maintenance cost Concrete Manufacturers [45,17,23,32,47]. Concrete paving blocks are utilized in a variety of commercial, municipal and industrial applications such as main and residential roads, sidewalks, driveways, parking areas, bus stops, indoor areas, factories and warehouses, container yards, airports, harbors, military applications, storm-water channels, embankment walls, cladding vertical surfaces, etc Concrete Manufacturers [45,23].

Concrete paving blocks are mainly composed of cement, water, coarse and fine aggregates. Due to the growing and widespread use of concrete paving blocks throughout the world, associated with the need for reducing the consumption of natural resources and production costs, researchers have focused on incorporating different solid wastes/by-products as alternative materials in paving blocks. Extensive researches have been conducted for utilizing

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recycled wastes, especially construction and demolition wastes, as replacement materials to conventional aggregates in the production of paving blocks [15,17,33,40]. Moreover, some researches are being carried out to investigate the possibility of using recycled wastes as cement substitution in the production of paving blocks for reducing the high amount of cement in paving blocks [24,25,32,44].

On the other hand, the manufacturing of Portland cement is accompanied by the generation of large quantities of solid wastes in the form of dust emissions. Dusts are generated from several locations of the production line. The dust collected from the exhaust gases of the rotary kiln in the control devices such as bag-houses or electrostatic precipitators to prevent the build up of excessive salts in the produced cement is known as cement kiln dust (CKD), while the dust collected during the extraction of the gas stream is by-pass dust (BPD) [46,18,42,12]. The main difference between CKD and BPD is related to the temperature at which these materials are produced. CKD is taken out of the kiln during where the temperature is about 300 °C, while BPD is from the kiln where the temperature is about 1000 °C [34].

CKD is a fine-grained, solid and highly alkaline by-product [12]. It consists of entrained particles of clinker, unreacted and partially calcined raw materials, and fuel ash enriched with alkali sulfates, halides and other volatiles [42]. It is enriched in sodium and potassium chlorides and sulfates [27]. Some of the generated CKD could be reused into cement kiln as raw feed. However, this is limited by the alkalis concentration in CKD, which may cause the alkalis content in cement to exceed the allowable limit [26]. The portion of CKD that is not returned back to cement industry is disposed off posing significant environmental problems. Disposal of CKD results in the contamination of surface and ground water by chemicals and heavy metals leached from CKD. In addition, CKD affects human health by causing serious health hazards including asthma, skin irritation and eyes problems [14,27,41].

Extensive researches are being conducted for the recycling of CKD such as for the stabilization of soil and sludge, in hot asphalt, glass industry, controlled low strength materials, mortar and concrete [3,22,27,30]. Sharif [38] examined the possibility of using 0–25% CKD as a partial replacement of Ordinary Portland Cement (OPC) and White Portland Cement (WPC) in paste. The use of CKD was found to significantly increase the water required for normal consistency of cement paste. While setting times and compressive strength of cement paste decreased by using CKD, the expansion in the autoclave test significantly increased. The author recommended limiting the content of CKD at 10% in cement paste. Colangelo et al. [11] investigated the effect of using 10–30% CKD as a replacement of sand and replacement of 10–20% of cement in self-leveling mortar. Using CKD as an addition to cement significantly increased the compressive strength of mortar, while using CKD as a replacement of cement decreased the 28-day strength. The authors recommended the replacement of up to 30% of sand by CKD in the manufacturing of self-leveling mortar. Maslehuddin et al. [26] assessed the effect of using 0–15% CKD to replace Type I and Type V cements in concrete. The compressive strength decreased, while the drying shrinkage and chloride permeability of concrete increased with the quantity of CKD. The authors suggested limiting the amount of CKD in concrete to 5%, from both the strength and durability perspectives, as it does not have a significant effect on concrete performance. Ozyildirim and Lane [31] evaluated the durability of concrete containing CKD and found that the replacement of cement in mortar with 10% CKD resulted in alkali-silica reaction expansions similar to those of the control mortar without CKD. In case of exposure to external sulfate attack, mixes containing CKD with higher sulfate and alkali content produced higher expansions than similar mixes containing CKD with low content.

It is clear that the characteristics of CKD mainly its high chlorides, sulfates and alkalis content have negative effects on the overall performance of cement paste, mortar and concrete, which consequently restrict the mount of CKD that can be used in structural applications. However, the shortcomings of using CKD can be avoided by being used in the production of non-structural concrete products such as paving blocks. Therefore, this study aims at investigating the possibility of recycling CKD in the production of blocks for pavement construction projects. CKD was used either as a partial replacement of cement at 10%, 20%, 40% and 60% or as an addition to cement at 20%. This application will not only help in solving the environmental problems generated from CKD disposal, but also will reduce the consumption of significant quantities of cement used in paving blocks industry. The properties of the produced paving blocks including compressive strength, tensile splitting strength, water absorption, abrasion resistance, slip/skid resistance and durability against hydrochloric acid attack were determined and compared with the requirements of ASTM C936/C936M-15, BS EN 1338-2003 and Indian Standard IS 15658:2006 for paving blocks.

2. Materials

Conventional paving blocks are composed mainly of cement, sand, crushed stone and water. The cement used was Portland cement (CEM I 42.5 N) produced by El-Suez cement Company, Egypt and conforming to BS EN 197-1 [9]. The specific gravity and specific surface area of the used cement were 3.15 and 3565 cm^2/g, respectively, while its 2 and 28-days compressive strength were 24.7 and 49.1 MPa, respectively. The chemical composition of cement is shown in Table 1. Crushed dolomite and natural sand were used as coarse and fine aggregates, respectively. Table 2 shows the characteristics of the used aggregates, while Fig. 1 shows their grading curves.

In this paper, cement kiln dust was investigated to be used as supplementary cementing material or as an addition to cement in the production of concrete paving blocks. It was obtained as a by-product generated during the clinker manufacturing process

Table 2
Properties of aggregates.

Property	Crushed dolomite	Sand
Specific gravity	2.66	2.56
Unit weight (t/m^3)	1.65	1.52
Absorption (%)	0.70	–
Clay and fine materials (%)	0.20	1.42
Impact index (%)	21.01	–

Table 1
Chemical composition of cement and CKD.

Material	Oxide (%)									
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Na_2O	K_2O	Cl^-	LOI
Cement	20.85	5.98	3.90	62.85	0.10	3.22	0.11	0.22	–	2.74
CKD	6.1	1.37	3.09	60.56	0.44	5.41	0.64	2.56	2.75	15.04