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Effect of wash water and underground water on properties of concrete

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Abstract

This study deals with the effect of different types of mixing water on properties of mortar and concrete such as compressive strength, setting times and workability. Water used for mortar and concrete include tap water, underground water and wash water from mixer washout operations in a ready-mixed concrete plant. This study analyzes the quality of these types of water. Then, tests were conducted on mortar and concrete. All the underground water and wash water tested meet the ASTM C94 requirements on mixing water for ready-mixed concrete. Concrete mixed with bottom wash water gave a shorter setting time and a lower flowability since bottom wash water contains some residual cement. Neither top and middle wash waters nor underground water significantly affected slump of fresh mortar. The compressive strength of concrete mixed with wash water or underground water is as good as that with tap water. Therefore, it is suggested that underground water should be considered as mixing water for concrete and wash water be recycled where tap water resources are scarce. However, it is advised that other properties such as durability or shrinkage be studied before use. © 2002 Published by Elsevier Science Ltd.

Keywords: Water quality; Wash water; Recycling; Compressive strength; Setting time; Underground water

1. Introduction

Water is an important ingredient of concrete: not only it participates the hydration of cement but also it contributes to the workability of fresh concrete [1–3]. The quality of mixing water is therefore critical to properties of fresh and hardened concrete including strength and durability. Most standards in the world specify that water used for concrete shall be reasonably clean and free of oil, acid, alkali, organic matter or other deleterious substances [4–8]. Drinking water (tap water) is largely used as mixing water for concrete [2,6,8–11]. However, drinking water resources are more and more scarce in developed countries and are quite expensive in developing countries. Underground water has been used by some concrete producers in Taiwan as mixing water for concrete to reduce production cost.

Another problem regarding water in concrete industry is wash water from washing mixers, trucks or chutes [2,6,8]. Because of environmental requirements, wash water cannot be run out of ready-mixed concrete plant as effluent without adequate treatment. The treatment process in this case is relatively expensive process for ready-mixed concrete producer [12].

This paper aims to investigate the possibility of using underground water as mixing water and recycling wash water in ready-mixed concrete plant [13]. Five types of water (tap water, underground water and top, middle and bottom wash waters) were first sampled from a ready-mixed concrete plant in central Taiwan. Their quality was then analyzed in laboratory and compared with the ASTM C94 specification [6,14]. The effects of water quality on workability, setting time and compressive strength of mortar and concrete were studied [13–15].

2. Materials and experimental program

The pH value, turbidity, total solids, chloride ion content and sulfate content were analyzed for tap water, underground water and wash water. Mortar samples with these

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Table 1
Properties and composition of cement, fly ash and blast-furnace slag

Item		Materials		
		Cement	Fly ash	GGBS
Physical properties	Fineness			
	Amount retained on a 45-μm sieve (%)	–	15	9
	Blaine method (cm^2/g)	3350	–	422
	Specific gravity	3.14	2.10	2.93
Chemical composition	Loss on ignition (%)	1.36	5.0	0.4
	SiO_2 (%)	21.0	55.5	34.8
	Al_2O_3 (%)	6.26	27.9	13.6
	Fe_2O_3 (%)	3.09	6.3	0.32
	CaO (%)	64.18	6.3	40.51
	MgO (%)	1.53	1.6	6.96
	SO_3 (%)	1.95	0.8	1.52
	Alkalinity (%)	–	0.3	1.8
	Sulfide sulfur (%)	–	–	0.5
	Free CaO	1.36	–	–
	Insoluble residue (%)	0.20	–	–
	C_3S	46.0	–	–
	C_2S	26.0	–	–
	C_3A	11.4	–	–
	C_4AF	9.4	–	–
	$C\overline{S}H_2$	4.73	–	–
Mortar	Air content of slag mortar (%)		–	3.5
	Slag activity index in 3 days (%)		–	72

water samples were prepared and setting time, compressive strength and fluidity were then tested. In addition, concrete samples were also prepared and tested for slump, slump flow, unit weight, air content and compressive strength.

2.1. Materials

2.1.1. Mixing water

Tap water (TW), underground water (UW) and wash water (WW) from a ready-mixed concrete plant of central Taiwan were used in this study. The underground water was pumped from the well and the wash water from the sedimentation pool. Because sedimentation pool is generally deep (6 m in this case), the impurities in wash water obviously depend on its depth in the pool. In order to take this factor in consideration, wash water was further separated into three levels, i.e. top level (WW-T), middle level (WW-M) and bottom level (WW-B). Their samples were taken at 0.5, 3 and 5 m under the water surface of sedimentation pool, respectively.

Table 2
Physical properties of aggregate

Properties	Coarse aggregates	Fine aggregates
Specific gravity (SSD)	2.63	2.62
Absorption (%)	1.04	2.38
Fineness modulus	–	3.02
Unit weight (kg/m^3)	1640	–

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

	Materials							
Concrete	Water	Cement	FA	GGBS	Fine aggregate	Coarse aggregate	SP	W/B[a]
C14	212	220	40.0	93.3	763	936	2.2	0.60
C21	182	270	20.7	48.3	809	992	2.7	0.54
C28	182	300	33.6	78.4	692	1042	3.0	0.44

[a] W/B: water/binder ratio.

2.1.2. Cement

A local Type I Portland cement was used. Its physical properties and chemical composition are shown in Table 1. The cement meets the requirements of ASTM C150.

2.1.3. Aggregates

The coarse aggregate were crushed rocks. The fine aggregate was natural sand. Their physical properties are shown in Table 2 and their grading meet the ASTM C136 requirements. The sand used for mortar samples was standard Ottawa sand, which meets ASTM C109 requirements.

2.1.4. Superplasticizer (SP)

An ASTM type G naphthalene-sulfonated SP was used in this study.

2.1.5. Mineral admixtures

A local Class F fly ash (FA) and a ground granulated blast-furnace slag (GGBS) were used. Their physical properties and chemical composition are shown in Table 1.

2.2. Mix proportion

2.2.1. Mortar

The mix proportion (weight ratio) of mortar was water/cement/standard sand = 0.485/1/2.75. Mortar cubes ($50 \times 50 \times 50$ mm) were prepared and subjected to curing at 23 ± 1.7 °C in air during the first 24 h and then in lime-saturated water until testing age.

2.2.2. Concrete

Three grades (14, 21 and 28 MPa designated as C14, C21 and C28, respectively) of concrete commonly used in Taiwan were designed following the mix proportion method

Table 4
Test methods of water quality

Item	Test method
pH value	ASTM D1293-99
Turbidity	ASTM D1889-00
Total solids	AASHTO T26
Chloride content	ASTM D512-89
Sulfate content	ASTM D516-90

Table 5
Results of water analysis

Test item	Water type TW	UW	WW-T	WW-M	WW-B	ASTM C94 requirement
pH value	6.7	7.8	11.2	11.9	11.8	–
Turbidity (NTU)	0.05	1.3	29.3	39.7	493.0	–
Total solids (ppm)	2130	2370	1530	3930	7130	< 50,000
Chloride ion (ppm)	10.45	5.7	13.48	14.73	20.8	< 1000
Sulfate ion (ppm)	125	118	210	235	203	< 3000

TW: Tap water; UW: Underground water; WW-T: Upper level of wash water; WW-M: Bottom level of wash water; WW-B: Middle level of wash water.

proposed by Su et al. [16] as shown in Table 3. A slump range of 220 ± 20 mm and a slump flow range of 500 ± 100 mm were specified for the three concretes to meet pumpability requirement.

2.3. Test methods

2.3.1. Water analysis

The pH values, turbidities, total solids, chloride ion contents and sulfate contents of different types of water were tested according to procedures of ASTM and AASHTO as shown in Table 4.

2.3.2. Mortar samples

The compressive strength of mortar cubes was tested according to ASTM C31. The flow values of fresh mortars were measured according to ASTM C230, and the setting time of fresh mortars was tested according to ASTM C403.

2.3.3. Concrete samples

The compressive strength of concrete specimens (120 × 240-mm cylinders) was tested according to ASTM C39. The slump and slump flow of fresh concrete were measured according to ASTM C143 and JASS T-503 [17]. The air content and unit weights of fresh concrete were determined according to ASTM C231 and ASTM C138.

3. Results and discussion

3.1. Water analysis

3.1.1. pH value, turbidity and total solids

Results of water analysis (average of three samples) are shown in Table 5. The pH values of the tested tap and underground water were between 6 and 8 while that of wash water were above 11. This is probably due to the fact that the wash water contains residual cement particles. The turbidities of tap and underground water were 0.05 and 1.3 NTU, respectively, which are much lower than the requirement of CNS [8] for tap water (4 NTU). Turbidity

Table 6
Qualities of water from other selected ready-mixed concrete plants in Taiwan

Plant	Water type	pH value	Turbidity (NTU)	Total solid (ppm)	Chloride ion (ppm)	Sulfate ion (ppm)
A	UW	7.7	19.1	270	6.69	43.2
	WW-T	12.7	25.0	2980	12.4	6.98
	WW-M	12.7	89.3	3040	14.3	10.2
	WW-B	12.7	354	11,050	20.1	9.38
B	UW	7.5	6.35	730	24.9	25.1
	WW-T	12.2	93.1	1200	27.7	22.4
	WW-M	12.4	54.3	1140	27.7	8.69
	WW-B	12.3	170	4820	30.6	7.78
C	UW	8.0	27.3	570	8.6	19.2
	WW-T	12.0	86.5	550	2.87	22.9
	WW-M	12.0	83.7	590	2.87	23.3
	WW-B	12.0	365	1460	2.87	21.8
D	TW	7.0	0.38	330	13.4	39.9
	UW	7.3	23.0	1030	83.4	80.0
E	TW	7.0	–	179	22.0	33.0
F	UW	6.7	–	133	22.0	16.7
G	UW	–	–	291	4.4	36.4
Ranges of measured data	TW	7.0	0.38	179–330	13.4–22.0	33.0–39.9
	UW	6.7–8.0	6.35–27.3	133–1030	4.4–24.9	16.7–43.2
	WW-T	12.0–12.7	25.0–93.1	550–2980	2.87–27.7	6.98–22.9
	WW-M	12.0–12.7	54.3–89.3	590–3040	2.87–27.7	8.69–23.3
	WW-B	12.0–12.7	170–365	1460–11,050	2.87–27.7	7.78–21.8
Average	TW	7.0	0.38	255	17.7	36.5
	UW	7.4	18.9	504	25.0	36.8
	WW-T	12.3	68.2	1577	14.3	17.4
	WW-M	12.3	75.8	1590	15.0	14.1
	WW-B	12.3	296.3	5777	17.9	13.0

Table 7
Properties of fresh mortars mixed with different types of water

Test item	Water type				
	TW	UW	WW-T	WW-M	WW-B
Flow value (%)	82	78	77	83	67
Initial setting time (min)	95	105	115	125	85
Final setting time (min)	240	225	225	255	225

of bottom wash water was as high as 493 NTU because of the suspended solids. Nevertheless, neither ASTM nor BS specifications have shown any turbidity requirement on mixing water. Total solids in tap water was close to that of underground water where as that of wash water increased with water depth from 1530 ppm for top wash water to 7130 ppm for bottom wash water.

3.1.2. Chloride ion

Table 5 shows tap water contains only 10.45 ppm of chloride ion. It meets the limits of ASTM C94 (1000 ppm for reinforced concrete and 500 ppm for prestressed concrete). It is even lower than the chloride ion limit for tap water (250 ppm for most countries in the world). The chloride ion in underground water is lower than that in tap water because chlorination was done during disinfection of tap water. The chloride ion in wash water increases with water depth from 13.48 ppm for top wash water to 20.8 ppm for bottom wash water due to the sedimentation of fine solids containing chloride.

3.1.3. Sulfate ion

Excessive amount of sulfate (SO_4^{2-}) content in mixing water results in formation of calcium sulfoaluminate (ettringite) in cement hydration, which may causes cracking of concrete. Table 5 shows that the sulfate content in underground water and top, middle and bottom wash waters were 117, 210, 235 and 203 ppm, much lower than the sulfates limit of ASTM C94 (1000 ppm).

3.1.4. Variation of water quality

Water qualities will vary with the location of sources (ready-mixed concrete plant location), season, etc. Table 6 compares the properties of mixing water used in the north, middle and south regions of Taiwan. The average values of pH, turbidity and chloride ion of waters from ready-mixed concrete plants of A, B, C, D, E, F and G are very close to those in Table 5, but the average values of total solid and sulfate ion from abovementioned seven plants are slightly lower than those from Table 5. This explains that the qualities of water samples in Table 5 are slightly lower than those at other locations. The mortar samples and concrete samples are mixed only with water samples listed in Table 5, which should present a more conservative conclusions and suggestions in this study.

3.2. Effect on properties of mortar

3.2.1. Setting time

Table 7 shows the initial setting time of all mortars mixed with underground water and top, middle level and bottom wash waters were within −10 and +30 min as compared to that of the control one (mixed with tap water). The final setting times of these samples were within −15 and +15 min as compared to that of the control, indicating that use of these types of water meet the ASTM C94 requirement on setting time, which specifies a tolerance of 60 min for initial setting time and 90 min for final setting time. The initial setting times of mortars mixed with underground water or top wash water were close to that of the control, while that mixed with bottom wash water was slightly shorter. This is probably because bottom wash water contains more alkalines ($Ca(OH)_2$, NaOH) than top wash water, which would shorter the setting time. There might be also due to bottom wash water contains partially hydrated cement and fine solids from mixed washout operations that may interfere the setting time.

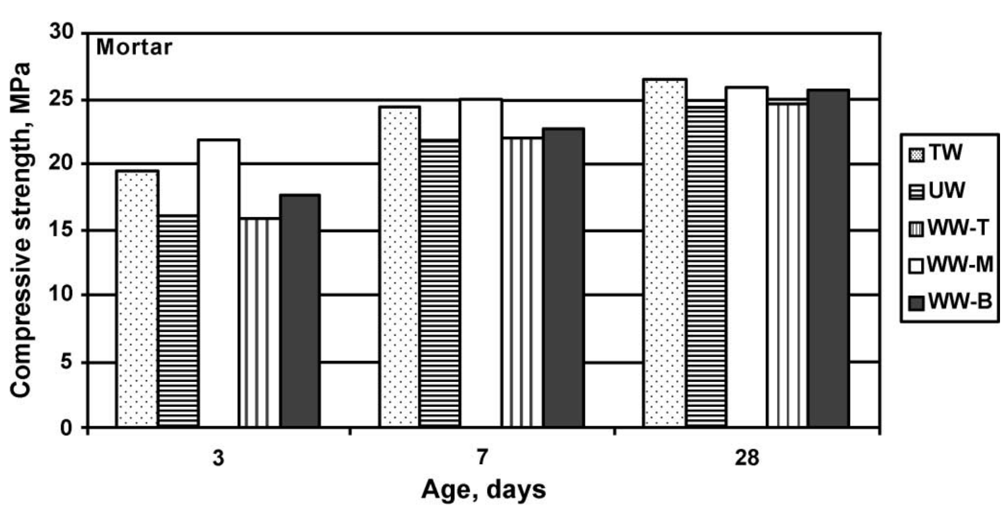

Fig. 1. Compressive strength of mortars mixed with different types of water.

3.2.2. Fluidity

Table 7 shows the fluidity of mortars mixed with underground water and top and middle wash waters were close to that mixed with tap water, while that mixed with bottom wash water was significantly lower. This is probably because bottom wash water contains more tin solids than other types of water.

3.2.3. Compressive strength

Results of compressive strength on mortars are presented in Fig. 1. The compressive strength of mortars mixed with underground water and top, middle and bottom wash waters after 7 days curing were 90%, 103%, 91% and 90%, respectively, of that mixed with tap water as shown in Table 8, which are higher than the minimum limit with 90% that specified in ASTM C94 and BS 3184 be accepted as mixing water for concrete. However, after 28 days of curing, the compressive strength of mortars mixed with the four types of water above was ranged 92–93% of that mixed with tap water.

3.3. Effect on properties of concrete

3.3.1. Workability

Regardless of types of water used, the slumps were all 210–240 mm as shown in Table 9, which matched the specified slump. All the slump values were very close, indicating that underground water or wash water has no significant adverse effect on slump of concrete. Slump flow of fresh concretes mixed with all five types of water were ranged from 500 to 550 mm, which are within the range of the specified slump flow of 500 ± 100 mm. The slump flows of fresh concrete mixed with tap water and underground water were very close, whereas that of bottom wash water were slightly lower than the others. This is probably because bottom wash water contains substantial amounts of residual cement and fine solids from washout operations of mixers and trucks, which can effect slump flow of fresh concrete.

3.3.2. Unit weight and air content

The unit weight of fresh concrete mixed with top, middle and bottom wash waters were slightly more than that mixed with tap water and underground water as shown in Table 9. This is probably because wash water contains more total solids. The air contents of concrete mixed with all five types of tested water were from 1.60% to 1.65%, indicating that air content was not showing appreciably affected by water quality.

Table 8
Relative compressive strength of mortar with different types of water (%)

Water type	Age 3 days	7 days	28 days
TW	100	100	100
UW	82	90	92
WW-T	112	103	98
WW-M	82	91	93
WW-B	91	90	98

Table 9
Properties of fresh concrete mixed with different types of water

Test item	Concrete	Water type TW	UW	WW-T	WW-M	WW-B
Slump (mm)	C14	210	210	230	210	220
	C21	220	230	230	230	230
	C28	240	210	230	240	230
Slump flow (mm)	C14	512	515	515	485	480
	C21	540	525	600	520	515
	C28	580	560	535	540	500
Unit weight (kg/m^3)	C14	2331	2331	2359	2316	2389
	C21	2316	2359	2349	2345	2331
	C28	2345	2316	2331	2359	2374
Air content (%)	C14	1.60	1.60	1.65	1.65	1.60
	C21	1.70	1.60	1.65	1.65	1.65
	C28	1.60	1.60	1.65	1.60	1.65

3.3.3. Compressive strength

The compressive strength of three concretes mixed with different types of water is shown in Table 10. It can be seen that the compressive strength of concrete mixed with other types of water is generally higher than that mixed with tap water.

The compressive strength of concrete mixed with underground water was slightly higher than that mixed with tap water.

Compressive strength of concrete mixed with wash water increased with the depth of water in sedimentation pool because the amount of solids particles (cement and other fine solids) in wash water increases with the depth of water and those particles may contribute to concrete strength especially at early age.

Even though the compressive strength of mortars mixed with wash water was slightly lower than that mixed with tap water, the compressive strength of concretes mixed with

Table 10
Relative compressive strength of concrete mixed with different types of water (%)

Water type	Age 7 days	28 days	56 days
TW	100	100	100
UW	101	116	107
WW-T	101	107	101
WW-M	110	110	103
WW-B	118	123	106
TW	100	100	100
UW	106	104	108
WW-T	111	100	98
WW-M	119	111	111
WW-B	121	111	112
TW	100	100	100
UW	112	110	107
WW-T	111	101	97
WW-M	114	103	100
WW-B	118	103	102

wash water was higher than that mixed with tap water, especially at early age. This is probably due to the high alkalinity of wash water (pH = 11 – 12), which contains dissolved calcium and sodium hydroxides. The alkaline nature of wash water would not only accelerate the cement hydration but also activate the pozzolanic reaction of mineral admixtures (FA and GGBS). Therefore, the compressive strength of concretes mixed with wash water was enhanced.

4. Conclusions and suggestions

1. All the five types of water (tap water, underground water and top, middle and bottom wash waters) used in this study met the requirements of ASTM C94 on mixing water for ready-mixed concrete.

2. As compared to the tap water tested, the underground water was higher in turbidity and lower in chloride content, while wash water was high in alkalinity, turbidity, solid content, chloride and sulfate. The solid contents and the turbidity of wash water increased with its depth in sedimentation pool due to the residue cement and solids.

3. As far as setting time of fresh mortar is concerned, the differences in initial setting time between mortar mixed with tap water and that mixed with other types of water were no more than 30 min and that in final setting time gave similar results.

4. After curing for 7 or 28 days, the compressive strength of mortars mixed with underground water and top, middle and bottom wash waters was 90 – 103% that mixed with tap water. However, these values were all superior to the ASTM limit (90%) on acceptation for mixing water of concrete.

5. Concrete mixed with underground water or wash water did not show significant adverse effect on slump but slightly affected slump flow.

6. The compressive strength of concrete mixed with wash water or underground water was higher than that mixed with tap water. Concrete mixed with bottom wash water was even 10% higher in compressive strength than that mixed with tap water.

7. Due to the activation of the pozzolanic reaction of FA and blast-furnace slag by the high alkalinity of wash water, the early strength development of concrete mixed with wash water was higher than that mixed with tap water.

8. Based on results reported in this study, it seems that underground water and wash water could be used as mixing water for ready-mixed concrete without affecting the compressive strength. However, the effects of underground water or wash water on hydration mechanism, durability or other properties of concrete need to be further investigated.

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