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INVESTIGATION OF SETTING TIME AND COMPRESSIVE STRENGTH OF READY-MIXED CONCRETE BLENDED WITH RETURNED FRESH CONCRETE

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Abstract

Returned fresh mix concrete (RFC) is a problem with both economic and environmental impacts. Therefore, investigators have recommended various ways to decrease the amount of RFC in manufacturing facilities. Among the most common procedures are dumping concrete in landfill, recycling it, using the aggregate, and using it to produce concrete blocks. In this study, the authors investigated the behavior of various proportions of RFC mixed with ready-mix plain and retarded concrete. The authors also studied the influence of aging by producing specimens after one, two, three, and four hours. In addition, the researchers investigated controlled and uncontrolled environments by mixing the samples both indoors and outdoors. Workability, setting time, and compressive strength of cylindrical mixed specimens was then evaluated. The results presented acceptable setting times and compressive strengths for most specimens, which means mixing RFC with ready-mix concrete is a suitable alternative for recycling RFC. It is also possible to mix higher proportion of RFC with plain concrete in comparison to retarded concrete, though it is difficult to estimate the optimum combination of RFC and plain concrete.

Keywords: Returned concrete, RFC, ready mix, compressive strength, recycle, setting time

1. Background

Waste concrete is a problem for the concrete manufacturing industry. The term used to define unused concrete that is returned to a facility inside a truck is leftover, and of this, 60% goes directly to a dump, while only 40% is used to produce other concrete blocks or recycled products [5]. Ready-mixed concrete, on the other hand, is the fresh concrete produced for delivery to purchasers [6]. The amount of waste concrete varies between 1% and 13% [1]. Part of this waste belongs to concrete returns to a plant from job sites [2], with around 2% to 10% of concrete

returning to a facility as leftover [3, 4]. Moreover, handling and disposing of returned concrete is expensive. Sometimes, companies need to transport it to landfills or provide space for storage [13].

There are various ways that returned concrete can be recycled to reduce cost and improve environmental effects. Returned concrete can be crushed and washed to recycle the aggregate [7]. The water produced in this process, which contains some fine sand and cement, can also be reused for mixing concrete [3], and part of this concrete, or removed aggregate, can be used as a base for pavement [8]. New techniques, which produce lower liquid and solid waste, have been introduced for producing aggregate from returned concrete [9]. In addition, investigators have suggested using some stabilizing additives to help returned concrete stay fresh for a longer time and allow for reusing it, with the addition of a super-stabilizer based on concrete hydration control [10, 11]. This stabilizer turns the concrete into a plastic concrete, which lasts up to 72 hours [12].

Additional costs and environmental concerns are among the two main factors forcing companies towards zero-discharge concrete production methods [14]. Studying the financial and technical aspects of recycled aggregate, as well as the re-use of water has dominated investigations related to recycled concrete. It has been noted that using a front-end loader process to produce a mixture with recycled aggregate is less expensive than other methods [15]. Additionally, proper classification and separation of recycled aggregate is needed before using it to manufacture concrete products [16]. However, using recycled fine aggregate to produce concrete is more environmentally-friendly than dumping it in landfills [17], and concrete beams made with recycled aggregate present lower cracking moments and closer cracks when compared to conventional concrete [18]. Related to environmental factors, using recycled aggregate has significant impact in reducing CO₂ emissions [19] and creates fewer greenhouse gases [20]. Since recycled aggregate has properties similar to regular aggregate [21], replacing regular aggregate with 50 % of recycled aggregate requires no modification for production [22]. Moreover, using 50 % of concrete wash water to produce cement mortar leads to an increase in compressive strength [23], and the slurry waste produced during concrete manufacturing could be used to produce cementitious paste [24].

In the United States of America, recycling and using aggregate for backfill and pavement base is more popular than producing materials with the recycled aggregate [25]. Most investigations have focused on using recycled aggregate or returned concrete for secondary production. Reusing returned fresh concrete (RFC) is another possible alternative. Based on the United States' Environmental Protection Agency (EPA) waste hierarchy presented in Figure 1, reusing the waste is preferred to recycling it.

Figure 1. Waste hierarchy [25]

While other investigations have suggested adding stabilizers and producing plastic concrete, in this research, the authors investigated mixing returned concrete with fresh concrete. Various methods of recycling RFC are presented in Figure 2.

Figure 2. Various methods of recycling returned fresh concrete

2. Methodology

The authors designed a set of experiments to investigate the behavior of ready mix concrete partly mixed with RFC, with required materials provided by local manufacturers. Table 1 presents the mix properties used in this research.

Table 1. Properties of concrete mixture

Constituent	Content	Weights (lb.)	Specific Gravity (lb./ft ³)	Absolute Volume (ft ³)
Cement, Type V	6.50 Sack	488.8	3.150	2.487
Fly Ash, Type F	20	122.2	2.320	0.843
SSD Sand	44	1442.2	2.792	8.278
Coarse Aggregate (3/4")	56	1852	2.817	10.536
Water	33.3Gals	277.7	1.000	4.451
Air		1.5%		0.405
Total		4183		27.000
Unit Weight (lb./ft ³)				154.9
Water/Cement				0.45
Aggregate/Cement				5.4

2.1. Test Procedure

In order to evaluate the effects of age and proportions of RFC on fresh and hardened concrete characteristics, researchers conducted the investigation in two phases:

- In the first phase, as a pilot, the researchers performed the study in a controlled (indoor) environment. In this phase, the researchers mixed one-, two-, and three-hour-old RFC with fresh concrete.
- In the second phase of this study, researchers carried out the experiment with one-, two-, three-, and four-hour-old RFC mixed with fresh concrete in an uncontrolled (outdoor) environment.

In addition, the researchers selected five different proportions of RFC, versus fresh concrete, in order to determine the optimum RFC mix proportion, which included 10 %, 20%, 30%, 40%, and 50%. Researchers mixed the RFC with both plain and retarded concrete, and specimens were marked based on indoor or outdoor mixing and RFC

proportion. For instance, IP10:90 means 10 % RFC Indoor mixed with 90 % Plain concrete. The mix and experimental sequence is presented in Figure 3.

Figure 3. mixing and testing sequence

2.2. Experiments and Relevant Standards

Once the concrete was blended, the researchers conducted the following fresh concrete characteristic tests and recorded results for each blend:

- Concrete temperature (ASTM 1064),
- Slump (ASTM C143),
- Unit weight (ASTM C138),
- Entrapped air (ASTM C231),
- Setting time (ASTM C403).

To determine the effects of age and proportion of RFC on compressive strength, 4-in by 8-in cylinders were produced based on ASTM C192. All cylinders were removed from their moulds and placed in a standard moist room, with free moisture on all of their surfaces until they were tested for compressive strength (ASTM C39) at ages of 7, 28 and 56 days.

3. Analysis of the Results

In order to make a better comparison, researchers performed a set of experiments on a control mix for both fresh and hardened conditions. The results of experiments on the control mix are presented in Table 2, which includes results for both indoor and outdoor mixes.

Table 2. Test results on fresh and hardened control mix

Mix ID	Slump (in)	Air Content (%)	Setting Time (minutes)		Compressive Strength (PSI)		
			Inside	Outside	7 Days	28 Days	56 Days
IP0:100	3.25	2.1	330	300	5470	7120	8290
IP0:100	3.5	2.7	300	220	-	-	-
IP0:100	3.25	2.6	290	200	-	-	-
IP0:100	2.5	2.5	315	210	4720	7030	8910
IR0:100	2.25	2.1	330	300	4570	7120	8290
IR0:100	3.5	2.7	300	220	-	-	-
IR0:100	3.25	2.6	290	200	-	-	-
IR0:100	3.5	2.5	315	210	4720	7030	8910
OP0:100	3.00	1.8	350	340	3830	5620	8290
OP0:100	4.00	1.9	345	245	5160	7490	8720
OP0:100	3.00	1.4	300	225	5000	6730	8150
OP0:100	4.00	1.4	340	270	5670	7140	8650
OR0:100	4.00	1.9	345	245	5160	7490	8720
OR0:100	3.00	1.4	300	225	5000	6730	8150
OR0:100	4.00	1.4	340	270	5670	7140	8910
OR0:100	3.00	1.8	350	340	3830	5620	8290

Researchers evaluated the workability of the specimens based on slump test results. Figures 4 and 5 illustrate the results of slump tests on specimens manufactured by mixing various proportions of RFC with plain and retarded concrete. The graphs demonstrate the amount of added water that was required for each mix in order to achieve the acceptable slump, versus the age of concrete specimens.

Figure 4. Effect of age and proportion of outdoor mixed plain RFC on water demand to maintain slump at 4+1 inches

As can be seen in Figure 4, one-hour-old samples required no additional water to achieve the targeted slump. Generally, the amount of required water per cubic yard increased with the age of concrete up to three hours, and then decreased.

Figure 5. Effect of age and proportion of outdoor mixed retarded RFC on water demand to maintain slump at 4+1 inches

Water had to be added to almost all of the retarded specimens in order to achieve the targeted slump. The amount of required water was between 1 and 7 gallons per cubic yard, as illustrated in Figure 5. The results of setting time for plain concrete mixed with RFC are presented in Figures 6 and 7, for specimens mixed indoors with plain and retarded fresh concrete.

Figure 6. Effect of age and proportion of indoor mixed with plain RFC on setting time

Figure 7. Effect of age and proportion of indoor mixed with retarded RFC on setting time

The setting time decreases for plain mixed samples as specimens ages increase, while the setting time for retarded concrete samples increases first, and then declines. For both specimen sets, the setting time is higher than the standard time. Specimens manufactured by mixing 10% RFC with 90% plain concrete present higher setting times, compared with other samples for indoor mixes. For retarded mixed specimens, IR20:80 presents the highest setting time among all specimens.

Figures 8 and 9 show the results for outdoor mixed specimens.

Figure 8. Effect of age and proportion of outdoor mixed with plain RFC on setting time

Figure 9. Effect of age and proportion of outdoor mixed with retarded RFC on setting time

As seen on the above graphs, the setting times for specimens mixed outdoors with plain concrete are lower than the standard time, while for retarded samples, the setting time is higher than the standard time and control specimen time. Additionally, for retarded specimens the setting time increases with the age of the samples.

The final test performed on the cylindrical specimens was a compressive test. The behavior of samples after 7 days, 28 days and 56 days followed similar trends. Figures 10 and 11 present the compressive strength for 28-day-old RFC specimens mixed with plain concrete. In the following paragraphs, the researchers will present and analyze the results of experiments on the 28-day-old specimens.

Figure 10. Compressive strength of RFC specimens mixed indoor with plain concrete

Figure 11. Compressive strength of RFC specimens mixed outdoor with plain concrete

Compressive strength is probably the most important parameter among all those mentioned in previous sections. The findings demonstrate that for RFC mixed with plain concrete in a controlled condition (indoors), all specimens had results with compressive strengths higher than the acceptance rate. In contrast, for outdoor mixing, several samples mixed after 4 hours were below the acceptance rate. However, for indoor mixing, two-hour-old specimens present lower compressive strength, while samples mixed outdoors show better results at the age of two hours old.

Finally, the results of the compressive tests on RFC specimens mixed with retarded concrete are presented in Figures 12 and 13 for indoor and outdoor mixing, respectively.

Figure 12. Compressive strength of RFC specimens mixed indoor with retarded concrete

Figure 13. Compressive strength of RFC specimens mixed outdoor with retarded concrete

The dominant point the graphs above demonstrate is that the compressive strength for almost all specimens at all ages is higher than the targeted value. The following specimens show compressive strength higher than the control mix:

- Up to 40% of 3-hour-old RFC mixed outdoor with plain concrete;
- Up to 50% of 2-hour-old RFC mixed outdoor with plain concrete;
- 20% of 4-hour-old RFC mixed outdoor with retarded concrete and;
- 30% of 3-hour-old RFC mixed outdoor with retarded concrete.

4. Discussion

Around 60 percent of returned concrete goes directly to a dump as a waste material. Based on waste hierarchy reusing waste is second recommended option for waste management. These two motives encouraged the authors to investigate using returned concrete. Producing new concrete was based on mixing returned and fresh concrete with adding extra water. The main concern was related to this added water, because water decrease the compressive stress of the concrete. It was expected to observe compressive stress lower than targeted values but the results of experiments demonstrated higher compressive strength. In this regard the best way to eliminate or

reduce the amount of water is to use the returned concrete immediately. The aged concrete will need more water which could be a negative point.

In addition, the experiments indicate that it is possible to mix up to 50 percent of returned concrete with fresh concrete and still have setting time and compressive strength higher than targeted values. On the other hand, instead of dumping 60 percent of the returned concrete as a waste, it is possible to mix great proportion of it with fresh concrete and produce concrete with acceptable setting time as well as compressive stress.

5. Summary and Conclusion

In this study, the authors investigated the behavior of various proportions of RFC mixed with plain and retarded ready-mix concrete of a commonly used Nevada ready mix design, namely 101/N45F003. The authors also studied the influence of this RFC under controlled and uncontrolled environments in a laboratory setting by producing and mixing varying proportions of one-hour, two-hour, three-hour, and four-hour old specimens to a fresh mix. Additionally, the researchers investigated the effects of indoor and outdoor mixing, as well as aging, and summarize the results as follows:

- 1) Most specimens showed compressive strengths above the acceptance rate.
- 2) It is possible to mix a higher proportion of RFC with plain concrete compared to retarded concrete.
- 3) It is difficult to estimate the optimum combination of RFC and fresh concrete.
- 4) In order to achieve targeted slump values, additional water has to be added to the mixes.
- 5) Setting time for most sets was higher than the standard time, except for the RFC sample mixed outdoors with plain concrete.

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