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# Effects of Wash Water on the Compressive Strength of Concrete

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# EFFECTS OF WASH WATER ON THE COMPRESSIVE STRENGTH OF CONCRETE

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## ABSTRACT

Due to the scale of concrete production throughout the world, there is potential for implementing methodologies that reduce the environmental impact of concrete processes. One intriguing solution is utilizing concrete wash water as mixing water. Concrete wash water is the water created by concrete production. If wash water can be reused, this would provide a safe disposal of the water and save millions of gallons of potable water per year (Indiana, 2014). For this to become a realistic option for concrete plants, it is important that the wash water does not decrease the compressive strength of concrete, otherwise the cost of additional cementitious materials to offset the compressive strength decrease will outweigh any financial benefit of recycling the wash water. Therefore, the purpose of this research project is to examine the effects of wash water on the compressive strength of concrete. In this program, 4 different concrete mix designs were developed; two using cement as the only cementitious material, and two with 25% of the cement replaced with fly ash. For both mix designs, three batches were mixed and tested, and with each batch the mixing water source was the only variable. The mixing water sources used were tap water, wash water collected at noon, and wash water collected in the evening. Although other research is necessary to affirm the conclusion, the results tentatively showed that using wash water as concrete mixing water has little effect on the compressive strength of concrete.

# 1 INTRODUCTION

Sustainable development and environmental impact of construction means and methods are a focal point within the construction industry. Concrete is the most significant and utilized building material within the world today, estimating that over ten billion tons of concrete are produced each year with 500 million tons in the United States alone (Meyer, 2004). The environmental burden of concrete production includes: one billion cubic meters of water per year worldwide, solid waste disposal problems due to construction debris, and the creation of one ton of $CO_2$ gas per ton of concrete produced (Meyer, 2004). Due to the scale of concrete production, it can be reasoned that reducing the environmental impact of concrete may provide major strides in ecologically responsible civil engineering. Recent attempts to reduce the environmental impact of concrete include recycling various waste materials within concrete and utilizing municipal wastewater as mixing water (Bolden, 2013; Chola, 2015).

Another emerging possibility to reduce the environmental impact of concrete is to incorporate concrete wash water in concrete mixes. Concrete wash water is formally potable water used to clean tools and equipment that have come into contact with fresh or hardened concrete, such as mixing drums, chutes, or buckets. Concrete wash water has a larger amount of suspended solids and a higher PH than potable water and therefore has EPA restraints in regards to its disposal (Griffiths, 2006; NSCEP, 2012). EPA and best management practices suggest that concrete wash water should either stored in a lined container on site or transported back to a ready mix plant to be collected in a lined pond. These requirements can create difficulties on smaller construction sites, as concrete trucks need to have enough room to navigate in and around the washout area. Additional complications can arise if multiple trucks need to wash their trucks in a short period of time, or if the rain threatens to flood the washout area. Similarly, most ready mix companies are unable to accommodate all of the wash water from their jobs, and creating new areas for wash water storage can be expensive (Wasserman, 2012). If wash water is found to have negligible effects on concrete properties, specifically compressive strength, a new standard of transporting wash water to the ready mix plant to be used as mixing water can be implemented. This practice would avoid on site complications that stem from containing wash water. Furthermore, recycling wash water in this manner can lower daily water usage of ready mix plants as wash water can account for 30% of their water usage (Papi, 2013).

Previous research has been conducted to determine the effects of using concrete wash water as mixing water. Wasserman (2012) examined the effect of wash water on concrete compressive strength. Wasserman concluded that using wash water as concrete mixing water provides a “statistically significant” increase in the compressive strength of concrete. Furthermore, Wasserman stated three assumptions he made in his research that are important to consider when analyzing wash water: tap water is consistent in its properties, admixture components left over from wash water will not affect newly made concrete, and that cement has been adequately tested and has consistent pH and specific gravity. Tran (2008) also investigated the effect of using concrete wash water as the mixing water has on the durability of concrete. Tran’s research focused on the effect that wash water has on de-icing salt induced corrosion of steel reinforcement, but it also examined the effect that wash water has on concrete workability, compressive strength and the capabilities of air entraining agents (AEA). Tran’s thesis determined that the workability of concrete is slightly reduced when using wash water and that the compressive strengths of wash water samples were similar to the control samples, measuring within 96%. Furthermore Tran concluded that the air content of concrete made with wash water is lower than the air content of concrete made with tap water. While unsure of the cause, he theorized that fine particulates in the wash water, the high alkalinity of the wash water or residual admixture within the wash water might have caused the decline in air content (Tran, 2008).

Currently, recycling concrete wash water for use as mixing water is restricted to low strength concrete mixes that lack air-entraining admixtures (Tran, 2008). These limitations partially stem from concerns that using concrete wash water can have a detrimental effect on steel reinforcement within concrete (Tran, 2008), but ASTM and state requirements contribute as well. ASTM C1603 provides a 50,000 ppm limit on suspended solids in concrete mixing and some state departments such as the Minnesota Department of Transportation require potable water in all concrete mixes for their jobs (Wasserman, 2012). Therefore, even if it is found that concrete wash water does not negatively affect compressive strength, other obstacles may hinder the progress of concrete wash water being applied as potential mixing water.

## 2. **EXPERIMENTAL PROGRAM**

The focus of this research is to ascertain the effects of using concrete wash water on the compressive strength properties of both cement only and fly ash concrete mixes. To accomplish this two different concrete mix designs were developed; one using cement as the only cementitious material and one substituting 25% of the cement with Class C fly ash. Both mix designs were batched with tap water and these mixes served as the control mixtures. The second and third batches of each mix design used 100% wash water collected from a concrete ready mix plant at approximately 12:00 pm (designated as NW for "noon water") and 8:00 pm (designated as EW for "evening water") as the mixing water. Wash water was collected from a lined pond at GCC Ready Mix, and stored in the quality control lab using five gallon buckets with lids. No work was done to remove the suspended solids within the wash water and the wash water was used within 5 days of collection. In total, this led to 3 batches for each mix design and this information is summarized in Table 1. These batches were completed in May 2016. In July 2016 the experiment was repeated with a 10 lb/yd$^3$ increase in mixing water for the cement only mix design and a 12.8 mL/yd$^3$ increase in air entraining agent (AEA) dose for both the cement only mix and the fly ash mix designs.

Table 1: Batching Matrix

| **Mix** | Concrete Mixing Water | | |
|---|---|---|---|
| | Tap Water | NW | EW |
| Portland Cement | X | X | X |
| Fly Ash | X | X | X |

In the case of this study all wash water, materials, and testing equipment, were provided by GCC Ready Mix in Springdale, AR. Additionally, all tests were performed in the Quality Control Lab at GCC Ready Mix.

# 3 MATERIALS AND METHODS

All mix designs were determined using the absolute volume method (Clute, 2003), and individual components consisted of Type I portland cement, water, 1" limestone, sand, an air entraining agent (AEA), and a water reducing agent (WRDA 35). For the fly ash mixes, 25% of the cement was replaced with Class C fly ash. For the July batches, the AEA dosage rate was increased 12.8 mL/yd$^3$, and the water content was increased 10 lb/yd$^3$ for the portland cement mix. The batch size was 1.7 ft$^3$ to accommodate a slump test, unit weight test, pressure meter test, and twelve cylinders per batch. The May and July Mix designs for the portland cement and fly ash mixes are shown in Table 2.

Table 2: Mix Proportions

| **Portland Cement** | | | **Fly Ash** | | |
|---|---|---|---|---|---|
| Cement | 565.0 | lbs/CY | Cement | 424.0 | lbs/CY |
| Fly Ash | 0.0 | lbs/CY | Fly Ash | 141.0 | lbs/CY |
| Sand | 1279.0 | lbs/CY | Sand | 1256.0 | lbs/CY |
| Rock | 1810.0 | lbs/CY | Rock | 1810.0 | lbs/CY |
| Water* | 184.0 | lbs/CY | Water | 184.0 | lbs/CY |
| AEA* | 74.6 | mL/CY | AEA* | 74.6 | mL/CY |
| WRDA 35 | 668.6 | mL/CY | WRDA 35 | 668.6 | mL/CY |
| 1. July portland cement mix used an additional 10 lb/CY<br>2. July portland cement and fly ash mixes used an additional 12.8 ml/CY of AEA | | | | | |

Rock, sand, cement, fly ash, and water were weighed and stored in five gallon buckets prior to mixing. Aggregates were gathered from stockpiles at the GCC ready mix plant. Due to limited storage capacity, enough aggregate for all mixes was unable to be stored simultaneously. This led to both coarse and fine aggregates being gathered in two shifts for both the May and July trial batches. Unfortunately, due to precipitation occurring between batching this created different moisture contents in the aggregates gathered. Although moisture contents were measured and recorded, no steps were taken to correct the moisture content differences between aggregates.

The mixing process and order was kept consistent throughout the study. The concrete was mixed in a portable tilting drum mixer with a max capacity of 2.5 ft$^3$. The mixer was sprayed with water and then emptied before adding initial water to prevent the mixing drum from absorbing water from the concrete mixture. A water reducing agent (WRDA 35) was added to the water before it was split into headwater and tailwater, with headwater consisting of approximately 2/3 of the total water. Similarly, the AEA was injected into the sand before the sand was added into the mixing drum. The order of materials added to the mixing drum from beginning to end: headwater, 2/3 rock, sand, cementitious materials, 1/3 rock, and tailwater. A small portion of the coarse aggregate was kept until after the cementitious materials were added to the mixture to help prevent the cementitious materials from coating the lip of the mixer. Each batch was mixed for approximately 5-6 minutes.

For all trial batches slump, unit weight, and air content were measured and recorded. Slump (ASTM C143), unit weight (ASTM C138), and air content (ASTM C231) were conducted in accordance with their corresponding ASTMs. For the trial batches conducted in July, concrete temperature was measured to ensure that excessive fresh concrete temperature would not impact long term compressive strength. For each of the trial batches a total of 12, 4 in. x 6 in. cylinders were cast. The compressive strength was measured at 1, 3, 7, and 28 days. At each age, three cylinders were tested. Cylinders were cured in an indoor water storage tank and all tests were performed indoors to mitigate the impact of air temperature on the concrete. Finally, the pH was measured for the wash water and tap water.

The notation in the tables and figures use the abbreviations MT, MNW, and MEW to represent the May tap water batch, the May noon water batch, and the May evening water batch, respectively. Similarly, the abbreviations JT, JNW, and JEW correspond to the July tap water batch, July noon water batch, and the July evening water batch, respectively.

# 4 RESULTS AND DISCUSSION

## 4.1 Alkalinity and pH

Concrete wash water typically has a higher pH than tap water, which hovers around 6-8. According to the Environmental Protection Agency, the pH of concrete wash water is approximately 12, while other researchers provide a range between 11-12 (Asadollahfardi, 2015; NSCEP, 2012; Wasserman, 2012). For comparison purposes, pH values of the wash water are provided in Table 3.

Table 3: pH of Mixing Water Samples

| Sample | pH |
|---|---|
| MT | 8.0 |
| MNW | 11.6 |
| MEW | 11.7 |
| JT | 7.8 |
| JNW | 11.9 |
| JEW | 12.2 |

## 4.2 Compressive Strength

From an engineering and construction perspective, compressive strength is the most emphasized property of concrete (Tran, 2008). Often the purpose of specifying fresh concrete properties such as a slump, concrete temperature, and air content is to limit the potential damage caused to the final compressive strength of the concrete. Ultimately, if it is determined that the compressive strength of concrete is harmed by using wash water it will be difficult to justify the added cement cost needed to achieve the specified compressive strength. In previous publications there seems to be a small concurrence between wash water providing similar compressive strength to tap water within concrete mixing, and in more than one instance, wash water surpasses compressive strength produced by tap water (Tran, 2008; Wasserman, 2012). However, the research conducted here indicates the compressive strength of mixes made with wash water were less than that of the mixtures cast with tap water.

In order to have appropriate comparisons, the portland cement mixes and fly ash mixes should be analyzed separately. The trials conducted in May and July have similar mix designs and therefore can be directly compared. A graphical comparison of compressive strengths of the cement only mixes can be seen in Figure 1. Similarly, a comparison between the compressive strengths of the fly ash mixes is shown in Figure 2. Except for one outlier in which the 28 day compressive strength values were approximately the same, the wash water samples had compressive strength values at least 10% lower than the tap water samples, with a maximum differential of 27%. For the portland cement mixes, the average compressive strength of the wash water samples was 12.4% lower than the tap water samples. Likewise, the average compressive strength of the fly ash mixes was approximately 17.3% lower than the control samples. For the majority of samples the compressive strength difference between the wash water samples and the tap water samples increased with the curing duration. The wash water samples did not have noticeably different setting times than the control samples.

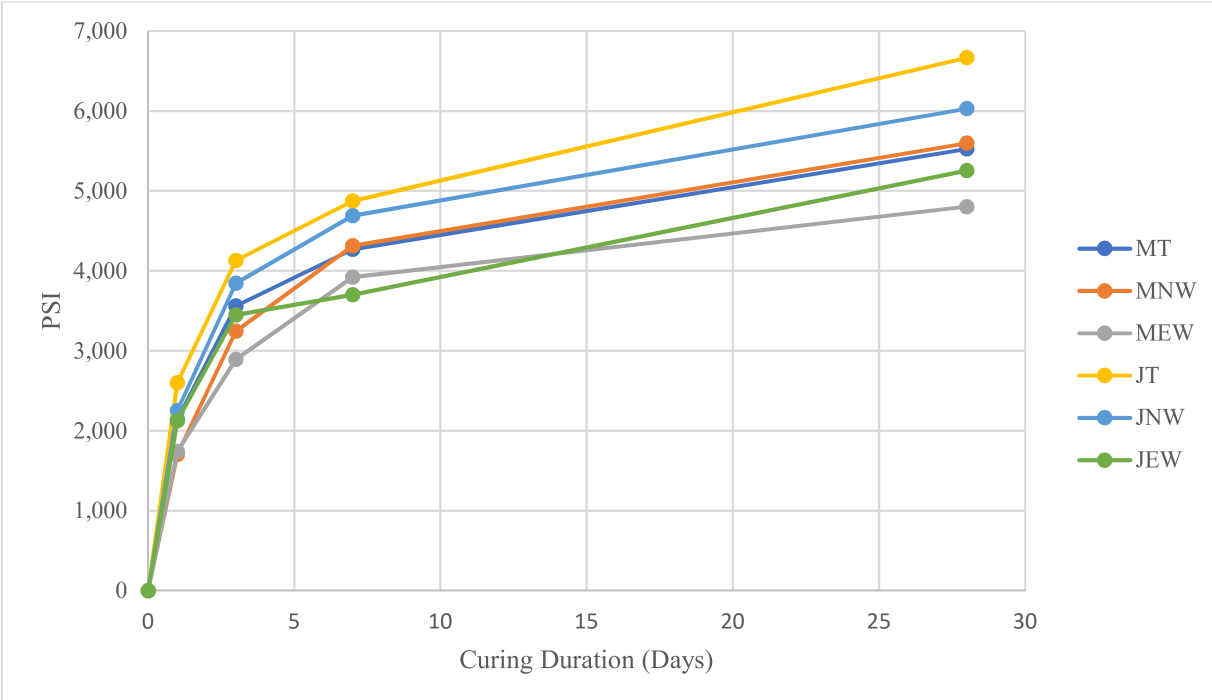


Figure 1: Cylinder Breaks for Portland Cement Concrete Mixes

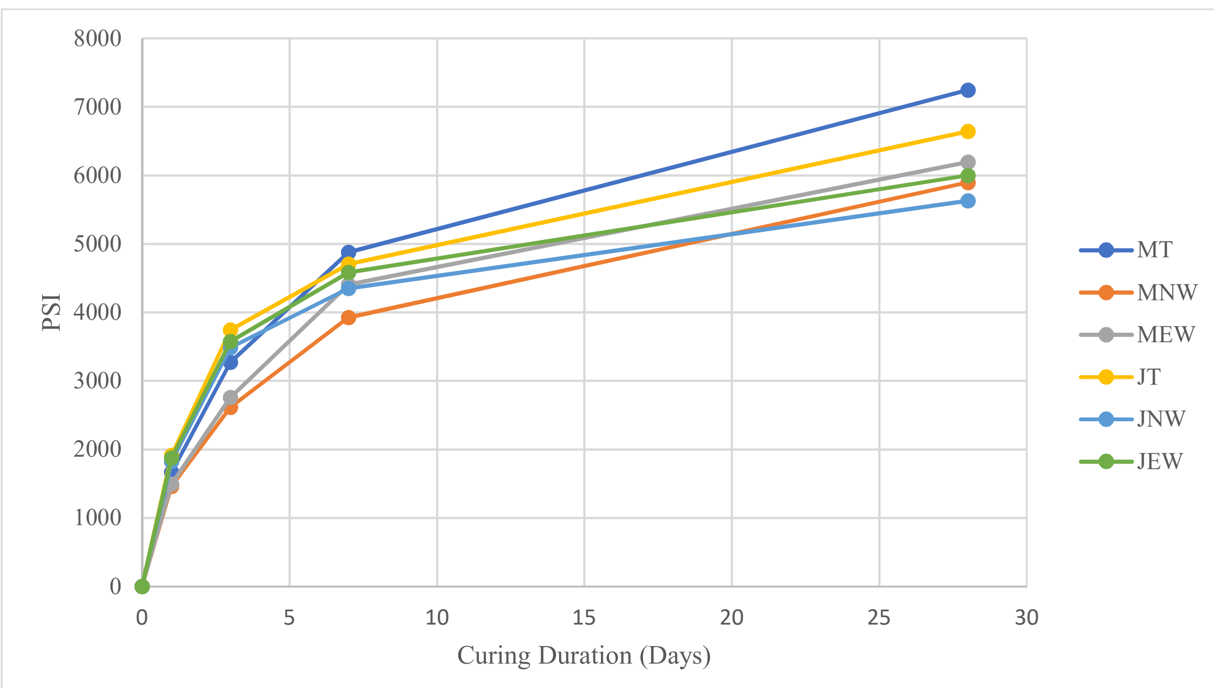


Figure 2: Cylinder Breaks for Fly Ash Concrete Mixes

### 4.3 Air Content and Slump

In a vacuum, the compressive strength values for the wash water samples seem low. However, a closer inspection of the slump and air contents of the samples provides some explanation for the disconnect between this research and research conducted by others. Due to the nature of fresh and hardened concrete properties, they typically work in conjunction with each other. As slump and air content increase, the compressive strength of concrete decreases. In every case except for one the slump difference between the wash water sample and the corresponding control was a minimum of ¾” with a maximum slump difference of 3.5”. This slump difference could provide an adequate explanation for the difference between the wash water samples and tap water samples. It is also worth noting that the outlier for slump and compressive strength was the same sample. Essentially, the only sample that had a similar slump to the control batch also had a similar compressive strength. Likewise, the sample with the largest slump difference to the control had the largest difference in compressive strength. The fresh concrete properties are denoted in Tables 4 and 5.

Table 4: Fresh Properties of Concrete for May Batches

| **Mix** | Fresh Concrete Properties | Water | | |
|---|---|---|---|---|
| | | MP | MNW | MEW |
| Portland Cement | Slump (in) | 4.25 | 4.0 | 5.5 |
| | Air Content (%) | 4.5 | 4.3 | 6.0 |
| | Plastic Unit Weight (pcf) | 148.28 | 146.22 | 142.5 |
| Fly Ash | Slump (in) | 6.25 | 8 | 8.5 |
| | Air Content (%) | 2.3 | 3.9 | 3.5 |
| | Plastic Unit Weight (pcf) | 149.04 | 145.35 | 145.5 |

Table 5: Properties of Fresh Concrete for July Batches

| Mix | Fresh Concrete Properties | Water | | |
|---|---|---|---|---|
| | | JT | JNW | JEW |
| Portland Cement | Slump (in) | 3.25 | 4 | 6.5 |
| | Air Content (%) | 4 | 4 | 5.9 |
| | Concrete Temperature | 80 | 80 | 78 |
| | Plastic Unit Weight (pcf) | 149.2 | 147.28 | 143.88 |
| Fly Ash | Slump (in) | 5 | 8 | 8.5 |
| | Air Content (%) | 4.8 | 3.9 | 3.5 |
| | Concrete Temperature | 80 | 80 | 80 |
| | Plastic Unit Weight (pcf) | 148.12 | 145.35 | 145.5 |

Air content varied between samples and did not have the same level of correlation with compressive strength as slump did. On multiple occasions the wash water samples had a lower air content and a lower compressive strength, a theoretical contradiction, as lowering air content should increase compressive strength. Although circumstantial, this seems to indicate that the wash water lowered the air content. Two possible explanations for this are that fine particles within the wash water are responsible, or that the high alkalinity from the wash water partially neutralizes the AEA (Tran, 2008). Moreover, the irregularities between the slumps are possibly due to differences in moisture content within the aggregates. In effect, the moisture content difference could have a small but noticeable effect on the water to cement ratio for the mixtures, therefore effecting the slump, air content, and compressive strength.

# 5 CONCLUSION

Overall, it is difficult to determine with certainty the effect of wash water on the compressive strength of concrete from this research, due to the inconsistencies within the water content of the samples. However, even with the disadvantage of having additional water, the wash water samples were no more than 20% less than the compressive strength provided by the tap water samples. Therefore, this research tentatively points to wash water providing similar compressive strength results. This conclusion is solidified when combined with other studies and would point to wash water being a potential option for concrete producers to consider. Nevertheless, future research is necessary to form a consensus opinion on the applicability of concrete wash water before it can become a mainstay in the industry.

Although inquiries have been made into the effects of wash water on concrete properties, there are other supplemental experiments that would be beneficial in determining the feasibility of implementing wash water as mixing water. First, a complimentary set of trials performed with the same constraints of this research but using a target slump instead of a set amount of water could be advantageous. In practice this method can be difficult to achieve for some mix designs, however it may provide more consistent results on the effect of wash water on compressive strength and air content. Additionally, examining the long term results of using wash water within concrete would be valuable. Although the loss of strength presented in this research is less than 20%, it is possible that concrete made with wash water would consequently create wash water with a higher PH or amount of suspended solids, potentially having additional or more pronounced effects on the fresh and hardened concrete properties. If so, this could damage the ability of construction companies to utilize wash water within their mix designs. Even so, if using wash water in concrete production seems to be untenable, another idea is to implement municipal wastewater as mixing water. In a similar vein to wash water, billions of gallons of wastewater are produced worldwide every year that can be a nuisance to discharge or store (Chola, 2015). If either wash water or municipal wastewater can become pragmatic water sources for concrete companies, tremendous amounts of fresh water and energy can be conserved.

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