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Effect of sludge water from ready-mixed concrete plant on properties and durability of concrete

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Abstract

Besides the increasing disposal cost, sludge water, a wastewater washout from ready-mixed concrete plant, has caused environmental impact problems. This paper investigates the utilization and recycling of sludge water as mixing water for concrete production. The basic properties of sludge water were obtained according to ASTM standards. The properties of dry sludge powder such as chemical compositions and physical properties were investigated. The properties of fresh concrete studied were unit weight, slump, and temperature rise. The mechanical properties of concrete, such as compressive strength and modulus of elasticity, were studied. The durability aspects, such as drying shrinkage and weight loss due to acid attack, were investigated. For parametric study, sludge water was used as a replacement of tap water varying from 0% to 100% by weight. The water-to-cement ratios were 0.5, 0.6, and 0.7, respectively. In this study the sludge water tested has a high alkalinity and the total solids content exceeding the limit of ASTM C94, contributing to the more porous and weaker matrix. As a result, when increasing the percentage of sludge water in mixing water, the drying shrinkage and weight loss due to acid attacks increased, and the slump and strength decreased. However, the unit weight and temperature of fresh concrete were not affected by the use of sludge water.

Keywords: Sludge water; Ready-mixed concrete; Mechanical properties; Durability; Acid attack

1. Introduction

Along with the increasing demand for ready-mixed concrete in the construction industry, also came together is sludge water (SW), a wastewater discharged from concrete mixing plants and agitator trucks. In general the procedure for disposing sludge water in the ready-mixed concrete plants consists of two types of sedimentation ponds. The first pond receives excess concretes and wash water from agitator trucks. Subsequently the sludge water and smaller sediments such as sand and cement materials are transferred to the second pond. After settling for a period of time, water from both ponds is recycled for cleaning agitator trucks. Excess concretes in the first pond, and muddy sludge in the second pond then are removed, and disposed of in the landfills. The disposal process is considerably expensive and also causes environmental problems due to the waste materials and high alkalinity in sludge water [1].

Instead of being disposed of, sludge water that meets the requirement of ASTM C94 specification [2] can be recycled and used as mixing water for concrete production if there are no significant effects on mechanical properties of concrete [1,3,4]. According to Sandrolini and Franzoni, fine-filler effects and actual water/cement ratio reduction due to fine solids contents in sludge water leads to the reduction of concrete capillary water absorption and porosity, and possibly improve the durability of concrete [5]. Concrete mixed with sludge water containing residual cement tend to give a shorter setting time and lower flowability [4]. Concerning the above situation, the effective use of the recycling sludge water in concrete production would be of

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great benefit both in disposal cost reduction and environmental conservation [6].

There has been limited investigation carried out on the recycling of sludge water that does not meet the ASTM C94 specification [2] as concrete mixing water, and particularly on the durability of concrete containing sludge water. When highly corrosive environments are expected, the pH and total acidity for the design life of structure is critical. In addition, designers must determine the potential for the development of sulfuric acid due to potential changes to the environment. Therefore, the aim of this paper was to investigate the effect of sludge water on mechanical properties and durability of concrete including drying shrinkage and weight loss due to sulfuric and hydrochloric acid attacks. The quality and properties of sludge water obtained from a ready-mixed concrete plant in Thailand were analyzed and compared with the ASTM C94 specification [2]. The tests for concrete properties were performed according to ASTM standards [7–14].

2. Experimental program

In this study, for concrete specimens tested, the sludge water was used as a replacement of tap water at 0%, 10%, 20%, 30%, 40%, 60%, 80%, and 100% by weight, respectively. The water-to-cement ratios (w/c) were 0.5, 0.6, and 0.7. The ratio by volume of paste to voids between compacted aggregates in dry state (γ) was 1.2, and the ratio by volume of sand to total aggregate (s/a) was 0.5. The properties of fresh concrete including initial slump, unit weight, and temperature rise were studied. The mechanical properties of concrete including compressive strength, flexural strength, and modulus of elasticity were carried out. The durability of concrete including the drying shrinkage and resistance to acid attack by monitoring the weight loss due to sulfuric and hydrochloric acid attacks were investigated.

2.1. Materials

(1) Cement: A standard Portland cement Type I.
(2) Mixing water: Tap water and sludge water (SW) obtained from a ready-mixed concrete plant in Thailand were used in this study. The process for preparing the sludge water samples started from transferring the sludge water consisting of both clear sludge water and sediments from the sedimentation pond to the preparation pond. To obtain a uniform sample of sludge water, the clear sludge water and sediments with the proportion of 1:1 by weight were prepared in a container. After uniformly mixed, the sludge water was ready for concrete specimen production.
(3) Aggregates: Coarse aggregates were crushed limestone with the maximum size of 20 mm and water absorption of 0.57%. Fine aggregates were local river sand with the fineness modulus of 2.53 and absorption of 0.71%. Their grading meets the ASTM C33 requirements [7].

2.2. Testing procedures

(1) The tests for unit weight of concrete in fresh state were performed according to ASTM Standard C138 [8].
(2) The concrete slump tests were performed according to ASTM Standard C143 [9].
(3) The temperature rise due to hydration reaction of concrete was monitored until the age of 5 days. The $260 \times 300 \times 400$ mm concrete specimens were cast in polystyrene foam boxes. Prior to casting a concrete specimen, a thermocouple was installed in the middle of each foam box to monitor temperature changes, and the data were collected using a Data Logger. After a specimen was cast, the foam box was kept in a 10 mm-thick wooden box. The box lid was closed and sealed.
(4) The compressive strength of concrete at the ages of 3, 7, 28, 60, and 90 days was performed in accordance with ASTM Standard C39 [10]. The concrete specimens were cast in 100×200 mm cylindrical molds.
(5) The modulus of elasticity of concrete at the age of 28 days was performed according to ASTM Standard C469 [11].
(6) The flexural strength of concrete at the ages of 3, 7, 28, 60, and 90 days were determined according to ASTM Standard C78 [12]. The concrete specimens were cast in the molds with the dimensions of $100 \times 100 \times 500$ mm.

Table 1
Mix proportions of concrete (kg/m^3)

Mix	Portland cement Type I (kg/m^3)	Water (kg/m^3)	Sludge water (kg/m^3)	River sand (kg/m^3)	Crushed limestone rock (kg/m^3)
OPC(0.5)	347	173	0	896	956
OPC(0.6)	309	185	0	896	956
OPC(0.7)	279	195	0	896	956
SW10(0.5)	347	156	17	896	956
SW10(0.6)	309	167	18	896	956
SW10(0.7)	279	176	19	896	956
SW20(0.5)	347	138	35	896	956
SW20(0.6)	309	148	37	896	956
SW20(0.7)	279	156	39	896	956
SW30(0.5)	347	121	52	896	956
SW30(0.6)	309	130	55	896	956
SW30(0.7)	279	137	58	896	956
SW40(0.5)	347	104	69	910	966
SW40(0.6)	309	111	74	910	966
SW40(0.7)	279	117	78	910	966
SW60(0.5)	347	69	104	910	966
SW60(0.6)	309	74	111	910	966
SW60(0.7)	279	78	117	910	966
SW80(0.5)	347	35	139	910	966
SW80(0.6)	309	37	148	910	966
SW80(0.7)	279	39	156	910	966
SW100(0.5)	347	0	173	910	966
SW100(0.6)	309	0	185	910	966
SW100(0.7)	279	0	195	910	966