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Enhancement of concrete properties by waste physicochemical treatment sludge of travertine processing wastewater

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ABSTRACT

Travertine treatment sludges are by-products derived from travertine marble processing plants. These treatment sludges are being generated in considerable amounts in marble production plants in Turkey. Various proportions (5–15% w/w of the cement) of physicochemical sludge admixtures obtained from the physico-chemical treatment (coagulation-flocculation) of a travertine processing plant wastewater were used ascement replacement for concrete with 250 kg/m^3 cement dosage. Slump tests were performed on fresh concrete, and compressive strengths were determined for 7 and 28 days hardened concrete samples. The freeze/thaw resistance, water absorption, capillary suction, void ratio and porosity were performed for the hardened concrete samples. Considering the properties of hardened concrete such as compressive strength, workability and physical properties, AS and NS are the admixtures that can be suggested both to enhance the concrete properties and to have a new utilization area for a waste material. Higher 28-day compressive strength of about 28.43 MPa (AS) and 28.82 MPa (NS) was achieved at 15% admixing level by weight of cement while reference sample compressive strength was 25 MPa.

1. Introduction

Concrete, a composite material made with cement, aggregates, admixtures and water comprises in quantity the largest of all man-made materials. Although aggregates make up three fourths of the volume of concrete, the active constituent of concrete is cement paste, and the properties and performance of concrete are largely determined by the properties of the cement paste.

The cement industry is one of the industrial producers of carbon dioxide (CO_2), creating up to 5% of worldwide man-made emissions of this gas, of which 50% is from the chemical process and 40% from burning fuel (World Business Council for Sustainable Development, 2012). Cement manufacture contributes greenhouse gases both directly through the production of $CO_2$when calcium carbonate is thermally decomposed, producing lime and CO_2 (EIA, 2006) and also through the use of energy, particularly from the combustion of fossil fuels. The carbon dioxide CO_2 produced for the manufacture of one tonne of structural concrete (using ~14% cement) is estimated at 410 kg/m^3 (density of 2.3 g/cm^3) (Samarin, 1999). The CO_2 emission from the concrete production is directly proportional to the cement content used in the concrete mix; 900 kg of CO_2 are emitted for the fabrication of every ton of cement (Natesan et al., 2003).

Admixtures confer several beneficial effects on concrete including reduction in water requirements, increased workability, controlled setting, accelerated hardening, improved strength, better durability, desired coloration and volume changes. The use of admixtures is generally based on trial and error because of an incomplete understanding of their mechanism of action (Ramachandran and Feldman, 1996).

Mineral admixtures refer to the finely divided materials which are added to obtain specific properties of cement mortar and concrete. The other hand, equally important, objectives for using mineral admixtures in cement concrete include economic benefits and environmentally safe recycling of industrial and other waste by-products. Many industrial wastes such as fly ash, silica fume, red mud, marble and other stone waste are rapidly becoming the main source of mineral admixtures for use in cement and concrete production.

In the last decades, many experiments and researches have been done to investigate the effect of different waste by-product materials on concrete properties when added to the concrete mixture in different ratios (Ramachandran and Feldman, 1996; Bravo et al., 2007; Su et al., 2015; Zhan and Poon, 2015).

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In another study, the use of aggregates from construction and demolition waste in the production of concrete was investigated. Workability of concrete was increased by use of these wastes instead of limestone aggregate and important differences were not observed in the mechanical properties of concrete (Bravo et al., 2007).

Brotons et al. (2014) tested the performance of concrete mixtures incorporating 5%, 10%, 15% and 20% of sewage sludge ash as sand and cement replacements. The addition of sewage sludge ash in concrete used for manufacturing blocks cured for 28 days provided densities and resistances similar to the control sample and significantly reduced the water absorption. The replacement of sand by the mineral addition significantly improved the concrete properties (Brotons et al., 2014).

Binici et al. (2007) investigated the influence of marble and limestone waste as additives on some mechanical properties of concrete. Setting time, abrasion resistance, compressive strength, workability of mortar were measured. The results showed that abrasion resistance was increased as the rate of fine marble and limestone waste was increased and these materials can be used for more durable concrete production (Binici et al., 2007). In other study, the use of marble waste and recycled aggregate from crushed concrete in the production of concrete was investigated. Workability of concrete and segregation resistance was increased by use of pieces of marble waste instead of limestone aggregate and important differences were not observed in the mechanical properties of concrete by using marble waste and recycled aggregate (Uygunoglu et al., 2014). Moreover, Gencel et al. (2012) determined that concrete pavement blocks made with coarse marble aggregates are of adequate quality. According to Andre et al. (2014) coarse aggregates from marble industry waste could enhance the workability, density and compressive strength of concrete. Uysal and Yilmaz (2011) showed that it is possible to successfully utilize waste limestone powder, basalt powder and marble powder as mineral admixtures in producing concrete. Soganciloglu et al. (2013) utilized andesite processing wastewater treatment sludge as concrete admixture, and they reported that the medium-strength (20–30 kPa of compressive strength) concrete produced with these admixtures displayed adequate mechanical properties for applications, especially in non-load bearing concrete constructive elements.

Travertine is a terrestrial sedimentary rock, formed by the precipitation of carbonate minerals from solution in ground and surface waters, and/or geothermally heated hot-springs. Travertine marble is often used as a building material (Dolphin, 1962; U.S. Gov. Print., 1970). It has been used as structural stone and also in ornamental elements such as sculptures as facade material, wall cladding, and flooring (Urosevic et al., 2010).

In large-scale travertine marble production plants, there are very different sources of waste during in the mining, processing and polishing stages and processing wastewater contains 2–10% marble particles (Ersoy et al., 2005). Direct discharge of travertine processing wastewaters into the environment will have adverse effects due to this travertine marble particles content. Although, physico-chemical treatment of travertine processing wastewater is difficult, the most common method is coagulation and/or flocculation via common coagulants or flocculants. The treatment of travertine processing wastewater will generate large quantities of physico-chemical sludges. In a previous study, different coagulants and flocculants (alum, $FeCl_3$, nonionic flocculant, sodium aluminate and sepiolite) have been studied for travertine processing wastewater, and different characteristics of these physico-chemical sludges were investigated (Onen et al., 2013). The land disposal of these physico-chemical sludges is not a feasible and environmentally acceptable ultimate disposal method due to pollution and large area requirement. Therefore, final disposal alternatives other than land disposal needs to be investigated.

There has not been any study on utilization of travertine wastewater physico-chemical sludge as concrete admixture. Therefore, the purpose of this study was the determination of feasibility of using this waste physico-chemical sludge obtained from the coagulation-flocculation treatment of travertine processing wastewater in concrete as admixture, and the determination of the effects of this admixture on physical and mechanical properties of concrete. Fresh concrete tests, slump and hardened concrete tests, such as compressive strength, freeze/thaw resistance, water absorption, capillary suction, void ratio, and porosity, were all performed, as well as the investigation of effects of types and dosages of admixtures.

2. Experimental program

2.1. Materials

The travertine marble processing wastewater are generated as a result of wet cutting of travertine marble. Wastewater properties and the chemical composition of the travertine particles are given in Table 1 (Beyazyuz, 2010).

Depending on the travertine particles, the high total solids (3.54 g/L) of wastewater may provide extra compressive durability in concrete. The CaO content was 54.57% and this high value potentially improve the properties of the concrete as lime is one of the important constituents of the concrete. The travertine particles in the wastewater were in colloidal size. Physico-chemical sludge (PS) admixtures used in this study were obtained by treatment of the wastewater via the coagulation-flocculation processes in which various coagulant and flocculants were occupied (Table 2).

The sludge provided the highest colloidal removal efficiencies in physico-chemical treatment (Beyazyuz, 2010) were used as the AS, NS and SS admixture samples in this study (Table 2). The properties of these sludge admixtures were given in Table 3. The values of suspended solids in Table 3 indicated that the colloidal matter (inorganic marble particles) in these sludges was in high concentration.

The mixing composition of the mixtures are given in Table 4. The cement used in all the concrete mixtures was CEM II 42.5R Portland cement type (TS, 2012). The water/cement ratio was kept constant at 0.6 for all samples. The gravel aggregate size was ranging from 5 to 22 mm in all mixtures. The fine aggregates (0–5 mm) were natural river sand.

2.2. Methods

2.2.1. Mixing and curing of concrete

The concrete mixtures were blended in horizontal axis cement mixers in Emir Construction Ready Mixed Concrete Plant (Konya-Turkey). The cementitious materials ingredients, coarse aggregates and fine aggregates were mixed and then the water and admixtures were slowly added. 150 × 150 × 150 mm cubic moulds were obtained. The samples were kept covered at 20 ± 2 °C for 24 h until demolding. Thereafter, samples were placed in curing tank

Table 1
Properties of travertine processing wastewater.

Parameter	Value	Parameter	Value	Parameter	Value
Temperature (°C)	11.5	SiO_2 (%)	0.67	Na_2O (%)	0.028
pH	9.7	Al_2O (%)	0.13	KO (%)	0.007
Alkalinity (mg/L $CaCO_3$)	1921.4	Fe_2O_3 (%)	0.07	TiO_2 (%)	0
Acidity (mg/L $CaCO_3$)	77.4	MgO (%)	0.67	MnO (%)	0.005
Total Solid (g/L)	3.54	CaO (%)	54.57		