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Effect of incinerated sugarcane filter cake on the properties of self-compacting concrete

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HIGHLIGHTS

- SCC mixed with incinerated sugarcane filter cake (ISFC) was studied.
- ISFC cake was used as a cement replacement up to 20% wt.
- Total powder contents of SCC were 450, 550 and 650 kg/m^3.
- ISFC has great potential to a significant extent in the production of SCC.
- SCC mixtures with ISFC have a larger superplasticizer demand (1.95–0.10%).

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ABSTRACT

Filter cake is a major residue of the sugarcane industry; more than 3 million tons of filter cake waste from the sugarcane industry are annually disposed in Thailand. This paper investigates the effect of incinerated sugarcane filter cake (ISFC) on the properties of self-compacting concrete (SCC). Fifteen SCC mixtures were investigated in this study. ISFC was used as a partial replacement of cement from 0%, 10%, 20%, 30% to 40% by weight of Portland cement (OPC). The powder materials were design to have three total powder contents of 450, 550 and 650 kg/m^3, whereas the water-powder (OPC plus ISFC) material ratio for all mixtures was kept constant at 0.40. The mixtures were designed to produce a controlled slump flow diameter of 700 ± 25 mm. Tests were performed on all mixtures to determine the properties of fresh SCC in terms of workability and stability. The mechanical properties of hardened SCC, such as the compressive strength and flexural strength, were also determined. The results show that SCC with 30% ISFC replaced Portland cement with a 650 kg/m^3 powder content has a compressive strength of more than 30 MPa for 28 days, which is larger than the compressive strength of mixes with 550 kg/m^3 and 450 kg/m^3 powder contents by approximately 24% and 60% at the identical percentage replacements.

1. Introduction

Self-compacting concrete (SCC) is one of the great innovations in concrete technology. Compared with traditional vibrated concrete, SCC has obvious advantages in terms of reducing construction costs and improving the construction environment, which are significant steps forward in the direction of sustainably developed concrete [1]. The difference between conventional concrete and SCC is the significantly greater flowability of the latter. SCC has three main abilities: (a) to flow under its own weight without vibration, (b) to flow through heavily congested reinforcement under its own weight, (c) and to become homogeneous without the aggregates becoming segregated [2]. The key point in SCC production is the mix proportions to obtain a highly fluid concrete. A high powder content of 500–600 kg/m^3 is often required in SCC [3]. Compared to vibrated concrete, unit SCC often requires higher volume binder levels (cement and highly supplementary materials), a lower coarse-aggregate volume ratio in the present technology [1,4], a generally high replacement level of cement by mineral additions and high dosages of a superplasticizer, and often, a viscosity-modifying agent [5]. A significant disadvantage of SCC is its higher cost compared to conventional concrete [6]. The concrete preparation requires the use of relatively expensive admixtures and additives that significantly affect the performance of SCC [7]. This requirement increases the cost of SCC and significantly elevates its environmental burden [1]. Various studies have been conducted to evaluate the behavior of SCC in fresh

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and hardened states under the effect of the partial replacement of Portland cement with a mineral admixture. The use of a by-product mineral admixture can decrease the cost of SCC and the amount of CO_2 production related to the use of Portland cement in concrete [8]. From this viewpoint, a cost-effective SCC design can be obtained by incorporating reasonable amounts of a mineral admixture [9]. At least some of the cement in SCC must be replaced with a high volume of by-product materials to reduce the cost of SCC to be significantly below that of conventional concrete [6]. The use of such materials reduces the cost and provides additional performance to SCC [10]. Moreover, in regions where these materials are not locally available, the cost of SCC increases, making it uneconomical. Therefore, alternative low-cost and locally available materials that can be used as mineral fillers for SCC production must be found to realize the technical and economic benefits of SCC [11]. Some researchers have focused their interest on the incorporation of industrial wastes into SCC, which can help to recycle waste, develop a new environmentally friendly concrete material technology [7], save on landfill space and reduce CO_2 emissions by using less cement and sand [4].

Sugar is one of the most important substrates in the human diet. In 2014, 1899 million metric ton (Mt) of sugarcane was produced worldwide. The top five nations, viz., Brazil, India, China, Thailand and Pakistan, accounted for more than 70% of the total sugar production in the world. Brazil is the largest sugarcane producer, which contributes approximately 737 Mt of total world sugarcane production, followed by India, at approximately 352 Mt; China, at approximately 125 Mt; Thailand, at approximately 103 Mt; and Pakistan, at 67 Mt. Thailand is the fourth largest producer of sugarcane in the world, the total production of which increased by nearly 60% in 2004–2014 [12]. In sugar mills, sugar is produced through several processes and produces a main solid waste in the sugar industry. The main by-products of the sugar industry that have greater economic value are: (i) Bagasse, (ii) Molasses and (iii) Filter Press Cake or Press Mud [13]. Filter cake is a by-product from the juice clarification and treatment process; raw juice has non-sugar impurities that are removed using a mixture of chemical reactants, such as sulfur and lime. Juice heating is compulsory for chemical reactions, which separate raw juice into two parts: a liquid form and a solid form, which are called syrup and mud or filter cake, respectively [14].

Filter cake is an industrial waste that is available from sugar mills. For every 100 tons of crushed sugarcane, approximately 3–3.3 tons of filter cake remain as a by-product [15,16]. In 2014, the annual availability of sugarcane filter cake was 57–63 Mt worldwide and 3.1–3.4 Mt in Thailand. Filter cake causes significant pollution and is considered to be a waste that poses management and final disposal problems in several sugar factories [15]. Random stacking occupies land and pollutes the air. Landfill pollutes underground water. Its safe disposal has always been a hot topic in Thailand as well as in the main producers [17]. Serious environment problems have occurred because filter cake is stacked around factories without safe disposal. It is important to find a new method to reasonably reuse filter cake. This method should be the better one so that the sugar industry and the environment can be sustainably developed [18]. This sugar industry waste is highly useful for energy production and can be used for metal absorption from wastewater [16] or to improve soil fertility in sugarcane fields [14]. However, its composition varies with the locality, cane variety, milling efficiency and clarification methods. For industrial use, filter cake from carbonation sugar mills contains 40–45% of calcium oxide (dry basis) and can be used (i) as building lime after calcination; (ii) to make cement, distemper paints, foaming agents, activated carbon, filter aids and proteins; or (iii) to prepare steroids and superior-quality wax [13].

The cement industry is known to be an important consumptive industry for raw material and energy [18]. The main chemical component of filter cake is CaO, which is also the main chemical compound of lime-based cement raw materials. Therefore, at least in theory, it can be used as an alternative of lime-based materials for cement clinker production. Haoxin et al. [17] explored the mechanisms of filter cake production in Portland cement clinker formation to effectively use filter cake in cement production as a lime-based raw material. The experimental results show that filter cake can reduce the apparent activation energy of calcium carbonate decomposition and increase the liquid phase amount. Appropriate filter cake replacement ratios are useful to promote C_3S formation and increase the C_3S content. Moreover, the compressive strengths of all mortars are related to the replacement ratios of limestone with filter cake. When the replacement ratio is less than 20%, all mortars have greater compressive strengths than the control. The compressive strengths are negatively affected when the ratio is more than 20%. The initial and final setting times are also prolonged for the specimens with more than 20% content of filter cake [18]. Makul and Sua-iam [19] investigated the properties of lightweight foamed concrete (LFC), where Type-1 Portland cement (OPC) was replaced by incinerated sugarcane filter cake, in terms of compensation for the fresh and hardened properties of cement. LFC was fabricated using the preforming method at a range of densities (900–1100 kg/m^3). Few researchers have investigated the effect of filter cake as a replacement for cement. The contribution of previous work is the knowledge of how to recycle this waste product as a raw material in concrete production. When it is used to replace cement, sugarcane filter cake reduces the total quantity of primary materials, which provides a safe and economical method to dispose of them. A previous literature survey did not find any study on the production of SCC mixtures that incorporated ISFC. This study aims to explore the effects of mixtures with 0%, 10%, 20%, 30%, and 40% filter cake as a cement replacement for producing SCC; various characteristics of the fresh and rheological properties and compressive strength of SCC were investigated.

2. Experimental details

2.1. Materials

Type-1 Portland cement (OPC) that conforms to ASTM C150 [20] was used as the cementitious material in all SCC mixtures. OPC with a specific area of 10,400 cm^2/g and a density of 3150 kg/m^3 was used. In this study, sugarcane filter cake with a density of 1900 kg/m^3 was a by-product of a sugar mill in the Singburi province in central Thailand. Sugarcane filter cake is the residue of the filtration of sugarcane juice. A large amount of sugarcane filter cake was disposed of in an open area, as shown in Fig. 1, which can significantly contribute to the environment and represents a public health problem.

The received sugarcane filter cake had a notably high loss on ignition (LOI). The combustion method to decrease the LOI was applied in this investigation. ISFC was produced by burning the filter cake in an electrical furnace and heating it at a constant rate of 10 °C/min from room temperature (23 °C) to 850 ± 20 °C. When the electrical furnace reached the target temperature, the temperature was maintained for 3 h. After this heating treatment, the incinerated sugarcane filter cake was allowed to naturally cool to room temperature, as shown in Fig. 2.

The chemical composition and physical properties of the OPC, as-received sugarcane filter cake and ISFC are listed in Table 1. For the as-received sugarcane filter cake, the calcium oxide (CaO) content was 51.78% and the LOI was 44.58%. After burning, the

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