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Investigation of Setting Time and Compressive Strength of Ready-Mixed Concrete Blended with Returned Fresh Concrete

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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

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

The Center for Sustainable Transportation Infrastructure (CSTI), in its 2012 study, estimated that out of all the concrete leaving the plant, between 2% and 7% of concrete returns to the plant unused as a returned fresh concrete (RFC). Disposal of both the truck wash water and RFC is a growing concern for the industry. Most industry personnel contacted during the investigation, agree that reusing is superior to recycling of this substantial RFC economically and environmentally. This study will determine if the reuse of RFC in subsequent batches compromises the quality of newly blended concrete.

The effect of RFC on fresh and hardened characteristics of subsequent batches was studied. This research will be performed in a laboratory where setting time and compressive strength will be tested for both the control and blends of varying proportion and age of plain or retarded RFC with subsequent fresh batches.

This study will discover the C1798/C1798M-16 (Standard Procedure for reusing returned fresh ready-mixed concrete) recommendation. In this procedure, it is stated RFC up to 8-hours old at 100F, treated with hydration stabilizing admixture, can be blended in up to 50% proportion with a new batch of RMC without adversely affecting the fresh and hardened characteristics of the blend. The reuse of RFC has been neither explicitly banned nor allowed by end users due to the uncertainties of the effects of the RFC on the properties and characteristics of the blend. This standard procedure has not encouraged the end users to reuse of RFC, despite its liberal allowance of reuse of RFC. Not only that, the prohibitive practices of the states of California and Iowa

experience in the reuse of RFC and the limitations set by ASTM C94 reinforces the negative perception surrounding the reuse of RFC in concrete blends.

A commonly used, Clark County qualified mix design No. 101, was batched both indoors and outdoors. Each batch was tested shortly after batching as a control sample. The concrete was then held for 1hr, 2hrs, 3hrs or 4hrs to simulate RFC. The simulated RFC was then mixed with newly batched concrete in various proportions. Both the control and blends were tested for slump, air entrapped, unit weight, setting time, and compressive strength as per ASTM standard and specifications. Thirty samples blended with indoor batched RFC and other 40 samples blended with outdoor batched RFC were tested in this investigation. The test results of this investigation showed that, for the mix design 101, retarded RFC up to three-hour-old and plain RFC up to two-hour-old can be used in 30% and 20% proportions respectively without affecting the fresh and hardened characteristics of subsequently blended concrete.

LIST OF ABBREVIATIONS

ASTM- American Society for Testing and Materials

AASHTO-American Association of State Highway and Transportation Officials

SSR&BC - Standard Specification for Road and Bridge Construction

USS (Clark County) - Uniform Standard Specifications Clark County Area

RMC – Ready-Mixed Concrete

RFC – Returned Fresh Concrete

IP – Indoor mixed plain RFC

IR – Indoor mixed retarded RFC

OP – Outdoor mixed plain RFC

OR – Outdoor mixed retarded RFC

10:90-1 – 10% one-hour old RFC blended with 90% fresh concrete

50:50-4 - 50% 4-hour old RFC blended with 90% fresh concrete

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DEDICATION

To my spouse, Tsion Tedla:

Her expectation always made me strive more.

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1 INTRODUCTION

1.1 BACKGROUND

Local and national industry practices and specifications of Ready-mixed Concrete (RMC) have placed limitations on delivery time and truck drum revolution; playing into the rise of construction material costs. These limitations are resulting in unnecessary and heightened construction material costs and environmental degradation (Trejo, 2014)

Industry standards and specifications have been devised and revised for the manufacturing, transporting, and placement of RMC. To deliver uniform and consistent concrete to a job site, ready-mixed concrete manufacturers have established various mixture proportions and mixing procedures. Ready-Mixed Concrete is provided by either in-transit mixer or volumetric concrete mixer and can be mixed in central mixers (central-mixed), in transit-mixed (also known as truck-mixed), or with a combination of both (shrink-mixed). Fresh and hardened properties of ready-mixed concrete can be influenced by the mixing process, delivery, and use; therefore, specifications at different time and depth have placed limits on the mixing, transporting and placing of concrete (Anderson, 2003)

It is estimated that out of ready-mixed concrete leaving the plant, between 2% and 7% of concrete returns to the station in the truck unused (Lobo, 1998). The reason for return was either the contractor ordered a little more than was necessary to complete the construction work or rejected due to discharge time or truck drum revolution limit.

RFC is defined as a fresh concrete returned to the manufacturer in a fresh state in a ready-mixed concrete transportation unit (ASTM C1798, 2016). RFC could be either over-ordered, left-over or rejected. Unused RFC incurs a cost due to the creation of reduced yield on raw materials and handling, transporting and tipping. If not used in its fresh state, RFC requires moving and storage space, crushing energy and a significant amount of water. Unused or non-recycled concrete is considered waste and its components contribute to the filling of landfills, increased water usage, depletion of natural resources, increased material transport, and increased greenhouse gas emissions (CSTI, 2010).

1.2 PROBLEM STATEMENT

At least public standards and specifications for construction of the states of California and Iowa permit RFC to be reused for some applications. There is also a standard specification for the reuse of RFC in a new batch of RMC known as ASTM C1798/C1798M-16. However, in the state of Nevada and in the incorporated Clark County, use of RFC neither is explicitly restricted nor is allowed for any sort.

1.3 THESIS OBJECTIVE

The objective of this research is to quantify the effects of concrete mixing variables, specifically mixing time and proportion of old concrete, on concrete setting time and compressive strength. This research will quantify the effect of age and proportion of plain or retarded RFC blended to RMC.

1.4 HYPOTHESIS

Eight hour old RFC at 100F concrete temperature, treated with hydration stabilizing admixture blended in up to 50% proportion to a new batch of RMC can be reused without adversely affecting the fresh and hardened characteristics of the blend.

1.5 SCOPE OF THESIS

Laboratory research will be conducted to meet the study's objective of quantifying the effects of concrete mixing variables, specifically mixing time and proportion of old concrete, on concrete setting time and compressive strength. The laboratory study will focus on evaluating the effect of RFC on fresh and hardened characteristics of RMC blended with RFC to determine age and proportion of RFC blended that would result a blend with comparable fresh and hardened characteristics to that of the control. Tests conducted on the fresh and hardened concrete included temperature, slump, entrapped air content, unit weight, setting time, and compressive strength.

1.6 STRUCTURE OF THESIS

This report is arranged in 9 sections. This section, section 1 introduces RMC and RFC and describes the problem statement, thesis objective, hypothesis, and scope of the research. Section 2 discusses methodology. Section 3 contains literature review on RMC and RFC related standards, specifications and research on RMC discharge and placement limitations, reuse of RFC, and the effect of discharge time and truck drum revolution on fresh and hardened concrete properties. Section 4 describes materials and section 5 details on tests and test procedures. Section 6 follows with results and results will be discussed and analyzed in section 7. And finally, section 8 and 9 present conclusion and recommendations respectively.

2 METHODOLOGY

The following tasks were performed to achieve the objective of the research (Figure 3.1).

Task I: Literature Review

Available standards, specifications and literature relevant to RMC and RFC will thoroughly be reviewed.

Task II: Identify the mix and materials

Commonly used mix design that matches the scope of the investigation will be identified.

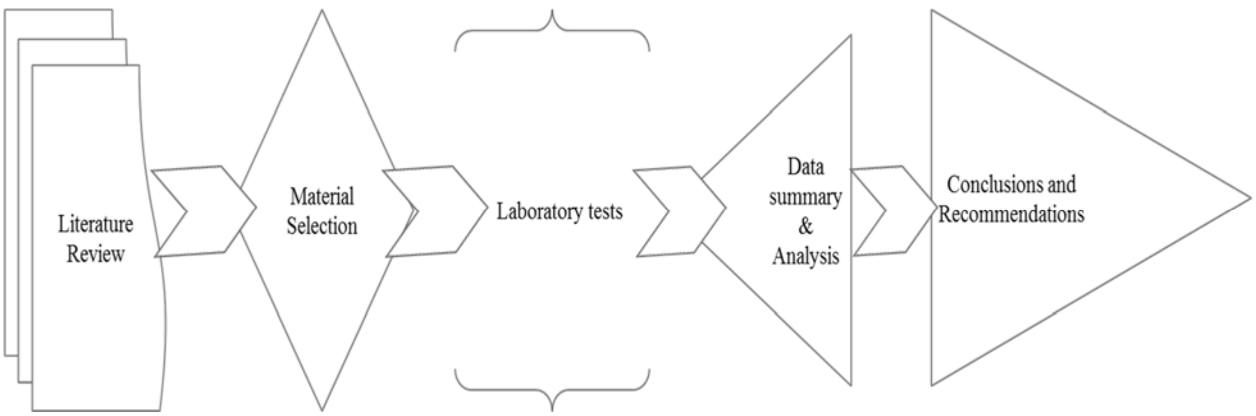

Figure 2-1: Research methodology flow

Task III: Laboratory test and test procedure

The study will be performed both indoors and outdoors to determine the effect of the varying proportion of plain or retarded RFC on subsequent batches of fresh blends. Sampling and test on fresh and hardened blended concrete will be performed as per ASTM standard procedures. Tests on fresh blended concrete will include concrete and ambient temperature, slump, unit weight, entrapped air content and setting time. Moreover, tests on hardened blended concrete will include compressive strength.

TASK IV: Result

Test results will be recorded and reported with notes of all known deviations from the prescribed procedures.

Task V: Analysis

Data will be analyzed for trends and requirement for uniformity of concrete.

TASK VI: Conclusions and Recommendations

Conclusions will be drawn based on the analysis of the extent to which the objectives are met and the degree to which the hypothesis is proven true or false.

3 LITERATURE REVIEW

Local and national specifications and standards on RMC and RFC were reviewed. In addition to specifications and standards, eight studies on the reuse of RFC ranging from 1989 to 2000 and seven studies on the effect of re-tempering, delivery time and truck drum revolution (TDR) on fresh and hardened characteristics of concrete covering from 1963 to 2002 were reviewed.

3.1 LITERATURE ON HISTORY OF READY-MIXED CONCRETE

The history of RMC goes back to 1913 when the first offsite mixed concrete was delivered to a job site in Baltimore, MD. Immediately one year after the first RMC, the Committee ASTM C9 on concrete and concrete aggregates was established (Gorman, 1998). Concrete was mixed and delivered first by a horse-drawn mixer and then Stephen Stepanian of Columbus developed a self-discharging motorized transit mixer, which was followed by gradually modernized ready-mixed concrete trucks (Dewar, 1998).

Due to the relatively low power output of truck/mixers, concrete mixing quality was an imminent issue. To address these imperfections and discrepancies, the National Ready-Mixed Concrete Association (NRMCA) approached the ASTM committee of C9 and the first C94 specification was published in 1935, which limited concrete discharge time to be within 90 minutes after mixing. Further, in 1958, this ASTM standard appended minimum and maximum TDRs.

However, the ASTM has removed the DRC limit and now defers to the purchaser (Trejo, 2014). Though there are attempts to eliminate and defer discharge time limits, the limitation has remained unchanged since its first implementation in 1935. Despite the removal of the drum revolution counts limit by the ASTM, NDOT and Clark County continue to enforce both drum revolution counts and discharge time restrictions.

3.2 LITERATURE ON SPECIFICATIONS ON RMC DISCHARGE & PLACEMENT

Along with ASTM C 94/C 94M and AASHTO M157, there are numerous local and national specifications available that constrain the manufacturing and delivery of RMC. Developed by governmental states or county agencies, the general purpose of these specifications is identical to that of ASTM C 94/C 94M and AASHTO M157 with the amendment that they are adapted to the specific use of their jurisdiction.

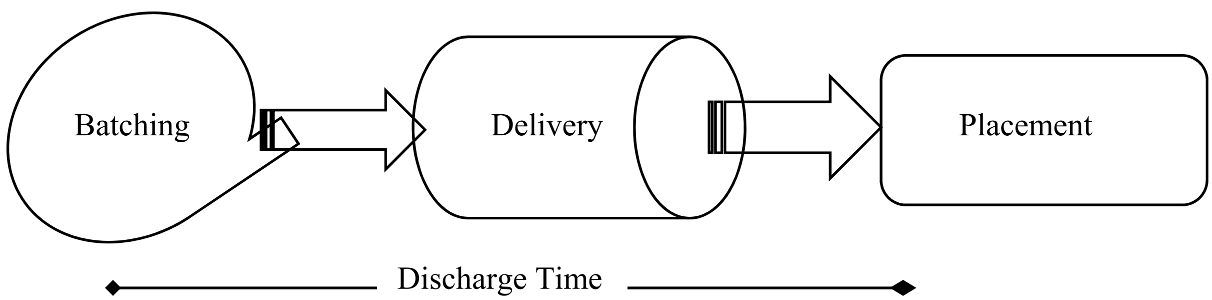

Figure 3-1: Ready-Mixed Concrete (RMC) Timeline

Both ASTM C94/94M and AASHTO M157 state that discharge time shall be 90 minutes. Discharge time is defined as a time between after the introduction of the water to the cement and aggregates or the introduction of the cement, to the aggregates and placement (Figure 3-1). However, the ASTM permits a waiver by the purchaser if the concrete is workable without the addition of water. Standard specifications of NVDOT and Clark County also have a provision for a long haul with a pre-approved mix design or new trial batch. This waiver is seldom used or preferred not to as the reasoning behind the waiver is not well understood (Trejo, 2014).

Earlier versions of ASTM C94/C94M required that RMC shall be discharged before the drum has revolved 300 revolutions after the introduction of the mixing water to the cement and aggregates, or the introduction of the cement to the aggregates (ASTM C94/C94M, 2009). In its latest version, however, it completely removes TDR constraint and leaves it to the discretion of the purchaser and manufacturer, which entitles both the purchaser and manufacturer of establishing a limit in their contract document (ASTM C94/C94M, 2013).

Table 3-1: Comparison of standards and specifications on RMC

Standards/ Specifications	Maximum Time to Discharge, Minutes	Drum Revolutions at Mixing Speed	Maximum Drum Revolutions
ASTM	90	NR	NR
AASHTO	90	NR	NR
SSR&BC(NDOT)	90	70-100	320
SSR&BC(CCBD&S)	90	70-100	300

ASTM- American Society for Testing and Materials
AASHTO-American Association of State Highway and Transportation Officials
SSR&BC - Standard Specification for Road and Bridge Construction
USS(Clark County) - Uniform Standard Specifications Clark County Area

There are differences in concrete placement limits between the standard specifications of Clark County, NDOT, ASTM and AASHTO (Table 3-1). These differences indicate a research gap where a thorough understanding of the effect of each constraint is needed.

3.3 LITERATURE ON THE REUSE OF RFC

It is estimated that out of concrete leaving the plant, between 2% and 7% returns to the facility in the truck unused (STIC, 2010). On a typical day in one of the RMC Suppliers in Henderson, for example, out of the 3,200 Cubic yards produced, 260 cubic yard was reported as RFC, which was either ordered in excess or rejected at the end of a job segment, shift or day (Materials Testing Corporation, 2017).

Due to the restrictions imposed by national and local jurisdictions on RMC and lack of thorough and detailed studies on the subject, RFC has not been addressed either way for use or non-use in most of the States. Returned concrete, as defined in ASTM C1798, is the fresh ready-mixed concrete, either leftover or a significant quantity not used on the construction site, which is returned to the plant in the concrete truck as excess material.

Though seemingly stalled, there have been efforts to advance reuse of RFC beyond the allowance to use it for nonstructural applications, as stipulated in the states of California's and Iowa's respective Standard Specifications for Public Works Construction (CalDRI, 2012). Moreover, industry personnel covered by the industry survey conducted by the author of this thesis indicated that reuse of RFC is somewhat typical for private nonstructural applications. Unfortunately, there are no documents describing best practices of RFC reuse. This is because there hasn't been a shared understanding of the effect the RFC may have, and it happens in the industry that there is this same question 'does reusing RFC in subsequent batches compromise the quality of the blended concrete?' with no substantiated answer.

A detailed review of ready-mixed concrete discharge and placement specifications and literature on placement constraints and RFC reuse will follow.

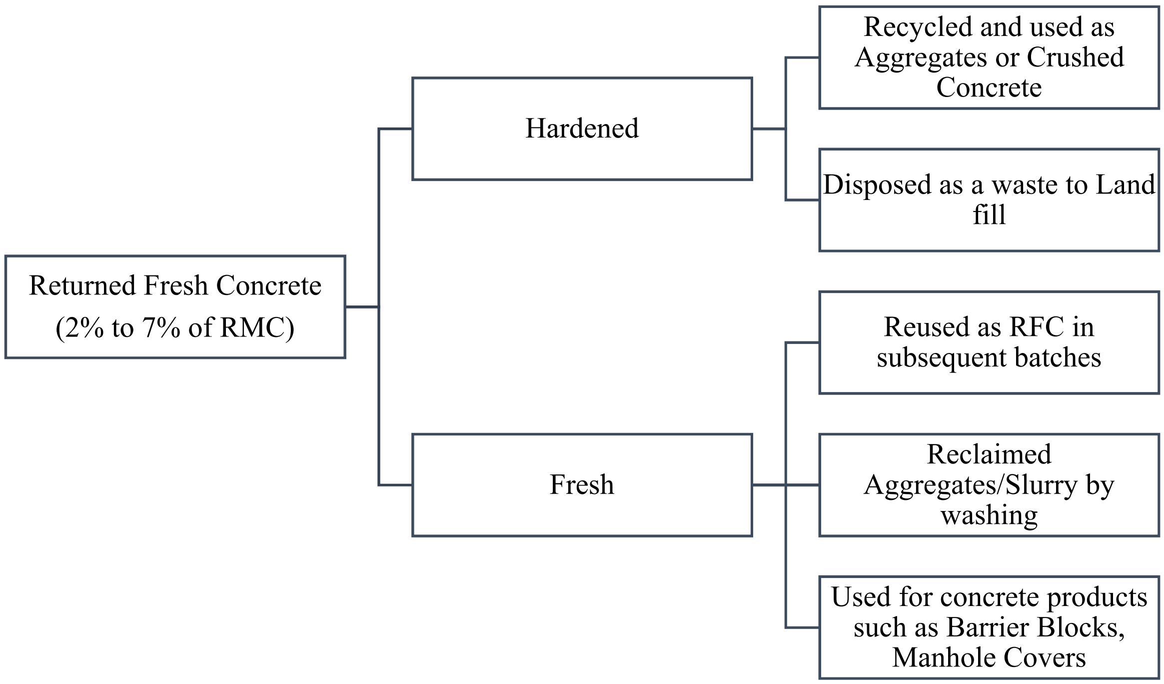

Figure 3-2: RFC reusing, recycling or disposal

RFC is defined as fresh concrete not yet discharged from a ready-mixed concrete transportation unit when it is returned to the manufacturer (Kinney, 1998). RFC could be either over-ordered, left-over concrete or rejected. Contractors over-order either to avoid short notice or to work around and are the primary source of returned concrete. As difficult as it is to match this RFC with a specific mix type to suitable customers on short notice, jurisdiction and user requirements have been stringent in allowing it to blend with subsequent batches (CalDRI, 2012).

RFC is either used in its fresh state in subsequent batches or for precast elements, or washed and used as reclaimed aggregates and slurry where water is required, or hardened and crushed to form base of base aggregate where energy and water is consumed; or otherwise unused and wasted to landfills, which requires storage and energy(figure 3-2). Overall management of fresh RFC incurs a cost due to land for landfills, increased water usage, depletion of natural resources, increased material transport, and increased greenhouse gas emissions (Kazaz, 2016).

To reduce environmental and economic costs of RFC, studies have shown three alternatives:

- Avoidance, which is the first and best way to reduce the amount of concrete subject to return at a job site;
- Reuse, which is the second and not commonly practiced reusing more RFC on subsequent batches before it hardens; and
- Recycle, which is crushing hardened concrete and use as base aggregate or aggregate in new concrete.

Among these, avoidance would be the most preferable as it represents a reduction of the material stream subject to waste or reuse. Reuse, on the other hand, would be next in preference because in theory it could be implemented with little cost to modify the blend and implement controlling mechanisms. Whereas, recycling requires capital and operational expenses for equipment and handling of hardened concrete, which still is a viable alternative to disposal.

Due to discharge time and TDR constraints reuse of RFC seems infamous to deal with. The ASTM seems to loosen the discharge and TDRs constraints and leave them to the discretion of the RMC manufacturers and users. The ASTM has gone further to the extent of publishing standard procedure designated as ASTM C1798/C1798M-16, and at least in the states of California and Iowa, RFC use is permitted for some applications. In the state of Nevada and incorporated Clark County, on the other hand, use of RFC it is neither allowed nor restricted of any sort. Although RFC is not being reused among state DOTs, a survey indicated that public work projects are allowed to reuse RFC in California and Iowa is authorized and encouraged as authorized by respective state's public resources code and standard specifications (CTS and Associates, 2012).

3.4 LITERATURE ON THE EFFECTS OF DISCHARGE TIME AND TDR ON FRESH AND HARDENED CONCRETE CHARACTERISTICS

The two noteworthy attributes of RMC rely upon numerous factors of which TDR and time are essential. TDR and time are reliant on constituent materials' proportion and the environmental conditions amid the complete cycle: blending, conveyance, and placement. To better grasp, the potential effect of these variables, a review of the research will follow.

With the invention of cementitious materials in composition and fineness and introduction of admixtures, various studies have been performed so as to validate the discharge time and TDR limitations imposed since the start of RMC. Most studies have approached the question of how long RMC can be held in a mixer and how many TDR can be tolerated without compromising fresh and hardened characteristics of concrete. These limitations have been everyday hindrances of the ready-mixed concrete producer and the end user. As a matter of fact, they were recognized before 2000 and they seem to get momentum after 2010 due to the emergence of construction sustainability.

Research has been done to study the effect of TDR and discharge time on fresh and hardened characteristics of concrete directly by varying the TDR and/or discharge time and indirectly by varying the re-tempering efforts and ambient and concrete temperatures.

Kirca (2000) studied the influence of mixing time on the workability of a concrete. The results of the study indicated that the extension of mixing time lead to a rise in temperature, and thereby slump loss. Another study by Gaynor (1998) on the effect of prolonged mixing on the rate of a slump, on the other hand, showed an increase in a slump with mixing time with a pronounced effect on high initial slump compared to that of the low initial slump. A study by Mustafa (2014) also proved that the concrete slump loss is proportional to the initial slump level.

Not only workability, but hardened characteristics as a function of discharge time and TDR have also been investigated. Prasittisopin (2013) studied the effect of mixing time and TDR on concrete with fly-ash as a cementitious material and reported that the effect they have on setting time, workability and compressive strength is negative. Moreover, a study to determine the effect of mixing time on compressive strength found that a decreased water to cement ration accounted from the loss of water from evaporation. This then lead to an increase in compressive strength as a function of mixing time. It was also deduced that the longer the mixing time, the more the grinding resulted in finer cement grains and more hydration (Kırca et al., 2002).

Effect of RFC reuse on the fresh and hardened concrete characteristics is related to the effect of extended mixing time, TDR and re-tempering. In this aspect, RFC could impact the fresh and hardened characteristics of a subsequent concrete batch with varying proportions based on:

- Age of the RFC;
- If water was added in the field to re-temper the RFC;
- Dosage of admixture (retarder, water reducer etc.) (CTS, 2012).

4 MATERIALS

A commonly used and a qualified material according to the Clark County Inter-Agency Quality Assurance Committee (IAQAC) mix designated as Nevada Ready Mix and Service Rock Products mix 101, or Cal Portland mix N45F003, or American Eagle Ready Mix AE650FA, or CEMEX's 1577290, was selected. This mix was identified as commonly used and approved by members of the technical committee of Southern Nevada Concrete and Aggregate Association (Table 1).

Table 4-1: Nevada Ready Mix 101 Mix proportion (MTC, 2017)

Constituent	Percentage	Weights, lb.	Specific Gravity	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
¾'', Coarse Aggregate	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^4	154.9
			Water/Cement	0.45
			Aggregate/Cement	5.4

A #67(¾'' rock) coarse aggregate and washed concrete sand all produced at Nevada Ready Mix's Lone Mountain quarry, along with cementitious materials Type V Mitsubishi Cement and Type F Headwaters Fly Ash (20%), and standard municipal water was used. Moreover, additives all from BASF/Master Builders of varying amount of a water-reducing admixture MasterGlenium 3030: Full-range water-reducing concrete admixture (superplasticizer) and set retarder MasterSet Delvo hydration controlling admixture were used.

5 TESTS AND TEST PROCEDURE

The investigation was conducted in two phases to evaluate the effect of age and proportion of RFC on fresh and hardened concrete characteristics:

- The study was first conducted in a controlled environment (indoors) with one-, two-, and three-old RFC blend as a pilot phase.
- It was then decided the investigation would be extended to include an uncontrolled environment (outdoors) where the investigation was performed both in a controlled and uncontrolled environment with one-, two-, three- and four-hours old RFC.

In a normal concrete situation, the basic process control factors are cement, water, aggregate, and additives, if any. On the other hand, in a concrete blended with RFC, there are additional control factors that need to be considered. Feasibility wise, it would be difficult if not impossible to study the RFC control process along with that of the normal case.

To avoid complexity and per the scope of the research, the following factors were deemed important:

1. The concrete mixture proportions
2. The age of RFC(RFC_a) when added to a newly mixed concrete
3. Workability
4. Ambient and concrete temperature (T_A and T_C)
5. The proportion (by mass) of RFC (RFC_p) in the blended batch

These factors either kept constant or variable, further helped to explore the proportion threshold in which RFC can be used in subsequent batches, to determine the application scope of the blend and to propose a control mechanism of the reuse.

Based on the combination of these constant and variable factors, the research evaluated the response variables such as water required to maintain slump, setting time and 28-day compressive strength of the blended concrete.

The mix design No. 101 was batched both indoors and outdoors, and concrete was tested shortly after batching (control). The concrete was then held for 1hr, 2hrs, and 3hours in the pilot phase and for 1hr, 2hrs, 3hrs or 4hrs in the extended phase and mixed with newly batched concrete in various proportions (10:90, 20:80, 30:70, 40:60, and 50:50), for example, 10% RFC and 90% newly batched concrete (Table 5-1).

Ages of concrete were simulated to RFC by holding the concrete for 1hr, 2hrs, 3hrs, and 4hrs while restoring workability at 4+1 inches by re-tempering with water or superplasticizer as indicated on the schematic in figure 5-1.

Table 5-1: Experimental Run Plan

Indoor mixing(I)								Outdoor mixing(O)							
Concrete type	RFC$_p$, %	RFC$_a$, Hrs	Blend ID	Concrete type	RFC$_p$, %	RFC$_a$, Hrs	Blend ID	Concrete type	RFC$_p$, %	RFC$_a$, Hrs	Blend ID	Concrete type	RFC$_p$, %	RFC$_a$, Hrs	Blend ID
	10	1	IR10:90-1		10	1	IP10:90-1				OP10:90-1		10	1	OR10:90-1
		2	IR10:90-2			2	IP10:90-2				OP10:90-2			2	OR10:90-2
		3	IR10:90-3			3	IP10:90-3				OP10:90-3			3	OR10:90-3
											OP10:90-4			4	OR10:90-4
	20	1	IR20:80-1		20	1	IP20:80-1			1	OP20:80-1		20	1	OR20:80-1
		2	IR20:80-2			2	IP20:80-2				)P20:80-2			2	OR20:80-2
		3	IR20:80-3			3	IP20:80-3				)P20:80-3			3	OR20:80-3
		4	IR20:80-4								)P20:80-4			4	OR20:80-4
Retarded(R)	30	1	IR30:70-1		30	1	IP30:70-1	Plain(P)	30		)P30:70-1	Retarded(R)	30	1	OR30:70-1
		2	IR30:70-2			2	IP30:70-2			2	OP30:70-2			2	OR30:70-2
		3	IR30:70-3			3	IP30:70-3			3	OP30:70-3			3	OR30:70-3
										4	OP30:70-4			4	OR30:70-4
	40	1	IR40:60-1		40	1	IP40:60-1		40	1	OP40:60-1		40	1	OR40:60-1
		2	IR40:60-2			2	IP40:60-2			2	OP40:60-2			2	OR40:60-2
		3	IR40:60-3			3	IP40:60-3			3	OP40:60-3			3	OR40:60-3
		4	IR40:60-4			4	IP40:60-4			4	OP40:60-4			4	OR40:60-4
	50	1	IR50:50-1		50	1	IP50:50-1		50	1	OP50:50-1		50	1	OR50:50-1
		2	IR50:50-2			2	IP50:50-2			2	OP50:50-2			2	OR50:50-2
		3	IR50:50-3			3	IP50:50-3			3	OP50:50-3			3	OR50:50-3
										4	OP50:50-4			4	OR50:50-4

Key:
I-Indoor Mixed
P-Plain RFC
10-10% RFC
90-90% RMC
1-1-hour old RFC

Key:
O-Outdoor Mixed
P-Plain RFC
20-20% RFC
80-80% RMC
2-2-hours old RFC

Key:
I-Indoor Mixed
R-Retarded RFC
20-20% RFC
80-80% RMC
2-2-hours old RFC

RFC$_p$ – proportion of RFC
RFC$_a$ – age of RFC

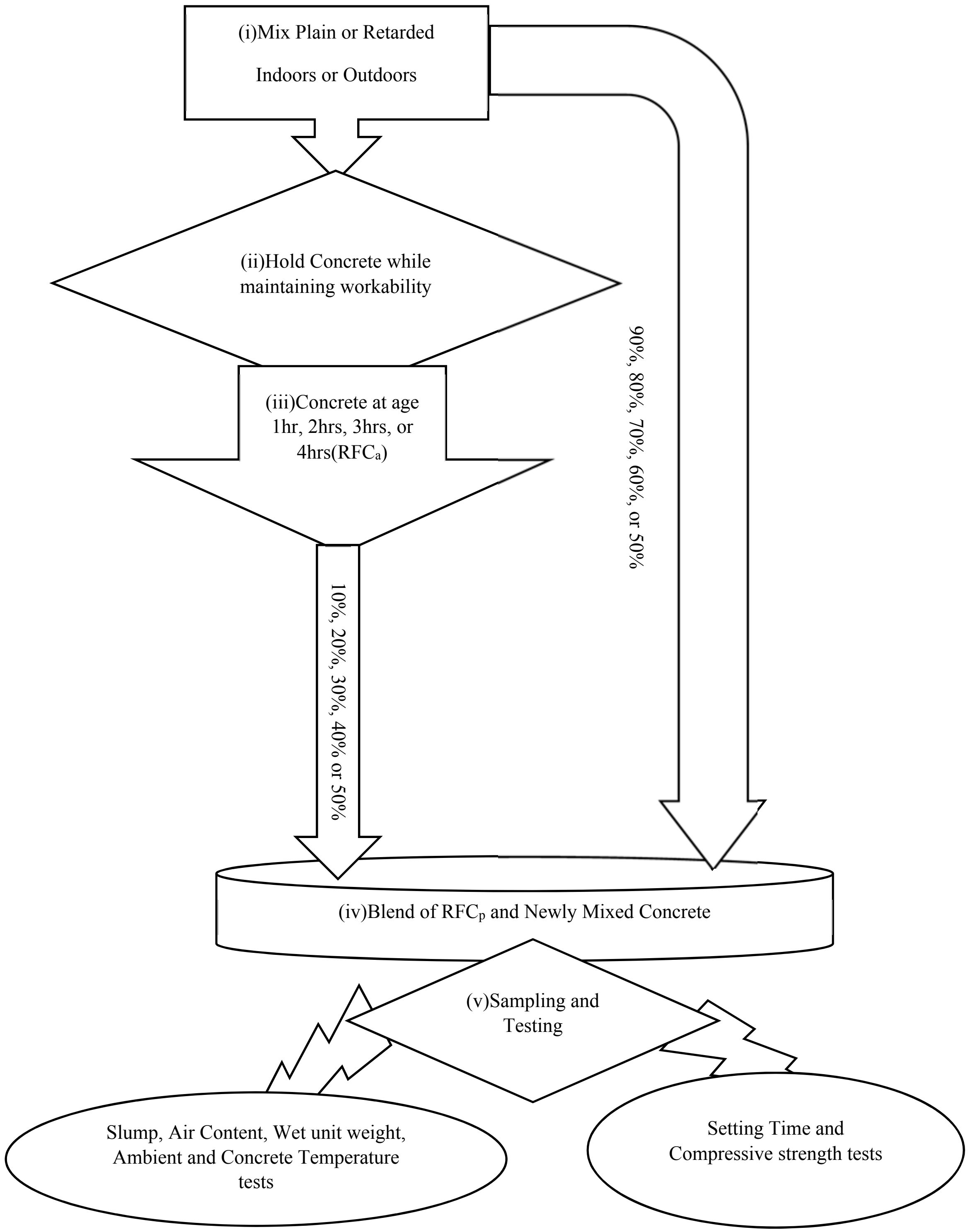

Figure 5-2: Experiment Plan Scheme

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

1. Concrete temperature (ASTM 1064),
2. Slump (ASTM C143),
3. Unit weight (ASTM C138)
4. Entrapped air (ASTM C231)
5. Setting time (ASTM C403)

Moreover, to determine the effect of age and proportion of RFC on compressive strength, a set of five 4-in by 8-in cylinders were molded (ASTM C192) from a sample of each control and concrete blended with a varying proportion of RFC. All cylinders were removed from the molds and placed in the standard moist room with free moisture on all their surfaces until they were tested for compressive strength (ASTM C39) one, three and one cylinders at an age of 7-, 28- and 56-days respectively.

6 RESULTS

Test data were collected and recorded as per respective ASTM standards. Test results are displayed below along with a comparison of test results for the fresh and hardened characteristics of the control mix to see if there was any evidence of significant batch-to-batch differences. Fresh and hardened concrete characteristics of control batches at various times of the research cycle are as shown in Table 6-1.

Table 6-1: Fresh and hardened characteristic test results of control mix batches

Mix ID	GLENIUM (oz/cwt)	Water (gal/CY)	DELVO (oz/cwt)	Temp (F) Amb	Temp (F) Conc	Slump (in)	Unit Weight	Entrapped Air (%)	Set Time(min) Inside	Set Time(min) Outside	Compressive Strength(psi) 7DD	Compressive Strength(psi) 28DD	Compressive Strength(psi) 56DD
IP0:100	1.0		N/A	86	73	3.25	155.6	2.1	330	300	4570	7120	8290
IP0:100	0.0		N/A	101	74	3.50	154.0	2.7	300	220			
IP0:100	2.0		N/A	107	76	3.25	154.8	2.6	290	200			
IP0:100	2.0		N/A	110	84	3.50	154.8	2.5	315	210	4720	7030	8910
IR0:100	1.0		0.0	86	73	3.25	155.6	2.1	330	300	4570	7120	8290
IR0:100	0.0		0.0	101	74	3.50	154.0	2.7	300	220			
IR0:100	2.0		0.0	107	76	3.25	154.8	2.6	290	200			
IR0:100	2.0		0.0	110	84	3.50	154.8	2.5	315	210	4720	7030	8910
OP0:100	0.0		N/A	84	75	3.00	155.6	1.8	350	340	3830	5620	8290
OP0:100	4.0		N/A	109	84	4.00	156.2	1.9	345	245	5160	7490	8720
OP0:100	0.0		N/A	106	88	3.00	156.0	1.4	300	225	5000	6730	8150
OP0:100	4.0		N/A	103	83	4.00	157.6	1.4	340	270	5670	7140	8650
OR0:100	4.0		0.0	109	84	4.00	156.2	1.9	345	245	5160	7490	8720
OR0:100	0.0		0.0	106	88	3.00	156.0	1.4	300	225	5000	6730	8150
OR0:100	4.0		0.0	103	83	4.00	157.6	1.4	340	270	5670	7140	8910
OR0:100	0.0		0.0	84	75	3.00	155.6	1.8	350	340	3830	5620	8290
			Mean	101	80	3.4	155.6	2.1	321	251	4825	**6745**	8523
		Std. Dev.	**ASTM C192**			2.00	2.5	0.8			574	812	
			Actual			0.38	1.06	0.50			591	622	307
			Coefficient of Variance			11%	1%	24%			12%	12%	4%

Fresh and hardened characteristics at various times of similar weather conditions were close and within the limits of reproducing similar batches (Tables 6-1 thru 6-5). The results for the effect of age and proportion of indoor or outdoor mixed and plain or retarded RFC on subsequent batches are as follows. Results will be displayed as the effect of age and proportion of RFC on fresh and hardened characteristics of subsequent batches (Tables 6-2 thru 6-5)

Table 6-2: Fresh and hardened characteristic test results of RMC blend with indoor mixed plain RFC

Mix ID	GLENIUM (oz/cwt)	Water (gal/CY	DELVO (oz/cwt)	Temp (F) Amb	Temp (F) Conc	Slump (in)	Unit Weight (pcf)	Entrapped Air (%)	Set Time(min) Inside	Set Time(min) Outside	Compressive Strength(psi) 7DD	28DD	56DD
IP10:90-1	2.0		N/A	70	71	3.50	155.8	2.3	345	390	5050	7120	8980
IP10:90-2	2.0		N/A	78	70	3.25	154.8	2.4	345	330	4430	6580	8220
IP10:90-3	5.3		N/A	96	73	3.00	156.6	3.0	270	240	5060	7140	8930
IP20:80-1	1.5		N/A	82	72	3.00	157.2	2.4	315	300	4770	6810	8110
IP20:80-2	4.0		N/A	80	71	3.00	155.8	2.5	330	270	4650	6940	8430
IP20:80-3	8.0		N/A	98	72	3.00	157.2	2.6	270	210	5290	7380	9540
IP30:70-1	3.0		N/A	86	72	3.50	155.6	2.8	345	300	5260	7370	8350
IP30:70-2	2.2		N/A	77	70	3.00	155.2	2.5	285	270	4680	6680	8380
IP30:70-3	8.0		N/A	97	73	3.00	159.2	2.1	270	225	5170	7640	8710
IP40:60-1	3.3		N/A	90	72	3.00	155.2	2.6	315	270	5200	7640	8800
IP40:60-2	6.0		N/A	80	72	3.50	155.6	2.4	270	240	4980	7330	8690
IP40:60-3	10.0		N/A	97	72	3.50	155.8	2.8	240	180	5430	7980	9370
IP50:50-1	4.6		N/A	82	69	3.00	156.0	2.6	315	270	5410	7460	8350
IP50:50-2	8.4		N/A	77	68	3.50	157.0	2.5	300	285	5050	6810	8580
IP50:50-3	10.0		N/A	101	72	3.25	154.8	2.5	255	185	4360	6790	7540
			Mean	86	71	3.20	156.1	2.5	298	264	4986	7178	8599
		Std. Dev.	ASTM C192			2.00	2.5	0.8			574		
			Actual			0.24	1.2	0.2			337	409	500
		Coefficient of Variance				7%	1%	9%			7%	6%	6%

Table 6-3: Fresh and hardened characteristic test results of RMC blend with outdoor mixed plain RFC

Mix ID	GLENIUM (oz/cwt)	Water (gal/CY	DELVO (oz/cwt)	Temp (F) Amb	Temp (F) Conc	Slump (in)	Unit Weight (pcf)	Entrapped Air (%)	Set Time(min) Inside	Set Time(min) Outside	Compressive Strength(psi) 7DD	28DD	56DD
OP10:90-1	8.0	0.0	N/A	109	86	4.00	152.1	2.6	360	270	6700	9460	10740
OP10:90-2	4.0	0.0	N/A	110	80	3.00	154.7	1.8	345	210	5120	7160	8310
OP10:90-3	4.0	5.0	N/A	112	80	3.00	157.2	2.0	270	210	5040	7360	8510
OP10:90-4	4.0	4.0	N/A	110	84	4.00	157.2	1.7	250	195	4710	7040	8000
OP20:08-1	4.0	0.0	N/A	110	78	4.00	155.0	1.9	310	225	5180	7460	8500
OP20:08-2	4.0	0.0	N/A	104	80	4.75	157.4	2.1	300	240	6920	8900	10110
OP20:08-3	4.0	7.0	N/A	109	79	4.50	156.8	2.1	290	195	4990	6800	7460
OP20:08-4	4.0	4.0	N/A	100	84	5.25	156.8	1.5	270	195	4110	6160	6840
OP30:70-1	4.0	0.0	N/A	107	78	3.00	155.8	1.8	330	220	4430	7160	9000
OP30:70-2	4.0	4.0	N/A	100	71	4.25	157.0	1.7	300	245	5230	7320	8560
OP30:70-3	4.0	2.0	N/A	105	85	4.00	157.2	1.5	280	190	5200	7100	8270
OP30:70-4	4.0	1.0	N/A	95	88	4.00	156.0	1.5	225	180	4610	6650	7760
OP40:60-1	4.0	0.0	N/A	108	78	3.75	157.4	1.8	305	210	4810	7550	8100
OP40:60-2	4.0	1.0	N/A	100	77	4.75	156.5	1.6	345	240	5300	7180	8340
OP40:60-3	4.0	4.0	N/A	100	85	3.25	155.4	2.0	250	195	4850	6920	8080
OP40:60-4	4.0	4.0	N/A	99	84	4.00	158.8	1.6	230	180	4680	6050	7420
OP50:50-1	4.0	0.0	N/A	109	77	4.00	155.5	1.7	340	210	4770	6780	7830
OP50:50-2	4.0	3.0	N/A	98	75	3.00	157.2	2.1	330	240	5400	7450	8470
OP50:50-3	4.0	6.0	N/A	107	79	4.50	156.4	1.7	285	205	4410	6460	7340
OP50:50-4	4.0	1.0	N/A	106	90	5.00	155.2	1.5	255	180	4020	5670	6660
		Mean		104	81	4.13	156.5	1.8	290	209	5024	6976	8046
		Std. Dev.	ASTM C192			2.00	2.5	0.8			574		
			Actual			0.68	1.4	0.3			719	866	964
		Coefficient of Variance				17%	1%	16%			14%	12%	12%

As can be seen from the tables, the fresh and hardened concrete characteristics of the blend with indoor or outdoor mixed plain RFC at the research times were close enough and within the limits of reproducing similar batches of concrete. This is reflected in the slump, unit weight, entrapped air content and compressive strength results in Tables 6-2 and 6-3. The single-operator standard deviations for a slump, unit weight, air content, and 7-day compressive strength of the blend with outdoor mixed plain RFC, for example, have been found to be 0.7 in., 1.4 lb/ft^3, 0.3 %, and 719 psi, respectively. The results don't differ from the single laboratory standard deviation indicated in the precision statement of ASTM C 192, Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory.

Table 6-4: Fresh and hardened characteristic test results of RMC blend with indoor mixed retarded RFC

Mix ID	GLENIUM (oz/cwt)	Water (gal/CY	DELVO (oz/cwt)	Temp (F)		Slump (in)	Unit Weight	Entrapped Air (%)	Set Time(min)		Compressive Strength(psi)		
				Amb	Conc				Inside	Outside	7DD	28DD	56DD
IR10:90-1	2.0		5.0	98	70	3.50	154.6	2.4	325	245	4970	6900	8590
IR10:90-2	3.0		10.0	90	72	3.75	155.4	2.3	365	285	4900	7020	8610
IR10:90-3	5.0		10.0	108	79	5.00	155.0	2.5	350	240	5330	7500	9100
IR20:80-1	5.0		5.0	101	75	3.25	154.8	2.5	350	260	4970	7350	9290
IR20:80-2	3.0		5.0	92	71	3.25	155.6	2.3	340	255	5070	7310	9410
IR20:80-3	6.0		10.0	106	76	3.00	155.8	2.7	360	255	5740	7990	9200
IR20:80-4	4.0		10.0	112	79	3.00	155.0	2.8	350	220	4990	7510	8890
IR30:70-1	1.0		5.0	103	75	3.50	154.8	2.5	340	230	4060	6610	8180
IR30:70-2	5.6		5.0	87	71	3.00	156.2	2.2	320	270	5040	7460	8960
IR30:70-3	2.0		10.0	107	75	3.50	154.0	2.5	375	295	4980	6960	8470
IR30:70-4	8.0		10.0	105	78	3.50	157.0	1.8	345	255	5320	7340	8600
IR40:60-1	4.0		5.0	95	71	3.25	155.4	2.7	375	285	5390	7750	9760
IR40:60-2	6.0		10.0	103	78	3.50	154.6	2.6	415	300	5610	7840	9070
IR40:60-3	5.0		10.0	95	79	3.00	156.6	1.8	325	270	4890	7370	8560
IR50:50-1	4.0		5.0	97	71	3.25	154.8	2.5	385	300	5420	7500	9720
IR50:50-2	5.5		10.0	103	73	3.50	155.0	2.4	475	330	4490	6960	8820
		Mean		100	75	3.42	155.3	2.4	362	268	5073	7336	8952
		Std. Dev.	ASTM C192			2.00	2.5	0.8			574		
			Actual			0.48	0.8	0.3			412	370	450
		Coefficient of Variance				14%	1%	12%			8%	5%	5%

Table 6-5: Fresh and hardened characteristic test results of RMC blend with outdoor mixed retarded RFC

Mix ID	GLENIUM (oz/cwt)	Water (gal/CY	DELVO (oz/cwt)	Temp (F)		Slump (in)	Unit Weight	Entrapped Air (%)	Set Time(min)		Compressive Strength(psi)		
				Amb	Conc				Inside	Outside	7DD	28DD	56DD
OR10:90-1	8.0	0.0	2.0	109	86	4.00	152.1	2.6	360	270	6700	9460	10740
OR10:90-2	4.0	3.0	2.0	103	81	4.00	155.8	1.8	410	280	5290	7190	8260
OR10:90-3	4.0	1.0	2.0	93	78	4.00	155.6	1.6	420	300	4470	6410	
OR10:90-4	4.0	3.0	7.0	84	75	4.50	152.0	1.4	475	385	4700	6960	
OR20:80-1	4.0	2.0	2.0	104	79	4.00	156.0	1.7	380	300	5320	7170	7980
OR20:80-2	4.0	3.0	2.0	102	80	4.00	156.4	2.0	375	300	6280	8290	
OR20:80-3	4.0		2.0	94	77	3.75	153.6	1.7	330	255	4850	6950	
OR20:80-4	4.0	5.0	4.0	85	74	3.00	154.1	1.4	390	330	5540	7350	
OR20:80-4R	4.0	3.0	5.0	81	69	3.00	154.3	1.8	460	400	5420	7690	
OR30:70-1	4.0	4.0	2.0	102	74	3.75	156.6	2.1	390	330	5190	7260	8830
OR30:70-2	4.0		2.0	93	78	3.75	154.4	1.9	330	255	4310	6230	
OR30:70-3	4.0	2.0	5.0	86	77	4.00	154.0	1.6	450	360	5530	6880	
OR30:70-4	4.0	5.0	5.0	83	71	4.00	154.4	1.6	410	350	4740	6330	
OR30:70-4R	4.0	3.0	4.0	81	74	3.50	154.1	1.9	420	360	5140	7420	
OR40:60-1	4.0	2.0	2.0	97	75	4.00	155.6	2.1	375	285	4270	6340	7250
OR40:60-2	4.0	7.0	5.0	101	78	4.50	156.4	1.7	385	305	5460	7650	
OR40:60-3	4.0	4.0	5.0		76	4.00	155.2	1.2		310	4600	6180	
OR40:60-4	4.0	5.0	8.0	87	70	4.00	154.8	1.5	400	325	5800	7230	
OR50:50-1	4.0	3.0	2.0	100	77	4.50	156.4	1.6	375	300	5080	6690	8100
OR50:50-2	4.0	7.0	5.0	101	78	4.00	156.5	1.7	390	330	4950	6370	
OR50:50-3	4.0	7.0	7.0	90	67	3.75	152.0	2.0	400	315	5360	6850	
OR50:50-4	4.0	6.0	7.0	91	79	3.50	153.9	1.6	420	360	5550	7420	
			Mean	94	76	3.89	154.7	1.8	397	318	5207	7105	8527
		Std. Dev.	ASTM C192			2.00	2.5	0.8			574		
			Actual			0.39	1.3	0.2			598	758	791
			Coefficient of Variance			10%	1%	14%			11%	11%	9%

7 ANALYSIS

7.1 PRECISSION AND BIAS

Single- and multiple-operator precision were used to verify the repeatability and reproducibility of the test results. This was determined by calculating standard deviation of the test results and showed test results were within the limits of ASTM C192 (Table 7-1)

Table 7-1: Precision and bias comparison

Precission and bias				
Test results / Blends/batches	Slump, in	Unit Weight, pcf	Air Content, %	7-day Compressive Strength, psi
ASTM C192, Unit operator	2.0	2.5	0.8	574
ASTM C192, Multi operator	2.8	4.0	1.1	981
Control	0.4	1.1	0.5	591
Outodoor mixed plain RFC	0.7	1.4	0.3	719
Outodoor mixed Retarded RFC	0.4	1.3	0.2	598

7.2 EFFECT OF RFC ON FRESH CHARACTERISTICS OF CONCRETE

Effects of age and proportion of RFC on fresh characteristics of subsequent batches will be assessed in the following section.

7.2.1 EFFECT OF RFC ON SLUMP

As the workability was maintained to be between 3 and 5 inches, the effect of RFC on workability will be assessed on the amount of re-tempering water required to maintain slump. The amount of additional water needed to maintain the slump of the retarded or plain RFC are as shown in Figures 7-1, 7-2, 7-3, and 7-4 in both XY and bar chart, as a function of the age and proportion of RFC. Amount of water required was dependent on age and proportion of RFC where retarded RFC required more than that of plain. As can be depicted in figures 7-1 and 7-4, all concrete blends required a significant amount of water to compensate the slump loss due to age and proportion of plain or retarded RFC.

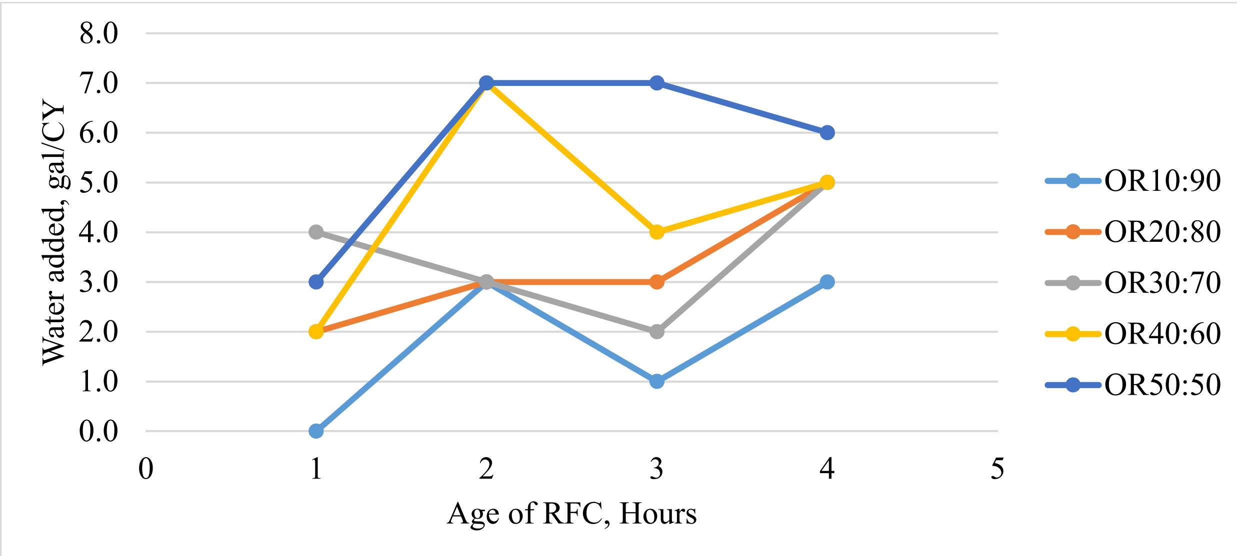

Figure 7-1: Effect of age and proportion of outdoor mixed retarded RFC on Water demand to maintain slump at 4+1 inches

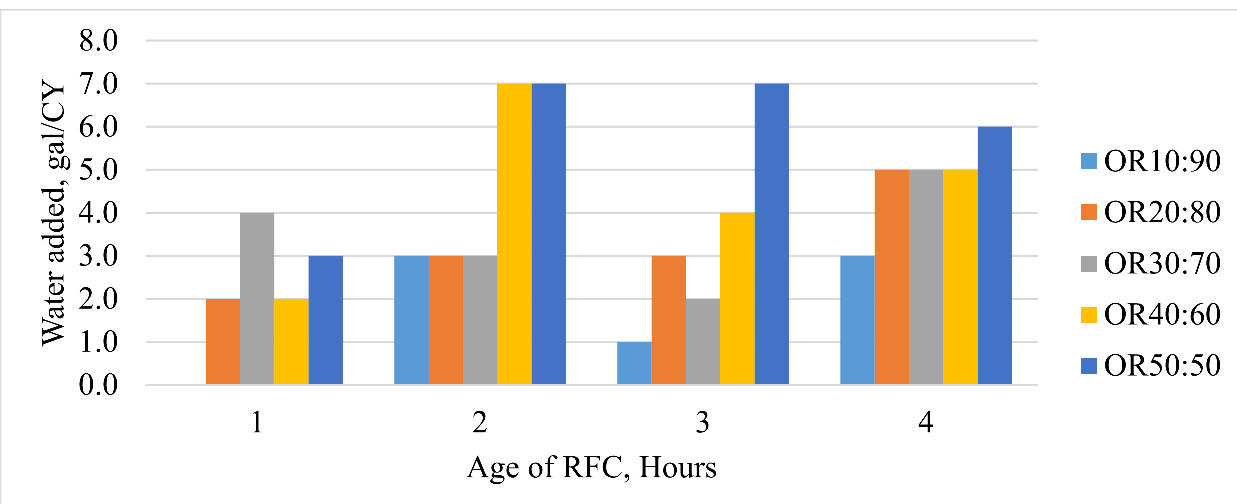

Figure 7-2: Effect of age and proportion of outdoor mixed retarded RFC on water demand to maintain slump at 4+1 inches

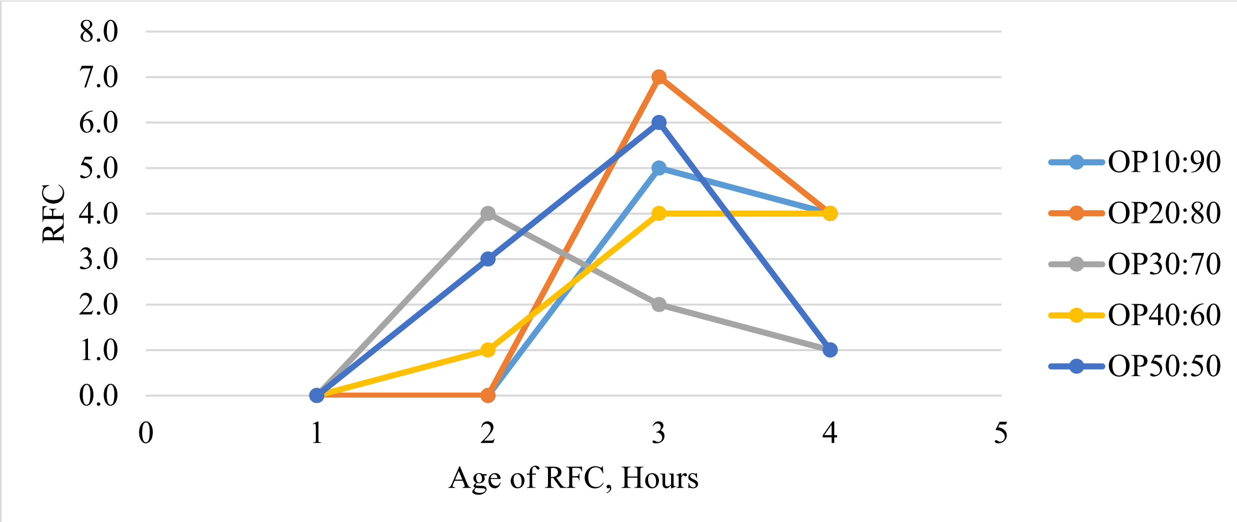

Figure 7-3: Effect of age and proportion of outdoor mixed plain RFC on water demand to maintain slump at 4+1 inches

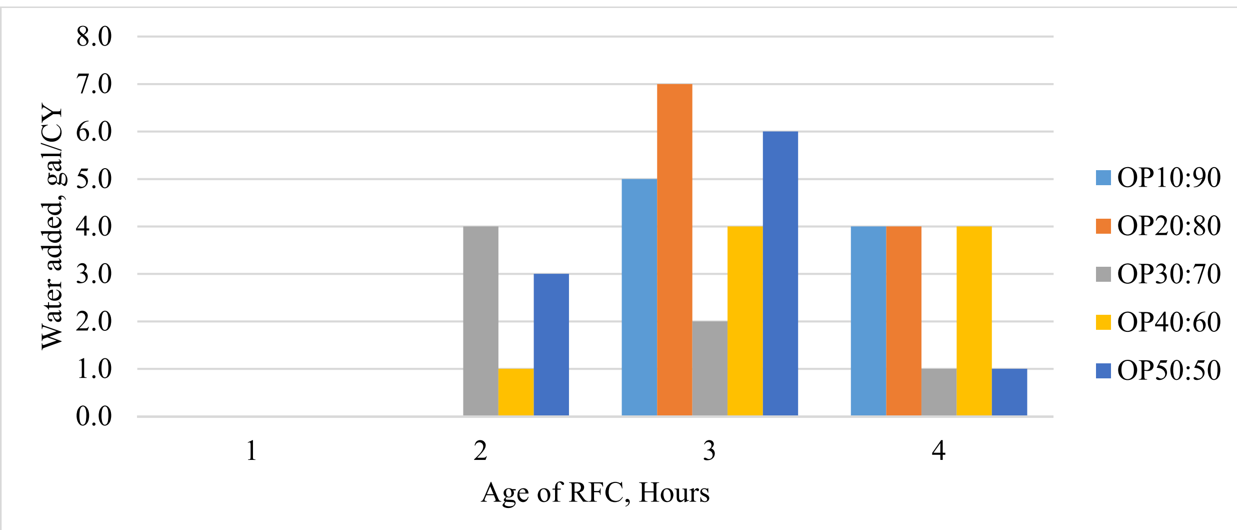

Figure 7-4: Effects of age and proportion of outdoor mixed plain RFC on water demand to maintain slump at 4+1 inches

Overall mixing water required increased with age and proportion of RFC.

7.2.2 EFFECT OF RFC ON SETTING TIME

The effect of age and proportion of plain or retarded RFC on the setting time of subsequent batches is shown in Figures 7.5 thru 7.12. Results indicate that; for one-, two-, and three-hour old indoor mixed plain RFC, setting time as measured from the time of sampling declined to approach to that of the control mix. As can be seen from Figure 7.5 and 7.6, when plain RFC is reused and mixed with fresh material, the older "original" concrete tended to control the resulting setting time of the blend concrete, but the amount of old concrete (10%, 20%, 30%, 40% or 50%) had only a minimal effect on the setting time except for 3-hour old RFC. This seems to prove that concrete held for two hours behaves like fresh concrete as the hydration reaction is not complete yet. The true simulation of the real world is better reflected in sample tested for setting time outdoors (Figure 7.6). The trend depicted that, except for one- and two-hour old 10% RFC blend concrete, up until three-hour old RFC for all proportions the concrete seems to set equivalently with decreasing trend with age of RFC.

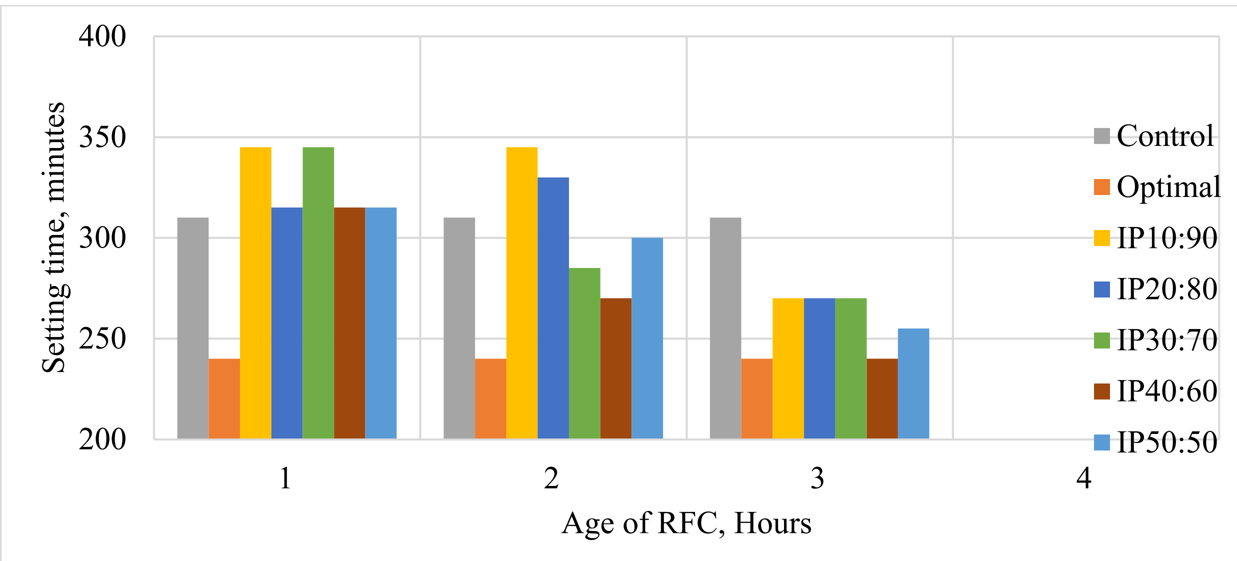

Figure 7-5: Effects of age and proportion of indoor mixed plain RFC on setting time of subsequent batches blended with RFC, sample tested indoors

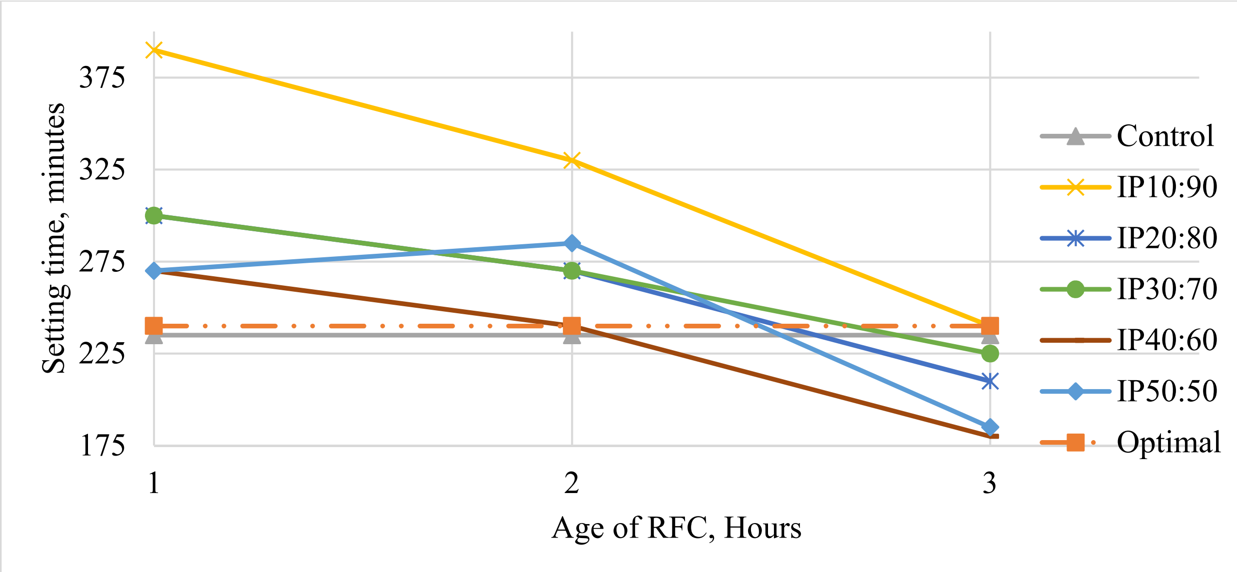

Figure 7-6: Effects of age and proportion of indoor mixed plain RFC on setting time of subsequent batches blended with RFC, sample tested outdoors

For one- and two-hour-old indoor mixed retarded RFC, on the other hand, indoor sampled setting time as measured from the time of sampling showed increments and then equates to the control mix. This seems likely to prove that all proportions of three old RFC will have no effect on the setting time of the blend. This is attributed to the effect of the retarder. As can be seen from Figure 7.7 and 7.8, all proportions have shown setting time higher than the control mix.

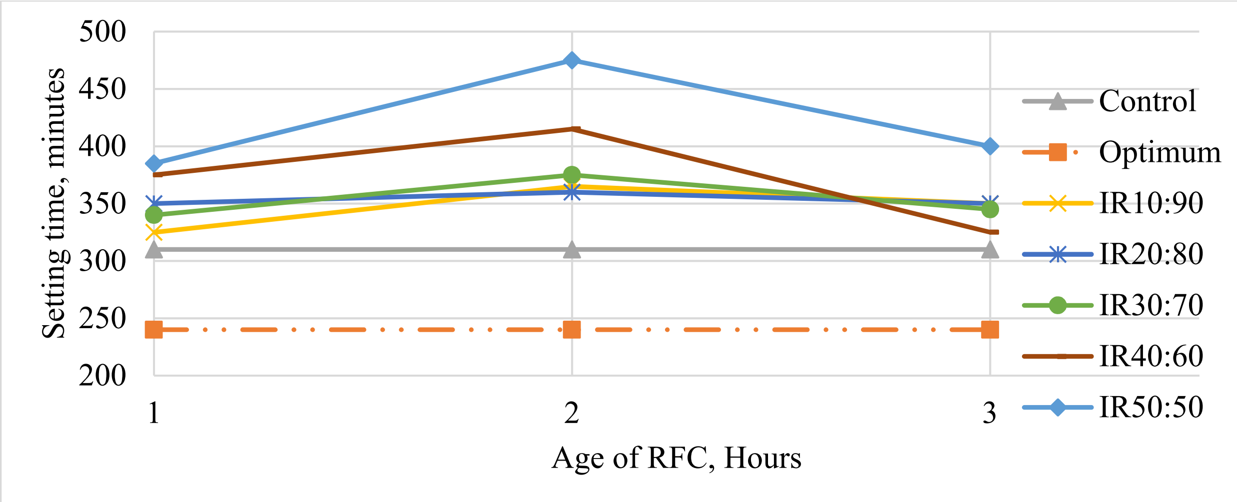

Figure 7-7: Effects of age and proportion of indoor mixed retarded RFC on setting time of subsequent batches with RFC, sample tested indoors

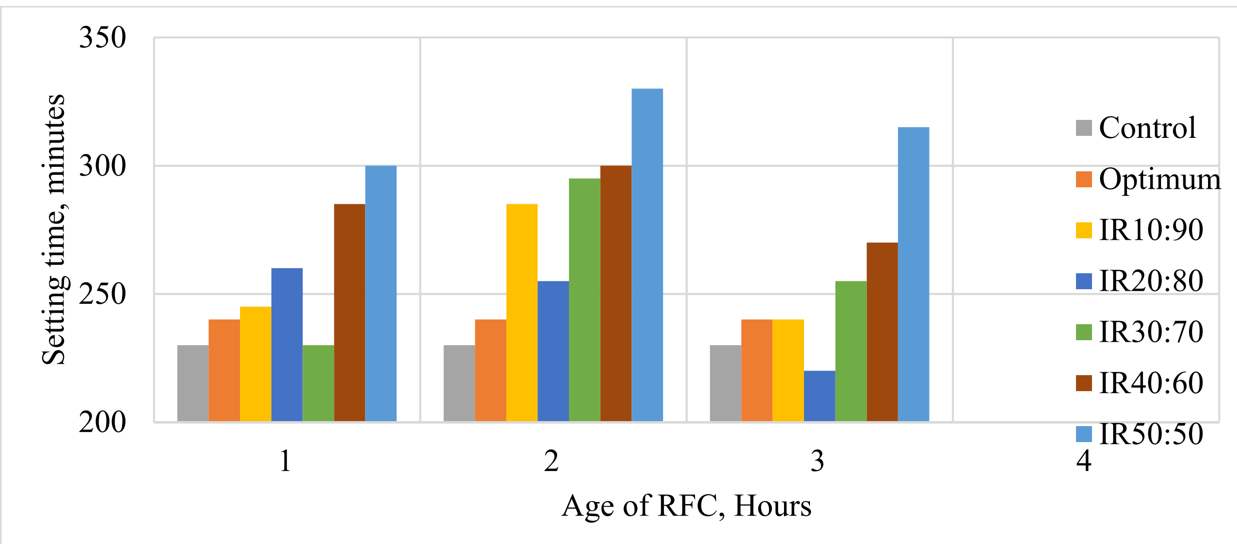

Figure 7-8: Effects of age and proportion of indoor mixed retarded RFC on setting time of subsequent batches with RFC, sample tested outdoors

Setting time, in general, was lower than the control mix and showed steady or insignificantly increasing for all proportions for 1- and 2-hour old outdoor mixed plain RFC and declined then after (Figure 7-9). This seem to support the setting time recorded for blends with indoor mixed plain RFC (Figure 7-6), which age and proportion of RFC has insiginificant effect on the blend up until two hours.

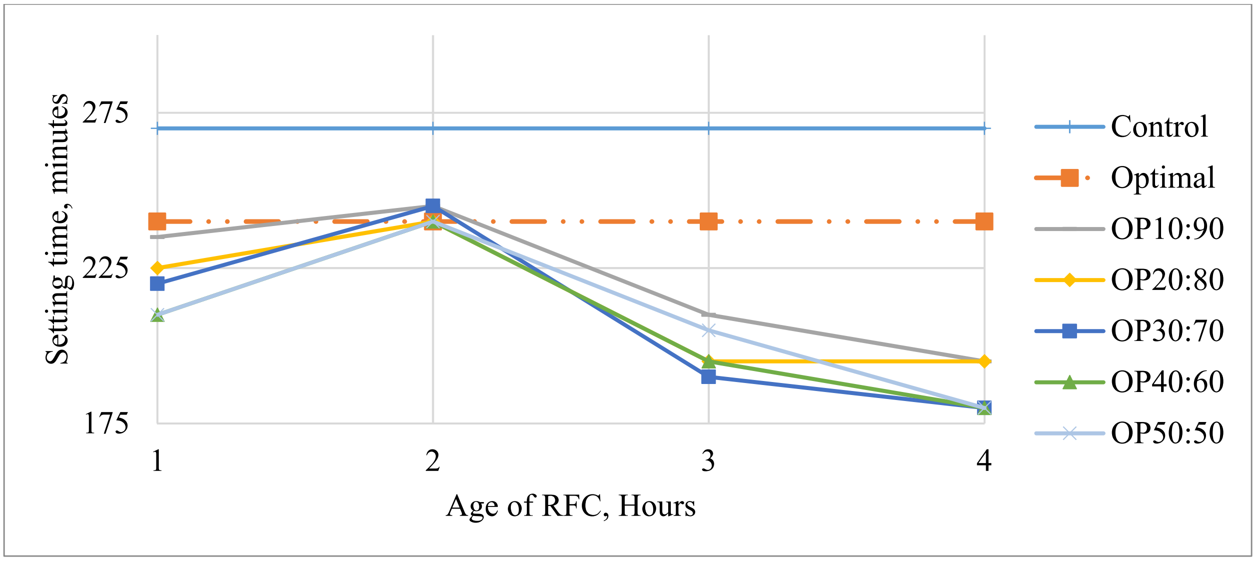

Figure 7-9: Effects of age and proportion of outdoor mixed plain RFC on setting time of subsequent batches with RFC, outdoor tested

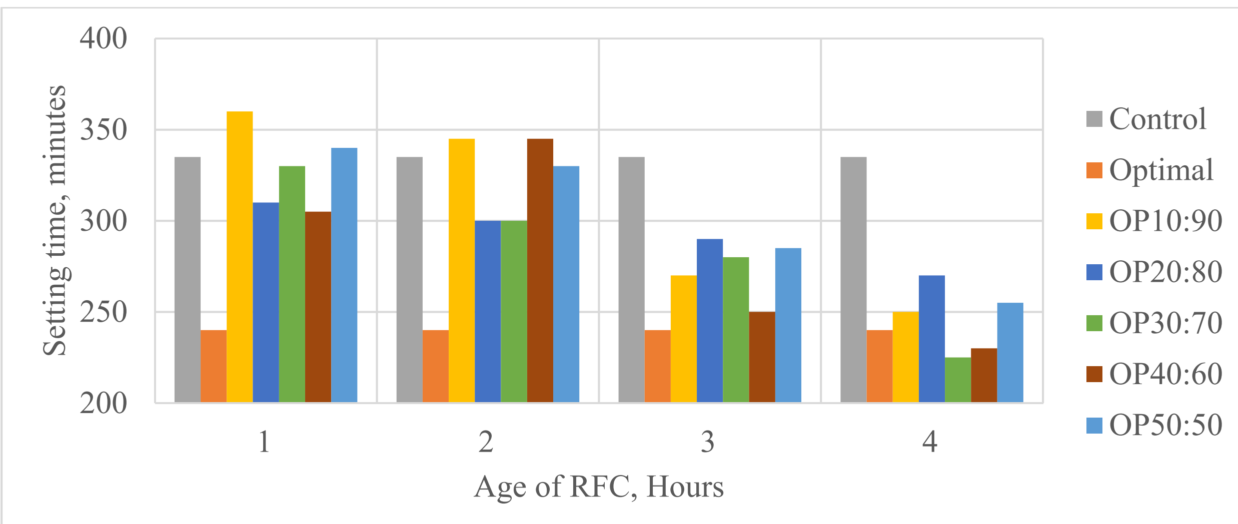

Figure 7-10: Effects of age and proportion of outdoor mixed plain RFC on setting time of subsequent batches with RFC, indoor tested

For all age and proportions of outdoor mixed retarded RFC, on the other hand, setting time, in general, was higher than the control mix and showed increasing trend for all proportions (Figures 7-11 and 7-12).

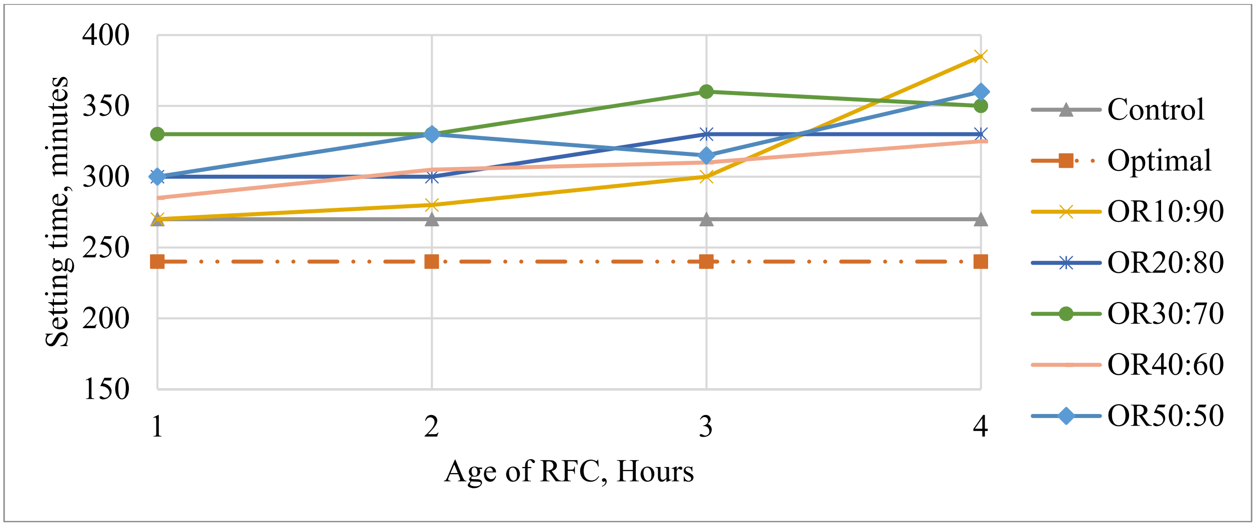

Figure 7-11: Effects of age and proportion of outdoor mixed retarded RFC on setting time of subsequent batches with RFC, outdoor tested

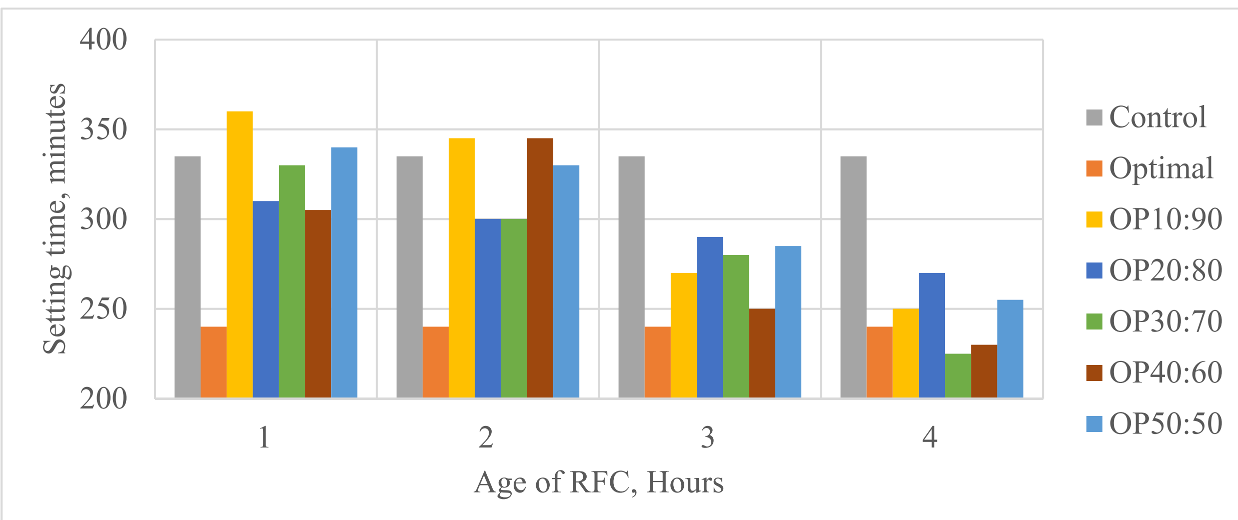

Figure 7-12: Effects of age and proportion of outdoor mixed retarded RFC on setting time of subsequent batches with RFC

7.3 EFFECT OF RFC ON HARDENED CHARACTERISTICS OF CONCRETE

7.3.1 EFFECT OF RFC ON COMPRESSIVE STRENGTH

7.3.1.1 Effect of Plain RFC on Compressive Strength

Five 4' by 8' cylinders were molded from each control and blended concrete after all admixtures and RFC were mixed. The 7-, 28- and 56-day Compressive Strength test results for these mixtures are given in Tables 6.1 thru 6.5, section 6. The effect of age and proportion of indoor or outdoor mixed, plain or retarded RFC is provided in figures 7.9 thru 7.12.

All proportions except for 20:80 showed less compressive strength in 2-hour than in 1-hour but higher in 3-hour old indoor-mixed plain RFC (Figure 7.9).

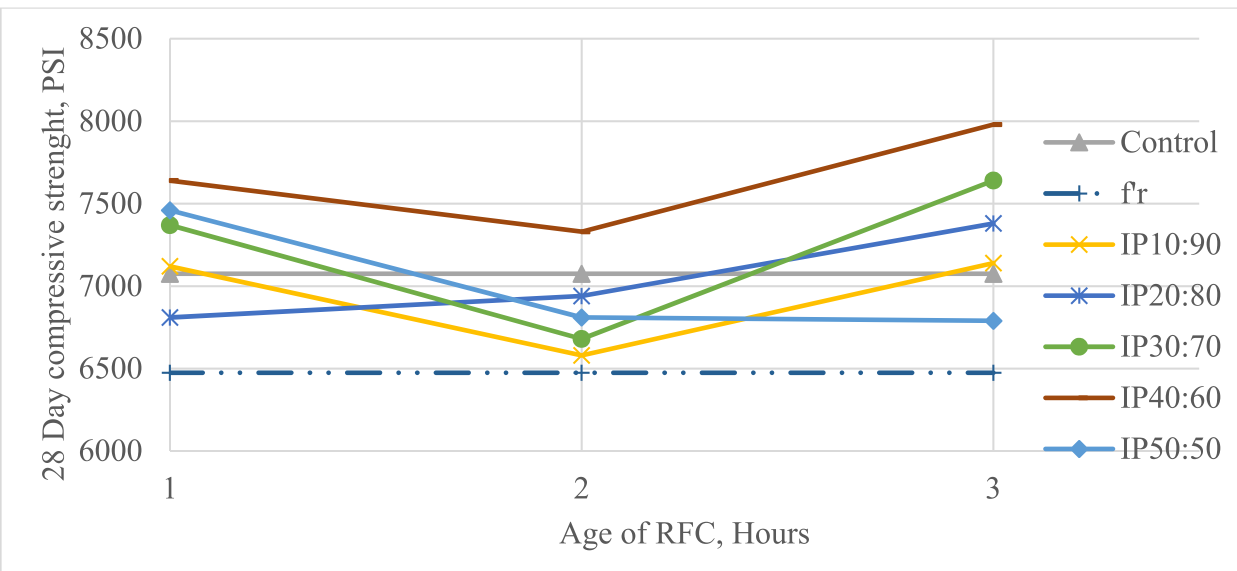

Figure 7-13: Effects of age and proportion of indoor mixed plain RFC on compressive strength of subsequent batch with RFC.

For outdoor-mixed plain RFC, on the contrary, 28-day compressive strength result showed an increase in the 2-hour old RFC but decreased in the 3-hour and 4-hour old RFC

(Figure 7.14). This is likely due to the temperature and grinding effect on water cement ratio. Up until two hours temperature affects the RFC to lose water favoring low water cement ration and after two hours the grinding effect causes aggregates finer thereby increasing the water cement ratio.

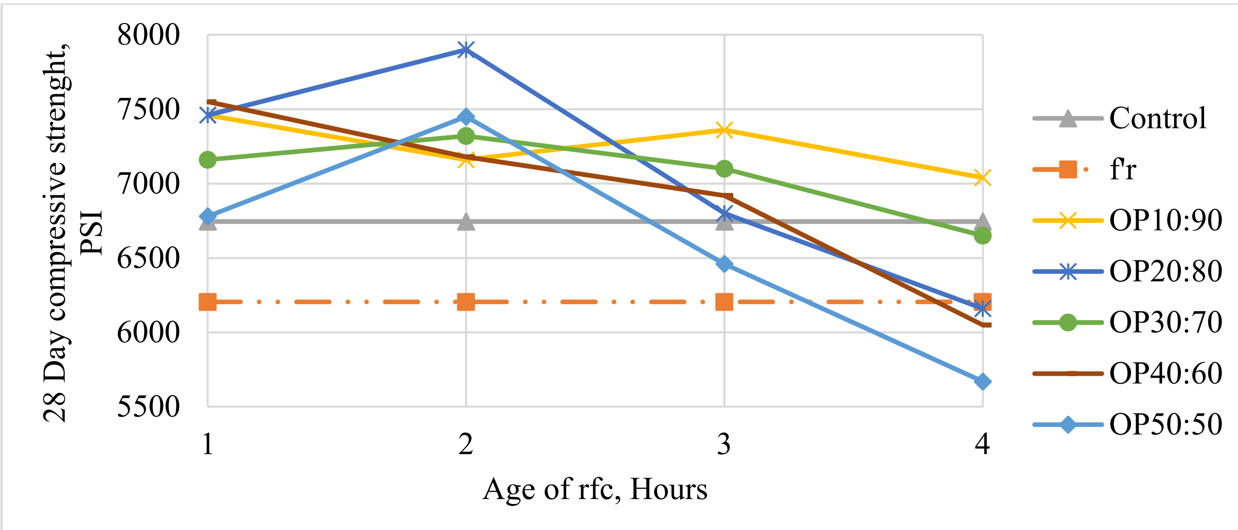

Figure 7-14: Effects of age and proportion of outdoor mixed plain RFC on compressive strength of subsequent batches with RFC

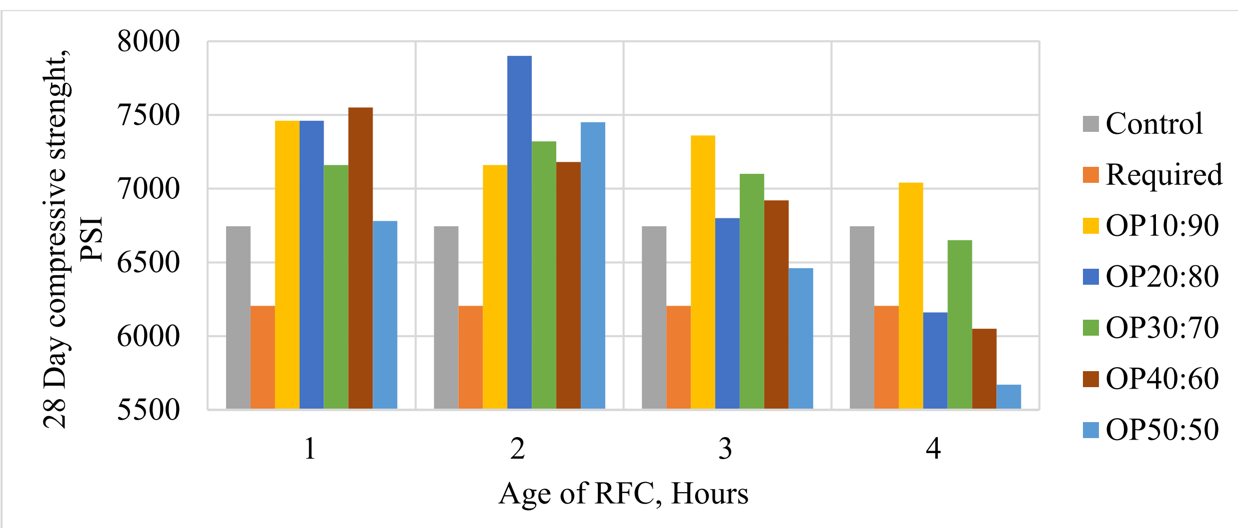

Figure 7-15: Effects of age and proportion of outdoor mixed plain RFC on compressive strength of subsequent batches with RFC

For all age and proportions of outdoor plain RFC compressive strength was higher than the control mix except at age 3hrs for OP40:60 and beyond and at age 4 for OP30:70 and beyond (Figures 7-14 and 7-15).

7.3.1.2 Effect of Retarded RFC on Compressive Strength

For indoor-mixed retarded RFC, on the contrary, 28-day compressive strength result showed an increase for the 2-hour old RFC and about equal for the 3-hour as to the 1-hour old proportion (Figure 7-16).

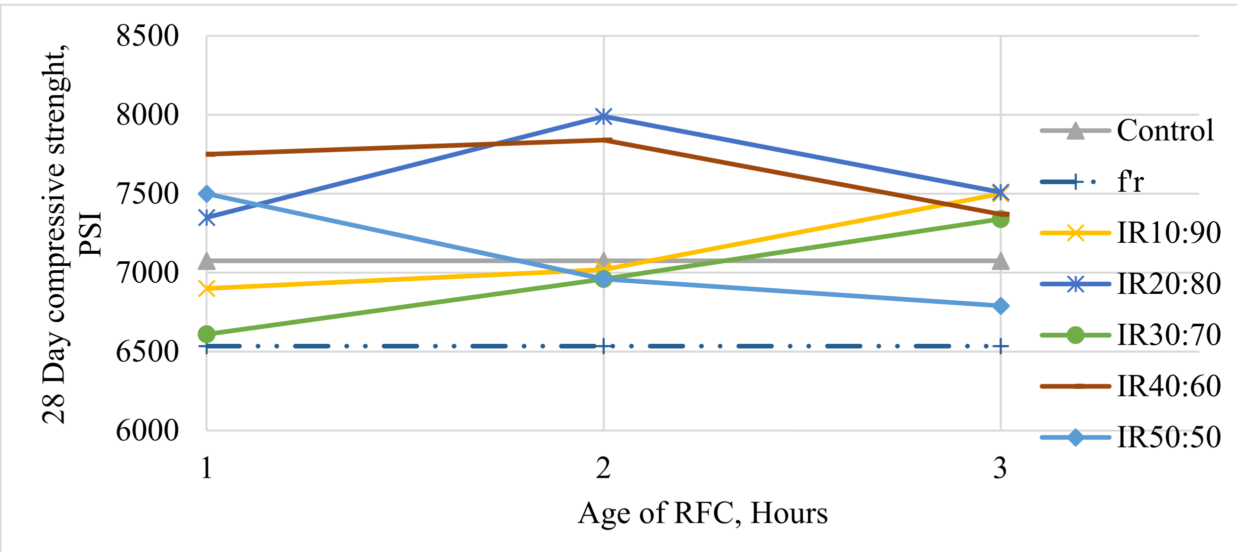

Figure 7-16: Effects of age and proportion of indoor mixed retarded RFC on compressive strength of subsequent batches with RFC

For outdoor-mixed retarded RFC, 28-day compressive strength result showed an insignificant increase between the 1-, 2-, and 3-hour old RFC but decreased for the 4-hour old RFC (Figure 7-17). This substantiates the effect indoor mixed plain RFC as can be seen in Figure 7-13.

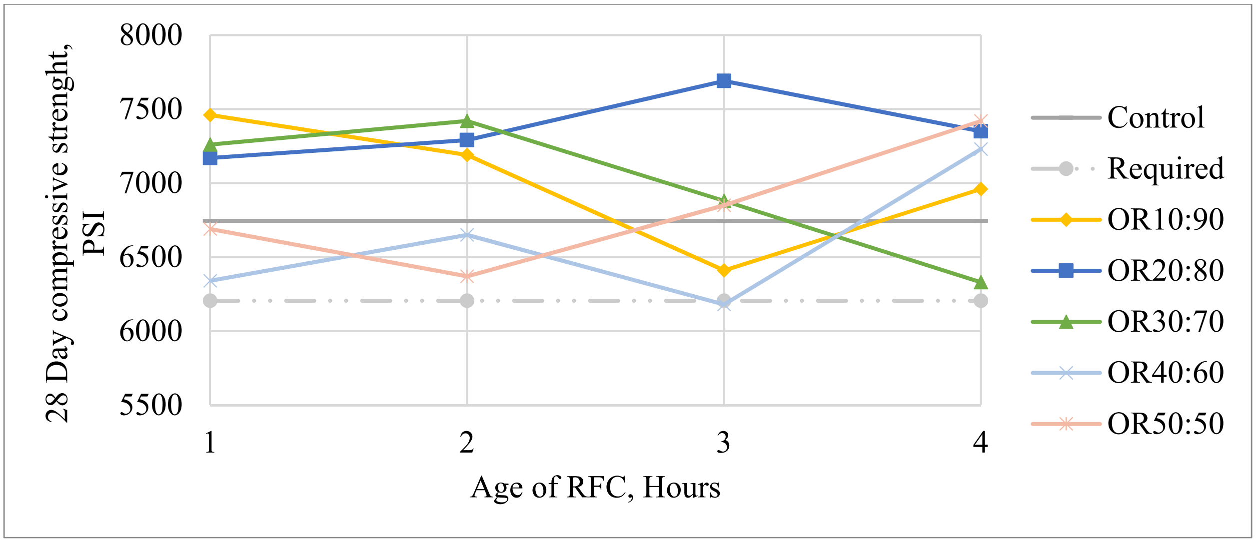

Figure 7-17: Effects of age and proportion of outdoor mixed retarded RFC on compressive strength of subsequent batches with RFC

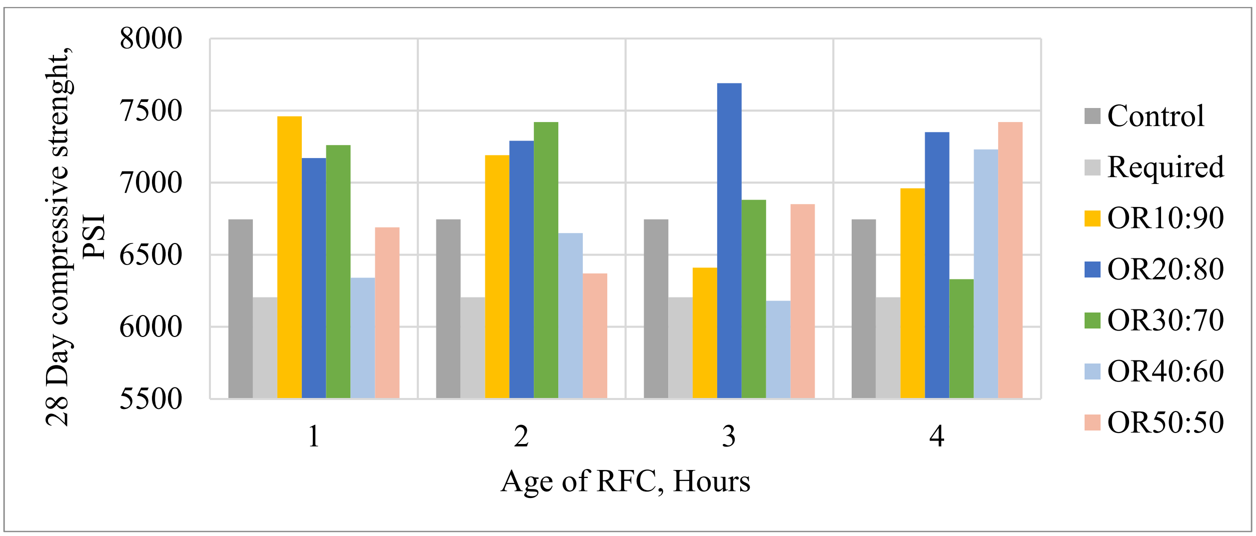

Figure 7-18: Effects of age and proportion of outdoor mixed retarded RFC on compressive strength of subsequent batches with RFC

Overall, blends with all ages and proportions of indoor or outdoor mixed RFC, 28-day compressive strength test results show higher than the required average compressive strength (ASTM C94/C94M, 2017) but only those of 10:90, 20:80 and 30:70 proportions showed higher than the control mix.

8 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

8.1 SUMMARY

The effect of RFC on subsequent blended RMC was investigated and the age and proportion of RFC that would have comparable fresh and hardened characteristics as that of the control has been determined. Even though concrete was mixed indoor and outdoor, only outdoor results are summarized below as to consider the worst scenario.

Table 8-1:Summary of setting time and compressive strength of RMC blended with outdoor mixed plain or retarded RFC as compared control

Mix	Setting Time, min				Compressive Strength, psi			
	@1hr Old RFC	@2hrs Old RFC	@3hrs Old RFC	@4hrs Old RFC	@1hr Old RFC	@2hrs Old RFC	@3hrs Old RFC	@4hrs Old RFC
Control	250				6750			
OP10:90	270	210	210	195	9460	7160	7360	7040
OP20:80	225	240	195	195	7460	8900	6800	6160
OP30:70	220	245	190	180	7160	7320	7100	6650
OP40:60	210	240	195	180	7550	7180	6920	6050
OP50:50	210	240	205	180	6780	7450	6460	5670
OR10:90	**270**	**280**	**300**	**385**	**9460**	**7310**	**7190**	6960
OR20:80	**300**	**300**	**255**	**330**	**7170**	**8290**	**6950**	7350
OR30:70	**330**	**255**	**360**	**350**	**7260**	**7420**	**6880**	6330
OR40:60	285	305	310	325	6340	7650	7410	7230
OR50:50	300	330	315	360	6690	6370	6850	7420

Setting time of all blends of RMC and outdoor mixed plain RFC fall below that of control mix whereas those with outdoor mixed retarded RFC surpass the control mix. As far as compressive strength is concerned, subsequent batches blended with:

1. Up to 40% of 3 hours old outdoor mixed plain RFC;
2. Up to 50% of 2 hours old outdoor mixed plain RFC;
3. 20% of 4 hours old outdoor mixed retarded RFC; and
4. 30% of 3 hours old outdoor mixed retarded RFC fall above that of control.

Table 8-2: Summary of setting time and compressive strength of RMC blended with outdoor mixed plain or retarded RFC as compared to economical

Mix	Setting Time, min				Compressive Strength, psi			
	@1hr Old RFC	@2hrs Old RFC	@3hrs Old RFC	@4hrs Old RFC	@1hr Old RFC	@2hrs Old RFC	@3hrs Old RFC	@4hrs Old RFC
Optimum	180				6200			
OP10:90	**270**	**210**	**210**	**195**	**9460**	**7160**	**7360**	7040
OP20:80	**225**	**240**	**195**	**195**	**7460**	**8900**	**6800**	6160
OP30:70	**220**	**245**	**190**	**180**	**7160**	**7320**	**7100**	6650
OP40:60	**210**	**240**	**195**	**180**	**7550**	**7180**	**6920**	6050
OP50:50	**210**	**240**	**205**	**180**	**6780**	**7450**	**6460**	5670
OR10:90	**270**	**280**	**300**	**385**	**9460**	**7310**	**7190**	6960
OR20:80	**300**	**300**	**255**	**330**	**7170**	**8290**	**6950**	7350
OR30:70	**330**	**255**	**360**	**350**	**7260**	**7420**	**6880**	6330
OR40:60	**285**	**305**	**310**	**325**	**6340**	**7650**	**7410**	7230
OR50:50	**300**	**330**	**315**	**360**	**6690**	**6370**	**6850**	7420

Considering an optimal setting time of 180 minutes and required compressive strength all mixes with both plain and retarded outdoor mixed RFC surpass optimal except the mixes with proportion of 40% 4-hours old plain outdoor mixed RFC.

8.2 CONCLUSIONS

In this investigation only one commonly used mix picked and factors included were few due to the scope of the study. Even then the test results boost the confidence that widening the scope and incorporating most factors for further study seems feasible.

Age and proportion of RFC both greatly impact water requirements to restore workability. The effect was also greatly dependent on the use of retarder on RFC. During the investigation minimum and maximum ambient temperature was 95F and 109F and that of concrete was 71F and 90F respectively.

In conclusion, assuming similar mix proportion in a comparable working environment the following can be concluded.

1. Three hours old retarded RFC can be used with a maximum proportion of 30%
2. Two hours old retarded RFC can be used with a maximum proportion of 40%
3. Two hours old plain RFC can be used with a maximum proportion of 20%

Table 8-3: Maximum age and proportion of RFC at maximum re-tempering water allowed to maintain slump

Mix with	Maximum Age, Hours	Maximum Proportion, %	Maximum Retempering Water, gal/CY
Plain RFC	2	20	0.0
Retarded RFC	3	30	5.0
Retarded RFC	2	40	3.0

8.3 RECOMMENDATIONS

I. Though it requires a thorough research and study, as per the study results on the most common mix, it is advisory to:
   a. Limit RFC usage to projects and conditions where setting characteristics are less critical
   b. Limit age and proportion of RFC to 2 hours old and 20% plain RFC maximum respectively
   c. Limit age and proportion of RFC to 3 hours old and 30% retarded RFC maximum respectively

II. Further investigation is recommended on the same mix design in half an hour old interval of the RFC and in both cold and hot seasons of southern Nevada.

III. Further investigation is recommended on other common mix designs as an individual and when mixed to other closely related mix designs.

APPENDIX A: TEST RESULTS OF CONTROL RMC

Mix ID	GLENIUM (oz/cwt)	Water (gal/CY	DELVO (oz/cwt)	Temp (F)		Slump (in)	Unit Weight	Entrapped Air (%)	Set Time(min)		Compressive Strength, PSI		
				Amb	Conc				Inside	Outside	7DD	28DD	56DD
IP0:100	1.0		N/A	86	73	3.25	155.6	2.1	330	300	4570	7120	8290
IP0:100	0.0		N/A	101	74	3.50	154.0	2.7	300	220			
IP0:100	2.0		N/A	107	76	3.25	154.8	2.6	290	200			
IP0:100	2.0		N/A	110	84	3.50	154.8	2.5	315	210	4720	7030	8910
IR0:100	1.0		0.0	86	73	3.25	155.6	2.1	330	300	4570	7120	8290
IR0:100	0.0		0.0	101	74	3.50	154.0	2.7	300	220			
IR0:100	2.0		0.0	107	76	3.25	154.8	2.6	290	200			
IR0:100	2.0		0.0	110	84	3.50	154.8	2.5	315	210	4720	7030	8910
OP0:100	0.0		N/A	84	75	3.00	155.6	1.8	350	340	3830	5620	8290
OP0:100	4.0		N/A	109	84	4.00	156.2	1.9	345	245	5160	7490	8720
OP0:100	0.0		N/A	106	88	3.00	156.0	1.4	300	225	5000	6730	8150
OP0:100	4.0		N/A	103	83	4.00	157.6	1.4	340	270	5670	7140	8650
OR0:100	4.0		0.0	109	84	4.00	156.2	1.9	345	245	5160	7490	8720
OR0:100	0.0		0.0	106	88	3.00	156.0	1.4	300	225	5000	6730	8150
OR0:100	4.0		0.0	103	83	4.00	157.6	1.4	340	270	5670	7140	8910
OR0:100	0.0		0.0	84	75	3.00	155.6	1.8	350	340	3830	5620	8290
			Mean	101	80	3.4	155.6	2.1	321	251	4825	**6745**	8523
		Std. Dev.	**ASTM C192**			2.00	2.5	0.8			574	812	
			Actual			0.38	1.06	0.50			591	622	307
			Coefficient of Variance			11%	1%	24%			12%	12%	4%

APPENDIX B: TEST RESULTS OF RMC WITH PLAIN OR RETARDED INDOOR MIXED RFC

Mix ID	GLENIUM (oz/cwt)	Water (gal/CY	DELVO (oz/cwt)	Temp (F) Amb	Temp (F) Conc	Slump (in)	Unit Weight (pcf)	Entrapped Air (%)	Set Time (min) Inside	Set Time (min) Outside	Compressive Strength, PSI 7DD	28DD	56DD
IP10:90-1	2.0		N/A	70	71	3.50	155.8	2.3	345	390	5050	7120	8980
IP10:90-2	2.0		N/A	78	70	3.25	154.8	2.4	345	330	4430	6580	8220
IP10:90-3	5.3		N/A	96	73	3.00	156.6	3.0	270	240	5060	7140	8930
IP20:80-1	1.5		N/A	82	72	3.00	157.2	2.4	315	300	4770	6810	8110
IP20:80-2	4.0		N/A	80	71	3.00	155.8	2.5	330	270	4650	6940	8430
IP20:80-3	8.0		N/A	98	72	3.00	157.2	2.6	270	210	5290	7380	9540
IP30:70-1	3.0		N/A	86	72	3.50	155.6	2.8	345	300	5260	7370	8350
IP30:70-2	2.2		N/A	77	70	3.00	155.2	2.5	285	270	4680	6680	8380
IP30:70-3	8.0		N/A	97	73	3.00	159.2	2.1	270	225	5170	7640	8710
IP40:60-1	3.3		N/A	90	72	3.00	155.2	2.6	315	270	5200	7640	8800
IP40:60-2	6.0		N/A	80	72	3.50	155.6	2.4	270	240	4980	7330	8690
IP40:60-3	10.0		N/A	97	72	3.50	155.8	2.8	240	180	5430	7980	9370
IP50:50-1	4.6		N/A	82	69	3.00	156.0	2.6	315	270	5410	7460	8350
IP50:50-2	8.4		N/A	77	68	3.50	157.0	2.5	300	285	5050	6810	8580
IP50:50-3	10.0		N/A	101	72	3.25	154.8	2.5	255	185	4360	6790	7540
			Mean	86	71	3.20	156.1	2.5	298	264	4986	7178	8599
		Std. Dev.	ASTM C192			2.00	2.5	0.8			574		
			Actual			0.24	1.2	0.2			337	409	500
		Coefficient of Variance				7%	1%	9%			7%	6%	6%
Mix ID	GLENIUM (oz/cwt)	Water (gal/CY	DELVO (oz/cwt)	Temp (F) Amb	Temp (F) Conc	Slump (in)	Unit Weight	Entrapped Air (%)	Set Time (min) Inside	Set Time (min) Outside	Compressive Strength, PSI 7DD	28DD	56DD
IR10:90-1	2.0		5.0	98	70	3.50	154.6	2.4	325	245	4970	6900	8590
IR10:90-2	3.0		10.0	90	72	3.75	155.4	2.3	365	285	4900	7020	8610
IR10:90-3	5.0		10.0	108	79	5.00	155.0	2.5	350	240	5330	7500	9100
IR20:80-1	5.0		5.0	101	75	3.25	154.8	2.5	350	260	4970	7350	9290
IR20:80-2	3.0		5.0	92	71	3.25	155.6	2.3	340	255	5070	7310	9410
IR20:80-3	6.0		10.0	106	76	3.00	155.8	2.7	360	255	5740	7990	9200
IR20:80-4	4.0		10.0	112	79	3.00	155.0	2.8	350	220	4990	7510	8890
IR30:70-1	1.0		5.0	103	75	3.50	154.8	2.5	340	230	4060	6610	8180
IR30:70-2	5.6		5.0	87	71	3.00	156.2	2.2	320	270	5040	7460	8960
IR30:70-3	2.0		10.0	107	75	3.50	154.0	2.5	375	295	4980	6960	8470
IR30:70-4	8.0		10.0	105	78	3.50	157.0	1.8	345	255	5320	7340	8600
IR40:60-1	4.0		5.0	95	71	3.25	155.4	2.7	375	285	5390	7750	9760
IR40:60-2	6.0		10.0	103	78	3.50	154.6	2.6	415	300	5610	7840	9070
IR40:60-3	5.0		10.0	95	79	3.00	156.6	1.8	325	270	4890	7370	8560
IR50:50-1	4.0		5.0	97	71	3.25	154.8	2.5	385	300	5420	7500	9720
IR50:50-2	5.5		10.0	103	73	3.50	155.0	2.4	475	330	4490	6960	8820
		Mean		100	75	3.42	155.3	2.4	362	268	5073	7336	8952
		Std. Dev.	ASTM C192			2.00	2.5	0.8			574		
			Actual			0.48	0.8	0.3			412	370	450
		Coefficient of Variance				14%	1%	12%			8%	5%	5%

APPENDIX C: TEST RESULTS OF RMC WITH PLAIN OR RETARDED OUTDOOR MIXED RFC

Mix ID	GLENIUM (oz/cwt)	Water (gal/CY	DELVO (oz/cwt)	Temp (F) Amb	Temp (F) Conc	Slump (in)	Unit Weight	Entrapped Air (%)	Set Time (min) Inside	Set Time (min) Outside	Compressive Strength, PSI 7DD	Compressive Strength, PSI 28DD	Compressive Strength, PSI 56DD
OR10:90-1	8.0	0.0	2.0	109	86	4.00	152.1	2.6	360	270	6700	9460	10740
OR10:90-2	4.0	3.0	2.0	103	81	4.00	155.8	1.8	410	280	5290	7190	8260
OR10:90-3	4.0	1.0	2.0	93	78	4.00	155.6	1.6	420	300	4470	6410	
OR10:90-4	4.0	3.0	7.0	84	75	4.50	152.0	1.4	475	385	4700	6960	
OR20:80-1	4.0	2.0	2.0	104	79	4.00	156.0	1.7	380	300	5320	7170	7980
OR20:80-2	4.0	3.0	2.0	102	80	4.00	156.4	2.0	375	300	6280	8290	
OR20:80-3	4.0		2.0	94	77	3.75	153.6	1.7	330	255	4850	6950	
OR20:80-4	4.0	5.0	4.0	85	74	3.00	154.1	1.4	390	330	5540	7350	
OR20:80-4R	4.0	3.0	5.0	81	69	3.00	154.3	1.8	460	400	5420	7690	
OR30:70-1	4.0	4.0	2.0	102	74	3.75	156.6	2.1	390	330	5190	7260	8830
OR30:70-2	4.0		2.0	93	78	3.75	154.4	1.9	330	255	4310	6230	
OR30:70-3	4.0	2.0	5.0	86	77	4.00	154.0	1.6	450	360	5530	6880	
OR30:70-4	4.0	5.0	5.0	83	71	4.00	154.4	1.6	410	350	4740	6330	
OR30:70-4R	4.0	3.0	4.0	81	74	3.50	154.1	1.9	420	360	5140	7420	
OR40:60-1	4.0	2.0	2.0	97	75	4.00	155.6	2.1	375	285	4270	6340	7250
OR40:60-2	4.0	7.0	5.0	101	78	4.50	156.4	1.7	385	305	5460	7650	
OR40:60-3	4.0	4.0	5.0		76	4.00	155.2	1.2		310	4600	6180	
OR40:60-4	4.0	5.0	8.0	87	70	4.00	154.8	1.5	400	325	5800	7230	
OR50:50-1	4.0	3.0	2.0	100	77	4.50	156.4	1.6	375	300	5080	6690	8100
OR50:50-2	4.0	7.0	5.0	101	78	4.00	156.5	1.7	390	330	4950	6370	
OR50:50-3	4.0	7.0	7.0	90	67	3.75	152.0	2.0	400	315	5360	6850	
OR50:50-4	4.0	6.0	7.0	91	79	3.50	153.9	1.6	420	360	5550	7420	
			Mean	94	76	3.89	154.7	1.8	397	318	5207	7105	8527
		Std. Dev.	**ASTM C192**			2.00	2.5	0.8			574		
			Actual			0.39	1.3	0.2			459	522	791
			Coefficient of Variance			10%	1%	14%			9%	7%	9%
Mix ID	**GLENIUM (oz/cwt)**	**Water (gal/CY**	**DELVO (oz/cwt)**	**Temp (F) Amb**	**Temp (F) Conc**	**Slump (in)**	**Unit Weight (pcf)**	**Entrapped Air (%)**	**Set Time (min) Inside**	**Set Time (min) Outside**	**Compressive Strength, PSI 7DD**	**Compressive Strength, PSI 28DD**	**Compressive Strength, PSI 56DD**
OP10:90-1	8.0	0.0	N/A	109	86	4.00	152.1	2.6	360	270	6700	9460	10740
OP10:90-2	4.0	0.0	N/A	110	80	3.00	154.7	1.8	345	210	5120	7160	8310
OP10:90-3	4.0	5.0	N/A	112	80	3.00	157.2	2.0	270	210	5040	7360	8510
OP10:90-4	4.0	4.0	N/A	110	84	4.00	157.2	1.7	250	195	4710	7040	8000
OP20:08-1	4.0	0.0	N/A	110	78	4.00	155.0	1.9	310	225	5180	7460	8500
OP20:08-2	4.0	0.0	N/A	104	80	4.75	157.4	2.1	300	240	6920	8900	10110
OP20:08-3	4.0	7.0	N/A	109	79	4.50	156.8	2.1	290	195	4990	6800	7460
OP20:08-4	4.0	4.0	N/A	100	84	5.25	156.8	1.5	270	195	4110	6160	6840
OP30:70-1	4.0	0.0	N/A	107	78	3.00	155.8	1.8	330	220	4430	7160	9000
OP30:70-2	4.0	4.0	N/A	100	71	4.25	157.0	1.7	300	245	5230	7320	8560
OP30:70-3	4.0	2.0	N/A	105	85	4.00	157.2	1.5	280	190	5200	7100	8270
OP30:70-4	4.0	1.0	N/A	95	88	4.00	156.0	1.5	225	180	4610	6650	7760
OP40:60-1	4.0	0.0	N/A	108	78	3.75	157.4	1.8	305	210	4810	7550	8100
OP40:60-2	4.0	1.0	N/A	100	77	4.75	156.5	1.6	345	240	5300	7180	8340
OP40:60-3	4.0	4.0	N/A	100	85	3.25	155.4	2.0	250	195	4850	6920	8080
OP40:60-4	4.0	4.0	N/A	99	84	4.00	158.8	1.6	230	180	4680	6050	7420
OP50:50-1	4.0	0.0	N/A	109	77	4.00	155.5	1.7	340	210	4770	6780	7830
OP50:50-2	4.0	3.0	N/A	98	75	3.00	157.2	2.1	330	240	5400	7450	8470
OP50:50-3	4.0	6.0	N/A	107	79	4.50	156.4	1.7	285	205	4410	6460	7340
OP50:50-4	4.0	1.0	N/A	106	90	5.00	155.2	1.5	255	180	4020	5670	6660
		Mean		104	81	4.13	156.5	1.8	290	209	4932	6976	8046
		Std. Dev.	**ASTM C192**			2.00	2.5	0.8			574		
			Actual			0.68	1.4	0.3			719	866	964
		Coefficient of Variance				17%	1%	16%			15%	12%	12%

APPENDIX D: NEVADA READY MIX'S MIX DESIGN 101

NRM

PROFESSIONAL ENGINEER STATE OF NEVADA
ANDRE DOUVILLE
Exp. 12/31/18
CIVIL
No. 016267
1/15/17

Contractor:
Project:

Date: January 15, 2017

Mix Number: **101**

Strength:	4500 psi @ 28 Days
Slump:	4"
Description:	3/4 inch Pump/Place Mix
Batch Plant:	Lone Mtn / Arville / Bonanza
Aggregate Source:	Lone Mountain
Application:	Cast-In-Place Concrete
Class of Concrete:	D Modified

MIX PROPORTIONS

MATERIALS	% USED	SP. G.	ABS VOL	WEIGHTS		COMPLIANCES	SOURCE
Cement Type V	6.50 Sk.	3.150	2.487	488.8	Lbs	ASTM C 150	Mitsubishi
Fly Ash Type F	20 %	2.320	0.843	122.2	Lbs	ASTM C 618	Headwaters
Concrete Sand (SSD)	44 %	2.792	8.278	1442.2	Lbs	ASTM C 33	Lone Mountain
Size #4 (1 1/2"x 3/4")	0 %	2.819	0.000	0.0	Lbs	ASTM C 33	Lone Mountain
Size #67 (3/4"x #4)	56 %	2.817	10.536	1852.0	Lbs	ASTM C 33	Lone Mountain
Size #89 (3/8"x #16)	0 %	2.823	0.000	0.0	Lbs	ASTM C 33	Lone Mountain
Water Design	33.3 GALS.	1.000	4.451	277.7	Lbs	ASTM C 94	LVVWD
ADMIXTURES	(As per manufacturer's recommendations)						
Pozzolith 322N						ASTM C 494 *(Type A)*	BASF
Glenium 3030	(Optional)					ASTM C 494 *(Type A & F)*	BASF
1.5 % Air in Design			0.405				
TOTALS		VOLUME:	27.000	4183	Lbs/Cu. Yard		

C-33 Date: August 2016

AGGREGATE GRADATIONS

SIEVE	Size #4 (0 %)	Size #67 (56 %)	Size #89 (0 %)	SAND (44 %)	COMBINED GRADING
2"	100.0				100.0
1 1/2"	97.0				100.0
1"	30.0	100.0			100.0
3/4"	2.0	96.0			97.8
1/2"	0.0	65.0	100.0		80.4
3/8"	0.0	38.0	95.0	100.0	65.3
#4	0.0	2.0	42.0	100.0	45.1
#8		1.0	8.0	93.0	41.5
#16			1.0	58.0	25.5
#30				33.0	14.5
#50			1.0	17.0	7.5
#100				9.0	4.0
#200	0.1	0.4	0.3	2.8	1.5

Methods: All concrete will be batched, transit mixed and transported according to ASTM C 94. This mix was proportioned based on project specifications as provided by the customer. Materials Testing Corporation is not responsible for any criteria not submitted for consideration in mix proportioning.

Maximum W/C Ratio:	0.45	Plastic Unit Weight:	154.93 Lbs/Cu Ft
Maximum Gallons/Sack:	5.12	Maximum Gallons/Cwt.:	5.45

MTC
Materials Testing Corporation

Elu Chavez
Quality Control Manager

Notes: * For Extended or Accelerated Set Times and Temperature Control: add **BASF Delvo Stabilizer** or **BASF Pozzolith NC534**

Maximum Slump: * 8 inch slump with the addition of High Range Water Reducer

151 CASSIA WAY • HENDERSON, NEVADA 89014-6616 • PHONE (702) 457-1115 • FAX (702) 457-9070

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CURRICULUM VITAE

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Education:

1. Bachelor of Science in Engineering – Industrial Engineering, 2003

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   Final project paper for the fulfillment of Bachelor of Science in Industrial Engineering:

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Work Experience:

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Thesis:

Investigation of Setting Time and Compressive Strength of Ready Mixed Concrete Blended with Returned Fresh Concrete

Thesis Examination Committee:

Moses Karakouzian, PhD., PE.	Committee Chair
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