USE OF RECYCLED CEMENT-BASED SLURRY WATER FOR MAKING CONCRETE

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G.L. Low[1], K.Y. Ng, W.L. Ng, C.T. Tam[2], R.B.W. Heng[3]
[1]*School of Design & the Environment, Singapore Polytechnic, 500 Dover Rd S(139651)*
[2]*Department of Civil Engineering, National University of Singapore, 10 KentRidge Crescent, S(117576)*
[3]*School of Engineering, Sheffield Hallam University, Pond Street, Sheffield, S1 1WB*
E-mail: me_gl2002@yahoo.com

ABSTRACT

Due to limited water resources in Singapore and the escalating cost of potable water, industries are constantly encouraged and challenged not only to generate less wastewater, but to recycle, reuse or reclaim as much as possible. In the construction industry, a substantial amount of potable water is consumed annually. If the wastewater generated from some construction-related activities could be recycled and re-channelled as part of their consumption needs, a lot of savings would be realised and environmental sustainability practised. Unfortunately, due to a lack of performance-based industrial standards and emphasis, limited research data and inappropriate wastewater management practices, the use of recycled cement-based slurry water for making concrete has not been widespread.

Thus the aim of this paper is to define the limits and extent to which cement-based slurry water from the concrete batching plant can be recycled and totally reused for making concrete without the need for further treatment. The study focused on the effects of using such mixing water on the fresh and hardened properties of concrete with reference to acceptance criteria of existing standards. Results showed that concrete produced with slurry water was able to meet the performance criteria in terms of compressive strength, setting time and drying shrinkage when the S.G of the slurry water used was less than 1.03.

Keywords: *Ready-mix Concrete, Recycled, Slurry Water*

1.0 INTRODUCTION

From Public Utilities Board of Singapore (PUB) statistics, Singapore uses about 400 million m^3 of water annually, of which 45% is used by the industry [1]. From 1 July 2000, water-borne fees were again revised upwards, from 51 cents/m3 to 60 cents/ m^3 [2]. This is set to increase in the coming years. Thus it is only economically sensible to recycle and reuse scarce water as much as possible.

Currently, all the batching plants are using a substantial amount of potable water to batch concrete and in the construction industry, huge amounts of wastewater are generated everyday. This wastage can be generated as a result of water spillage, washing of concrete trucks, concrete drum mixers and batching plants. These wastes consist mainly of water, with a variable proportion of coarse and fine aggregates, cementitious powders and chemical admixtures. The number of concrete mixer trucks in Singapore is estimated to be 2100 units (in Year 2001) and with each using about 1 m^3 of potable water for the washing of mixer drums [3, 4], this means about 2100 m^3/day or 0.76 million m^3/year of wastewater is generated from the washouts. Assuming 1/3 of the trucks are currently not in service and an average 30% be recycled for batching purposes, this volume of water is more than sufficient to cater to all the concrete batching plants' daily production and operating needs. Currently, this water is drained into wash water pits or settling ponds where it may be recovered and used for washing the inside of concrete truck mixer drums; while the solids will be dredged and disposed into landfills. Literature review had shown that research data and relevant standards especially on the use of reclaimed water for making concrete are lacking. Coupled by the lack of cost-effective technological know-how to treat wastewater, inappropriate wastewater management and the thin profit margins caused by the economic downturn, recycling efforts have not been very successful.

As there are many different criteria by which water and wastewater quality can be tested, the literature review had enabled us to further confirm parameters for the analyses: Solids Content, Turbidity, pH, Chloride Content, Specific Gravity (S.G). For mortar or concrete, the performance requirements are setting time, workability or flow retention, compressive strength and drying shrinkage.

2.0 WASTEWATER MANAGEMENT PRACTICES

There are many ways of handling waste products generated from Ready Mix Concrete plants. Reclaimed aggregates have already been quite extensively used in many countries for concrete batching purposes [5]. Therefore, in this paper only the cement-based wastewater will be discussed. The common practices include:

1. Using concrete wash water pits or settling ponds at job sites or RMC plants for retaining disposed washout dumped directly from mixer trucks, of which the cementitious slurry is increasingly expensive to dispose off [5]
2. Using a series of settling ponds to recover washout that is relatively clean and free from solids for washing the inside of concrete truck mixer drums

3. Using CO_2 to neutralise alkaline cement-based wastewater (pH about 12) for reuse or for discharging into public sewers [6]
4. Using mechanical reclaimer units to recycle or reuse cement-based wastewater
5. Using chemical stabilising admixture systems or agents to temporarily stop the cement hydration process so that the wash water can be reused for making concrete. (eg MBT-study by Borger: concrete properties are not affected by use of stabilised wash water) [4]

Among these methods, most are either too costly to implement or require huge land space to be feasible. An alternative solution is to totally reuse the slurry water for concrete batching without the need for further treatment. This eliminates the labour, maintenance and equipment costs involved in the wastewater disposal as well as huge capital costs to acquire reclaimers and chemical stabilising admixture systems. At the same time zero-waste is achieved.

Although limited research data is available in this area, results so far have been encouraging [7]. A summary of the limited works done by past researchers is tabulated as shown in Appendix 1. More tests were carried out to supplement the findings of researchers so far and additional water quality parameters identified to study the effect of wash water on the fresh and hardened concrete properties and the extent to which recycled slurry water from the batching plant can be totally reused.

Major standard organisations such as CEN (European Committee for Standardization) have reevaluated the existing standard BS 3148:1980 -Water For Making Concrete-to produce a revised qualitative standard BS EN 1008: 2002 (to supersede BS 3148 on 1st December 2003) regarding the use of reclaimed water as mixing water for concrete. This standard dealt with various types of water including water recovered from processes in the concrete industry, water from underground sources, natural surface water, industrial wastewater, seawater and brackish water. In September 2004, ASTM also published two newly revised standards relating to mixing water-C1602-04 and C1603-04. C1602-04 dealt with the specification for mixing water used in the production of hydraulic cement concrete; while C1603-04 dealt with test method for measurement of solids in water. A summary of the major standards for mixing water for concrete is reproduced in Appendix 2.

3.0 METHODOLOGY

Water samples of different water qualities collected from typical concrete batching plants were used for cement and concrete testing to study the effects of slurry water on the cement setting time, water demand and fresh and hardened concrete properties. As for studies on the potential effect of their chemicals such as sulphate and chloride on cement hydration and pore structure, because their presence is only in traces and the normal engineering requirements for the use of recycled water do not call for such studies, they have not been conducted. However, the likely influence is not expected to be significant on the engineering properties of concrete. ASTM C94C/C94M classified these chemical tests as 'Optional' [8]. Such studies may be conducted in subsequent follow-up studies.

The samples were kept in tightly sealed 35-liter plastic containers until the day of sample casting. The parameters tested and defined for water quality were as shown in Table 1.

For simplicity of identification, the water samples were classified according to their turbidity, which give us information on the concentration of scattering particles in a medium (solids concentration), as shown in Table 2.

For concrete batching purposes, arrangement was made to ensure that the date of slurry water usage was within two days of its date of collection. To promote homogeneity, water in the sample containers was first agitated thoroughly before a sufficient amount required for sample casting was poured out into specified measuring cylinders. They were then stirred to keep the cement fines in suspension, before the samples were taken for S.G and turbidity measurements. As some of the cement particles settled rapidly, the S.G of the sample was read within 10 seconds, immediately after stirring. After that, they were poured into the concrete mixer drum

Table 1: Distribution of respondents

Parameters	Test Method
pH	Tested according to APHA standards methods
Total Suspended Solids (TSS)	Tested according to APHA, AWWA, WEF Standard Methods for Examination of Water and Wastewater Part 2130:1998
Turbidity	Measuredusing WP89–TPS 180–Degree Turbidity probe, according to APHA, AWWA, WEF Std Methods for Examination of Water and Wastewater Part 2130:1998
Specific Gravity (S.G.)	Measured using standard Hydrometer according to BS 1377:Part 2:1990

Table 2: Classification of mix water used for concrete cube casting

Classification	Type of Mixing Water
TW	Tap Water (Control)
SN	Slurry Water-supernatant
RW3	Slurry Water (Slight Concentrated–Turbidity < 1000 FTU)
RW4	Slurry Water (Medium Concentrated–Turbidity 1000 to 6000 FTU)
RW5	Slurry Water (Highly Concentrated–Turbidity >6000 FTU and S.G>1.02 based on *TSS Test)

**TSS test was used due to limitation of hydrometer beyond 1.03*

Table 3: Typical C35 concrete design mix per m³

Mix Ingredients	Mix Proportions
Cement (kg)	380
20mm Coarse Aggregate (kg)	1015
Sand (kg)	705
Water (kg)	205
Water/Cement Ratio (W/C) (excluding admixture amount)	0.539
Super-plasticisers (*l*/100kg binder)	0.7
Target Slump (mm)	150 ± 25

Table 4: Cement and concrete test

Type of Cement OPC	**Cement Properties** Setting time of cement and water demand (via the Standard Consistence Test)	**Test Details** Tested according to SS397: PT3: 1997; cross-reference to EN 196: 1995
Type of Concrete	**Concrete Properties**	**Test Details**
Fresh properties	Workability retention	Tested according to SS 78:PT A2: 1987
Hardened properties	Concrete compressive strength	100mm cubes were used and tested according to SS78: PartA16: 1987 (Compressive Machine–ToniPact2 (3000KM) operated at 0.5MPa/sec)
	Drying shrinkage	Tested according to ASTM C157-80; cross-reference to SS 78: PT B6: 1992 (Recommendations for Determination of Strain in Concrete

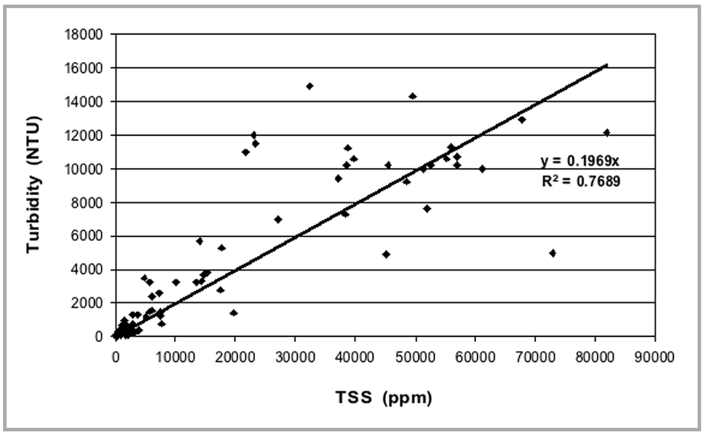

Figure 1: Correlation between turbidity and total suspended solids of slurry water

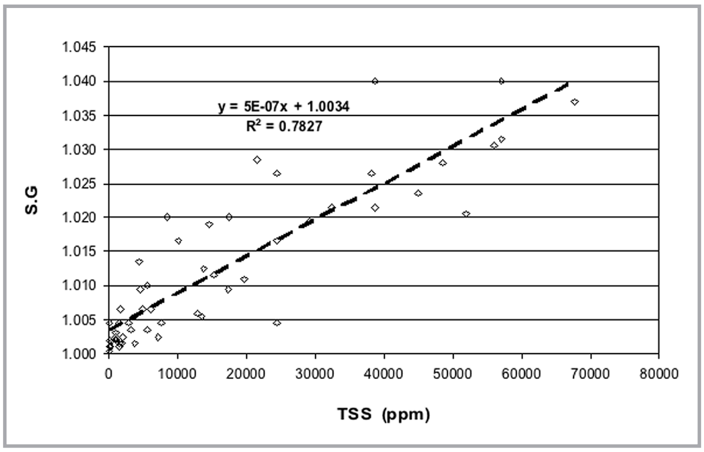

Figure 2: Correlation between S.G and total suspended solids of slurry water

to be mixed together with the rest of the ingredients. A typical mix design using Grade 35P concrete, slump= 150±25mm was chosen as this is the most commonly used grade in the construction industry. The mix design is as shown in Table 3. For the slurry water mixes, weight of mix water includes its cement particles. A minimum of 2 batches of concrete (each set comprising 3 nos. 100mm cubes for each of the test ages-1, 3, 7, 28 and 56 days) were cast for each type of water used and the average of the 2 batches used to analyse the concrete compressive strength. At least 30 Liters of fresh concrete was prepared for each batch and compaction was carried out in two layers [9] with the help of a vibrating table.

For cement, the effect of water quality on setting time and water demand (via the Standard Consistence Test) of the cement paste were studied. The performance of these parameters will directly impact the fresh and hardened properties of concrete.

For concrete, the fresh and hardened properties were studied. As for fresh property, the workability of the concrete over time was monitored. This is especially important for applications at the construction site where the ease of placing concrete is a concern. As for hardened properties, the compressive strength and the drying shrinkage were studied.

The properties studied and test methods used are as shown in Table 4.

4.0 RESULTS AND DISCUSSION
4.1. WATER QUALITY

Relationships were established using linear regression analysis, between the S.G. and the solid content of the water samples over a turbidity range, representing those of a typical batching plant where the water samples were collected and used for the whole study. The data collected was plotted as shown in Figures 1 and 2. This enabled the classification and understanding of the water types whenever any of the above three information is not readily available. With this relationship the TSS could be quickly estimated even before carrying out the actual test, by just taking turbidity or S.G. measurements because these can be obtained very quickly, unlike the TSS test which takes more than one day to perform.

The pH of the water samples was typically between the values of 12.3 to 13.3, regardless of the turbidity or solid content (See Figure 3).

4.2. CEMENT PROPERTIES
4.2.1. SETTING TIME AND WATER DEMAND

A study was done to examine the effect of cement-based slurry water on the setting time of cement paste. The mortar or cement paste test samples were prepared according to SS 397: 1997. Except for samples with S.G of 1.03 and above, the rest of the samples were able to achieve a standard consistence of 6±1mm based on a water-cement ratio of 0.276. As shown in Figure 4, as the SG of the slurry water increased, the setting time decreased as the S.G approached 1.05. Another observation was that for the case when the slurry water of S.G 1.03 and above was used in the mix, there was an additional of about 20% of tap water required to produce the paste of similar consistence, as compared to the control mix. However despite this increase in water content, not only did the setting time not prolong, there was a sharp fall in setting time; i.e. the cement paste set faster. Although the specifications allow for up to 1½ hours

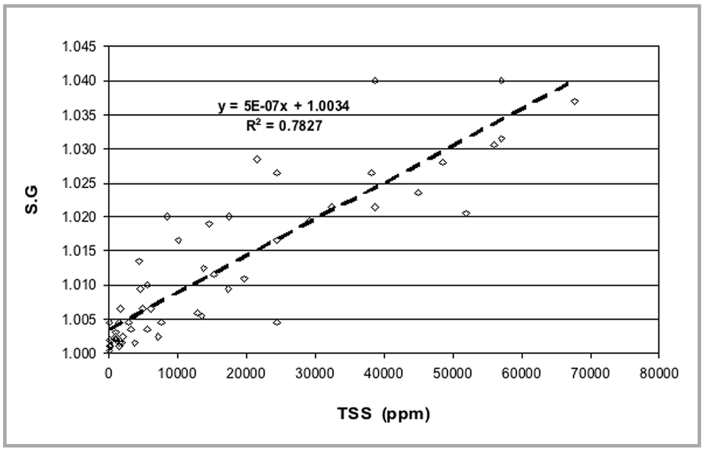

Figure 3: Graph of pH against total supended solids

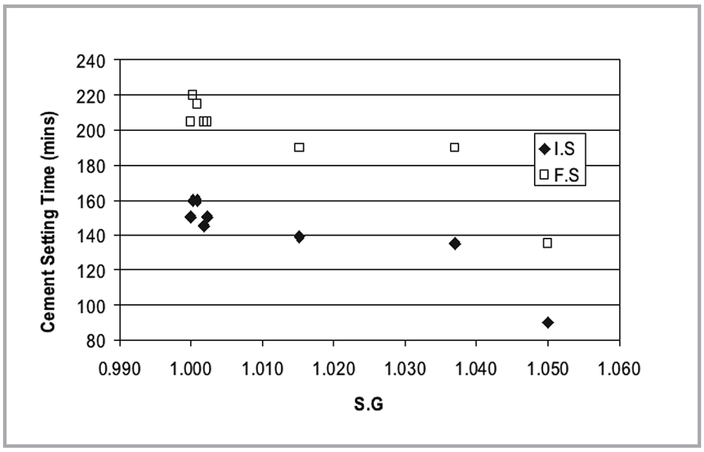

Figure 4: Effect of slurry water on setting time of cement

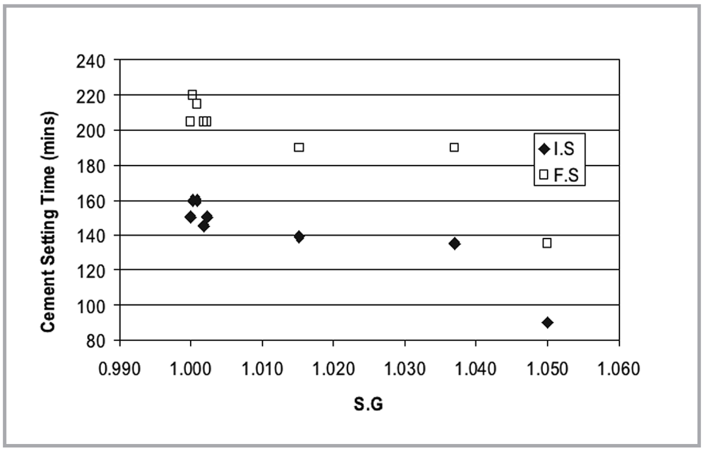

Figure 5: Effect of turbidity on water demand for standard consistence

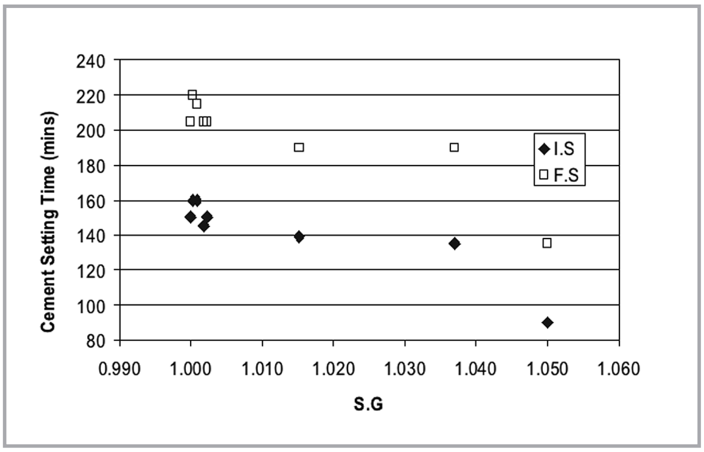

Figure 6: Effect of alkalinity (in terms of NaOH Concentration) on "WaterDemand" of cement paste

difference between the control and the slurry water mix, the expected increased in water demand and workability loss in concrete due to the use of concentrated slurry water were undesirable for concrete end-users. Thus, appropriate measures should be set up on RMC plants to control the S.G to preferably below 1.03 to minimise the need for additional action during usage.

To further study the cause for the increased water demand of the cement paste, the following two tests were done based on the standard consistence test of OPC cement.

For the first test, as the concentration of slurry water used was varied, the amount of mix water to obtain standard consistence of 6±1mm was noted. Results as shown in Figure 5 indicated that as the turbidity of the slurry water increased, a greater volume of slurry water was required to achieve the same consistence (From Figure 2, Turbidity of 14,000NTU corresponds to an S.G of about 1.02). A higher volume of solids in the cement paste leads to a higher degree of stiffness and hence more water is needed to bring it back to standard consistence.

A second test was carried out in a similar way except that a solution of N_aOH was used instead of slurry water. The purpose of this test was to find out the effect of the concentration of OH- ions in the slurry water- contributed by cement particles- on the water demand of the mix. The concentration of mix water was varied by adding N_aOH pellets to the de-ionised water. Apparently, as shown in Figure 6, alkalinity as contributed by N_aOH, directly affects the "mix water demand" of OPC. As the concentration of N_aOH ions increased, the "mix water demand" to achieve standard consistence also increased. Thus it can be concluded that the amount of suspended cement particles (thereby resulting in a physical effect) and the degree of alkalinity directly affect the setting time characteristics and the water demand of the cement paste, which thereby could lead to workability loss of the overall concrete mix. It would be expected that concrete using more concentrated slurry water would experience faster workability loss thereby requiring additional amount of mixing water or admixtures in order to achieve or maintain the same workability.

4.3. FRESH CONCRETE PROPERTIES

4.3.1. WORKABILITY RETENTION:

A typical design mix as shown in Table 5 was used to study the effects of slurry water concentration on the workability retention of the concrete. 42 Liters of fresh concrete was prepared for each batch and the concrete slump was monitored over one and a half hours. After mixing, the fresh concrete was left in the drum mixer and a plastic cover placed over the opening of the mixer to minimize moisture loss from the concrete to the atmosphere.

5 mins before the specified time at which slump was to be measured, the mixer was turned on and fresh concrete remixed for 5 mins. Immediately after that, temperature was taken and a fresh sample scooped for slump measurement. The used sample was discarded after the slump test was done.

The results in Figure 7 show that as the S.G of the mix water used for concrete increased (indicating more suspended cement particles present), the rate of loss of workability also increased over time (workability was reduced by as much as 70% after 1hr for the mix using slurry water of S.G of 1.03 as compared to 40%

Table 5: Typical C35 concrete design mix used for workability retention test

Mix Ingredients	Mix Proportions
Cement + Binder (if any) (kg/m^3)	380
20mm Coarse Aggregate (kg/m^3)	1015
Sand (kg/m^3)	705
Water (kg/m^3)	205
Water/Cement Ratio (W/C) (excluding admixture amount)	0.54
Super-plasticisers (*l*/100kg binder)	0.3
Retarded (*l*/100kg binder)	0.3
Target Slump (mm)	175 ± 25
Concrete Temperature (ºC)	30.0
Typical Ambient Temperature (ºC)	30.0

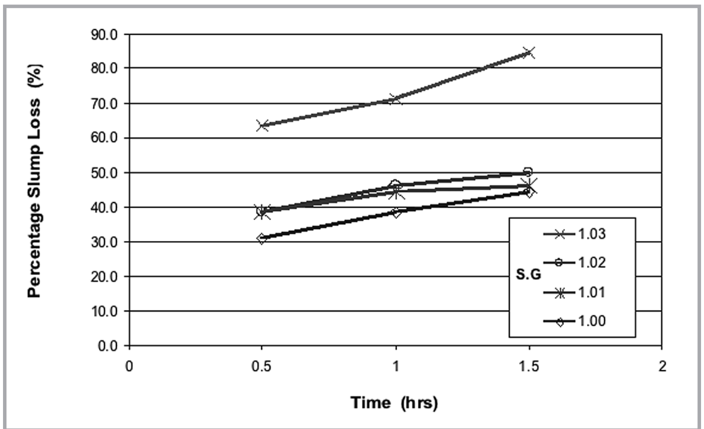

Figure 7: Workability loss of OPC concrete over time

for the mix using slurry water of S.G of 1.00). It was also observed for the mix using slurry water of S.G=1.03, extra water and super-plasticizer were added to achieve the same initial workability. This worked out to be an increase of about 12% of fresh water (water/cement ratio increased from 0.54 to 0.60) and twice the amount of super-plasticizer used.

4.0 HARDENED CONCRETE PROPERTIES

4.4.1. CONCRETE COMPRESSIVE STRENGTH:

According to most standards (Appendix 2) which used "90% of the control strength at 7 days or 28 days" as the deciding factor for the acceptance of the particular mixing water, results in Table 6 indicated that all the concrete satisfy this criterion. For concrete cast using concentrated slurry water (RW5), despite additional fresh water and admixture added to the mixes to achieve similar slumps, the 7th to 56th-day compressive strengths were able to match those of the control mix. Thus as reported [4], apart from having some form of control so as to ensure that the setting time and strength requirements are met, results in Figure 8 and Table 6 show that statistically there were not significant difference between the compressive strengths of concrete cast using slurry water or tap water [10]. This could be due to the fact that the cement fines present in the slurry water are still undergoing some form of hydration. Neville [11] remarked that since the solids present in the wash water are proper concrete ingredients, cement-based wastewater could be a bolster to concrete properties in certain aspects. Hurd [12] reported similar findings of concrete trial batches on the site made with reclaimed cement slurry. Another possible reason may be that the partially hydrated cement fines could help improve the packing against the surface of the aggregates, similar to pozzolans like silica fume, thereby reducing voids and enhancing the overall concrete matrix. However, as the concentration of slurry water used increased, the advantage over using tap-water decreased as well. This can be observed from the decreasing strength ratios over the control at 28 and 56 days corresponding to mix water from TW to RW4 respectively. Similar findings were also observed by Lobo and Mullings [10] who reasoned that the reduction in concrete strength had been due to the increased water content arising from additional tap water used for the concrete mix with slurry water of higher solid content.

4.4.2. CONCRETE SHRINKAGE:

Concrete was cast in the laboratory using tap water as the control and mix water of type RW5. Mix design was similar to Table 3, except the admixture dosage adjusted to produce a slump of 90 ±15 according to ASTM C157. The slurry water used was of an S.G of 1.02 and TSS of 29800 ppm (or 2.9% by weight; ASTM allowed up to 5% by weight). As shown in Figure 9, it can be observed that there was no significant effect of slurry water on drying shrinkage. The concrete cast using slurry water was well within the typical drying shrinkage range of 450 x 10-6 to 800 x 10-6. Any increase in the drying shrinkage may occur if increased water is added to the mix as a result of the suspended cement particles. However because the effective water/cement ratio -taking into account of the suspended cement fines-may not increase much, the overall increase in shrinkage is therefore reduced. This is similar to the findings of Meininger [13]. In 1972, he studied the effects of recycled wash water on some concrete properties such as drying shrinkage, water requirement

Table 6: Test results of all C35 concrete mix

Mix Water	Avg. Slump (mm)	Water/Cement Ratio, W/C	Admixture dosage (l/100kg cement)	% Of Ctrl Strength			Standard Error of The Mean (MPa)	
				7d	28d	56d	1d	3d
TW	175	0.54	0.7	100	100	100	1.88	0.89
SN	190	0.54	0.7	96	100	104	1.15	0.42
RW3	190	0.54	0.7	101	100	107	0.25	0.77
RW4	180	0.54	0.7	102	97	102	0.60	0.64
RW5	165	*0.54–0.69	*0.9–1.1	101	100	100	1.28	1.05

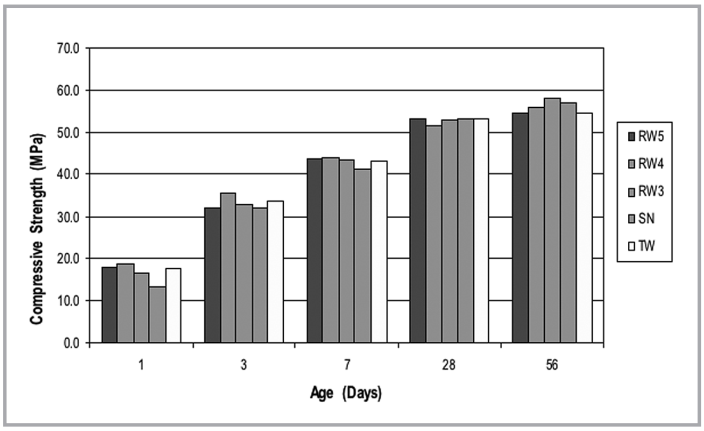

Figure 8: Compressive strength data of all C35 concrete mixes

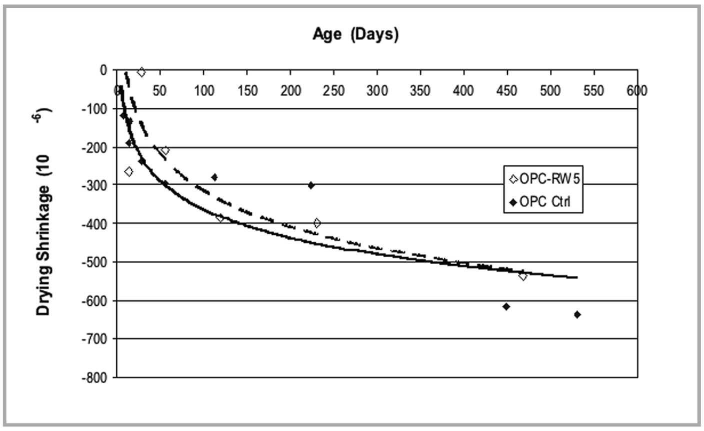

Figure 9: Drying shrinkage of OPC concrete

and compressive strength. He based his study on concrete batches containing 279 kg/m3 (470 lb/yard3) and 392 kg/m3 (660 lb/yard3) of OPC cement. For each batch, 28 litres (one cubic foot) of concrete was prepared using a laboratory concrete mixer. The concrete slump was maintained at about 100mm and the air content at 5%. Data was compared between concrete batches using tap water, clarified wash water (TDS about 3000ppm) and slurry water of two different volumes as shown in Figure 10 (TS about 100,000ppm or 10% by weight). He demonstrated that cement-based wastewater had not much effect ($\leq$ 10% compared to tap water batch) on the concrete drying shrinkage when less than 49.5 l/m3 was used.

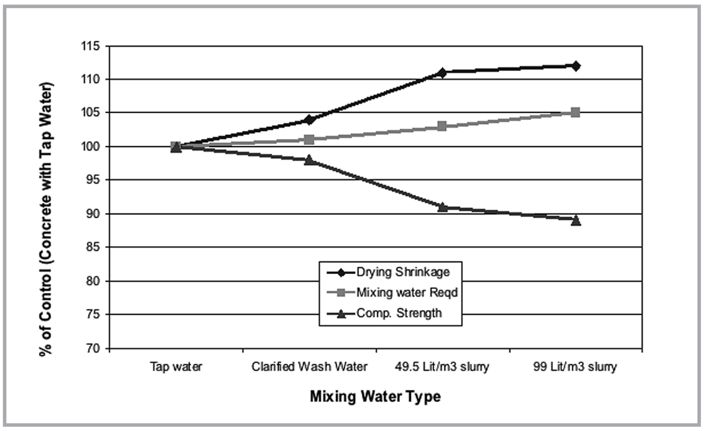

Figure 10. Study of concrete strength, mixing water requirement and compressive strength

4.3 ICT INFRASTRUCTURE AVAILABILITY AND ACCESSIBILITY

Tables 4 and 5 present the respondents' feedback on ICT infrastructure availability and accessibility inside and outside campus. Feedbacks were obtained on accessibility of ICT infrastructure inside and outside campus in terms of computer availability, internet availability and internet speed. More than half of the respondents agree that ICT infrastructure is accessible inside and outside campus. They are also satisfied with the internet speed inside and outside campus. Higher feedback (71.8%) on accessibility of ICT infrastructure outside campus was observed as compared to inside campus (56.1%). In general, 63.9% of the respondents agree that ICT infrastructure is accessible and available.

5. CONCLUDING REMARKS

Although most of the existing major current standards do not clearly specify the use of reclaimed water from RMC plants for batching of concrete, they serve as a major stepping stone for performance-based specifications using other water resources as alternatives to potable water for batching concrete. The publication of a much qualitative and detailed new standard BS-EN 1008: 2002 to replace the existing BS 3148:1980-Water for Making Concrete-is an excellent example.

The present study showed that water recovered from processes in the concrete batching industry can be totally reused for concrete batching as long as it can be established that the performance criteria of cement setting time, compressive strength, workability and durability requirements were not compromised. Our limited research data showed that concrete batched using cement-based wastewater can perform satisfactorily.

For mortar paste, results showed that the setting time of the cement paste is within the performance specifications when the S.G of slurry water used was less than 1.03. However, it was also observed that the water demand increased significantly when the S.G was beyond 1.02 and the amount of tap water required to produce a paste of similar consistence increased by 20% when the S.G reached 1.04.

For concrete, results showed that the percentage slump loss for fresh concrete produced using slurry water of S.G up to 1.02 was similar to the control. Workability was reduced by as much as 70% after 1hr when slurry water of S.G of 1.03 was used. In terms of compressive strength of hardened concrete, concrete produced using slurry water of S.G up to 1.02 was able to meet the specification requirement of 90% of the control strength at 7 and 28 days. In terms of drying shrinkage, results also showed that there was no significant difference in shrinkage performance between concrete produced using tap water with that using slurry water of S.G of 1.02 and TSS of 2.9% by weight.

Since it was also shown that increased slurry concentration, especially when S.G was beyond 1.03, resulted in an increase in water demand and to a certain extent, difficulty in controlling the water content and admixture dosage, careful adjustments to the mix design have to be made to ensure that workability and cement setting time of the concrete mix are not affected. Cement replacement with pozzolanic materials could be another area to look into if the concrete compressive strength and drying shrinkage are able to meet the performance requirements. For a more complete understanding of the performance behaviour of such concrete mixes, different cement types such as slag cement and Silica Fume (SF) as well as the effect of cement-based slurry water on different grades of concrete would be incorporated in future studies.

As such, recycled slurry water should not be regarded as waste but as another alternative source of raw material or ingredient for concrete. However, for this to be accepted into practice, more have to be done to educate and change the mindset of the construction industry players, and a change in emphasis with regards to waste management [5]. Only then will the use of reclaimed materials become more widespread and concrete making become sustainable.

6. ACKNOWLEDGEMENT:

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PROFILE

LOW GIAU LEONG

Mr Low Giau Leong has been working as a Research Engineer in the field of Concrete Technology for the past 10 years. He has presented and published technical papers in international conferences and prestigious engineering journals respectively. His recent paper titled "Potential Benefits of Recycling Slurry Water and Concrete Waste" published in the IES (Institute of Engineer, Singapore) journal was highly commended by the IES editorial board.

Appendix 1: Work of past researchers

Researcher	Type of Tests	Limitation	Conclusion	Reference	Remarks
Ullmann, G.R. [14]	1) Concrete compressive strength 150 by 300mm cylinders 2) Sample wash water used contained about 4600ppm of TS and 50-300ppm of SS	Only 7-day data	No statistically significant differences between the compressive strength of wash water batches and tap water batches	Re-use of Wash Water as Mixing Water. National Ready-Mixed Concrete Association, Technical Information Letter No. 298, Silver Spring, MD, March 1973, p. 4	
Meininger, R.C. [13]	1) Drying shrinkage, water requirement and compressive strength of concrete 2) Clarified wash water (TDS about 3000ppm) and slurry water (TS about 100,000ppm).	No tests done concerning slump loss and setting characteristics of concrete	Not much effect ($\leq$ 10% compared to tap water batch) on drying shrinkage and compressive strength of concrete when <49.5 l/m3 of wash water was used	Recycling Mixer Wash Water-Its Effect on RMC, NRMCA, Technical Information Letter No. 298, Silver Spring, MD, March 1973, p. 7.	
Abrams, D [15]	1) Strength, time of set, flow of concrete 2) Used 68 different water samples-seawater, mine & mineral waters, sewage water and water containing salt solutions	Those cements used were substantially different in chemical composition, fineness and setting characteristics from today's	Mix water is generally acceptable if it contains <6000ppm of TDS, <1% SO4, alkali water with max of 0.15%Na2SO4 or NaCl and 28d strength not affected (based on min strength ratio of 85% of Control)	Tests of Impure Waters for Mixing Concrete), published by ACI in 1924	
Borger, J, Carrasquillo, R.L. and Fowler, D.W [16]	1) Mortar cube strength, mortar bar expansion, mortar flow, setting time 2) Wash water of ages ranging from 1 to 48 hours	No tests done on concrete; no mention of other water quality parameters other than age of wash water.	1) Wash water of ages up to 8 hours can be successfully used in producing fresh concrete with the resulting concrete strength equal or higher than that of concrete made with tap water 2) Use of wash water may increase concrete resistance to sulphate attack 3) Mortar flow not affected for cement pastes using wash water of age after 8 hrs 4) Although wash water of age 24hrs set faster, all setting times were within 20% of control	Use of Recycled Wash Water and Returned Plastic Concrete in the Production of Fresh Concrete, Advanced Cement Based Materials, Nov. 1994 l(6) pp. 267-274.	Also performed test using stabilising admixture
Hurd, M.K [12]	1) Compressive strength (cylinder), drying shrinkage, slump of OPC and FA Concrete 2) Slurry water (S.G=1.03) and clarified slurry	Slump of concrete using slurry water too low (50mm)	7&28d compressive strength increased as more slurry used; while shrinkage and slump decreased	What happens to leftover ready mix, Concrete Construction Vol 31, No.3, 1986	Results of trial batches made with reclaimed cement slurry using screw reclaimer unit

Appendix 2: Current standards on mixing water for concrete

Standards	Compressive strength	Setting Time	Impurities	Others
The American Standard [2]ASTM C94-98c- Standard Specification for RMC	7d mortar strength made with test water ≥ 90% of Control (distilled water)	< 1 hour quicker or < 1½ hour later than Control (distilled water)	• Cl^- 500 ppm • SO_4^{2-} 3000 ppm • Alkalis as Na_2O equivalent 600 ppm • Total solids 50,000 ppm (AASHTO T26)	[1]Portland Cement Association (PCA) permits the use of wash water for mixing concrete with a tolerance of up to 50,000 ppm of TS
British Standard, Appendix A to BS 3148:1980- Water For Making Concrete	28d average compressive strength of the concrete test cubes or specimens are > 90% of the control, based on BS 4550: Part 3/3.4	Control & test specimen don't differ by > 30 min	• Combined total of common ions- Ca^{2+} + Mg^{2+}, Na^+, K^+, HCO_3^-, SO_4^{2-}, Cl^-, NO_3^- and less frequently CO_3^{2-} ≤ 2000 ppm • Cl^- ≤ 500 ppm • SO_4^{2-} ≤ 1000 ppm (of Sulphur Trioxide) • Combined total of HCO_3-and CO_3^{2-} ≤ 100 ppm (to prevent setting time problems)	–
[3]Japanese Standard- Annex 9 to JIS A-5308-1989- Water to Serve for Mixing RMC	7d and 28d mortar strength ≥ 90% of Control mix according to JIS R 5201 (similar to SS 397 or EN 196)	Initial Set ≤ 30 mins Final Set ≤ 60 mins of Control	Cl^- ≤ 200 ppm	Sludge Solid Content ≤ 3% of weight of cement in concrete. (Defined as the substance obtained by drying the sludge at 105-110°C)
[4]German Guideline for the Manufacture of Concrete Using Residual Water, Residual Concrete and Residual Mortar (1995)	Not clear; applies only to water with "exposed aggregate concrete additives".	Not clear; applies only to water with "exposed aggregate concrete additives".	Cl^- ≤ 4500 ppm	Fines in the residual water ≤ 1% by mass of total aggregates by controlling density of the homogenised water to ≤ 1070 kg/m^3
British Standard BS-EN 1008: 2002- Mixing Water for Concrete- Specification for sampling, testing and assessing the suitability of water, including water recovered from processes in the concrete industry, as mixing water for concrete	7d average compressive strength of the concrete or mortar test specimens are ≥90% of the control.	Control & test specimen don't differ by > 25% Initial Set min. of 1 hr; Final Set max. of 12 hrs	• Cl^- 500 to 4500 ppm (depending on concrete type) • SO_4^{2-} <2000 ppm • Alkalis as Na_2O equivalent < 1500 ppm • Sugars ≤ 100ppm • P_2O_5 ≤ 100ppm • NO_3^- ≤ 100ppm • Pb_2+ ≤ 100ppm • Zn_2+ ≤ 100ppm	• pH ≥ 4 • Fines in the residual water ≤ 1% by mass of total aggregates • Assume negligible solids if density of the homogenised water to ≤ 1.01 kg/l • If density of the homogenised water to > 1.01 kg/l, the amount of solid material and water shall be taken into account in the concrete mix design, up to a max of 1.15 kg/l.

Notes:

1. PCA [17]: "…when cement fines are returned to the concrete in reused wash water, 40,000 to 50,000 ppm can be tolerated…"
2. ASTM 1602-04 has the same specifications for Compressive Strength, Setting Time and Impurities as C94-98c except it includes testing frequency relating to the type and density of mixing water used for concrete production.
3. This standard has provisions specifically for "recycled water", defined as "sludge water and supernatant water obtained by treating the wastewater used for washing the concrete adhering to the transportation unit, mixer, hopper and the like of the plant and the returned concrete…"
4. Though not a standard, this guideline permits the use of recycled concrete (termed Residual Concrete) and recycled water (termed Residual Water). However, usage is limited to certain groups of concrete and "can only be used in a location where the original materials were added.