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Use of increasing amounts of bagasse ash waste to produce self-compacting concrete by adding limestone powder waste

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ABSTRACT

Bagasse ash is an abundantly available combustion by-product in the sugarcane industry. We examined the effect of adding limestone powder to self-compacting concrete mixtures in which large amounts of bagasse ash were employed as a fine aggregate replacement. A Type 1 Portland cement content of 550 kg/m^3 was maintained in all of the mixtures. The fine aggregate was replaced with 10, 20, 40, 60, 80, or 100% bagasse ash and limestone powder by volume. Mixtures were designed to yield a slump flow diameter of 70 ± 2.5 cm. The workability (slump flow, T_{50cm} slump flow time, V-funnel flow time, and J-ring flow) and hardened properties (ultrasonic pulse velocity and compressive strength) of each mixture were measured, and blocking assessments were performed. The volumetric percentage replacement of 20% limestone powder in fine aggregate incorporating 20% bagasse ash effectively enhanced the workability and hardened properties of self-compacting concrete.

1. Introduction

Sugarcane requires ample sunlight, warmth, and water, limiting its cultivation to semi-tropical regions. It is a particularly important product in developing countries (Wakamura, 2008). In 2011, the total worldwide production of sugarcane was approximately 1794 million tons. Thailand is the fourth largest producer of sugarcane in the world (Crop production, 2013), with a total production of approximately 98 million tons (Office of Cane and Sugar Board, 2012). Much of the raw mass of sugarcane becomes waste during the refining process. Since refineries are normally built in locations where commercial power is unavailable, the factories generate their own electricity by burning bagasse to provide steam for back-pressure steam turbine generators as well as process heating (Wakamura, 2008). The resulting bagasse ash (BA) represents approximately 0.62% of the sugarcane weight (Cordeiro et al., 2004), or 607,600 tons per year in Thailand. Fig. 1 is a flow chart of the raw sugar production process and the resulting by-products.

In Thailand, most of the BA is deposited in landfills. The many landfills required are rapidly becoming an environmental burden (Chusilp et al., 2009a; Somna et al., 2012) (Fig. 2). In recent years, the use of agricultural and industrial by-products in concrete production has been the focus of a great deal of research because of the pozzolanic activity of ash materials, including the ash derived from combustion of sugarcane solid wastes (Villar-Cociña et al., 2008).

BA may be classified as a probable pozzolanic material, with the main factors affecting reactivity being the crystallinity of the silica present in the ash and the presence of impurities such as carbon and unburned material (Martirena et al., 1998). Good pozzolanic properties are obtained in BA heated between 800 and 1000 °C for 20 min (Villar-Cociña et al., 2008) or treated by air calcination at 600 °C for 3 h. The improved pozzolanic properties are due to the presence of amorphous silica, low carbon content, and high specific surface area (Cordeiro et al., 2009). Cordeiro et al. (2004) demonstrated that the pozzolanic activity of BA may be significantly increased by mechanical grinding in a vibratory mill. Ground BA with a loss-on-ignition of less than 10% provided an excellent pozzolanic material and could be used to partially replace Portland cement in concrete (Chusilp et al., 2009b). Many researchers have reported that BA exhibits satisfactory behavior in blended cementitious materials in concrete and has great potential for use in other applications (Alavéz-Ramírez et al., 2012). Singh et al. (2000) noted that the addition of 10% BA increased the compressive strength of cement paste at all ages of hydration. The chemical deterioration of blended cement is also reduced due to the pozzolanic nature of BA and the reduced permeability of BA-containing mixtures.

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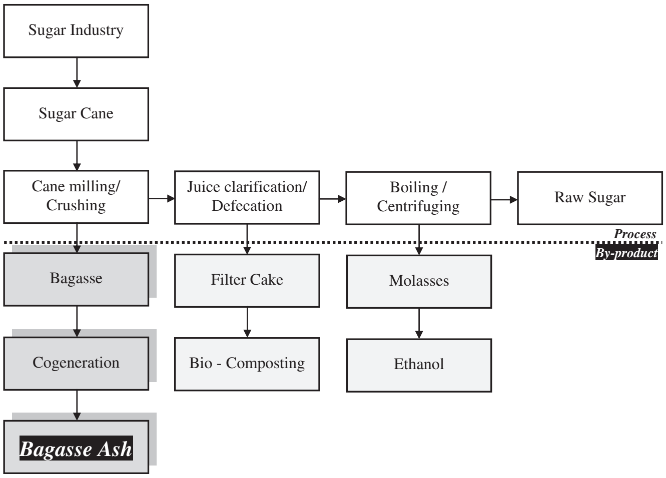

Fig. 1. Sugar production process.

Replacement of fine aggregate with up to 20% BA resulted in equivalent or higher compressive strength and reduced water permeability and chloride diffusion (Ganesan et al., 2007; Chusilp et al., 2009a; Amin, 2011). Cordeiro et al. (2008) reported that the physico-chemical properties of BA are appropriate for use as a mineral admixture and that its reactivity is mainly dependent on particle size and fineness, concluding that it is possible to produce high-strength concrete by using finely ground BA. Another study reported that concrete mixtures containing up to 30% ground BA exhibited compressive strengths of 65.6–68.6 MPa at 28 days (Rukzon and Chindaprasirt, 2012). The cost of SCC could be reduced by 36% by incorporating BA along with the standard concrete ingredients (Akram et al., 2009).

The construction of highly congested reinforced concrete elements requires the fresh concrete mixtures to be very fluid. The risk of material separation in concrete is especially great for heavily reinforced structures with high placement heights and excessive vibratory compaction during consolidation (Mehta and Monteiro, 2006). The compaction procedure is normally performed by untrained labor and the supervision of the process is inherently difficult. Although poorly compacted concrete may be repaired, the overall durability of the structure is often reduced. In addition, the normal concrete placement process involves safety and environmental risks, including 'white finger syndrome' and high noise levels (Gaimster and Dixon, 2003). These factors make it important for concrete to exhibit a low resistance to flow. The concrete must also possess moderate viscosity to maintain homogenous deformation through restricted sections such as closely spaced reinforcements (Khayat, 1999).

Fig. 2. Landfill disposal of BA.

Self-compacting concrete (SCC) is a highly flowable, non-segregating concrete that can spread into place, fill formwork, and encapsulate reinforcements without mechanical consolidation. It is often referred to as "healthy concrete" (Walraven, 2003) due to the reduced noise pollution and decreased employee risk (American Concrete Institute, 2007). SCC was originally developed in 1988 to produce durable concrete structures during a shortage of skilled construction workers in Japan (Okamura and Ouchi, 2003). The functional requirements of fresh SCC are different from those of vibrated fresh concrete. For instance, the RILEM technical committee (RILEM Technical Committee, 2006) stated that fresh SCC must possess the key properties of: (i) filling ability, (ii) passing ability, and (iii) resistance to segregation. The use of supplementary cementitious materials in SCC could reduce material costs while enhancing the self-compacting ability. Recent developments in SCC research are centered on the addition of supplementary cementitious materials with the objective of reducing solid waste disposal problems. Substantial energy and cost savings are possible when industrial by-products such as BA and LS are used in concrete production.

Limestone powder (LS) is commonly used as a secondary raw material in SCC formulation (Domone, 2008). This material is a by-product of stone crushing operations and normally presents a serious problem in terms of disposal, pollution, and health hazards. Ground limestone is generally considered an inert filler, although addition of limestone improves the hydration rate of cement. Physico-chemical changes occurring during Portland cement hydration are accelerated by the presence of calcium carbonate ($CaCO_3$), which increases the hydration rates of tricalcium silicate (C_3S) and cement and the precipitation rate of calcium carbosilicate hydrate (Péra et al., 1999; Ye et al., 2007). Adding fillers can increase the densities of the paste matrix and the interfacial transition zone between the matrix and the aggregate, thereby improving concrete performance (Shuhua and Peiyu, 2010).

In SCC mixtures, limestone fillers are associated with a small particle size, which enhances the packing density and decreases the amount of water entrapped in the system. When large volumes of limestone filler were added to SCC mixtures, self-compacting properties were achieved at a lower water-to-cement ratio of Type 1 Portland cement mixed with $CaCO_3$. Moreover, the volume of the continuous phase of lubricating paste was increased. Paradoxically, SCC mixtures must possess both high flowability and high segregation resistance (Yahia et al., 2005; Felekoglu, 2007; Esping, 2008). Using blends of LS and mineral admixtures such as fly ash, rice husk ash, blast furnace slag, or natural pozzolans improves the overall performance of SCC (De Weerdt et al., 2011; Makhloufi et al., 2012; Rizwan and Bier, 2012; Sua-iam and Makul, 2013).

With the increased production and utilization of concrete, as well as the rapidly increasing consumption of natural aggregates that constitute the bulk of concrete, it is important to consider the environmental impacts of this material. The use of recycled aggregates can play key roles in reducing landfill waste and conserving natural aggregates, with many environmental benefits. Previous studies have examined the possibility of using waste materials as natural aggregate replacements in concrete (Richardson et al., 2011; Bravo and de Brito, 2012; Marie and Quiasrawi, 2012; Zhao et al., 2013). This work investigated the interaction between LS and BA when used as partial fine aggregate replacements in SCC mixtures. The workability (slump flow, J-ring flow, and V-funnel flow) and hardened properties (compressive

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