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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

(7) The drying shrinkage of concrete was measured in accordance with ASTM Standard C596 [13]. The values of drying shrinkage were measured up to 120 days.

(8) The resistance of concrete to acid attack was tested in 5% sulfuric and hydrochloric acid solutions. After being cured in water for 28 days, the concrete specimens were submerged in the acid solutions. The values of concrete weight loss were measured up to 120 days.

2.3. Concrete mix proportions

Details of mix proportions of concrete used in this study are presented in Table 1 where OPC(Z) denotes a concrete mixed with tap water only, and Z denotes the water-to-cement (w/c) ratio. For an SWX(Z), SW denotes a concrete in which sludge water was used as tap water replacement at the percentage of X by weight, and Z stands for the water-to-cement (w/c) ratio.

3. Test results and discussion

3.1. Properties of sludge water

3.1.1. Chemical compositions and physical properties

Test results of the chemical properties of tap water and sludge water are presented in Table 2. It was found that the sludge water had a pH value of 12, which is more than the value of 7 for tap water. This is due to the presence of cement in the sludge water. The total solids content of sludge water was equal to 63,400 parts per million (ppm), which is greater than the limit of 50,000 ppm specified by ASTM C94 standard [2]. The amount of chloride ion (Cl^-) and sulfate ion (SO_4^{2-}) of sludge water and tap water are found to be under the standard limit.

Table 2
Chemical properties of sludge water and tap water

Chemical properties	ASTM C94	Tap water	Sludge water
pH	–	7	12
Chloride ion (Cl^-), ppm	$\leqslant$1000	145	25
Sulfate ion (SO_4^{2-}), ppm	$\leqslant$3000	35	12.7
Total solids content, ppm	$\leqslant$50,000	150	63,400
Specific gravity	–	1.0	1.03

ppm = Part per million.

In this study, the dry sludge powder was obtained by drying sludge sediment at a temperature of 110 ± 5 °C. The chemical properties of dry sludge powder and Portland cement Type I are presented in Table 3. The amounts of chemicals in dry sludge powder including Al_2O_3, Fe_2O_3, MgO, K_2O, Na_2O, SO_3, and free CaO are similar to those of Portland cement. For the amount of SiO_2 in dry sludge powder (26.87%), which is higher than that of Portland cement (20.84%), this may be due to the presence of sand in the concrete production. The amount of CaO in dry sludge powder (32%), is less than that of Portland cement (62%); this is because in the sludge water CaO, commonly found in major chemical compounds of Portland cement (C_3S, C_2S, C_3A and C_4AF), dissolved from the excess concrete in the washing process resulting in the smaller amount of CaO.

The physical properties of dry sludge powder and Portland cement are also presented in Table 3. The LOI content is the loss on ignition of material after burnt at 950 ± 50 °C. The sludge powder has a LOI of 25.5% compared to 0.96% in the Portland cement. The higher LOI implies that more carbon particles, which are extremely porous and absorbent, could lower the strength of concrete. This is due to the unburnt carbon particles and excess water in sludge powders, in the form of unhydrated cement, hydrated cement, and hydration products, on the

Table 3
Physical properties of dry sludge powder at temperature 110 ± 5 °C compared with Portland cement Type I

Materials	Chemical composition (%)								
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	Na_2O	SO_3	Free CaO
Portland cement Type I	20.84	5.22	3.2	66.28	1.24	0.22	0.1	2.41	0.99
Dry sludge powder	26.87	6.91	3.17	3.2	1.51	0.98	0.18	3.92	0.62

Physical properties	Portland cement Type I	Dry sludge powder
1. Loss on ignition (%)	0.96	25.5
2. Moisture content (%)	0.19	0
3. Specific surface area (Blaine fineness) (cm^2/g)	3248	9940
4. Specific gravity	3.14	2.5
5. Fineness (% passing)		
$\geqslant$75 μm	0.5	8.99
75 μm	5.25	9.85
45 μm	3.6	4.94
$\leqslant$36 μm	90.62	76.22
6. Strength index (compared with the control)		
At the age of 7 days	100	64
At the age of 28 days	100	71

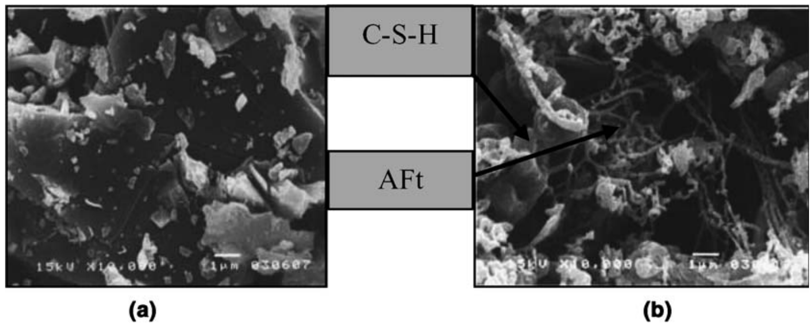

Fig. 1. Micrograph of particles at 10,000-time magnification: (a) Portland cement Type I and (b) sludge powder.

discontinuous structure of C-S-H gel, which is unstable and soluble. As a result, the Blaine fineness (calculated by the duration of air volume absorbed into the particle) of the sludge powders is more than that of Portland cement. The specific gravity and bulk density of sludge powder are found to be less than those of Portland cement. Compared with ASTM C311 standard [14], the strength activity index at the ages of 7 and 28 days are equal to 64% and 71%, respectively, which mean the use of dry sludge sediment as a cement replacement of 20% by weight has adverse effect on the compressive strength of mortar. However, when incorporating in concrete, the sludge powders are in the form of solutions and suspended solids in water, which their actual proportions in concrete are less than the mix proportions shown in Table 1.

The micrographs at 10,000-time magnification of cement particles and sludge sediments are shown in Fig. 1. It was found that the unhydrated cement particles exist as different angular particles, but the sludge sediments appear in shapes like ettringite (AFt) seen as long slender needles and calcium silicate hydrate (C-S-H) gel.

3.2. Properties of fresh concrete

3.2.1. Slump

Fig. 2 presents the comparative results of slump tests, where SW *X* denotes concrete mixed with sludge water as a replacement of tap water at the percentage of *X* by weight. It was found that increasing the percentage of sludge water replacing tap water tends to reduce the concrete slump. This is because the sludge water contains a large amount of sediments in the forms of solids, such as unhydrated cement, hydrated cement and fine particles, which tend to increase the amount of water to be adsorbed at the surface and absorbed into the particle, and consequently lower the concrete slump. By increasing the water-to-cement (w/c) ratio, it results in the increase of concrete slump due to the additional amount of free water in concrete.

3.2.2. Unit weight of fresh concrete

Fig. 3 shows test results of the unit weight of fresh concrete. As shown concrete with the higher percentage of sludge water as tap water replacement tends to have the higher unit weight, but do not produce any significant difference compared to the normal concrete (OPC). This is because the specific gravity of sludge water (1.03) is only a little higher than that of tap water (1.00). Overall, when increasing the water-to-cement (w/c) ratio, the unit weight of concrete is reduced due to the increase of the amount of water.

3.2.3. Temperature rise of concrete

Test results of the temperature rise from room temperature for the concrete mixed with tap water only (OPC) and those mixed with various percentage replacements of

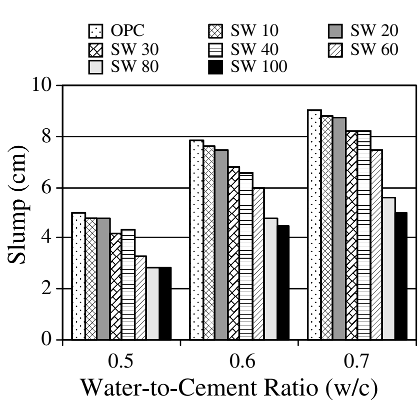

Fig. 2. Slump of fresh concrete.

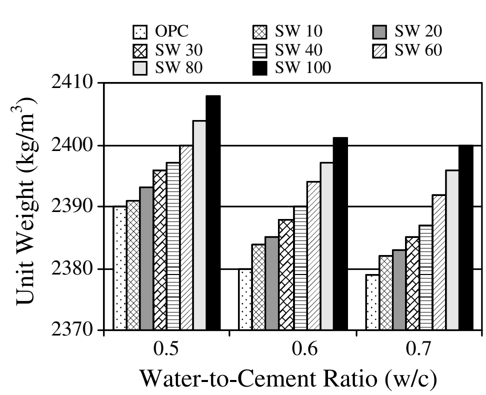

Fig. 3. Unit weight of fresh concrete.

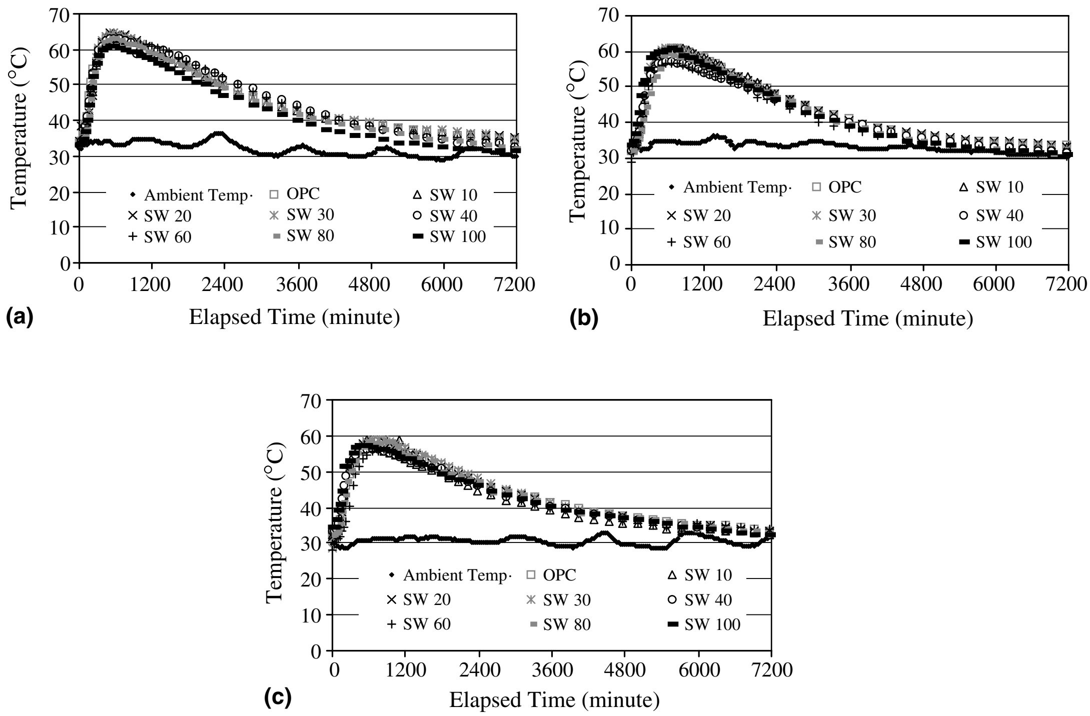

Fig. 4. Temperature of concrete (measured inside the specimens): (a) w/c = 0.5; (b) w/c = 0.6; (c) w/c = 0.7.

sludge water are presented in Fig. 4. Due to the hydration reaction, cement particles react with water and generate the heat causing temperature to rise rapidly to the peak within 12 h, and then decrease slowly close to room temperature within 5 days. From the results, the concretes mixed with sludge water tend to have a little increment in temperature at the beginning due to a small amount of unhydrated cement particles in sludge water. It shows that the utilization of sludge water in the concrete mixes has no significant effect on the temperature rise due to the hydration reaction. Noticeably, the increase of water-to-cement (w/c) ratio tends to lower the temperature rise of concrete due to the reduction of cement content in the mix.

3.3. Mechanical properties of concrete

3.3.1. Compressive strength

Fig. 5 shows test results of the compressive strength of control concrete (OPC) and concretes mixed with sludge water as a replacement of tap water. It was found that increasing the percentage of sludge water tends to reduce the compressive strength of concrete. During the hydration process, the rod-like ettringite found in sludge transforms to unstable compounds such as mono sulfate aluminates, and finally dissolve. As a result, there are additional pores in the concrete matrix, which eventually lowers the density of concrete and causes the lower strength [15]. Also with the higher alkalinity in the matrix, these conditions contribute to the increase of thickness of the duplex film, a layer within the interfacial transition zone between cement paste and aggregate. Consequently, these phenomena cause the weaker bond between aggregate and cement paste, which yield the lower compressive strength of concrete [16].

From results in Fig. 5, the concretes mixed with the maximum of 40% by weight of sludge water replacing tap water yielded the compressive strength more than 90% of that of the control concrete which is above the recommended value by ASTM C94 standard [2] for concrete mixing water. Overall the compressive strength of concretes mixed with sludge water is in the range of 85–94% of normal concrete. For the influence of various water-to-cement ratios (w/c), 0.5, 0.6 and 0.7, respectively, it was found that increasing the water-to-cement ratio (w/c) tends to reduce the compressive strength of concrete.

3.3.2. Modulus of elasticity at the age of 28 days

Test results of the modulus of elasticity of normal concrete (OPC) and concretes containing sludge water at the age of 28 days are shown in Fig. 6. The results show that the modulus of elasticity of concrete decreases when the proportion of sludge water as a replacement of tap water increases. This is due to the sludge water consisted of unhydrated cement particles, hydrated cement, and fine particles, contributing to the discontinuity between the calcium silicate hydrate (C-S-H) gel and aggregates, which eventually leads to decreasing the modulus of elasticity of concretes. Another contribution to the lower modulus is the additional pores from the dissolution of existing ettringite in sludge water. When comparing the values of the modulus of elasticity of concretes tested with the value suggested by the ACI 318 [17], as seen in Fig. 6(b), it was found that the modulus of elasticity of the control concrete

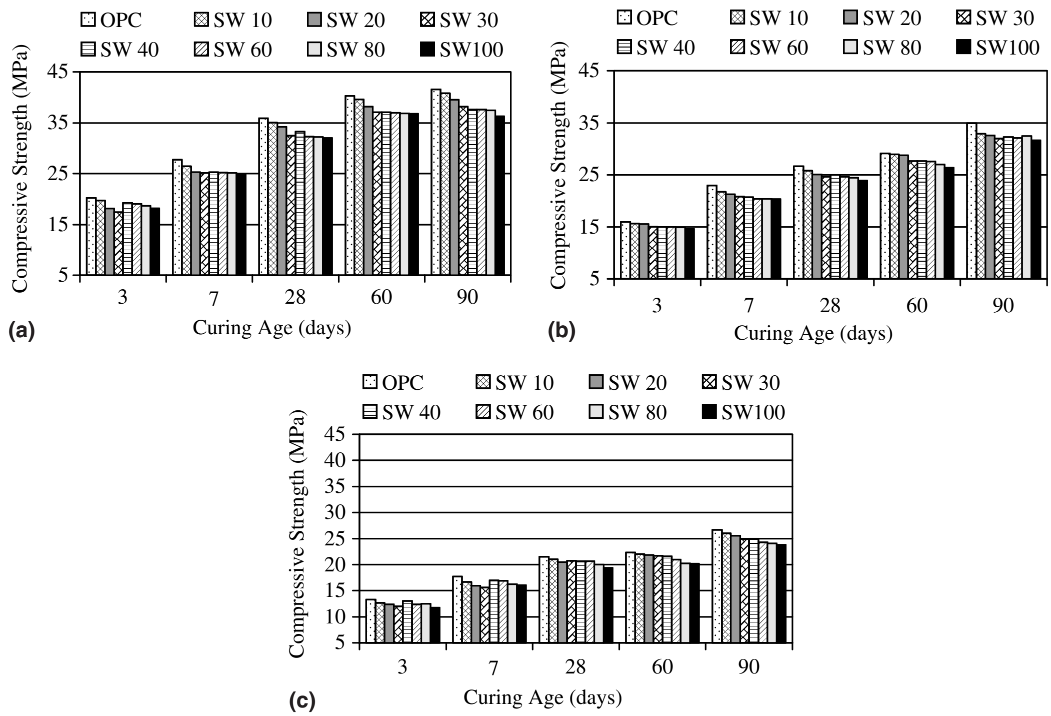

Fig. 5. Compressive strength of concrete: (a) w/c = 0.5; (b) w/c = 0.6; (c) w/c = 0.7. Remark: OPC denotes concrete mixed with tap water and SWX denotes concrete mixed with sludge water as a replacement of tap water at the percentage of *X* by weight.

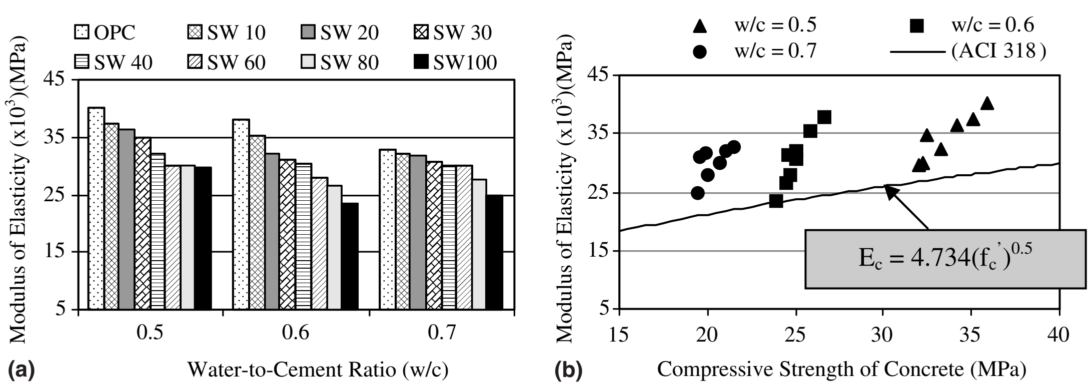

Fig. 6. (a) Modulus of elasticity of concrete at the age of 28 days and (b) modulus of elasticity of concrete, with ACI 318 suggestion [17].

(OPC) and the concretes containing sludge water are higher than the ACI suggested values.

3.3.3. Flexural strength

As shown in Fig. 7, overall the rate of flexural strength development is rapid at the beginning, until 28 days of curing it becomes flat due to decreasing rate of hydration reaction. It was found that increasing the percentage of sludge water replacing tap water tends to reduce the flexural strength of concretes tested. Except for concretes with 10% replacement of sludge water, after 7 days of curing, the flexural strength of concretes mixed with sludge water as tap water replacement are noticeably lower than those of the control concretes (OPC). Similar to the results of compressive strength, increasing the water-to-cement ratio (w/c) reduces the flexural strength of concrete. Overall results indicate the same trend as previously described that the bond strength between cement paste and aggregate is weaker when increasing the amount of sludge water as a tap water replacement, and also by the increase of water-to-cement ratio (w/c).

3.4. Durability of concrete

3.4.1. Drying shrinkage

From test results seen in Fig. 8, it was found that the concretes mixed with sludge water replacing tap water yield the higher drying shrinkage. Increasing the percentage replacement of tap water tends to increase the drying shrinkage. The sludge water due to the dissolution of

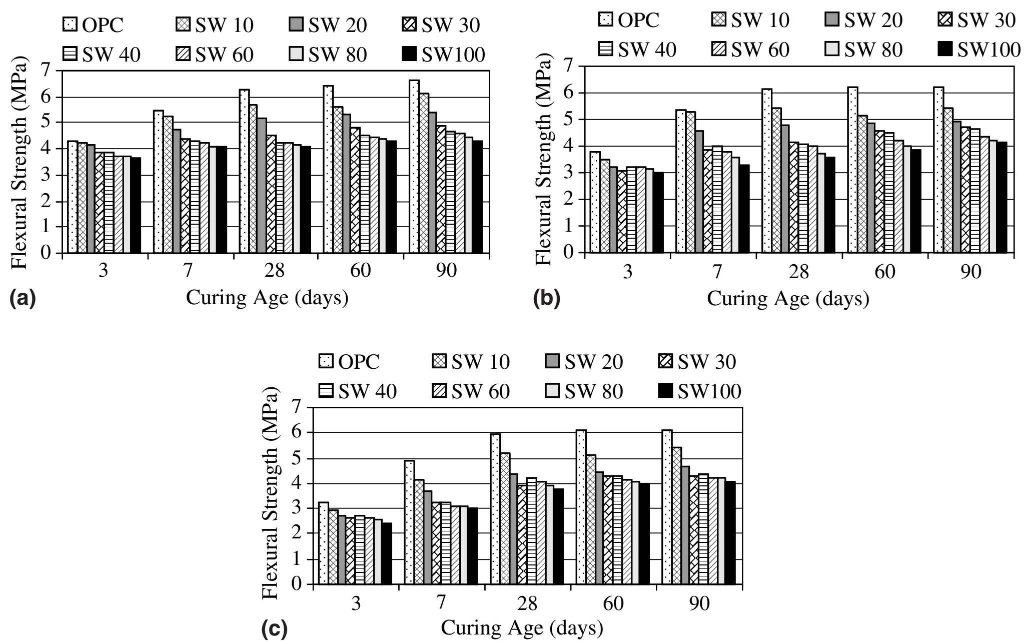

Fig. 7. Flexural strength of concrete: (a) w/c = 0.5; (b) w/c = 0.6; (c) w/c = 0.7.

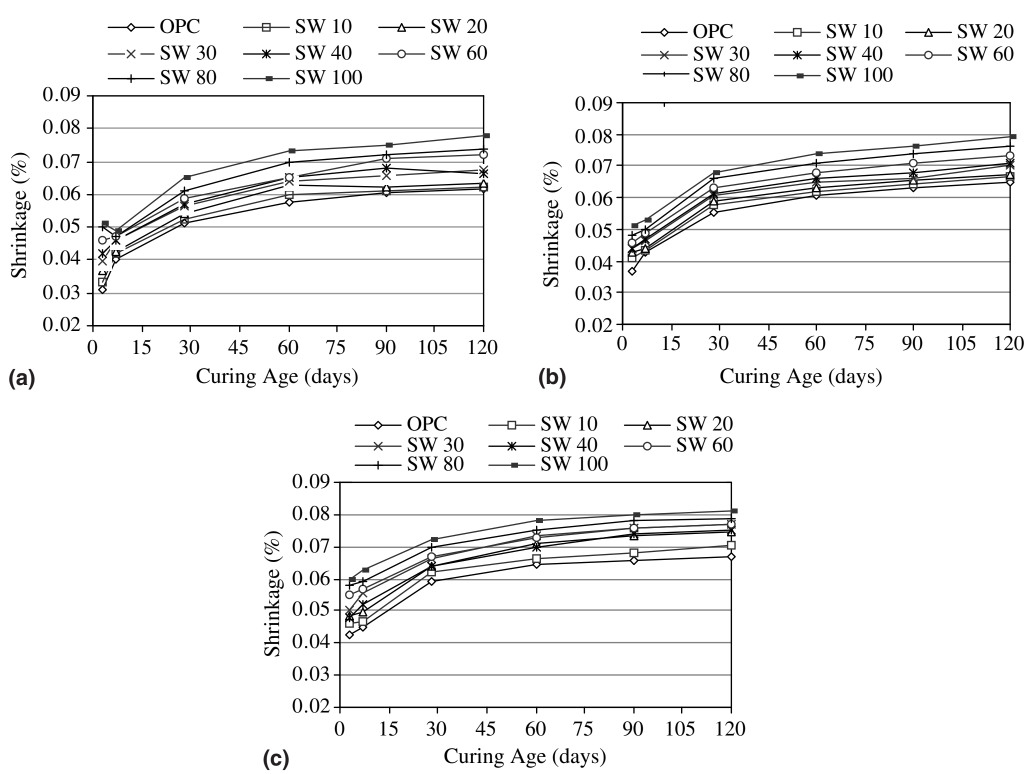

Fig. 8. Drying shrinkage of concrete: (a) w/c = 0.5; (b) w/c = 0.6; (c) w/c = 0.7.

unstable ettringite yields more capillary pores compared to the normal concrete (OPC). The pore water gradually migrates to the atmosphere causing the more porous matrix and shrinkage. From the results, the drying shrinkage rates are high at the beginning because the concretes were transferred from the 100% relative moisture condition to air drying in the ambient atmosphere (60 ± 5% relative moisture) that the free moisture in the matrix and on the surface dissipates at a faster rate. After a period of time, only moisture in the matrix have migrated to the atmosphere, and some of the capillary pores have shrunk to trap the moisture inside that cause the slower rate of shrinkage.

The important controllable factor affecting shrinkage is the amount of water per unit volume of concrete. The higher water-to-cement (w/c) ratio yields the higher drying shrinkage.

3.4.2. Resistance to acid attack

3.4.2.1. Sulfuric acid attack. The effect of the addition of sludge water on the sulfuric acid resistance was investigated. Results presented in Fig. 9 show that the sludge water have a negative effect on the acid resistance. The percentage of weight loss due to the acid attack increases when increasing the proportion of sludge water replacing tap water. A faster rate of weight loss was observed at the beginning period and over time the weight loss continues with a slower rate. The reaction between calcium hydroxide ($Ca(OH)_2$) in the concretes and sulfuric acid (H_2SO_4) yields a soluble product of calcium sulfate or gypsum ($CaSO_4 \cdot H_2O$) as a layer on the surface of concrete, and also with forming by loose bonds the layer is prone to leaching and deterioration.

For the concretes mixed with sludge water, another contribution to the higher percentage weight loss compared to the control concrete is the additional calcium hydroxide, in the form of unstable ettringite, causing the concrete matrix to be more porous and susceptible to the acid attack through the capillary pores. From the results, the higher the water-to-cement (w/c) ratio adding more water in the matrix also yields the more porous concrete that is prone to more negative effect on the acid attack.

3.4.2.2. Hydrochloric acid attack. Results presented in Fig. 10 show that the sludge water has a negative effect on the resistance to hydrochloric acid attack. The reaction between calcium hydroxide ($Ca(OH)_2$) in the concrete and hydrochloric acid (HCl) forms calcium chloride ($CaCl_2$) which is a soluble product. The higher percentage of sludge water as tap water replacement indicates that the additional calcium hydroxide results in the higher percentage of weight loss compared to the control concrete. A faster rate of weight loss occurred at the beginning, and over time, the weight loss continued with a slower rate. When increasing the amount of sludge water replacing tap water, concrete is more susceptible to leaching and deterioration due to the acid attack. In comparison with hydrochloric acid, sulfuric acid attack is more damaging to concrete as it combines an acid attack and a sulfate attack.

3.5. Suggestions for the use of sludge water in concrete production

Due to the variation of properties of sludge water such as total solids content, chloride, sulfate, etc. before using sludge water for concrete production in the field, the basic properties including physical and chemical properties should be investigated periodically. This shall be done for the determination of adjusting the amount of sludge water in the concrete mix.

For the use of sludge water, with a total solids content of or less than 63,400 ppm, as a partial or total replacement of tap water, the concrete mix proportions shall yield the compressive strength not less than 90% of normal concrete as per ASTM C94 standard [2]. From the test results, an increase in proportion of sludge water as a replacement of tap water had a negative effects on the drying shrinkage

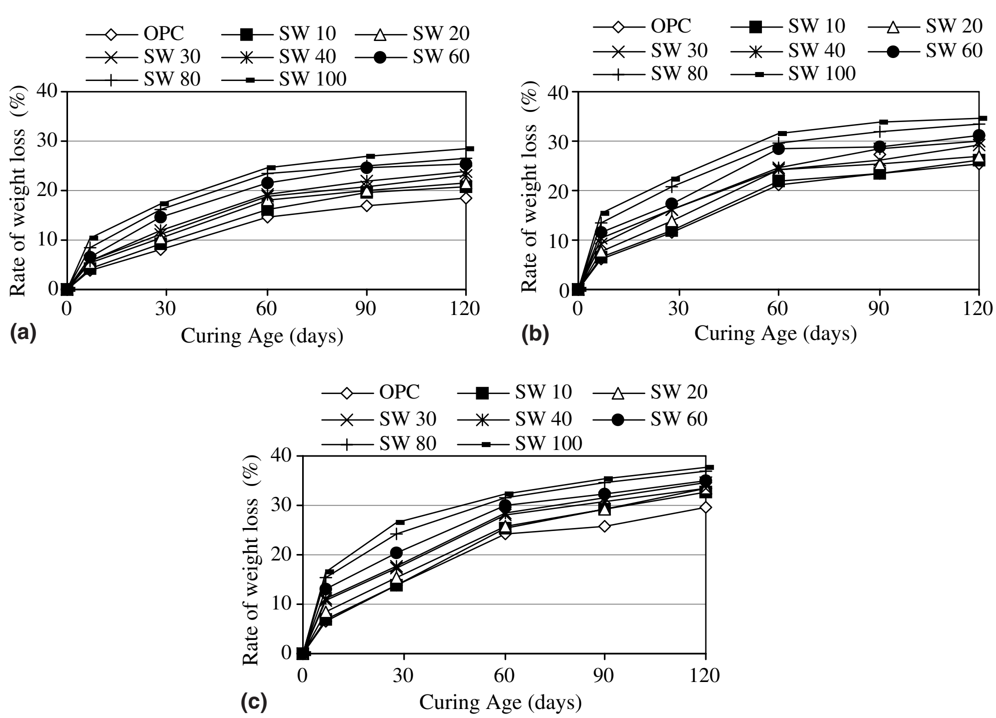

Fig. 9. Weight loss due to sulfuric acid attack: (a) w/c = 0.5; (b) w/c = 0.6; (c) w/c = 0.7.

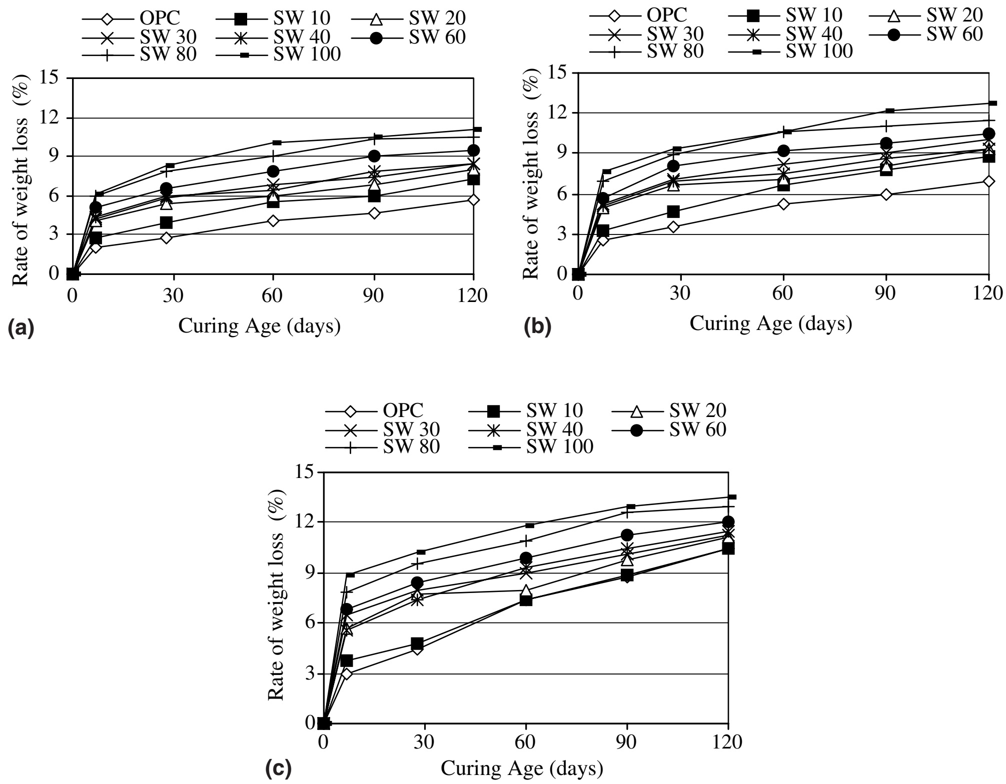

Fig. 10. Weight loss due to hydrochloric acid attack: (a) w/c = 0.5; (b) w/c = 0.6; (c) w/c = 0.7.

and the resistance to acid attack. It can be concluded that sludge water is applicable to use in concrete production with consideration of the type of structure, with no effect on the temperature change of concrete during the curing period.

4. Conclusions

(1) Sludge water from the ready-mixed concrete plant has alkalinity of pH 12, which is considerably higher than that of tap water, and has a total solids content of 63,400 ppm exceeding the value of 50,000 ppm as per ASTM C94 standard.
(2) The compressive strength, flexural strength and modulus of elasticity of concrete tend to decrease with an increase in the proportion of sludge water as a replacement of tap water. Overall, the compressive strengths of concretes mixed with sludge water are in the range of 85–94% of normal concrete, which are comparable to ASTM C94 requirement on mixing water for concrete. When compared with ACI 318 standard, the modulus of elasticity of concretes mixed with sludge water is more than the suggested value.
(3) The increase of the proportion of sludge water as a replacement of tap water have no effects on the unit weight of fresh concrete and the temperature change of concrete during curing. On the other hand, the slump of concrete containing sludge water tends to decrease when compared with the normal concrete mixed only with tap water.
(4) Due to an increase in soluble products from the reactions between the acids and the additional calcium hydroxide of concretes mixed with sludge water, an increase in proportion of sludge water as a replacement of tap water had a negative effect on the drying shrinkage and the resistance to acid attack.

Acknowledgments

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References

[1] Borger J, Carrasquillo RL, Fowler DW. Use of recycled wash water and returned plastic concrete in the production of fresh concrete. Adv Cem Based Mater 1994;1:267–74.
[2] ASTMC 94. Standard specification for ready-mixed concrete. Philadelphia: American Society for Testing and Materials; 2002.

[3] Chini AR, Muszynski LC. Reuse of wastewater at concrete plants in Florida in the production of fresh concreted. Mag Concr Res 2001;53(5):311–9.

[4] Su N, Miao B, Liu F. Effect of wash water and underground water on properties of concrete. Cem Concr Res 2002;32:777–82.

[5] Sandrolini F, Franzoni Elisa. Waste wash water recycling in ready-mixed concrete plants. Cem Concr Res 2001;31:485–9.

[6] Moon HY. Properties of cement matrix mixed with ready-mixed concrete sludge and residual water, Hanyang University of Korea, ICCMC/IBST 2001. p. 519–25.

[7] ASTM C33. Standard specification for concrete aggregates. Philadelphia: American Society for Testing and Materials; 2002.

[8] ASTM C138. Standard test method for density (unit weight), yield, and air content (gravimetric) of concrete. Philadelphia: American Society for Testing and Materials; 2002.

[9] ASTM C143. Standard test method for slump of hydraulic cement concrete. Philadelphia: American Society for Testing and Materials; 2002.

[10] ASTM C39. Standard test method for compressive strength of cylindrical concrete specimens. Philadelphia: American Society for Testing and Materials; 2002.

[11] ASTM C469. Standard test method for static modulus of elasticity and Poisson's ratio of concrete in compression. Philadelphia: American Society for Testing and Materials; 2002.

[12] ASTM C78. Standard test method for flexural strength of concrete (using simple beam with third-point loading). Philadelphia: American Society for Testing and Materials; 2002.

[13] ASTM C596. Standard test method for drying shrinkage of mortar containing hydraulic cement. Philadelphia: American Society for Testing and Materials; 2002.

[14] ASTM C311. Standard test methods for sampling and testing fly ash or natural pozzolans for use as a mineral admixture in Portland-cement concrete. Philadelphia: American Society for Testing and Materials; 2002.

[15] Neville AM. Properties of concrete. London, England: Pitman Books Limited; 1995.

[16] Bendsted J, Barnes P. Structure and performance of cement. London, England: Spon Press; 2002.

[17] ACI Committee 318. Building code requirements for structural concrete. Michigan, USA: American Concrete Institute; 2002.