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Use of ready-mixed concrete plant sludge water in concrete containing an additive or admixture

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ABSTRACT

In this study, we investigated the feasibility of using sludge water from a ready-mixed concrete plant as mixing water in concrete containing either fly ash as an additive or a superplasticizer admixture based on sulfonated naphthalene-formaldehyde condensates (SNF). The chemical and physical properties of the sludge water and the dry sludge were investigated. Cement pastes were mixed using sludge water containing various levels of total solids content (0.5, 2.5, 5, 7.5, 10, 12.5, and 15%) in order to determine the optimum content in the sludge water. Increasing the total solids content beyond 5–6% tended to reduce the compressive strength and shorten the setting time. Concrete mixes were then prepared using sludge water containing 5–6% total solids content. The concrete samples were evaluated with regard to water required, setting time, slump, compressive strength, permeability, and resistance to acid attack. The use of sludge water in the concrete mix tended to reduce the effect of both fly ash and superplasticizer. Sludge water with a total solids content of less than 6% is suitable for use in the production of concrete with acceptable strength and durability.

1. Introduction

Sludge water is the waste wash water from concrete mixing plants and agitator trucks. With the growing demand for ready-mixed concrete, the disposal of sludge water is becoming an increasing environmental concern. Each working day approximately 700–1300 l of wash water are required for a single concrete truck (Sandrolini and Franzoni, 2001). Due to the large amount of suspended matter and high alkalinity untreated sludge water cannot be legally discharged into urban sewers (Borger et al., 1994). In general, the procedure for sludge water disposal utilizes two series-connected sedimentation basins. The first basin receives leftover concrete and wash water from the concrete plant and trucks. The overflow sludge water containing suspended fine particles is transferred to the second basin. After a settling period, the water from both basins is reused for cleaning agitator trucks. Leftover concrete and sediment from the first basin and muddy sludge from the second basin are placed in a landfill.

Sludge water that meets the requirements of ASTM specification C94 (ASTM C94, 2004) may be reused as mixing water for concrete production with no significant effects on the properties of the concrete (Borger et al., 1994; Chini and Muszynski, 2001; Su et al., 2002). It has been found that fine-filler effects and a reduction of the actual water/cement ratio due to the fine solids content of sludge water lead to a reduction in concrete capillary water absorption and porosity, and possibly improve the durability of the concrete (Sandrolini and Franzoni, 2001). Concrete mixed with sludge water containing residual cement tends to exhibit a shorter setting time and lower flowability (Su et al., 2002). Nevertheless, the complete recycling of sludge water has been considered in concrete mixing plants because of the great benefit in terms of disposal cost reduction and environmental conservation (Chini and Muszynski, 2001; Su et al., 2002; Paolini and Khurana, 1998).

The feasibility of using sludge water in concrete mixtures was demonstrated in a previous paper (Chatveera et al., 2006). There has been limited interest in recycling sludge water that does not meet the ASTM C94 specification, particularly for concrete containing additives or admixtures. To ensure the durability of concrete in highly corrosive environments it is critical to consider the pH and total acidity over the design life of the structure (Chang et al., 2005; Aydin et al., 2007; Roy et al., 2001). In particular, designers must evaluate the possibility of sulfuric acid exposure due to environmental pollution. This paper aims to investigate the effect of sludge water on the workability, setting time, strength, and durability (permeability and sulfate resistance) of concrete

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containing either an additive (fly ash) or an admixture (superplasticizer). The sludge water was obtained from a ready-mixed concrete plant in Thailand, and was analyzed and compared with the ASTM C94 specification (ASTM C94, 2004). The concrete properties were tested according to ASTM and JIS standards (ASTM C94, 2004; ASTM C33, 2004; ASTM C494, 2004; ASTM C109, 2004; ASTM C191, 2004; ASTM C143, 2004; ASTM C403, 2004; ASTM C39, 2004; JIS A1404, 1977; ASTM C267, 2004). An investigation of the use of sludge water in mixes containing both an additive and an admixture will be carried out in the future.

2. Experimental program

2.1. Materials

(1) Cement: a standard Type I Portland cement.
(2) Mixing water: tap water and sludge water (SW) obtained from a ready-mixed concrete plant in Thailand were used.
(3) Aggregates: the coarse aggregate was crushed limestone with a maximum size of 20 mm and water absorption of 0.57%. The fine aggregate was local river sand with a fineness modulus of 2.53 and water absorption of 0.71%. Their grading met ASTM C33 requirements (ASTM C33, 2004).
(4) Fly ash was used as a partial cement replacement additive. A Type F superplasticizer based on sulfonated naphthalene-formaldehyde condensates (SNF) was used as an admixture according to ASTM C494 (2004).

2.2. Testing procedures

2.2.1. Basic properties of mixing water

The chemical and physical properties of the sludge water and tap water were tested according to ASTM C94 (2004). Tests of the dry sludge powder included determination of chemical composition, particle size distribution, and microstructural characterization using scanning electron microscopy (SEM).

2.2.2. Cement paste specimens for properties of sludge water

Sludge water samples were collected from the concrete plant three times at 2 week intervals. The sludge water samples were passed through a #50 sieve (0.30 mm) to control the size of suspended particles and maintain homogeneity. Measurements of specific gravity and total solids content were performed using a 0.01 g precision scale. The samples were mixed with tap water to prepare specimens with total solids contents of 0.5, 2.5, 7.5, 10, 12.5, or 15%. The water/cement ratio of all cement pastes was maintained at 0.3 by weight.

In order to determine the optimum total solids content for sludge water to be employed in concrete mixes, the following tests were carried out on cement paste specimens prepared using sludge water:

(1) The 7 day compressive strength was tested according to ASTM C109 (2004).
(2) The initial and final setting times were maintained within $-1{:}00$ and $+1{:}30$ h of the control in accordance with ASTM C191 (2004).

2.2.3. Concrete specimens

Samples of sludge water collected at three separate times were adjusted to a total solids content of 5–6%. For the concrete specimens tested, the ratio of paste volume to void volume between compacted aggregates in the dry state (γ) was 1.3, and the volume ratio of sand to total aggregate (s/a) was 0.425. The specimens were prepared using either fly ash as an additive or superplasticizer as an admixture.

Details of the concrete mix proportions are presented in Table 1, in which CC denotes the control concrete mixed with tap water, F represents a concrete containing fly ash as a cement replacement at 20 wt%, S denotes a concrete mixed with superplasticizer at 1 wt%, and W represents concrete prepared using sludge water without fly ash or superplasticizer. For example, a sample identified as WF1 denotes a concrete prepared using sludge water (W) and containing fly ash (F), in which the sludge water was obtained during the first collection period (Sandrolini and Franzoni, 2001). The identification WS1 denotes a sample prepared using sludge water and containing superplasticizer, with the same sludge water collection period as the previous example. In future studies, concrete specimens containing both fly ash and superplasticizer will be investigated.

The durability and mechanical properties of the concrete specimens were determined by performing the following tests in triplicate:

(1) A concrete slump test in accordance with ASTM C143 (2004).
(2) Setting time measurements according to ASTM C403 (2004).
(3) Compressive strength tests at 1, 3, 7, 28, 56, and 91 days in accordance with ASTM C39 (2004).
(4) Water permeability testing at 28 days in accordance with JIS A1404 (1977). The water permeability test measures axial water flow through the sample under constant pressure for 1 h, and assumes continuity of flow. The permeability coefficient was used to quantify water transport into the concrete, and was calculated assuming laminar flow through the cracked material based on Darcy's law.
(5) The ASTM C267 (2004) standard was modified for testing the resistance to acid attack at 1, 3, 7, 28, 56, and 91 days. A 5% sulfuric acid solution was chosen for this accelerated laboratory investigation. The density of the acid solution was 1.84 g/cm^3.

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

Materials	Concrete test specimens									
	Period 1						Period 2		Period 3	
	CC	F	S	W	WF1	WS1	WF2	WS2	WF3	WS3
Cement (kg)	350	280	350	350	280	350	280	350	280	350
Fine aggregate (kg)	764	764	764	764	764	764	764	764	764	764
Coarse aggregate (kg)	1046	1046	1046	1046	1046	1046	1046	1046	1046	1046
Tap water (kg)	198	187	163	–	–	–	–	–	–	–
Sludge water (kg)	–	–	–	210	198	173	202	173	197	178
Fly ash (kg)	–	70	–	–	70	–	70	–	70	–
Superplasticizer (ml)	–	–	3500	–	–	3500	–	3500	–	3500

Table 2
Chemical properties of sludge water and tap water

Chemical properties	ASTM C94	Sludge water	Tap water
Chloride ion (Cl^-), ppm	$\leq$1000	18.5	25.2
Sulfate ion (SO_4^{2-}), ppm	$\leq$3000	14.0	22.5
Total solids content, ppm	$\leq$50,000	56,400	50.3
Alkalinity (Na_2O+$0.658K_2O$), ppm	$\leq$600	515*	–
Alkalinity ($CaCO_3$), ppm	–	1874	42.1
Specific gravity	–	1.06	0.99
pH	–	12.8	7.5

* tested with dry sludge powder. ppm = part per million.

Table 3
Chemical compositions of materials

Chemical compositions (%)	Dry sludge powder	Portland cement Type 1	Fly ash
SiO_2	25.05	17–25	44.82
Al_2O_3	7.39	3–8	21.53
Fe_2O_3	3.99	0.5–0.6	13.73
CaO	31.33	60–67	25.24
MgO	1.59	0.1–5.5	2.78
K_2O	0.85	0.3–1.5	2.00
Na_2O	0.00		1.14
SO_3	0.03	1–3	2.89
Free Cao	0.00	0.00	0.00
LOI	21.07	<3	<1

3. Test results and discussion

3.1. Basic properties of sludge water

The chemical properties of sludge water and tap water are listed in Table 2. Two types of alkalinity measurement were performed. The first type, described by ASTM C94 (2004), reports the alkalinity in terms of equivalent alkali units calculated from the chemical equation $Na_2O + 0.658K_2O$. This alkalinity measurement is not widely used due to the requirement for special equipment and testing in the dry state. In the second type, alkalinity is reported as the total alkalinity in the form of calcium carbonate ($CaCO_3$). This measurement is widely used for water analysis due to the convenience of testing samples in the liquid state.

The average total solids content of the sludge water samples was 56,400 parts per million (ppm), which is greater than the limit of 50,000 ppm specified by ASTM C94 (2004). The pH and alkalinity of the sludge water samples were higher than the tap water. Levels of chloride ion (Cl^-) and sulfate ion (SO_4^{2-}) in both the sludge water and tap water were below the limits specified in the standard.

Dry sludge powder was obtained by drying sludge sediment at a temperature of 110 ± 5 °C. The chemical properties of dry sludge powder in comparison with Portland cement Type I and fly ash are presented in Table 3. The composition of the dry sludge powder was found to be intermediate between Portland cement and fly ash. The increased amount of SiO_2 in dry sludge powder (25.05%) relative to Portland cement may be due to the presence of sand in concrete production. The amount of CaO in the dry sludge powder (31.33%) was less than in Portland cement due to sludge water dissolved from the excess concrete in the washing process resulting in smaller amount of CaO.

The loss on ignition (LOI) content is the loss of material that occurs after burning at 950 ± 50 °C. The sludge powder had a very high LOI (21.07%). However, the LOI of sludge powder is not directly related to the carbon content because of the large amount of bound water released at elevated temperatures. The bound water is present as hydrated cement and as the hydration products of a discontinuous calcium silicate hydrate (C–S–H) gel, an unstable, soluble material whose morphology is strongly dependent on the environment (Kosmatka et al., 2002). Fig. 1 compares high-resolution micrographs of cement particles and dry sludge powder. The dehydrated cement particles are angular and blocky, while the morphology of the sludge powder resembles ettringite (AFt), with long, slender needles and C–S–H gel.

The particle size distribution of the dry sludge powder, fly ash and Type I Portland cement are presented in Fig. 2. The particle size ranges of dry sludge powder, fly ash and Portland cement Type I are classified as the coarsest to the finest by the mean particle size of 50.32, 49.29 and 28.58 μm respectively.

3.2. Properties of sludge water for concrete mixing

The relationship between the specific gravity and total solids content of sludge water was linear as described by Eq. (1). If the total solids content of the sludge water are known, the water volume required for a concrete batch may be calculated from the specific gravity using Eq. (1):

$$Y = 0.008X + 0.95 \tag{1}$$

in which X represents the total solids content (%) and Y is the specific gravity of the sludge water (Fig. 3).

There is an initial rapid increase in the compressive strength of concrete samples. Therefore, the compressive strength of the cement pastes was tested after 7 days, by which time the compressive strength had reached a plateau. Figs. 4–6 depict the normalized 7 day compressive strengths and setting times of

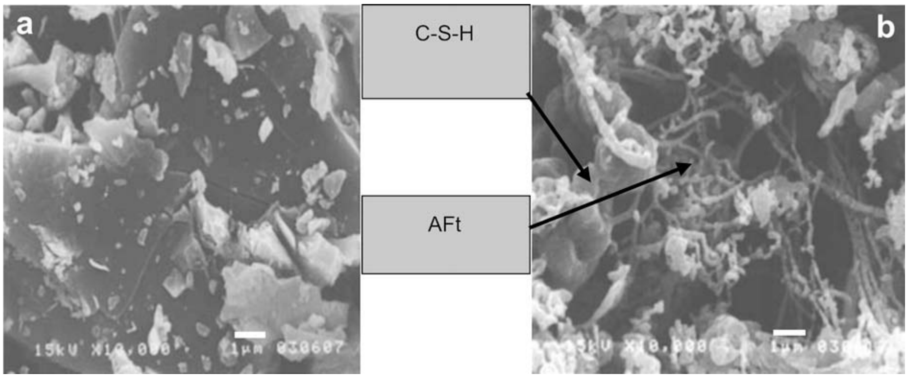

Fig. 1. Micrograph of particles at 10,000 – time magnification. (a) Portland cement Type I and (b) sludge powder.

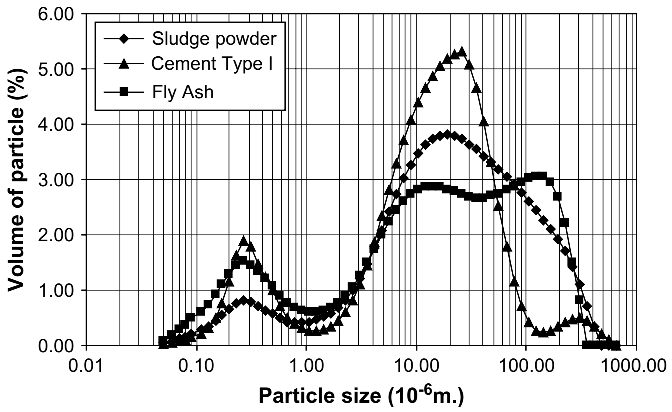

Fig. 2. Particle size distribution of materials.

cement pastes mixed using various sludge water samples. Test results were normalized with respect to control cement pastes (CC) prepared using tap water (0% total solids content). The control mixtures had an average 7 day compressive strength of 834 kg/cm^2, an initial setting time of 155 min, and a final setting time of 192 min. From Fig. 4, the compressive strengths of specimens mixed with sludge water containing less than 5% total solids were comparable to the control specimen. The compressive strengths of mixes prepared using sludge water containing less than 6% total solids were at least 90% of the control. The setting times were up to 90 min shorter than the control (Figs. 5 and 6), outside the ASTM C94 recommendation for mixing water (ASTM C94, 2004). By testing various sludge water samples obtained periodically over 4 weeks, it was found that sludge water meeting the ASTM C94 standard contained between 5.41 and 6.13% total solids, with an average value of 5.6% or 56,400 mg/L.

One important effect of increased total solids content is the high alkalinity in sludge water (Chatveera et al., 2006). This affects the hydration reaction and causes the dissolution of calcium carbonate and calcium silicate hydrate (Greenberg and Copeland, 1960). For cement paste mixed with sludge water, the overall results suggest that increasing the total solids content tends to reduce the compressive strength and shorten the setting time (Steinour, 1960; Maria et al., 2001; Martinez-Ramirez and Palomo, 2001).

3.3. Properties of concrete containing either additive or admixture

The fine sediment particles and high alkalinity of sludge water definitely affected the properties of the finished concrete. The previous test results were focused on determining allowable limits on solids content in the mixing water. This section examines the effect of mixing water containing the maximum recommended total solids content on the performance of concrete mixes containing fly ash or a superplasticizer admixture.

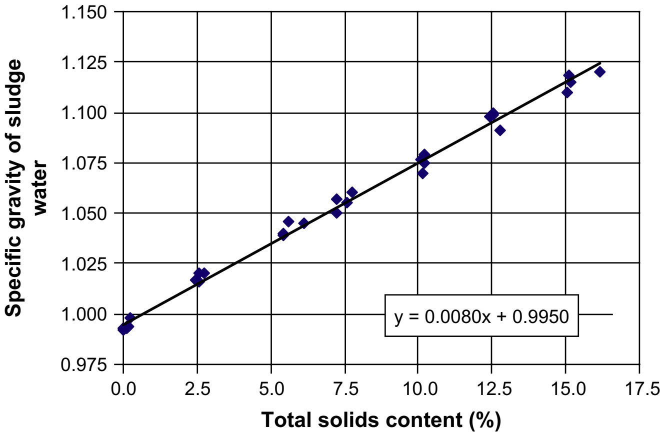

Fig. 3. Relationship between total solids content and specific gravity of sludge water.

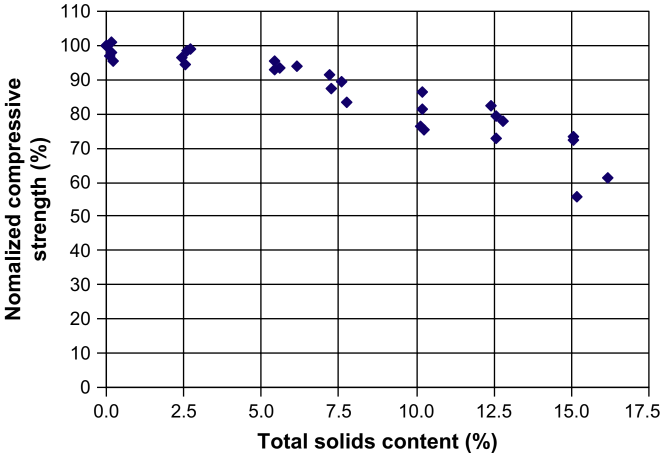

Fig. 4. Relationship between normalized compressive strength and total solids content of sludge water.

The sludge water samples were adjusted to obtain a total solids content between 5 and 6%. The quality control process consisted of testing the setting time and 1 day compressive strength of cement pastes prior to using the sludge water for mixing concrete. Concrete mixes were prepared containing either fly ash or superplasticizer according to the proportions listed in Table 1.

3.3.1. Water requirement of concrete

The concrete mixtures were all designed to produce a slump of 10 ± 2.5 cm. The slump of all of the mixtures fell between 8.0 and 9.3 cm. The water requirements of each mixture were compared with the control mix to determine the efficiency in water reduction when sludge water was used. Fig. 7 depicts the normalized mixing water content of concretes mixed with either additive (fly ash) or admixture (superplasticizer). The W concrete specimens using sludge water without additive or admixture required 6.06% more water than the control concrete (CC). F-type concrete specimens

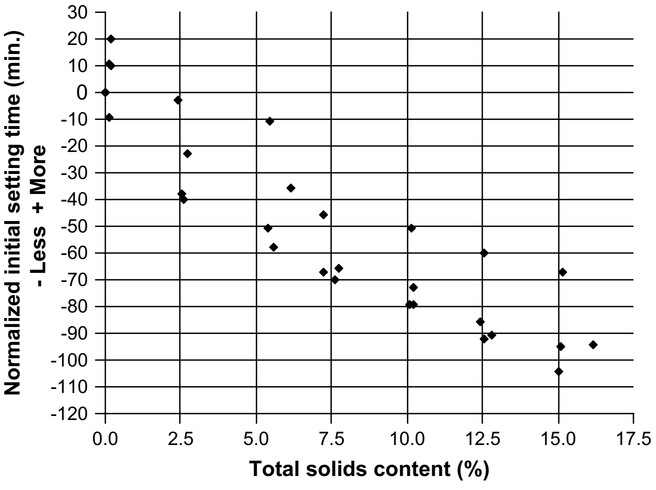

Fig. 5. Relationship between normalized initial setting time and total solids content of sludge water.

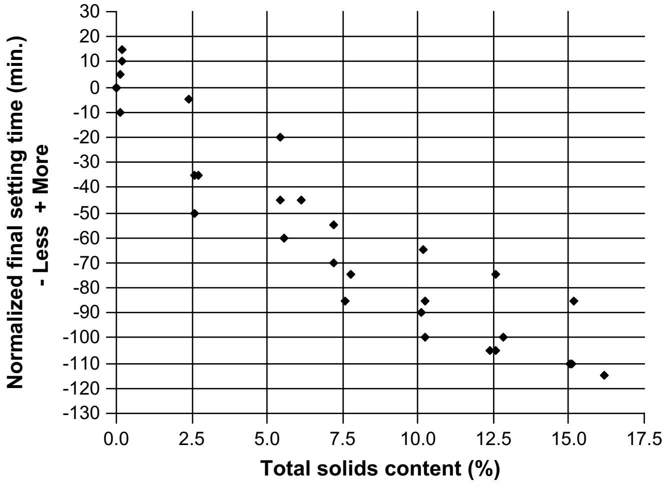

Fig. 6. Relationship between normalized final setting time and total solids content of sludge water.

using fly ash as a partial cement replacement and tap water as the mixing water required 5.72% less water than the control. This is because fly ash has a smoother surface and is more spherical in shape than Portland cement. This lubricates the mixture and assists the easy movement of other materials in the paste (Cheerarot and Jaturapitakkul, 2004; Bouzouba et al., 1997; Paya et al., 1995), resulting in a slightly lower water requirement.

In the case of concrete mixes prepared using sludge water as mixing water and fly ash as a partial cement replacement, the WF1, WF2, and WF3 specimens required the same amount of water as the control within 2%. For the concrete mixes containing the superplasticizer, the S concrete consumed 15.47% less water than the control and still met the ASTM C494 standard. In mixes prepared using sludge water as mixing water and containing superplasticizer as an admixture, the WS1, WS2, and WS3 concretes required between 7.89 and 10.42% less water than the control. The efficiency of the additive or admixture in promoting flowability was dramatically reduced when sludge water was employed. However, when using either fly ash or superplasticizer with sludge water, the concrete mixtures required approximately the same amount of water as the control specimens, and significantly less than concrete mixed with sludge water and not containing an additive or admixture.

3.3.2. *Setting time of concrete*

The initial and final setting times for the concrete mixes are plotted in Fig. 8. For the W mix prepared using sludge water, the initial and final setting times were approximately 20 min longer than the control mixture (CC). This is because sludge powder contains a large amount of porous sediment such as unhydrated cement and fine particles that require more water for hydration, consequently slowing the setting time [7]. Mixtures employing fly ash as a partial cement replacement and tap water as mixing water (F) had initial setting times 51 min longer and final setting times 42 min longer than the control concrete. Concrete mixtures containing fly ash (F) have longer setting times because the large amounts of SO_3 and Al_2O_3 in fly ash react with CaO in Portland cement to produce additional ettringite (Bououbaa et al., 2004; Udoeyo and Dashibil, 2002). For mixes containing sludge water and fly ash (WF1, WF1, and WF3), the initial setting times were 41–62 min longer and the final setting times were 51–71 min longer than the control concrete. The WF2 mixture required 1.85% more water than the control concrete and resulted in the longest setting time.

For mixes incorporating superplasticizer as an admixture, the initial setting time of the specimen mixed with tap water (S) was increased by 86 min, while the final setting time increased by 85 min, exceeding the ASTM C494 recommendation. When superplasticizer-containing mixtures were prepared using sludge water (WS1, WS2 and WS3), the initial setting times were 12–31 min longer and the final setting times were 4–38 min longer than the control mixture. The extended setting times observed in mixes not containing superplasticizer are the result of the increased water required by these mixtures. Specimens mixed with sludge water required longer setting times due to the increased water required to produce the same flowability.

Specimens prepared with tap water and superplasticizer (S) had longer setting times due to the water-reducing effect. Use of sludge water (WS1, WS2 and WS3) lowered the effectiveness of the water-reducer and resulted in a setting time that was somewhat shorter, but still longer than the control mixture. This is due to the presence of fine solids in the sludge water, leading to a reduction in capillary water absorption and an increase in the actual W/C ratio (Sandrolini and Franzoni, 2001). This effect is similar to the results observed in the concrete water requirement tests.

3.3.3. *Slump of fresh concrete*

Fig. 9 depicts the slump loss of concrete samples containing no superplasticizer. Concrete W prepared with sludge water displayed a shorter time slump loss than the control concrete. This is because sludge water contains absorbent porous sediments that require more water for hydration, resulting in increased slump loss (Chatveera et al., 2006). In the case of concrete mixtures containing fly ash, concrete F mixed with tap water and concretes WF1, WF2, and WF3 mixed with sludge water exhibited a decrease in slump

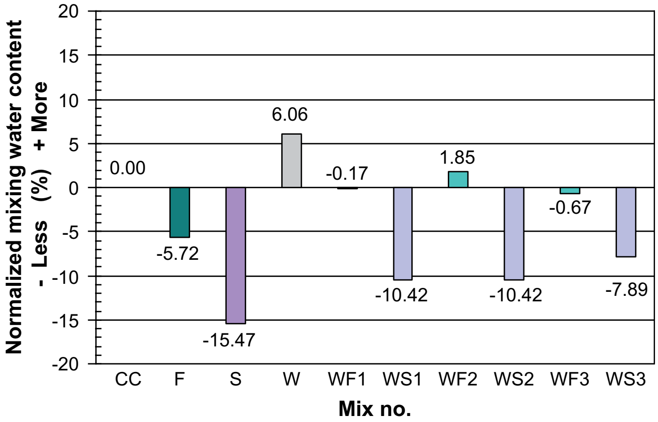

Fig. 7. Normalized mixing water content of concrete specimens.

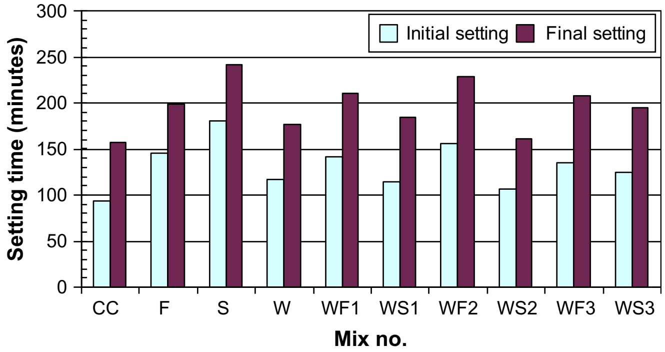

Fig. 8. Setting time of concrete specimens.

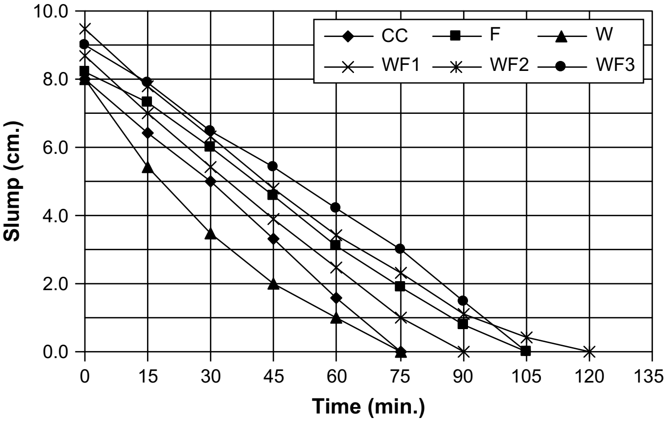

Fig. 9. Slump of fresh concrete (1).

loss compared to the control concrete. The use of sludge water had no significant effect on the slump for fly ash-containing mixtures.

Fig. 10 is a graph illustrating the slump loss of concretes containing superplasticizer. Mixing concrete S with tap water resulted in a slump time 60 min longer than the control concrete. For concrete samples containing superplasticizer and mixed with sludge water (WS1, WS2, and WS3), the slump times were between 30 and 45 min longer than the control concrete. Using sludge water as the mixing water in superplasticizer-containing mixtures noticeably decreased the slump loss. The slumps changed rapidly in the first 30 min, and concrete mixtures prepared using sludge water (WS1, WS2 and WS3) reached zero slump 15–30 min faster than the admixture-containing concrete mixed with tap water.

3.3.4. *Compressive strength of concrete*

Figs. 11–13 compare the normalized compressive strength of various concrete specimens to the control concrete. The results were normalized with respect to the control concretes (CC), which had average 1, 3, 7, 28, 56, and 91 day compressive strengths of 105, 185, 240, 317, 352 and 371 kg/cm^2 respectively. When fly ash or superplasticizer was added to reduce the amount of water required, both the F concrete containing fly ash and the S concrete containing superplasticizer produced higher compressive strengths than the control concrete. The W concrete using sludge water without admixture or additive required more water and resulted in a lower compressive strength (between 92 and 96% of the control concrete).

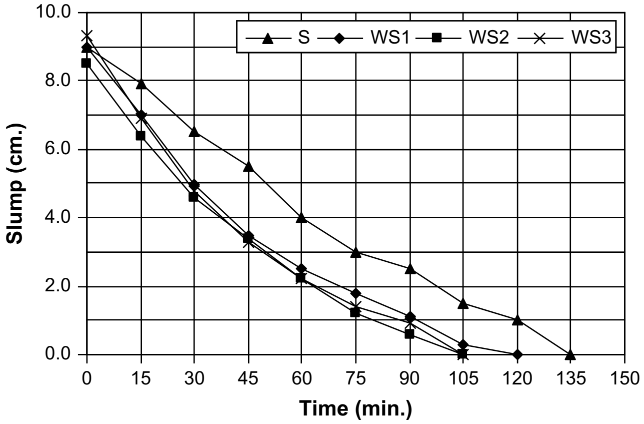

Fig. 10. Slump of fresh concrete (2).

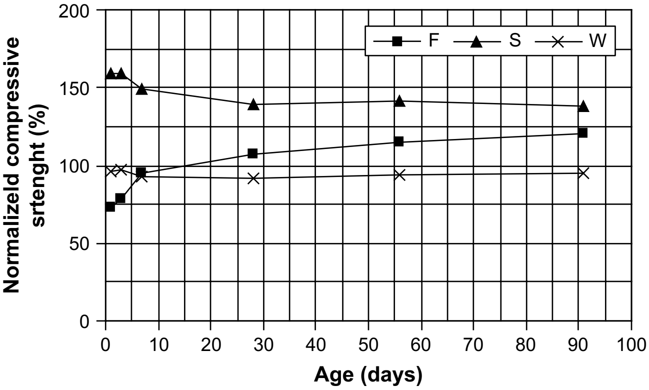

Fig. 11. Compressive strength of concrete (1).

The F concrete mixed with tap water displays a strength development curve typical of concrete mixtures containing fly ash, with a lower early compressive strength gradually increasing to approximately 120% of the control mixture strength after 91 days (Fig. 12). For the WF1, WF2, and WF3 concrete mixtures prepared using sludge water, the compressive strengths at 91 days were between 94 and 105% of the control concrete, and 10–17% lower than the fly ash concrete mixed with tap water (F).

Fig. 13 is a graph of the compressive strength over time for concrete mixtures containing superplasticizer. The compressive strength of S concrete mixed with tap water was higher than the control concrete as well as the value specified by the ASTM C494 Type F standard. The compressive strengths of the WS1, WS2, and WS3 concretes mixed with sludge water were higher than the control concrete, but did not meet the ASTM C494 Type F standard. Compared to the S concrete mixed with tap water, the compressive strengths of the WS1, WS2, and WS3 concretes were lower by approximately 8–13%.

3.3.5. *Permeability of concrete*

The normalized results of the water permeability tests are presented in Fig. 14. The highest permeability occurred in W concrete prepared using sludge water without fly ash or superplasticizer. The permeability of W concrete was higher than the control concrete, while the permeabilities of the other concretes were lower than the control concrete.

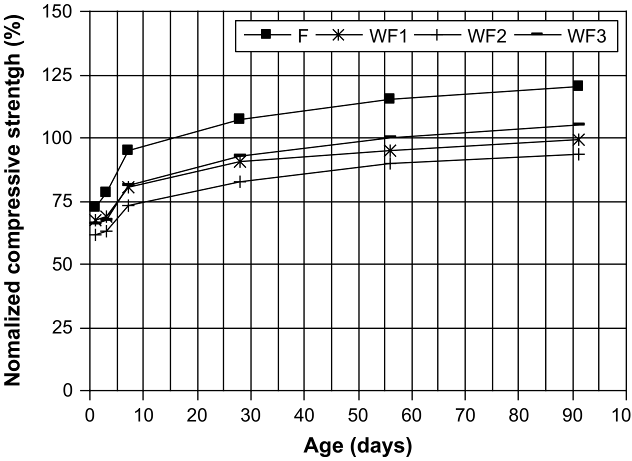

Fig. 12. Compressive strength of concrete (2).

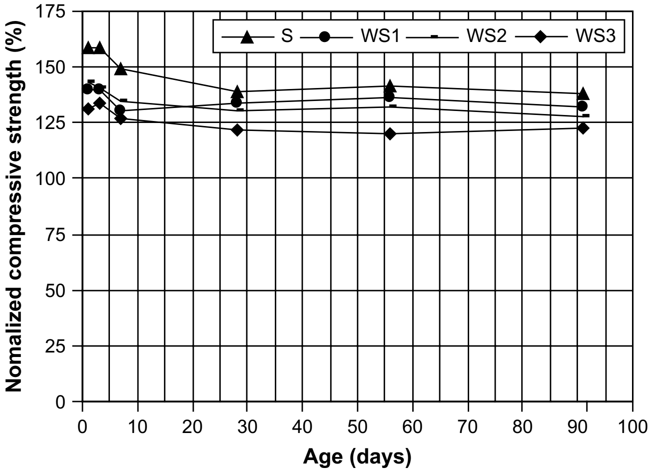

Fig. 13. Compressive strength of concrete (3).

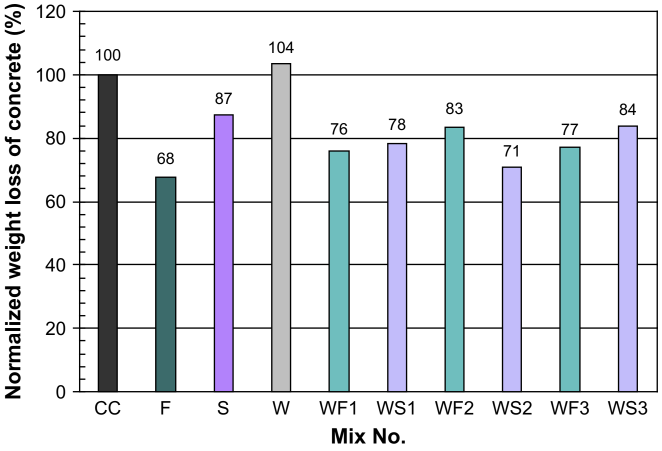

Fig. 15. Resistance of concrete to acid attack.

Among concretes containing fly ash, the lowest water permeability occurred with F concrete mixed using tap water. The permeabilities of concretes prepared with sludge water were lower than the control concrete, but higher than the F concrete by 7–65%.

The water permeabilities of all concretes containing superplasticizer as an admixture were lower than the control concrete regardless of whether they were prepared with sludge water or tap water. The permeabilities of concretes prepared using sludge water (WS1, WS2, and WS3) were between 86 and 106% of the mixture prepared with tap water (S).

3.3.6. *Resistance of concrete to acid attack*

The resistance to acid attack was tested in 5% sulfuric acid solution after the samples were cured in water for 91 days. The normalized weight losses due to acid attack are presented in Fig. 15. The weight loss of W concrete was approximately 4% greater than the control concrete. The weight losses of the other concretes were lower than the control concrete.

Among concretes containing fly ash, the weight loss of F concrete mixed with tap water was the lowest. The WF1, WF2 and WF3 concretes mixed with sludge water exhibited lower weight losses than the control concrete, but more than the F concrete by 12–23%.

The weight losses of all concretes containing superplasticizer were lower than the control concrete. The weight losses of concretes WS1, WS2, and WS3 mixed with sludge water were between 81 and 96% of the samples prepared using tap water (S). Using sludge water in combination with either fly ash or superplasticizer appears to improve the resistance of concrete to acid attack.

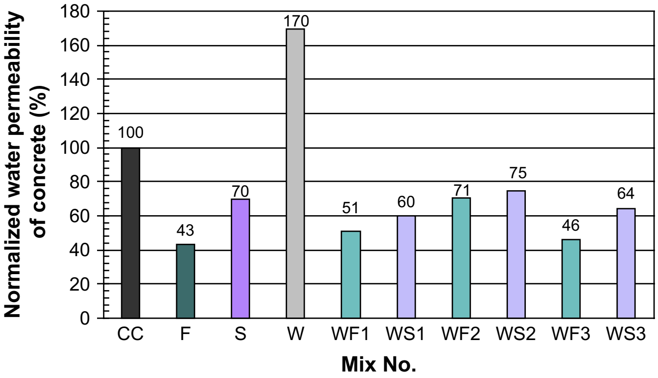

Fig. 14. Water permeability of concrete.

4. Conclusions

(1) Due to the presence of unburned carbon particles and excess water in the form of hydrated cement and hydration products (e.g. C–S–H, $Ca(OH)_2$, ettringite, etc.), sludge powder has a higher loss on ignition (LOI) than materials such as Portland cement and fly ash.

(2) Mixing concrete using sludge water requires additional water to produce comparable workability. The use of sludge water leads to negative effects on the flowability of concrete containing fly ash and the effectiveness of water-reducing agents (superplasticizers) due to additional fine particles and the reduction of the actual water content. Using sludge water without additives (fly ash) or admixtures (superplasticizer) leads to longer setting times, but has no significant effect on the slump. For concretes containing superplasticizer, the use of sludge water leads to a noticeable reduction in the setting time and slump of the concrete.

(3) The compressive strengths of concretes prepared using sludge water were lower. The use of sludge water leads to a reduction of approximately 4–8% in the compressive strength for concretes without additives or admixtures, 10%–17% for concretes using fly ash as an additive, and 8–13% for concretes containing superplasticizer as an admixture. However, when sludge water was used in combination with either fly ash or superplasticizer, the compressive strengths of the resulting concretes were higher than the control concrete made from Portland cement and tap water.

(4) Using sludge water for mixing concrete without additives or admixtures negatively affects the acid resistance. However, when using sludge water with either fly ash or superplasticizer, the durability was better than the control concrete.

(5) Compared with tap water, the sludge water was higher in alkalinity, pH, specific gravity, and total solids content. However, sludge water with a total solids content of less than 6% could be used in the production of admixture-containing concrete with acceptable strength and durability.

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