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Utilization of andesite processing wastewater treatment sludge as admixture in concrete mix

Merve Soganciouglu [a], Esra Yel [a,*], Ulku Sultan Yilmaz-Keskin [b]

[a] Selcuk University, Environmental Engineering Department, Turkey
[b] Selcuk University, Civil Engineering Department, Turkey

HIGHLIGHTS

- Utilization of sludge from treatment of andesite processing wastewater in concrete.
- Physicochemical treatment sludge was replaced at 0.5–1.5 wt% of the cement.
- Changes in the properties of concrete with additive were investigated.
- The effect of the additives on the mechanical and physical properties varied.

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ABSTRACT

The dried physicochemical sludge from the coagulation–flocculation treatment of an andesite processing plant wastewater was used as concrete admixture in powder form. Various physicochemical sludges obtained with various coagulant/flocculants (alum, $FeCl_3$, and sepiolite) were experienced dry particulate (powder) form of the sludge was replaced at 0.5–1.5% w/w of the cement for 250 kg/m^3 cement dosage. The admixture doses were complied with local standard. Slump tests were conducted on fresh concrete, and compressive strengths were measured for 7 and 28 days hardened concrete samples. Physical properties, namely freeze/thaw resistance, water absorption, capillary suction, void ratio and porosity were determined at the end of 28 days for the hardened concrete samples. The concrete consistency (slump) was improved up to 16–18 cm from 14.5 cm by the admixture. The best compressive strength was achieved with 0.5% w/w for admixtures. The admixture sludges obtained with organic flocculants were worse than the other admixtures. The structural changes after freeze/thaw tests were very close to the reference concrete (concrete without admixture); only the capilary suction had increased. The results confirmed that up to 0.5% of physicochemical sludge can be replaced with cement in concrete for use in certain non-load bearing structures that require medium strength concrete.

1. Introduction

Andesite, a type of marble, is a heat and frost resistant volcanic rock that has been commonly used in architecture, building, and art, since ancient times. Large-scale andesite production has generated a considerable amount of waste materials; almost 70% of this gets wasted in the mining, processing, and polishing stages. These wastes have a serious impact on the environment since they contain non-degradable, diverse-sized marble particles. Direct discharge of andesite processing wastewaters into the environment will have considerable adverse effects due to inert andesite colloids content.

The most common method for the treatment of marble processing wastewaters is coagulation and/or flocculation via common coagulants or flocculants. However, the physico-chemical treatment of andesite processing wastewater is more difficult than for other types of marble. The treatment of a large volume of andesite processing wastewater will generate large quantities of physico-chemical sludges. Different coagulants and flocculants have been studied for andesite processing wastewater, and the different physico-chemical sludge from these have different characteristics [1]. The land disposal of these physicochemical sludges has also some adverse effects on the environment, for example, high concentrations of aluminium in the alum-sludge can cause phosphorus fixation in the soil, which hinders plant growth. There are also potential problems due to the large area of land required. Therefore, final disposal alternatives other than land disposal need to be investigated.

Concrete is an inorganic composite material typically made from hydraulic cement, fine and coarse aggregate, mineral and chemical admixtures, and water. It is one of the most widely used

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* Corresponding author. Tel.: +90 3322232091; fax: +90 3322410635.
E-mail address: etarlan@selcuk.edu.tr (E. Yel).

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materials in construction. The structural properties of plain concrete depend primarily on the chemical reactions between the cement, water, and other mix constituents, as well as on the homogeneity of the concrete components. Both cement and concrete production generate considerable quantities of air-pollutant emissions. Dust is usually the most visible of these pollutants. The air pollutants commonly emitted from cement manufacturing plants include carbon dioxide (CO_2), sulphur dioxide (SO_2) and nitrous oxides (NO_X). Due to the increased demand for construction projects, which obviously increases the amount of raw materials used, the incorporation of by-products has become a common practice [2–6]. The concrete industry has considered using recycled/recirculated industrial wastes (as by-products) as concrete admixtures in order to reduce the demand for cement within the scope of sustainable material management.

Two different approaches to the research on this subject has been focused on the use of admixtures (waste products) as aggregate replacement or cement replacement (filler) in concrete. Introducing an organic waste into a concrete matrix causes changes in the behaviour of the cement since it acts as a setting retardant and cause interference which some heavy metals have with the hardening reactions of the cement [7,8]. Therefore, in most of the studies, inorganic materials have been preferred as aggregate or cement replacement admixture.

One type of inorganic admixtures is marble waste. Some studies investigate effects of marble waste as an 1–10% aggregate replacement (0.2–4.7 mm for fine and 4.7–19 mm for coarse aggregate) on the conventional concrete mixtures [5,6,9,10]. These studies indicated that the marble waste admixtures as aggregate replacement either improved or did not change the properties of the concrete such as mechanical properties, consistency, durability, fresh properties, compressive strength and chemical resistance [5,9,10]. In some studies, small losses (about 10%) on the concrete properties, e.g. compressive strength, by using marble aggregates as admixture were reported as acceptable [10].

In some other studies marble powder (7–50 μ) was used as cement-replacement admixture either alone [11–13] or together with other powder materials such as diatomite [14]. Compressive strength, consistency, and other properties (mechanical, and chemical) were studied and similar to aggregate admixtures, the fresh and hardened concrete properties were either improved, or very closed to the same type of concrete without admixture [11–15]. These additives were also studied for self-compacting concrete [11,12]. It was reported that the higher the amount of waste marble powder additive the longer the setting times and the lower the strength of the specimens for all the curing periods [13]. Moreover, in some studies, the concrete mixtures were evaluated based upon the simultaneous cement and sand substitution by waste marble particles [10].

All these studies utilized waste marble particles either aggregate-sized or colloid. Colloid-size particles are either in dust (dry form) or in bulk liquid (process wastewaters). Marble processing wastewaters mainly originated from cutting process in which water is used as cooling agent for blades. The marble cutting dust enters into that water and so-formed wastewater contains high amounts of colloids whose gravity sedimentation is inefficient due to particle size. Physico-chemical treatment methods such as coagulation and/or flocculation has been applied [1]. When the physico-chemical treatment sludge was dried, powder-sized coagulated/flocculated particles can be obtained. The utilization of this physico-chemical sludge as a cement replacement concrete admixture has not been studied.

Therefore, this study will introduce an ultimate disposal method implementation instead of disposing this treatment sludge to the land. The purpose is the evaluation of the dried physico-chemical sludge in concrete as cement replacement admixture. The effects of andesite processing wastewater coagulation–flocculation sludges, as powder form admixture, on the fresh and hardened properties of concrete were investigated. Fresh concrete tests, consistency, and hardened concrete tests, such as compressive strength, freeze/thaw resistance, water absorption, capillary suction, void ratio, and porosity, were all carried out.

2. Materials and methods

2.1. Physico-chemical sludge admixtures

In andesite processing plants, raw andesite powder containing wastewater was generated as a result of wet cutting [1]. The andesite processing wastewater properties and the chemical composition of the andesite particles in it are given in Table 1. The calcium content was 5317.64 ppm and this high value may provide additional properties to the concrete. The magnesium, lead, and iron were also present, which may also have effects on the concrete. The wastewater total solid and suspended solids were equal, and very high in concentration. This implies that no dissolved solids existed, all the solids were suspended (i.e., andesite particles). The andesite particles in the wastewater were colloidal in size and were not settleable. Therefore, the physicochemical sludge (PCS) used as the admixture in this study was obtained by physicochemical treatment of the wastewater by the coagulation–flocculation processes which were followed with various coagulant and flocculants (Table 2). The sludge provided the highest colloid removal efficiencies [1] were used as the PCS samples in this study.

At the end of coagulation–flocculation process, flocs were separated from the bulk liquid by gravity settling. Settled sludge was in the liquid form with approximately 5% solids. The sludge samples were dried at room temperature in the laboratory. They were then used as the powder form (<0.1 mm) in concrete as admixture at the cement replacement ratios indicated in Table 2. The admixture doses indicated in the table were between 0.5% and 1.5%. As compared to literature these were not high but consistent with the local standards, i.e., The Turkish Standards [16] which suggest cement replacement admixture ratios up to 5%. Also to comply with the objective of this study, investigation of the utilizability of the admixtures is important.

Table 1
Properties of andesite processing wastewater.

Parameter	Value	Parameter	Value
pH	8.4–9.5	K (ppm)	0.0
Total solid (g/L)	25–37	Pb (ppm)	0.16
Total suspended solid (g/L)	25–37	Cd (ppm)	0.25
Ca (ppm)	5317.64	Zn (ppm)	0.57
Mg (ppm)	199.34	H_2CO_3 (ppm)	39.0
Na (ppm)	288.03	Cr (ppm)	0.0
Fe (ppm)	13.83		

Table 2
The studied additives and applied cement ratios.

Additive name	Composition of the additive[a]	Utilized ratio (%w/w cement)
Physico-chemical sludge1 (PCS1)	Andesite colloids (99.75%) + Alum (0.25%)	0.5, 0.75, 1, 1.25, 1.5
Physico-chemical sludge2 (PCS2)	Andesite colloids (99.8%) + $FeCl_3$ (0.2%)	0.5, 0.75, 1, 1.25, 1.5
Physico-chemical sludge3 (PCS3)	Andesite colloids (99.95%) + Poly Aluminium chloride (0.05%)	1
Physico-chemical sludge4 (PCS4)	Andesite colloids (99.99%) + Anionic flocculant (0.007%)	1
Physico-chemical sludge5 (PCS5)	Andesite colloids (99.99%) + Cationic flocculant (0.007%)	1
Physico-chemical sludge6 (PCS6)	Andesite colloids (99.6%) + Pumice (0.4%)	1
Physico-chemical sludge7 (PCS7)	Andesite colloids (98.73%) + Sepiolite (1.27%)	0.5, 0.75, 1, 1.25, 1.5
Physico-chemical sludge8 (PCS8)	Andesite colloids (98.62%) + Zeolite (1.38%)	1

[a] Percentages in the parantheses indicate the weight percent of that component in the sludge additive.