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Recycling of high volumes of cement kiln dust in bricks industry

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A B S T R A C T

Sustainability involves that the needs of the present generation are met without wasting, polluting, harming or destroying the environment. Cement industry is one of the major industries that exert the environment due to its high natural resources and energy requirements and the emission of significant amounts of carbon dioxide. Nowadays, there is a global need to use waste materials to substitute cement for limiting its environmental impact and converting these wastes into useful products for sustainability. This paper investigates the feasibility of using cement kiln dust (CKD) as a partial substitute of cement in the production of solid cement bricks. Two types of cement (i.e., ordinary Portland cement and sulfate resisting cement) and two cement contents (i.e., 150 and 200 kg/m^3) were used. A total of twelve mixes were prepared with 0%, 30% and 50% substitution percentage of cement by CKD. Compressive strength, unit weight, water absorption and performance of bricks after submersion in magnesium sulfate and sewage water were evaluated. In addition, the environmental impact and economics of this application were also assessed. The results showed that up to 50% CKD could be utilized for manufacturing economical and environmental-friendly bricks with acceptable properties. Nevertheless, it is preferable to use CKD with sulfate resisting cement instead of ordinary Portland cement. This application will not only reduce the environmental problems associated with CKD disposal but also it will be a step towards sustainable development by reducing the demand of cement needed in bricks industry, hence reducing energy requirements and CO_2 emissions during cement manufacturing process.

1. Introduction

Cement is a strategic commodity since it is a key component in construction industry. It is one of the most widely used materials on the earth. Approximately 3.6 billion metric tons of cement is produced globally every year, with volume predicted to rise to more than 5 billion metric tons by 2030. The industry is growing particularly rapidly in developing countries having a high demand for infrastructure and housing (Felekoğlu et al., 2007).

Cement is made by combining clinker with gypsum. The cement production process requires thermal energy for producing clinker in rotary kilns. Manufacturing of one ton of ordinary Portland cement requires 60–130 kg of fuel oil or equivalent and about 110 KWh of electricity (Felekoğlu et al., 2007). In average, it requires about 2.8 ton raw materials (including fuels and other materials) (Marku et al., 2012). In the meanwhile, cement industry is arguably regarded as the second largest producer of greenhouse gases (Najim et al., 2014). Every ton of cement releases 0.9–1.1 ton of carbon dioxide (CO_2), a major greenhouse gas, into the atmosphere, which adversely affects earth's climate pattern (National Ready Mixed Concrete Association, 2012). The high-energy requirements and the release of significant amounts of CO_2 make cement production a concern for global warming.

On the other hand, significant quantities of dust, commonly known as cement kiln dust (CKD), are generated during the manufacturing of Portland cement clinker by the dry process. CKD is a fine-grained, solid and highly alkaline waste removed from cement-kiln-exhaust gas to prevent the build up of excessive salts in the produced cement (Daous, 2004). It is enriched in sodium and potassium chlorides and sulfates, as well as volatile metal compounds (Naik et al., 2003). 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 (i.e., not more than 0.6%) in addition to decreasing the efficiency of the kiln and creating equipment failures (Maslehuddin et al., 2009). The portion of CKD

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that is not returned back to cement industry is disposed off. On the worldwide scale, every year, approximately 30 million tons of CKD are generated and approximately 80% of it remains stockpiled or landfilled posing significant environmental problems (Hossain et al., 2007; Konsta-Gdoutos and Shah, 2003). Disposal of CKD results not only in the consumption of land, but also in the contamination of surface and ground water by chemicals and heavy metals leached from CKD (Naik et al., 2003; Sreekrishnavilasam and Santagata, 2006). In addition, CKD affects human health by causing serious health hazards including asthma, skin irritation and eyes problems (Fadhil et al., 2013). Hence, researches are being conducted to find out efficient ways for using CKD. Some examples of these applications are: using CKD as a stabilizing agent for sludge and wastes, as agricultural soil amendment, as an anti-stripping agent in hot asphalt, as a sanitary liner and in glass industry (Adaska and Taubert, 2008; Naik et al., 2003). In addition, CKD has been investigated for being utilized in controlled low strength materials (Lachemi et al., 2010), in soil stabilization (Ozaa and Gundaliya, 2013), as a removal of hazard minerals (Salem et al., 2012) and as an activator for pozzolans (Bondar and Coakley, 2014).

On the other hand, as discussed previously, cement is not considered as an environmental-friendly material from the standpoint of resource and energy consumption and environmental problems resulting from its manufacturing process (i.e., release of greenhouse gases and generation of significant amounts of CKD) (Moriconi, 2007). Thus, cement industry, like the rest of construction industry, is facing a number of challenges relating to energy resources, scarcity of raw materials and growing environmental concerns. Therefore, the implementation of “sustainable construction” concept has become an essential requirement. Sustainability involves that the needs of the present generation are met without wasting, polluting, destroying the environment and without compromising the ability of the future generations to meet their needs (Hameed et al., 2012). This is accomplished by using less natural materials, consuming less energy, causing lower levels of pollution, and reducing wastes while gaining the same benefits that can be achieved by using traditional materials and methods. Recycling of wastes in construction industry becomes an increasingly important for sustainable construction, as it could lead to several economical and environmental benefits (Abdelfatah and Tabsh, 2011). According to this new vision, recycling of wastes/by-products to partially substitute cement is highly encouraged for limiting the environmental impact of cement industry and converting these wastes into useful products for sustainable construction. For many years, industrial wastes such as slag, fly ash and silica fume have been successfully used as supplementary cementing materials in construction industry (Al-Jabri et al., 2006). Similarly, extensive researches are being carried out for utilizing CKD in cement-based materials (Abd El-Aleem et al., 2005; Bondar and Coakley, 2014; Marku et al., 2012). However, the variability in the characteristics of CKD from plant to plant, depending upon the feed raw materials, type of kiln, dust collection facility and the fuel used leads to uncertainty in its performance and limits its potential application in cement-based materials (Sreekrishnavilasam and Santagata, 2006). Furthermore, using of CKD with high amounts of sulfate, alkalis and chlorides reduces the workability, setting times and strength and increases the risk of sulfate expansion, alkali-silica reaction, and steel corrosion in reinforced concrete (Adaska and Taubert, 2008). For these reasons, most of studies have restricted the percentage of CKD in cement-based materials at 5–10% for achieving satisfactory performance (Kunal et al., 2012; Maslehuddin et al., 2009). Nowadays, several researches are being conducted to improve the influence of CKD in cement-based materials by removing/lowering its alkalis content using physical, chemical or biological treatments. However, most of these treatments are expensive and the percentage of CKD in cement-based materials is still very limited (Gebhardt, 2001; Kunal et al., 2014).

It is evident that although extensive researches are being conducted to find out alternative applications for CKD rather than disposal, its characteristics restrict its widespread usage and limit its recycling level. Exploring economical ways to make use of CKD as a value added material has been of great concern. This study was conducted as the first part of the work focused on the recycling of high volumes of CKD in construction industry. In this research, CKD was utilized as a partial substitute of cement (i.e., 0%, 30% and 50%) for manufacturing solid cement bricks. This application not only helps in utilizing high volumes of CKD, but also reduces the consumed quantity of cement in bricks industry. The physico-mechanical properties of the produced bricks were evaluated by determining their unit weight, water absorption and compressive strength, while the durability characteristics were assessed by determining the change in the compressive strength of bricks after being submerged for 10 months in aggressive solutions. In addition, the environmental and economical evaluation was also conducted to select the most economical and environmental-friendly mix.

2. Materials

Crushed dolomite and natural sand were used as coarse and fine aggregates, respectively. The nominal maximum size of crushed dolomite was 14 mm and fineness modulus of sand was 2.6. The density of coarse and fine aggregates was 2.7 and 2.5 t/m^3, respectively. Two types of cement were used; ordinary Portland cement CEM I 42.4N (PC) and sulfate resisting cement CEM I-SR 42.5N (SR) from El-Suez cement company. Cements were tested for compliance with European Standards BS-EN:197-1 (2011) and their chemical composition is presented in Table 1.

Cement kiln dust was obtained from El-Suez Cement Company, Egypt. The density of CKD was 3.12 t/m^3, which is comparable to that of cement. Table 1 depicts the chemical composition of CKD. The used CKD constituted mainly of CaO accompanied with significant anions of chloride and sulfate. Compared with cement, CKD is characterized by higher alkalis (in particular potassium), sulfate, chloride and LOI. High alkali content is one of the reasons precluding the recycling of CKD back into the kiln, as it would cause the alkali content in the clinker to exceed the maximum allowable value (Sreekrishnavilasam and Santagata, 2006). Moreover, SiO_2 and CaO contents were found to be lower in CKD than those found in cement. The mineralogical characterization of CKD was determined by X-ray diffraction (XRD) test using X'Pert Pro X-ray vertical diffractometer equipped with monochromatic Cu-Kα radiation source. The test was run at 40 kV and 30 mA. Scanning was performed in the range of $5^\circ \leq 2\theta \leq 60^\circ$ with a scan rate of 2° per minute. XRD pattern of CKD is presented in Fig. 1(a). XRD analysis indicated that lime is the major crystalline phase in CKD whereas sylvine, halite, quartz, portlandite and calcite are minor phases. Fig. 1(b) shows the grading of CKD as determined by laser diffraction. It is obvious that particle size distribution of CKD used ranged from 0.6 to 6 μm with an average particle size of 2.45 μm. Furthermore, the D10 and D90 for CKD were 1.5 and 3.6 μm, respectively. On the other hand, cement typically consists of 15% particles below 5 μm diameter and 5% particles above 45 μm with an average particle size of about 15 μm (Baghchesaraei and Baghchesaraei, 2012). Hence, CKD appears to be finer than cement. These findings are in agreement with Marku et al. (2012) findings that CKD has chemical, mineralogical and physical characteristics quite different from Portland cement.