Recycled Water in Ready Mixed Concrete Operations

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Introduction

Process and storm water management at ready mixed concrete operations is a growing issue for the industry. As regulations and enforcement governing discharge from plant sites evolve, the option of reusing these sources of water will become a necessity, thus moving the industry toward zero-discharge facilities. It is important that positive terminology is used in describing the source of water and that the customer is informed of its use in a positive manner. In this article, the term *recycled* water will be used for mixer wash water, storm water or *gray water*. Concrete producers face the dichotomy whereby their customers are generally resistant to allowing the use of recycled water in their concrete while producers are forced to move in that direction because it's the environmentally responsible thing to do and there is a cost, sometimes unquantified, associated with its disposal. It's true that when moving toward zero discharge the producer has to make an investment in equipment, people and training, but in the relatively short term this investment will be recovered in a successful application. Producers who are leaders in environmental management initiatives have demonstrated this fact, without including cost of compliance and enforcement penalties.

The initial need for using recycled water in concrete came from California in the early 1970s due to evolving environmental regulations. NRMCA members collected data of water from typical sedimentation pits and the effects on concrete when this water was used as mixing water. Based on these evaluations, criteria were developed and in 1978, ASTM C 94, *Specification for Ready Mixed Concrete* was revised to permit the use of wash water as mixing water in concrete. State highway agencies for the most part still do not allow its use or if they do, their requirements are more conservative than C 94. The criteria or requirements for wash water in C 94 have not changed since they were originally incorporated in the standard. In the '70s, producers in California were looking for some relief to use some of their recycled water and reduce the quality of effluent from their production facilities and were not really striving for zero-discharge facilities. They retained the problem of cleaning out debris from sedimentation pits, handling it and disposing it in landfills. The industry's needs have changed and so should the standard to allow an increased use of wash water while protecting the consumer. Current technology better facilitates the collection of process and storm water with the associated solids, water treatment and automated measurement and batching.

ASTM C 94 has criteria for wash water that can be invoked at the option of the purchaser. While these are optional requirements, the uninitiated producer, relative to use of recycled water, should try to remain within these limits for any structural concrete or slab application. The requirements apply to the total mixing water in concrete and are essentially limits on the water chemistry for alkalis, sulfates and chlorides for reasons related to concrete durability. The other limiting criterion is the amount of total solids, which is limited to 50,000 parts per million (ppm) or 5 percent by mass of the total mixing water. This amounts to about 15 pounds of solids in 1 cubic yard of a typical concrete mixture. Does it matter if the solids added to the mix from recycled water exceed this limit? It depends on the concrete ingredients, characteristics of the recycled water, time of year and everything else that one could think of. The important issue is that the concrete meets the requirements of the job specification and the purchaser does not observe, or perceive, any diminished quality or batch-to-batch variation. It takes just one bad story to generate a negative perception and essentially kill any initiative to move forward on this important issue. ASTM committees have been deliberating for the last several years on revising the provisions for mixing water, and while the consensus process can be frustrating, it hopefully achieves a better standard that satisfies the producers and their customer.

This is a brief report of portions of

the research conducted at the NRMCA Alfred H. Smith Research Laboratory to answer some questions on reusing recycled water in concrete. The study was intended to simulate a practical situation where a producer has an environmental management system that includes a returned concrete reclaimer that generates recycled water slurry. The slurry is kept agitated in tanks and is used in a controlled manner as a portion or all of the batch water in concrete mixtures. An important point to note is that the characteristics of the slurry in this tank will be quite variable as water is removed and added to it from truck wash out during any production day. Figure 1 illustrates the variation of solids content with time from an actual recycled water holding tank. Adding this variable product without control is sure to cause batch-to-batch variations of concrete properties. It is imperative that the producer has a system in place that recognizes this variability and adjusts for it so that the customer does not see differences in concrete performance properties in subsequent loads of concrete.

The first phase of the study also includes a situation where a producer might use relatively clear water from a sedimentation pit after the solids have settled out. The reader is advised that the data and trends are very specific to the materials and conditions used in this study.

Procedures

The first phase of the NRMCA study was to quantify the basic effects of using recycled water on fresh and hardened concrete properties. A typical air-entrained portland cement concrete mix design without any admixtures was selected using stock materials from the research laboratory. The design mixture characteristics and proportions are provided in Table 1. The experimental variables used in Phase I of the study are listed in Table 2. Note that the solids contents of the recycled water, at 30 and 60 lb/yd^3, are at levels that are double and four times the current limit for solids in ASTM C 94. This series was replicated three times for a total of 48 concrete batches.

Table 1 – Design Proportions and Characteristics of Concrete

Portland Cement	600 lb/cu.yd
Mixing Water	300 lb/cu.yd.
Natural Sand	1,100 lb/cu.yd.
Limestone coarse aggregate, max. size 1 inch	1,800 lb/cu.yd.
Air content	4 to 6%
Slump	3 to 5 inches

Table 2 – Experimental variables in Phase I of the Study

Water	• Tap water (Control) • Clarified recycled water • Recycled water at 30 lb solids per cubic yard • Recycled water at 60 lb solids per cubic yard
Age of slurry	• 4 ± 1 hour • 1 day • 3 days • 9 days

Recycled water

A concrete mixture was mixed in a 1 cubic foot mixer, tempered with water to a very high slump and water slurry was decanted over a 150 µm (No. 100 sieve). The water slurry passing the sieve was captured in a five-gallon bucket and represented the wash water from the mixer. This wash water was kept agitated using a motorized paddle to keep the solids in suspension for the duration of the testing. The water slurry solids content varied from about 40 percent solids by mass to about 25 percent toward the end of the series at nine days as it was periodically diluted to maintain a sufficient volume for the tests. A portion of the recycled water was allowed to stand for about two hours and clear water was siphoned off the top to represent clarified recycled water.

Figure 2 – Laboratory Set-up to Maintain Agitated Recycled Water Slurry

When concrete mixtures were made, samples of the recycled water slurry were obtained and the density was measured by determining the mass of water in a container of known volume. The water slurry sample was then dried to constant mass in a microwave oven to determine the percentage of solids by mass. At least two samples of recycled water were tested in this manner on each day and the average was used to establish the water slurry density and solids content. Solids were filtered out from the water slurry to measure the loss on ignition and specific gravity. This information is useful to quantify the progressing degree of hydration of cement in these solids. Loss on ignition is the loss in mass when an oven-dried sample is heated to 750°C. A portion of the solids was dissolved in acid to determine the insoluble residue. Since cementitious materials dissolve in acid, the insoluble residue represents the fine

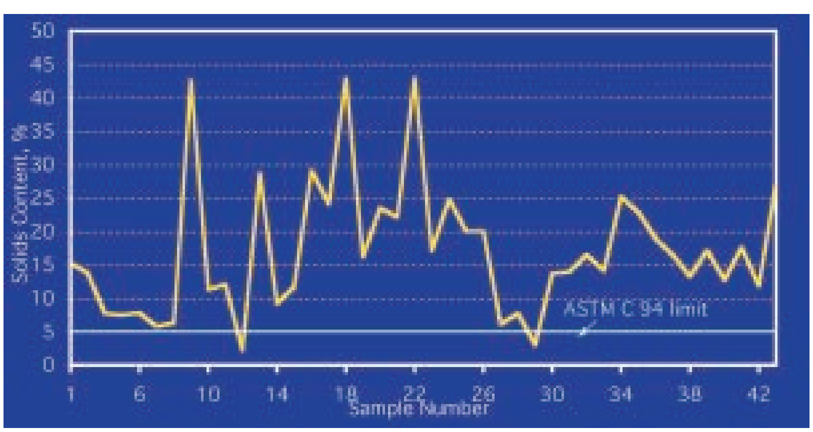

Figure 1 – Variation in Solids Content in Recycled Water. Courtesy: M.D.A. Thomas, U of New Brunswick

sand fraction, which was about 10 percent of the mass of the dry solids.

Concrete batches

On each day, four concrete batches with the four types of mixing water listed in the first row of Table 2 were mixed. The concrete batches were nominally 0.75 cubic foot size batches in a 1 cubic foot revolving drum laboratory mixer. Standard ASTM procedures were used to mix the concrete batches and to conduct the fresh and hardened concrete tests. To achieve the target solids contents in the mixing water, recycled water slurry with known solids content was diluted with a calculated quantity of tap water used. Clarified recycled water was used at 100 percent of the added water in those respective batches.

Testing

Concrete mixtures were mixed to a target slump of 5 inches. After the initial mixing for eight minutes, slump and density were measured. Air content (gravimetric) was calculated from the measured density. Concrete from these tests was returned to the mixer. The mixer was covered to prevent evaporation and the concrete was periodically agitated and retempered with water as necessary to retain the target five-inch slump until approximately 30 minutes after the ingredients were batched in the mixer. This was done to simulate a 30-minute delivery time of ready mixed concrete and what might typically occur in practice. It is important to note that the batches were adjusted to achieve a similar target slump and not to a constant water-cement ratio.

After the 30-minute period, the concrete was discharged into a sample container and the mass of discharged concrete was determined so that precise mixture proportions could be calculated.

Fresh concrete tests included slump, temperature and density. Initial setting time was measured by two methods. The first method was in accordance with ASTM C 403 by the penetration resistance on a wet-sieved mortar. On several batches, the heat evolution (or heat signature) of the concrete was measured to estimate the initial setting time. A 4 x 8-inch cast cylinder was placed in an insulated 5-gallon container. A thermocouple embedded in the center of the cylinder was connected to a data logger to obtain the rate of heat evolution of the concrete. A correlation was established between initial set from the C 403 method and a point on the heat signature curve. After some confidence was achieved with this correlation, set time was measured using the heat signature for the batches in the third round of replication.

Specimens for hardened concrete tests from each batch included four 4 x 8-inch cylindrical specimens for compressive strength determination at seven and 28 days; one 4 x 14-inch cylinder with embedded gage studs for drying shrinkage measurement; one 4 x 14-inch cylinder for freeze-thaw testing; and one 4 x 8-inch cylinder for rapid chloride permeability testing.

Results and Discussion

The results of three replicate batches for the same experimental condition were very reproducible and within typical batch-to-batch variation quantified for procedures used at the research laboratory. The average value of three replicates of each condition is reported in many cases in the subsequent discussion. Detailed data on calculated concrete mixture proportions, slump, temperature, air content and hardened concrete test results are available and are not reported here for the sake of brevity. Concrete temperatures were in the range of 70 to 75ºF and air contents and slumps were at target levels within the acceptable tolerances.

Water Demand

Figure 3 illustrates the calculated mixing water content for all the batches at 30 minutes to achieve and maintain the target five-inch slump. The chart indicates that the mixing water content for the nine control batches was quite similar and averaged about 308 lb/yd^3. The chart also indicates the effects of using clarified recycled water and recycled water slurry to incorporate 30 and 60 lb/ solids per yd^3. The recycled water slurry was used at ages of four hours, one day, three days and nine days as indicated in Table 2.

When clarified water was used, the mixing water content was essentially similar to the control batches.

When recycled water slurries were incorporated to achieve the target solids content of 30 and 60 pounds, the mixing water demand to achieve and maintain the target slump increased. The increase is proportional to the amount of solids and the age of the recycled water slurry. With four-hour old slurries, the increase in mixing water was minimal, but as the slurry is aged past one day, a higher water demand is noticeable.

By monitoring the loss on ignition and specific gravity of the slurry solids, it was observed that the continued cement hydration with time causes the solids to get finer and of a lower specific gravity. These finer or *fluffier*

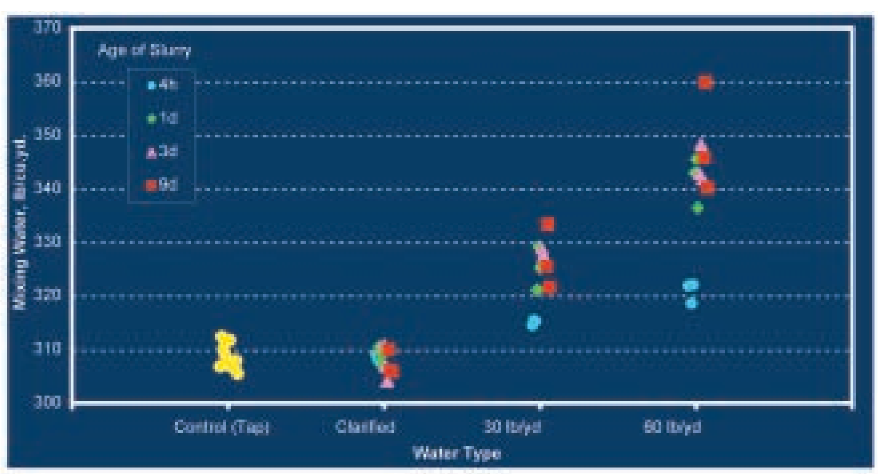

Figure 3 – Mixing Water Content for Individual Concrete Batches

Recycled Water

at the University of Toronto

In 1996, ready mixed concrete producers in Ontario, Canada, commissioned the University of Toronto to conduct a study, similar to the NRMCA study, on the effects of wash water in concrete. The important differences in the U. of Toronto study were that wash water slurries were used from concrete production facilities and laboratory mixtures were prepared to a constant water cement ratio. Results from this study and several field study cases of external slabs on grades placed in 1996 were reported to the Canadian Standards Association (CSA) in 1998 (personal communication, Dr. M.D.A. Thomas, currently at the University of New Brunswick).

The experimental variables in this study were:

Table 1: Experimental Variables

	Air entrained	Non-air entrained
Cement content, kg/m^3 (lb/cu.yd.)	375 (630)	250 (420)
w/cm ratio	0.40	0.62
Solids from recycled water, kg/m^3 (lb/cu.yd.)	• 0 (control) • 10 (17) • 20 (34) • 40 (67)	• 0 (control) • 20 (34) • 40 (67)

The study included an evaluation on a wide range of concrete properties. Selected data are reported here.

The study also measured the chemistry of the recycled water and the alkalies, chlorides and sulfates were significantly below the limiting criteria in ASTM C 94. Increased scaling was observed when concrete slabs made with recycled water at a higher solids content were tested by ASTM C 672, *Test Method of Concrete Surfaces Exposed to Deicing Chemicals*. Field slabs have not revealed an increased scaling. ASTM C 672 does result in a more severe exposure and indication of scaling that has not been observed in field concrete.

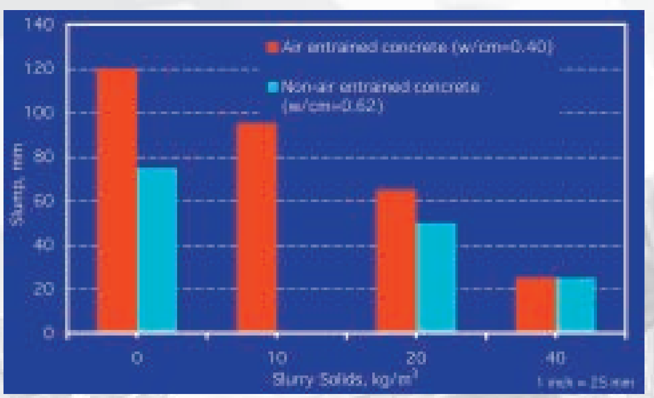

Figure 1.1: Slump of air entrained and non-air entrained concretes

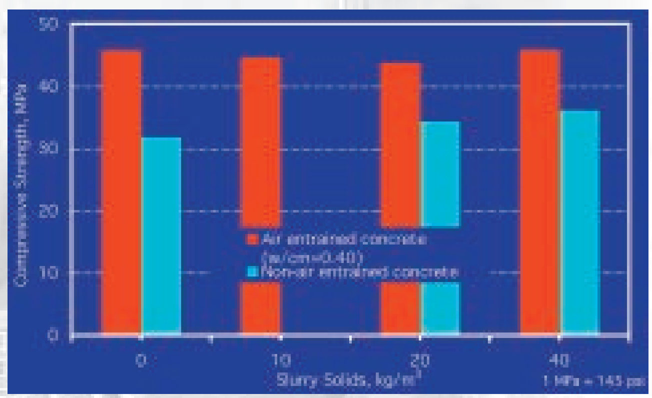

Figure 1.3: 28-day compressive strength of air entrained and non-air entrained concretes

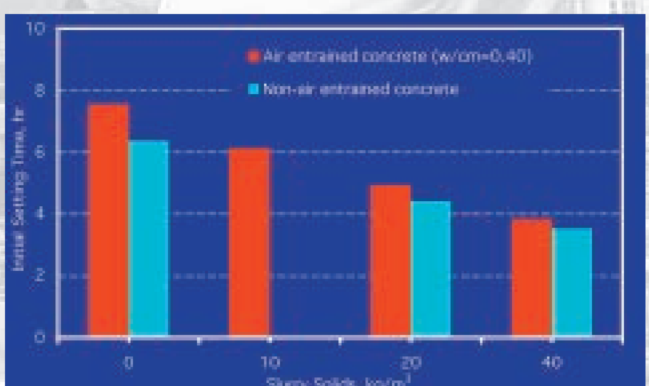

Figure 1.2: Setting time of air entrained and non-air entrained concretes

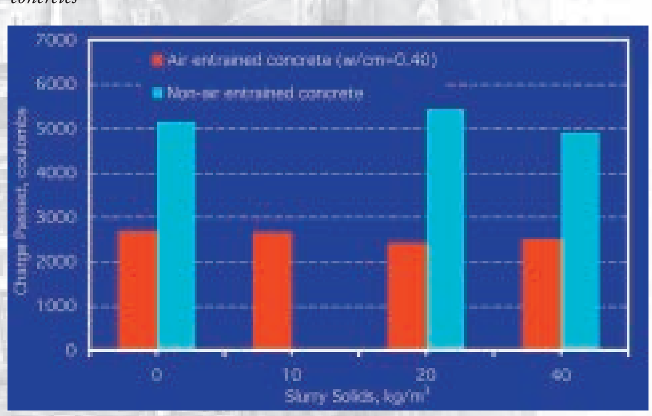

Figure 1.4: ASTM C 1202 results for air entrained and non-air entrained concretes

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Study

This study also indicates that the primary issue with the use of recycled water at higher solids content is the acceleration of the setting time. At the same w/cm ratio strength, permeability, shrinkage and other characteristics were similar to the control batches.

Figure 1.1 illustrates the slump of the concrete mixtures. Since the w/cm ratio was constant, using an increasing solid content from recycled water slurries resulted in lower slump.

Figure 1.2 illustrates the setting characteristics of the concrete mixtures. Similar to the NRMCA study, increasing solids content resulted in faster set times in both types of concrete

Figure 1.3 illustrates the compressive strength of these mixtures. As concrete was mixed to a constant water-cementitious materials ratio, similar strengths were obtained regardless of the amount of solids from recycled water in the mixtures.

Figure 1.4 illustrates the results of ASTM C 1202, *Test Method for Electrical Indication of Concrete's Ability to Resist Chloride Ion Penetration*, also known as the rapid chloride permeability test. For similar materials, a higher value of the charge passed will result in concrete with a higher permeability. It can be concluded from Figure 1.4 that the permeability was not affected when recycled water slurry was used in these mixtures of the same w/cm ratio. ■

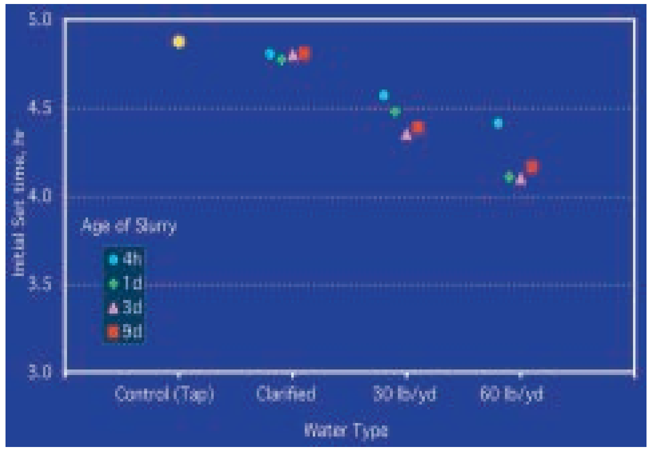


Figure 4: Initial Setting Time of Concrete

particles cause the increased water demand. Specific gravity of dried slurry solids varied from around 3.10 at four hours to 2.50 and lower at ages one day and later.

Initial Setting Time

Figure 4 illustrates the effects of using recycled water on initial setting time. Values reported are the average of three replicate batches for each condition. The setting time of the control is the average of nine concrete batches.

The initial setting time of the control batch was around 4.9 hours. The setting time of the batches with clarified recycled water was similar to that of the control batches. When recycled water slurry was used, the setting time was accelerated and the faster setting time was proportional to the amount of solids and the age of the water slurry.

The primary problem with reusing recycled water with solids in concrete is the effect on setting time. Hydrated cement and calcium hydroxide (hydrated lime) are known to accelerate setting characteristics. Problems with setting with the use of recycled water slurry will be exacerbated in summer but can possibly be used to advantage in cooler temperatures. These set time data illustrate that the four-hour old slurry had lesser effect on setting time than slurry that was aged for one day or longer. Setting times of concrete with slurries aged for one day or longer were essentially similar, possibly because most of the cement solids had hydrated at one day.

Compressive Strength

Figure 5 illustrates the 28-day compressive strength of concrete batches representing each experimental condition. The data represents the average of three replicate batches for each condition.

The compressive strength data reflects the well-known fact that increased water content in the concrete will cause a reduction in strength. The reduction in strength correlates well to the additional water used in the respective batches. The lower compressive strength of batches containing recycled water with higher solids content could be adjusted for by reducing the water content of these batches using appropriate mixture adjustments. (See Figure 5)

The data also show that the batches with the four-hour-old slurry did have a compressive strength similar to the control batches, which is related to the lower mixing water demand and

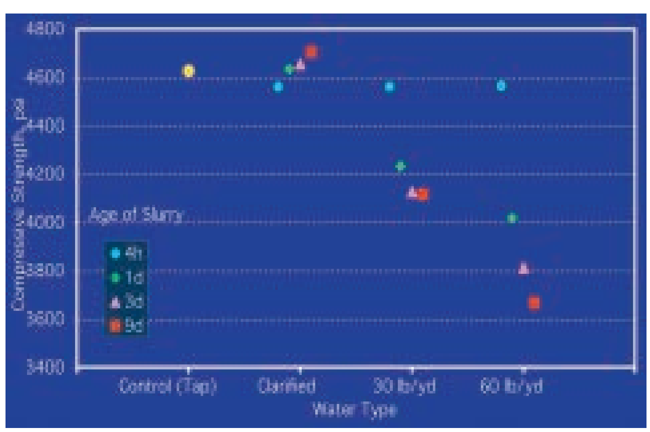


Figure 5: Compressive Strength at 28 days

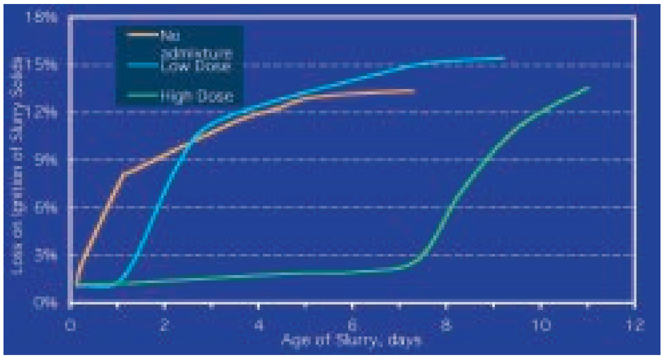


Figure 6 – The progression of hydration of the cement (effectiveness of the admixture dosage) was quantified from the loss on ignition on the dry solids from the slurries.

possibly some cementing value from unhydrated cement solids.

Durability Properties

Data on drying shrinkage, freeze-thaw resistance and rapid chloride permeability were collected and are not included or illustrated in this report. Mixtures that had a higher mixing water content had a concomitant increase in results for drying shrinkage and rapid chloride permeability. These higher values can be offset if appropriate steps are taken to reduce the mixing water content of those mixtures.

Freezing and thawing was conducted in accordance with Procedure A of ASTM C 666, which is the most severe exposure of freezing in water and thawing in water. The samples were exposed to in excess of 600 freeze-thaw cycles. Typical evaluations are conducted for 300 cycles. All the samples had adequate air contents and the durability factor for all conditions exceeded 90 percent when the tests were terminated. Typical failure criteria for freeze-thaw evaluations are when the durability factor falls below 80 percent in 300 cycles. The severe exposure of Procedure A caused scaling of the freeze-thaw specimens. Mass loss quantified to an average 2.5 percent of the original mass of the specimen. There was no distinct experimental condition that showed a higher level of scaling.

Phase II

With the observation that recycled water slurries used at four hours did not cause significant detrimental effects on mixing water demand and setting time, the second phase of the study was designed to evaluate whether the treatment of wash water with a hydration stabilizing admixture (HSA) could offset some of the negative effects with high solids recycled slurries observed in Phase I of the study. Phase II also included a condition where the mixing water using recycled water slurry was at the ASTM limit for solids content of 15 pounds per cubic yard.

The same concrete mix design and procedures were used for Phase II of the study. The details of the experimental conditions are listed in Table 3. The data was generated from two replications of the experimental series.

Table 3 – Experimental variables in Phase II of the Study

Water	• Tap water (Control) • Recycled water at 15 lb solids per cubic yard • Recycled water at 45 lb solids per cubic yard
HSA Treatment	• No admixture • Low Dosage (1.5 day protection) • High Dosage (8 day protection)
Age of slurry	• 4 ± 1 hour • 1 day • 7 days

In this phase of the study, the recycled water slurry was obtained in the same manner and placed in three separate containers. Two of these containers were dosed with the hydration stabilizing admixture at two hours after the initial contact of water with the cement. The two hours was chosen to simulate when a mixer truck might return to the plant and wash out with water that contained HSA.

The *Low* dosage was established from other tests to maintain the cement solids from hydrating about 1.5 day and the *High* dosage was established to keep the cement solids from hydrating for eight days. The progression of hydration of the cement (effectiveness of the admixture dosage) was quantified from the loss on ignition on the dry solids from the slurries. These results are illustrated in Figure 6. A low loss on ignition value corresponds to a low degree of hydration of cement. Data in Figure 6 are from the actual slurries used in the concrete batches.

Within ASTM C 94 Limits

Figures 7 and 8 illustrate the setting time and 28-day compressive strength of concrete, respectively, of concrete batches with solids content at the 50,000-ppm limit (or 15 lb/yd^3) of ASTM C 94. The slurry ages were four hours, one day and seven days. Mixing water requirements were 0 (at four hours) to 15 lbs/yd^3 higher than that of the control batches for target slump.

The data indicate that setting time (expressed as percent of control) and strength were similar to control, except for modest setting time acceleration

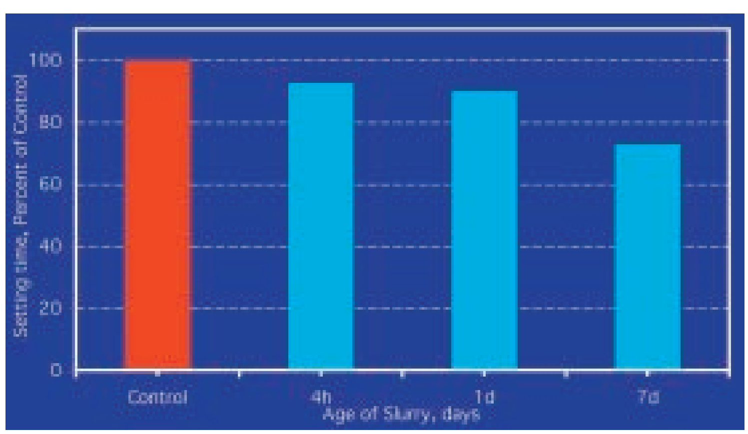


Figure 7 – Setting time of concrete batches with recycled water at the ASTM C 94 solids limit

Simple Procedures for Quality Control When Using Recycled Water

The primary criteria for *questionable* sources of mixing water in ASTM C 94 are for setting time and strength. When compared to using tap water (control), the setting time should not be accelerated by more than one hour or retarded by more than 90 minutes; and the seven-day strength should not be less than 90 percent of control. Test methods referenced in ASTM C 94 are those used for cement testing – ASTM C 109 standard mortar cube, and ASTM C 191 Vicat set. Equipment for these tests typically is not used in laboratories at concrete plants and a revision is being attempted to permit these tests on concrete samples with the same criteria.

While the solids content is the requirement in the standard, producers will typically measure the density (specific gravity) of recycled water slurry and establish blending percentages of slurry and tap (or well) water to meet a target density. A water slurry at 50,000 ppm correlates to a density of about 1.03 g/mL.

The following are recommended tests and procedures that can be used to determine blending percentages of recycled water slurry and tap water to comply with a limit on solids.

Figure 2.1 – Density measurement of water by mass

Figure 2.2 – Density measurement of water using a hydrometer

Density

The more accurate method is to determine the mass of recycled slurry water in container of known volume (Figure 2.1). Another common procedure is the use of a hydrometer (Figure 2.2). This is less accurate as the solids tend to settle rapidly.

To determine the density, use a cylindrical container with a glass or Plexiglas plate that fits over it. Calibrate the volume of the container in accordance with procedures used for calibrating air or unit weight buckets, as in ASTM C 29.

Obtain the mass of the empty container and plate.

Take a representative sample of recycled slurry water from the pit and fill it in the container. Cover the container with the plate ensuring that there are no air bubbles in the container. Wipe the outside dry and obtain the mass. The density is the net mass of water in the container divided by its volume.

The operator might also obtain hydrometer readings on a separate sample of recycled water slurry at the same time and this will serve as calibration for the density measurement if the hydrometer will be used during production.

Solids content

The quickest way is to dry a sample of recycled water slurry in a microwave oven (Figure 2.3). Use a glass dish with fiberglass cloth (check at boat repair shop). Obtain the empty mass of the dish and the cloth.

Pour the recycled water slurry sample from the density measurement into the glass dish and cover with the fiberglass cloth to prevent loss of solids during drying.

Figure 2.3 – Determining solids content in a microwave oven

Place the dish in a microwave oven and dry it until all the water has evaporated. Determine the mass of the dish until two subsequent weighings do not change by much (0.5 g). The percentage of solids in the recycled water slurry can now be calculated. Convert percent solids to ppm by multiplying by 10,000.

Develop a correlation

Make these measurements on recycled water slurry on several days to cover the range of solids contents that will be anticipated at a production facility. Add to this data with periodic tests on the recycled water slurry. Establish a linear relationship (for simplicity) between the slurry density and the solids content (see Figure 2.4). Based on target density of the mixing water, one can calculate the blending percentages.

Example

Figure 2.4 illustrates a sample relationship of recycled water density and solids content in ppm. This relationship holds only for this particular concrete plant. A spreadsheet and graphing software (like MS Excel) can be used to plot this relationship and obtain an equation.

In this example the relationship between the solids content and the density is as follows:

Solids content, ppm = 1356495 (Density) – 1348016

If the density of the slurry on a particular day is 1.10, using this equation, the solids content is approximately 144,000 ppm.

To determine blending percentage of this recycled water slurry and tap water (assume density of 1.00 and total dissolved solids of 2000 ppm for simplicity), for a target solids content, the following relationship can be used:

$RW \times S_{RW} + (1 - RW) \times S_{TW} = TS$

Where:

RW = Recycled slurry water
TW = Tap water = (1-RW)
S_{RW} = Solids content of recycled slurry water
S_{TW} = Solids content of tap water
TS = Target solids content (limit) in mixing water

The percent recycled slurry water can be calculated by rearranging the previous equation:

$$RW = \frac{(TS - S_{TW})}{(S_{RW} - S_{TW})}$$

If the target solids content is the ASTM C 94 limit or 50,000 ppm, the percentage recycled water slurry to blend with tap water in this example will be:

$$RW = \frac{(50{,}000 - 2000)}{(144{,}000 - 2000)} = 34\%$$

The same equation can be used if the preference is to work with water density, where the respective water density replaces the solids content.

Blending recycled water slurry and tap water is frequently done with in-line water density gages and automated adjustments. Ensure that the software is doing these calculations accurately and calibrate these density gages using the simple procedures described here. The producer should check the density of recycled water at a minimum frequency of two per day. When mixing water is used at a higher solids content, there are other adjustments necessary to batch ingredients to compensate for the water and solids in the recycled water slurry and to establish more accurate mixture proportions and water-cement ratio. The producer should also document strength and setting time data to provide to the customer on request. ■

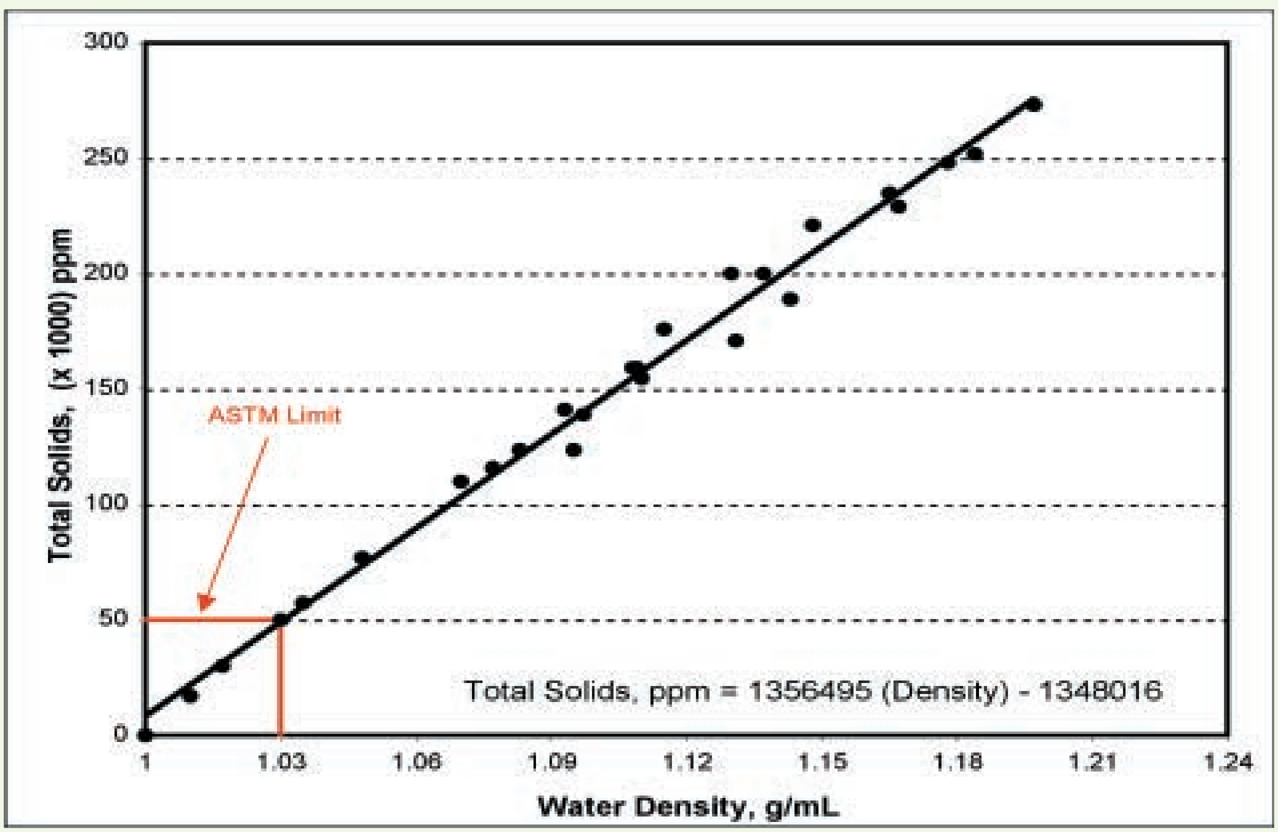


Figure 2.4 – Correlation between density and solids content for recycled water slurry

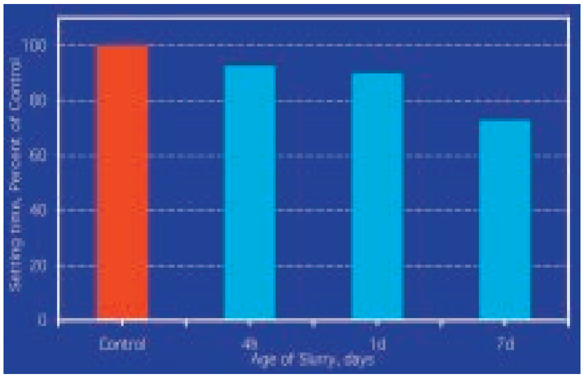


Figure 8 – 28-day compressive strength for concrete batches with recycled water at the ASTM C 94 solids limit

and lower strength for the batches with the seven-day-old slurry. These deviations from control for concrete with the four-hour and one-day-old slurries are within permissible limits for water in ASTM C 94.

HSA Treated Slurries

Figures 9 and 10 illustrate selected data for setting time and 28-day compressive strength of concrete, respectively, of concrete batches with and without slurries treated with the HSA admixture. The concrete batches used recycled water slurries such that 45 pounds of solids per cubic yard were incorporated in the batches. As expected from Phase I, the batches with the untreated slurries had a higher mixing water requirement to achieve the target slump and an associated reduction in strength is noted. Setting time of these batches, was accelerated relative to the control batches.

In the batches that had the slurry with the *Low* dose of HSA, the setting time and strength with the one-day-old treated slurries were similar to control batches, but the same negative effects were observed when this slurry was used at an age of seven days. Recall that the HSA dosage was selected to prevent cement hydration for about one day.

In batches with the slurry treated with the *High* dose of HSA, the setting time and strength of batches using the seven-day-old treated recycled water slurry were similar to that of the control batches.

These data illustrate that hydration stabilizing admixtures can work to facilitate the use of recycled water slurries at solids content that exceed the current limits of ASTM C 94.

Achieving this state will require some capital expense and company commitment. For this option to be economically viable, the goal should be to establish a mass balance such that the volume of recycled water generated at a concrete production facility is completely used in a defined period. The economics will need to consider the market area of operation and the cost of regulatory compliance.

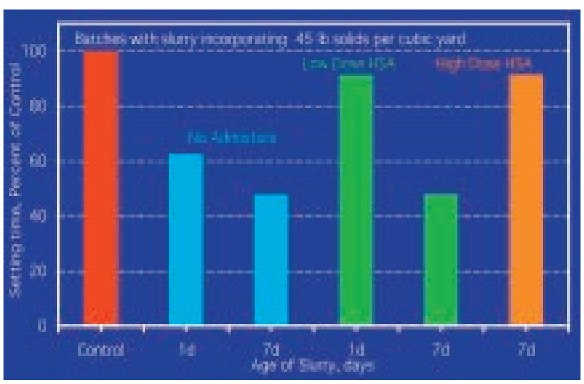
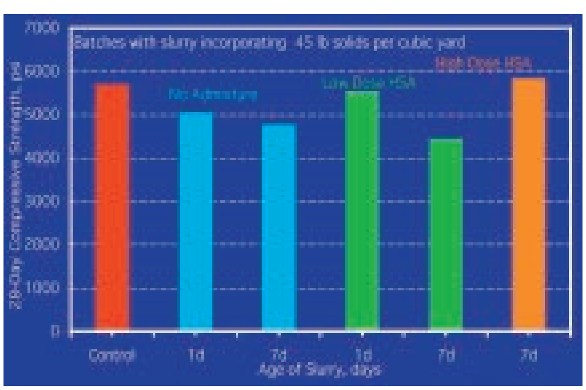


Figure 9 - Setting time of concrete batches with HSA treated and untreated recycled water at 45 pound solids per cubic yard

Figure 10 – 28-day Compressive Strength of concrete batches with HSA treated and untreated recycled water at 45 pound solids per cubic yard



There are many examples in Japan, Europe, Canada and the U.S. where these types of systems are being successfully used.

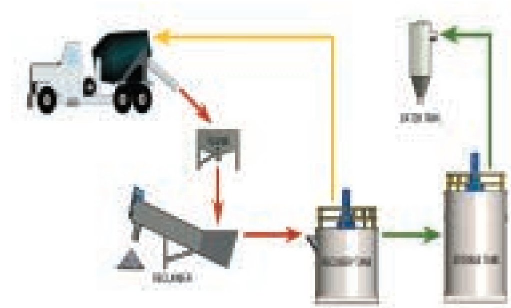


Figure 11 – Schematic of HSA treated concrete wash out system Courtesy: Knelson Concrete Recovery System

Another option for the producer is to maintain a certain consistency of the recycled water solids in consecutive batches while ensuring that it meets job performance requirements. Some reclaimer manufacturers will install a separate feed tank. When recycled water reaches a certain solids content, it is diverted to this feed tank and this water is used as batch water. This tank now has a constant solids content and can be used in fixed quantities to maintain batch-to-batch consistency.

Conclusions

These conclusions are pertinent to the materials and conditions used in this research study. These observations are based on mixing concrete to a target slump. The associated effects on concrete properties, except for setting time, were primarily a result of the additional mixing water needed to achieve and maintain the target slump of five inches.

1. Using recycled water with a solids content at or less than the ASTM C 94 limit should comply with the mixing water criteria for strength and setting time in the standard. However, recycled water aged to seven days seemed to have marginally detrimental effects in this study.
2. Performance properties of concrete batches with clarified recycled water were similar to the control batches. The data from this study indicates that the use of clarified water should be able to comply with the mixing water criteria in ASTM C 94.
3. Using recycled water slurries at signifi-

cantly higher than the ASTM C 94 limit for solids resulted in increased mixing water demand and accelerated setting time. The effects were more pronounced with an increase in the age of the slurry past one day and an increase in the solids content.

4. At the higher solids content, four-hour-old slurries had a minimal effect on the setting time and water demand of the concrete mixtures. Setting time and strength for these batches were similar to control. This indicates that hydrated cement in the slurry solids at later ages is the primary reason for the negative effects on water demand and setting time.
5. Mixtures that had a higher water content due to the use of higher solids recycled slurry had an associated reduction in strength and increase in drying shrinkage and rapid chloride permeability results.
6. Freeze thaw results of all concretes in this study were acceptable, indicating that when recycled water is used, attaining adequate air entrainment and strength will provide durable concrete in freeze-thaw environments.
7. Results of this laboratory study indicate that hydration stabilizing admixtures can be used to overcome the negative effects of age and higher solids content in recycled mixing water. ■

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