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Development of High Early-Strength Concrete for Accelerated Bridge Construction Closure Pour Connections

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Abstract: Accelerated bridge construction (ABC) has become a popular alternative to using traditional construction techniques in new bridge construction and existing bridge deck replacement because of the reduction of time spent in field activities. A key feature of bridges built using ABC techniques is the extensive use of prefabricated components. Prefabricated components are joined in the field using small volume closure pours involving high performance materials (steel and concrete) to ensure adequate transfer of forces between components. To date, the materials developed for closure pours have been based on proprietary components, so a need has arisen for development of mixes that use generic components. The goal of this research was to create a method to develop concrete mixtures that are designed using generic constituents and that satisfy performance requirements of accelerated bridge construction closure pours in New England, primarily high early strength and long-term durability. Two concrete mixtures were developed with a primary goal of reaching high-early strength while maintaining constructability. The secondary goal of the concrete mixtures was to be durable; therefore, measures were taken during the development of the concrete mixture to generate a mixture that also had durable properties.

I. INTRODUCTION

A. General

Accelerated bridge construction (ABC) is a construction technique that has become popular with existing bridge deck replacement and even with some new bridge construction projects because of the reduction in on-site activities. By reducing the on-site activities, ABC techniques reduce the overall construction time, which results in economic savings. ABC techniques also create safer roadway conditions and reduce traffic delays when compared to traditional construction techniques.

B. Research Objective

The main objective of this research project was to develop and validate concrete mixtures that develop high-early strength without detrimentally affecting their long-term performance. The concrete mixtures designed for this research project were developed for use in ABC in New England; therefore, attention was paid to conditions specific to the environment in the region

C. Scope of Work

The concrete mixtures developed in this research project have a primary goal of achieving high-early strength while maintaining constructability. The concrete mixtures were designed to achieve a compressive strength of 4000 psi in 12 hours. This strength development was defined in consultation with the project technical committee and the PCI-NE Bridge Technical Committee. The constructability of the concrete was evaluated qualitatively by the ability to cast the concrete into common molds used for various material tests, and by measuring slump or spread tests depending on mix flowability, and through set time tests. Trial batches were modified through an iterative process, until desired strength and constructability goals are met.

The research project activities initiated with a literature review that summarizes technical articles and reports related to this research area. A survey was conducted to document the current experience of personnel in DOTs and other transportation agencies within the New England. Currently, most materials used for closure pours contain proprietary components, such as ultra-high-performance concrete (UHPC) that contains steel fibers, or rapid setting concrete that contains proprietary cements (Ultimax Cement, Rapid Set DOT Cement, etc.). The proprietary Research has been conducted by the Federal Highway Administration (FHWA), the American Concrete Institute (ACI) and the New Jersey Department of Transportation (NJDOT) that demonstrates UHPC and rapid setting concrete can successfully meet the demands required of connections between prefabricated components (Al-Manaseer et al. 2000;

Balaguru and Bhatt 2001; Najm and Balaguru 2005; Russell and Graybeal 2013). Rapid setting concrete mixtures have shown to reach 2000 psi (14 MPa) in as little as 3 hours. UHPC has displayed a range of ultimate strengths from 20 to 30 ksi (140 to 200 MPa

D. Hydraulic Cements

Several studies have investigated the effect of cement type on of high-early strength development in concrete. Many cements that are used to produce a high-early strength concrete mixture are proprietary, such as Ultimax Cement and CTS Cement. The compressive strength of concrete containing Ultimax Cement was determined to be 20 to 40% higher than concrete containing ASTM Type I/II Cement, without chemical or mineral admixtures being added to any mix (Al-manaseer et al. 2000). Other proprietary cement types have shown similar effects on strength gain of concrete (Balaguru and Bhatt 2001). The objective of this research is to develop a mix using non-proprietary materials; therefore, the use of these proprietary cements was not considered an option.

Non-proprietary cement considered for this project were ASTM Type I, I/II, II and III. While ASTM Type I/II cement is the most widely used and available, ASTM Type III cement is high early strength so it seemed the most appropriate for the requirements of high early strength development in this project. ASTM Type III cement has shown to have the most significant strength gain increase at 1 day and earlier, compared to other non-proprietary cements (Freyne et al. 2004). During this study Freyne et al. also found that ASTM Type III cement reached the highest splitting tensile strength of the non-proprietary cements tested in their research. The early strength development of ASTM Type III cement has been attributed to a greater fineness of particles, which often exceeds 500 m^2surface area per kg of cement (500 m2/kg). The increased fineness of cement means results in a higher surface area of cement particles that interact with mixing water in the concrete mixture compared with normal strength cement (ASTM Type I/II). The larger surface area has a direct effect on the rate at which cement hydrates, predominantly during the early period of hydration, and therefore, the rate at which strength is gained (ACI Committee E-701 2013). Accordingly, ASTM Type III was the hydraulic cement type selected for this research project.

E. Aggregates

Aggregate properties significantly affect the workability of fresh concrete, as well as the strength, durability, density and thermal properties of hardened concrete. The following sections discuss these effects.

F. Additional Cementitious Materials

Fly Ash

Fly-ash is a byproduct of burning coal that has been crushed and ground. There are two groups of fly ash: Class F and Class C. These two groups are defined by the way they are produced. Class F fly ash is normally produced from coals with higher heat energy, such as bituminous and anthracite and Class C fly ash is typically produced from burning lignite or subbituminous coal, as defined in *ASTM C618: Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete.* The largest difference between the two groups of fly ash in terms of chemical composition is that Class C fly ash has a significantly higher percentage of calcium oxide than Class F. Due to the different means of production, and

therefore, different chemical composition, Class F and Class C fly ash have different performance characteristics.

As previously discussed, Class F and Class C fly ash are defined by the way they are produced. Therefore, the geographic availability of each group of fly ash is dependent on the type of coal that is burned in a specific area. It is not always economically achievable to have both groups of fly ash available to an area. This becomes important because a concrete mixture containing fly ash must comply with the availability of the product in a region. In general concrete mixtures that contain fly ash as a partial replacement of Portland cement will have higher ultimate strengths but lower early strengths in comparison to concrete containing Portland cement as the sole Cementous material in the mixture (ACI Committee E-701 2013) (Akkaya et al. 2007).

Class C fly ash typically shows a higher rate of reaction at early ages resulting in concrete with higher early strength than concrete containing Class F fly ash, but strengths are still lower than concrete containing only Portland cement. Elevated temperature curing has a greater effect on the strength gain of concrete containing fly ash than concrete without fly ash (ACI Committee 232 2003).

Fly ash also affects set time of concrete. Generally, fly ash has been found to retard the set time of concrete, with greater retardation occurring at higher replacement levels (Brooks et al. 2000). This property may be useful in hot weather concreting conditions. Fly ash in concrete mixtures has been shown to improve the workability of concrete or to reduce the water to cementitious material ratio (w/cm) to maintain a given workability. This property has been attributed to the general spherical shape of fly ash particles (Brown 1980).

Studies have shown that the permeability of concrete incorporating the use of fly ash is significantly lower than that of concrete without fly ash. This is due to the pore refinement that occurs as a result of the long term pozzolanic action of fly ash (ACI Committee E-701 2013).

Decreased permeability will have positive effects on the long-term durability of the concrete. Since the primary use of the concrete mixtures developed in this research are for areas where deicing salt use is anticipated, high permeability detrimentally affects durability. Consequently, fly ash will be tested as a partial replacement of Portland cement during this research project to control shrinkage strains and to provide long-term durability. To increase the early strength of concrete as desired for this project, the use of chemical admixtures was investigated.

Typical values for fly ash replacement of Portland cement is 15 to 35% by mass of total Cementous material (ACI Committee 232 2003). Class F fly ash is recommended to be added at smaller replacement percentages than Class C, where Class F fly ash replacement ranges between 15 to 25% of cement by mass and Class C fly ash typically is used to replace 20 to 35% of cement content by mass (ACI Committee 211 2008). The most effective method to determine the performance of a given quantity of fly ash in a concrete mixture and establish the desired mixture proportions is to conduct trial batches using the aggregates and cement that will be used for the mixture.

G. Chemical Admixtures

Water-reducing Admixtures

There are many different types of water reducing admixtures, including conventional water reducers, mid-range water reducers and high-range water reducers (HRWR). The purpose of water reducing admixtures as stated by ACI Committee 212.3R (2010) in their *Report on Chemical Admixtures for Concrete* is to: "reduce the water requirement of the mixture for a given slump, produce concrete of higher strength, obtain specified strength at lower cement content, or increase the slump of a given mixture without an increase in water content." Conventional water reducers will reduce the water added to concrete between approximately 5 and 12% and HRWRs will reduce the water by more than 30%, with mid-range water reducers falling somewhere in between (ACI Committee E-701 2003). The strength of concrete containing HRWR is normally higher than what is expected of the lower w/cm ratio alone.

H. Proportioning

Water-to-Cementitious Materials Ratio

The water-to-cementitious materials ratio (w/cm) has a significant impact on many properties of plastic and hardened concrete. In fact, w/cm has been recognized as the most important quantity associated with strength and durability (Hover and Stokes 1995). Lower w/cm ratio results in higher compressive strength and lower permeability. By lowering the w/cm ratio, the water content is decreased and in turn, drying shrinkage and cracking is also reduced (Kosmatka et al. 2003).

II. OBJECTIVE

The Development of High Early-Strength Concrete for Accelerated Bridge Construction Closure Pour Connections.

III. LITERATURE

A literature review was performed on each of the constituents that will be considered in the development of the high-early strength concrete mixture designs.

IV. DEVELOPMENT OF CONCRETE MIXTURE DESIGN:

A. Methodology

To develop the concrete mixture designs intended for the application, a series of iterative trial batch concrete mixtures were conducted. The trial batch concrete mixtures had a goal of achieving adequate strength and constructability, while taking measures to generate a concrete mixture with durable properties. The iterative process of mixing and testing trial batch concrete mixtures led to the development of two selected concrete mixture designs. Two of the concrete mixtures, which satisfied the target strength and constructability properties were selected for further testing. Once selected, a set of additional short-term tests were conducted. For this research project, short term tests refer to tests that take less than 30 days to complete. Finally, a concrete mixture design specification was developed for ABC closure pour concrete mixtures, where guidelines are provided to develop concrete mixtures for this specific application.

This chapter provides an overview of the experimental testing performed throughout this project, which is shown in this figure. This chapter also discusses the trial batches which were mixed and tested, as well as the iterative process used to develop the concrete mixtures designs. A full report of trial batch test results is provided in Chapter 5. Test results of the selected concrete mixtures are discussed in Chapter 6 as well.

B. Trial Batches

An essential process used for concrete mixture design is the development of trial batches, which is used to determine preliminary compliance. For this research project, three selected performance requirements were used to evaluate whether a concrete mixture design met strength and constructability needs. The tests performed at this stage along with the corresponding standards used to perform each of these tests. This iterative process is described as a loop that starts with trial batches and ends with selected concrete mixtures.

C. Additional Short-term Testing

The additional short-term tests performed on the two selected concrete mixtures. The air content was determined and used as an indicator of freeze-thaw resistance, which is an important property to enhance long-term durability.

The bond strength between the concrete and reinforcing bars was evaluated using a bar pullout test. Two typical sizes of reinforcing bars used in concrete decks, No. 4 and No. 6, were used for the bar pullout test. The reinforcing bars were epoxy coated in this test method, also to mimic typical connections in ABC.

D. Long-term Testing

The two long-term tests that are recommended to be performed on the two concrete mixtures can be found in Table 3-3. Because of the timeline of the project, these tests have not been performed; rather, these tests are recommended to gain a more complete understanding of durability properties of the two selected concrete mixtures.

Concrete Property	Standard Followed
Freeze-Thaw Resistance	ASTM C666-08
Chloride Permeability	ASTM C1543-10a & ASTM C672-12

E. Proportioning

Various methods were used to determine proportioning of the trial batch concrete mixtures. The first method used was to replicate select state-of-practice concrete mixtures. The compressive strength and constructability results from these trial batches were not satisfactory; therefore, two other methods were considered. One method was to follow the *Guide for Selecting Proportions for High-Strength Concrete Using Portland Cement and Other Cementitious Materials* written by ACI Committee 211 (ACI 211.4R) and the other was to use maximum compaction of aggregates, which has also shown to achieve high-strength of concrete. Both of these methods produced reasonably satisfactory results, in terms of compressive strength and workability. Test results supporting this statement can be found in Chapter 6. Although both methods produced acceptable results, the maximum compaction of aggregates method was chosen to be used for further trial batches.

F. Replication of State-of-Practice Concrete Mixtures

The first trial batch concrete mixtures that were mixed and tested for this research project consisted of two state-of-practice concrete mixtures. The two state-of-practice concrete mixtures that were chosen from Table 2-1 were those that contained non-proprietary, ASTM Type III cement. The intention of mixing these concrete trial batches was to obtain compressive strength results similar to those reported in Table 2-1, and then modify the concrete mixture designs to achieve other desired properties. When the state-of-practice concrete mixtures were mixed, the results obtained were not as expected; the compressive strengths were reaching less than half of the target compressive strength in the first 12 hours, and the consistency of the concrete was very stiff, almost to a degree where it could not be cast into cylindrical molds for the compressive strength tests. To improve these results, some slight modifications of the admixtures were made, such as increasing the high-range water reducer or decreasing the air-entraining admixture. These modifications made only slight changes to the compressive strength and workability properties of the concrete; therefore, at this point, it was decided to try different approaches to proportioning.

G. ACI 211.4 Guidelines Report Method

As mentioned, one alternative approach used to determine optimal proportioning was the *Guide for Selecting Proportions for High-Strength Concrete Using Portland Cement and Other Cementitious Materials* written by ACI Committee 211 (ACI 211.4R). This guideline was followed step-by-step to determine concrete mixture proportions. *Step* 1 in the guide requires a 28-day compressive strength target to be defined.This target 28-day compressive strength was used to provide guidelines on the maximum coarse aggregate size to be used.

Component	Material	ACI 211.4R Guidelines Mix	Units
Coarse aggregate	1/2" crushed stone	1753	lbs.
	3/8" crushed stone	-	lb
Fine aggregate	Concrete sand	490	lb
Cement	Type III Portland cement	1079	lb
Fly ash	Class F	-	lb
Free Water	N/A	337	lb
Chemical Admixtures	Accelerator	-	fl oz
	Superplasticizer	4591	fl oz

Concrete Mixture Trial Batch Developed Using ACI 211.4R Guideline

H. Water-to-Cementitious Materials Ratio

The baseline w/cm ratio used for trial batch concrete mixtures designed using the maximum aggregate compaction method was found from the ACI 211.4R guidelines. An initial w/cm ratio was chosen to be 0.26 using the procedure described in Section 3.3.2: ACI 211.4 Guidelines Report Method. A ratio of 0.29 and 0.32 were also used in the development of trial batch concrete mixture designs. A decrease in the w/cm ratio was used to increase strength of the trial batch concrete mixture. The w/cm ratio was also adjusted to improve the consistency, and, therefore the workability of the fresh concrete. A w/cm ratio equal to 0.29 was used in both of the selected concrete mixtures. The process followed to select this w/cm is described in Section 3.3.3.6: Determining Selected Concrete Mixtures.ACI 211.4 Guidelines Report

I. Volume of Paste to Volume of Voids Ratio

The volume of paste to volume of voids (Vpaste/Vvoids) ratio is used as a way to determine the amount of paste that should exist within a concrete mixture. The Vpaste/Vvoids ratio is calculated by finding the paste volume of a concrete mixture and dividing it by the volume of voids between combined compacted aggregates. The paste is comprised of all cementitious materials and water (including any water contained in the admixtures used). As discussed in Section 2.1.5.2 of the literature review, the ideal Vpaste/Vvoids ratio typically lies within the range of 1.25 and 1.75. For this research project, a Vpaste/Vvoids ratio of 1.75 was chosen as a starting point for the trial batch concrete mixtures.

J. Accelerating Admixture

Accelerating admixtures were not used in most trial batch concrete mixtures. As discussed in Section 2.1.4.3 of the literature review, accelerating admixtures have shown to cause increased drying shrinkage in concrete mixtures. So, although the accelerating admixtures will help to reach the high-early strength goal of this research project, it could negatively impact durability through increased shrinkage. Therefore, the strength goals were reached mostly through proportioning of the concrete mixtures and through the use of a HRWR admixture.

For reasons that will be discussed in Section 3.3.3.6, there were two trial batch concrete mixtures where accelerating admixture was used. For both of these cases, two-thirds of the maximum dosage recommended by the manufacturer was used as the dosage. The basis for this dosage was a study performed by Rear and Chin (1990) where early compressive strengths were evaluated for various types of cement, fly ash and accelerating admixtures. The peak early compressive strength most commonly occurred with an accelerating admixture dosage equal to two-thirds the maximum dosage recommended by the manufacturer.

K. *Determining Selected Concrete Mixtures*

In this subsection, the iterative process used to develop and establish the two-trial batch concrete mixtures is discussed. These two mixtures were selected as the concrete mixtures that will undergo further testing planned for this research project. These concrete mixtures were selected based on their strength and constructability performance. This selection process is depicted in Figure 3-1. The proportions used to develop trial batch concrete mixtures based on the maximum compaction of aggregates method are shown in Table 3-5. The compressive strength values reported in this table are the average values from all compressive strength testing performed on the concrete mixture throughout this research project. In the consistency column of Table 3-5.

L. *Alterations to Selected Concrete Mixtures*

Once further testing began on the two selected concrete mixtures, variability in results was observed, as discussed in Chapter 5. One property that was variable throughout mixing and testing of concrete mixtures was the consistency of the fresh concrete. The two selected concrete mixtures, MIX 6 and MIX 15, yielded some results where the consistency was too thick and stiff. To mitigate this concern, a study was conducted on the HRWR dosage, as discussed in Section 3.3.3.5.1. Based on the results found from this study, the HRWR dosage was changed to the optimal dosage found for increasing the flowability of the fresh concrete, which was 16 oz./cwt. As shown in Table 3-6, the change in HRWR dosage is denoted by "HD", creating MIX 6-HD and MIX 15-HD. The 12-hour compressive strength results were not significantly affected by the change in HRWR dosage. The slump/spread results were improved with the change in the HRWR dosage, which can be seen in Section 5.2.1 of the results chapter.

V. LABORATORY TESTING AND PROCEDURES

A. *Preparation and Storage of Materials*

All materials used for the research project were stored in the UMass, Amherst Gunness Structural Engineering Laboratory (Gunness Lab) after receiving them. The following section will describe the care and/or special preparation required for each of the materials used.The ASTM Type III cement used for this project was stored in the Gunness Lab at laboratory temperature and humidity. The cement bags were stored on top of a wood pallet, covered in a layer of plastic and kept away from heaters, windows and water to avoid extreme changes in temperature and humidity.

Both the coarse and fine aggregates were stored in sealed 32-gallon plastic barrels in the Gunness Lab, also at temperature and humidity conditions in the laboratory. Prior to mixing each batch of concrete in the laboratory, the coarse and fine aggregates were oven dried and then brought to a saturated surface-dry (SSD) condition. The aggregates were dried by placing them in an oven heated to 230°F for 24-hours. The aggregates were then allowed to cool to room temperature for at least 24-hours. This process was followed to ensure the aggregates to be completely dry and the aggregate temperature to be ambient. The absorption capacity was determined for each aggregate size from each aggregate source, as stated in section 4.3 Aggregate Testing Procedures.

B. *Mixing Procedure*

All concrete batches were mixed at the University of Massachusetts, Amherst Gunness Structural Engineering Lab. Mixing of concrete was performed in accordance with ASTM Standard C192: *Standard Practice for Making and Curing Concrete Test Specimens in the Laboratory*. A STOW Model CM6 concrete mixer, with a capacity of 6 cubic feet (165 liters) was used to mix all machine mixed concrete batches. The first concrete batches, which are not reported in the previous chapter, were approximately 0.27 cubic feet in volume. This volume was too small to be mixed in the concrete mixer, and, therefore, were mixed by hand in a 25.75" x 17.75" x 3.5" round edged aluminum pan. Adequate mixing was not able to be obtained using this method, due to the high cement content. The concrete became very clumpy and dry to the point that the concrete could not be cast in molds for testing; therefore, this hand mixing method was discontinued and larger volumes were mixed. Since the machine mixing procedure proved favorable, it was used for all subsequent trial batches, and all trial batches reported from this research project are only those mixed using the concrete mixer.

VI. RESULTS OF CONCRETE MIXTURE TESTING

A. *Strength*

1) *Compressive Strength*

The compressive strength was measured for every batch of every concrete mixture prepared during this project. A table providing the compressive strengths measured for each batch can be found in APPENDIX B. As stated in Section 1.3: Scope of Work, the compressive strength goal for the concrete mixtures developed in this project was to reach 4000 psi in 12 hours. When developing the concrete mixtures, the compressive strength was a major factor used in determining two concrete mixtures that would be

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selected for further testing. This plot is presented only to provide an idea of the general trends in the compressive strength data, not to provide compressive strength values of specific trial batch concrete mixture. The compressive strength that trial batch concrete mixtures reached in 12 hours ranged from 1000 to 5900 psi. The compressive strength increased an average of 2000 psi in the following 12 hours, reaching between 3800 and 7600 psi at 24 hours of curing. The compressive strength after 7 days of curing was between 6500 and 9400 psi, yielding an overall average 7-day compressive strength equal to 8000 psi. The compressive strength at 28 days of curing ranged from 7500 to 12000 psi, yielding an overall average 28-day compressive strength equal to 10000 psi.

Concrete Mixture	Batch	Compressive Strength (psi)			
		12-HOUR	24-HOUR	7-DAY	28-DAY
MIX 6-HD	a	4280	5940	-	-
	b	3500	5870	-	-
	c	3870	5710	7680	10560
	d	3570	5660	-	-
	e	3970	5340	-	-
	f	3840	5470	-	-
	Average	3840	5660	7680	10560
MIX 6-HD-H	a	5140	6160	-	-
	Average	5140	6160	-	-
MIX 15-HD	a	3970	5620	-	-
	b	3700	5360	-	-
	c	3930	5350	7500	10300
	d	3670	5140	-	-
	Average	3820	5370	7500	1030
MIX 15-HD-H	a	5200	6160	-	-
	Average	5200	6160	-	-

B. Constructability

Slump/Spread

A slump or spread measurement was taken for every concrete mixture that was prepared for this project. In APPENDIX C, a full tabulated list of slumps and spread measurements taken for each concrete mixture is provided. Great variability existed in the consistency of trial batch and selected concrete mixtures, not only between different concrete mixture designs, but also within one concrete mixture design. This can be clearly seen with the two selected concrete mixtures, MIX 6-HD and MIX 15-HD, as shown in Table 5-5. For MIX 6-HD, the consistency ranged from a slump value of 3 inches to a flowable mixture that had a spread value of 21 inches. An example of MIX 6-HD with a flowable consistency can be seen in Figure 5-3 and an example of MIX 6-HD with a thick consistency can be seen in Figure 5-4. Similarly, MIX 15-HD ranged in consistency from a mixture with a slump of 4 inches to a mixture with a spread of 30 inches. Photos demonstrating flowable versus thick and stiff consistencies of MIX 15-HD are provided in Figure 5-5 and Figure 5-6.It is unclear the exact causes of variability in the consistency, and, therefore the slump and spread readings.

Concrete Mixture	Test Executed	Slump or Spread Reading (inches)
6-HD	spread	21
		19
		18
		17
	slump	8
		5
		3
15-HD	spread	30
		21
		18
		16
		16
	slump	4

Slump and Spread Values for Selected Concrete Mixtures

C. Set Time

Set time penetration tests were executed as described in Section 4.5.2. The set time was measured for the two selected concrete mixtures as well as various other trial batch concrete mixtures. The penetration resistance of each concrete mixture over time is presented in Figure 5 As defined by ASTM C403 and depicted in Figure 5-9, the initial and final set time are defined as the time at which the penetration resistance reaches 500 and 4000 psi, respectively. Of all the concrete mixtures tested in this project, the earliest time that initial set occurred was 3.5 hours, indicating that the concrete mixture would start to lose its plasticity after 3.5 hours.The trial batch concrete mixtures are shown in a gray scale, and the two selected concrete mixtures are shown in shades of blue in Figure 5-9. The shade of the lines representing trial batch concrete mixtures indicates the amount of fly ash that was used as a cement replacement. The darker the line, the greater the percent fly ash replacement, where the lightest lines contain 0% fly ash replacement and the darkest lines contain 25% fly ash replacement, excluding the two selected mixtures shown in blue. As shown in Figure 5-9, the initial and final set times were extended with a higher percentage of fly ash.

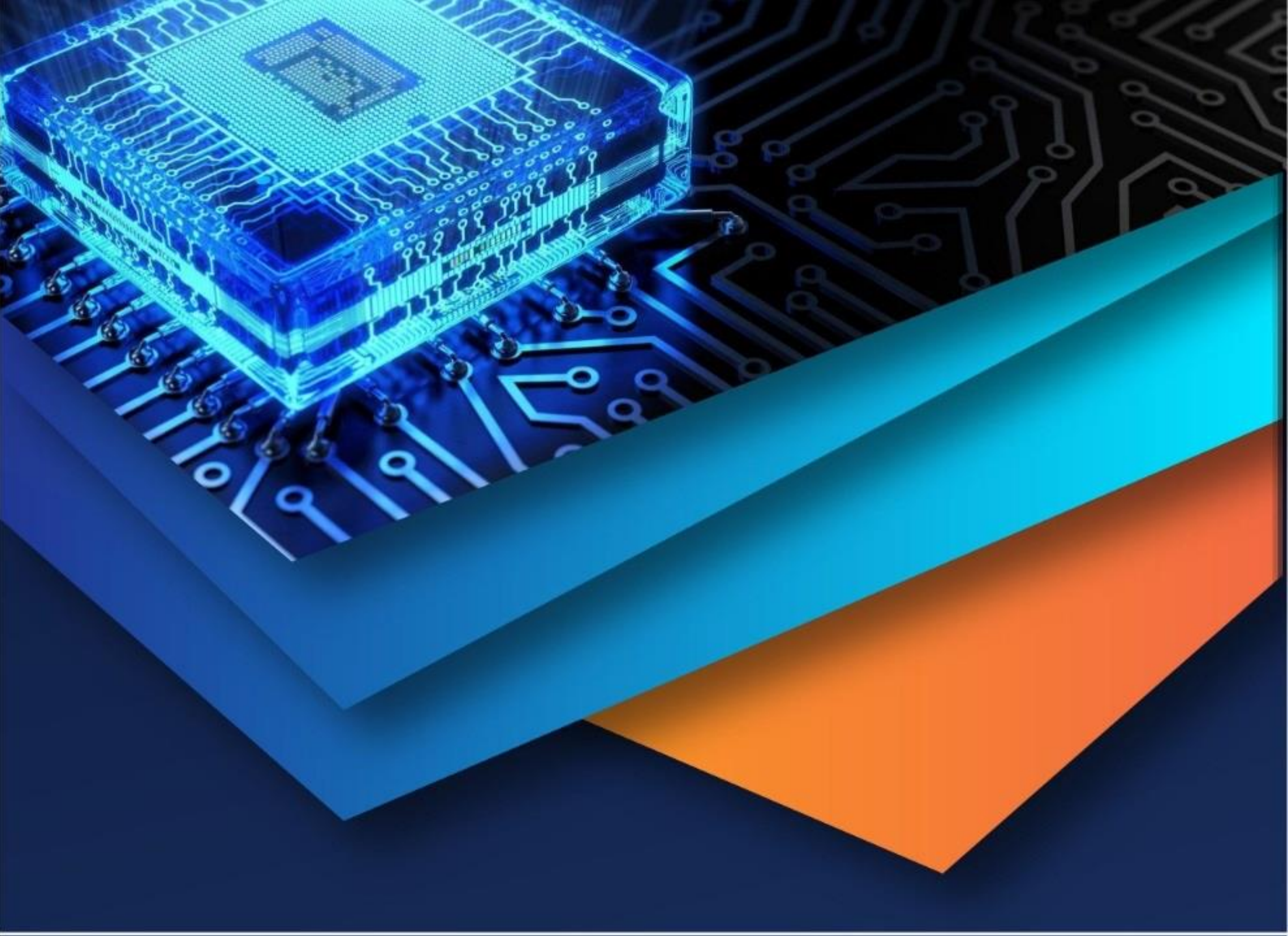
D. Additional Testing

Air Content

The air content was measured for the two selected concrete mixtures as well as some trial batch concrete mixtures, as shown in Figure 5-10. The air contents of the trial batch concrete mixtures are shown in orange and the air contents of the two selected concrete mixtures are shown in green. The air content was somewhere in the range of 1 to 3.5% for all concrete mixtures that were measured. The trial batch concrete mixtures in which air content was measured were MIX 6, 14, 15, 16, 17 and 18. This is most likely caused by the higher paste content in these concrete mixtures. However, the trend did not continue with lower Vpaste/Vvoids ratios. There was no difference seen in air contents between trial batch mixtures with a Vpaste/Vvoids ratio equal to 1.5 and trial batch mixtures with a Vpaste/Vvoids ratio equal to 1.25.

VII. CONCLUSIONS

Currently, most concrete mixture designs used for accelerated bridge construction closure pours are proprietary, making it difficult to specify these mixtures in federally funded projects. Therefore, the use of these materials in accelerated bridge construction projects is hindered. The goal of this research was to create a method to develop concrete mixtures that are designed using generic constituents and that satisfy performance requirements of accelerated bridge construction closure pours in New England, primarily high early strength and long-term durability. Two concrete mixtures were developed with a primary goal of reaching high-early strength while maintaining constructability. More specifically, a compressive strength equal to 4000 psi in 12 hours and a slump greater than or equal to 3 inches without segregation occurring. The secondary goal of the concrete mixtures was to be durable; therefore, measures were taken during the development of the concrete mixture to generate a mixture that also had durable properties. To develop the concrete mixtures, various proportioning methods were studied. There were three methods considered: (1) building upon past experience by using state-of-practice concrete mixtures; (2) following ACI 211.4R Guidelines; and (3) targeting a mixture with maximum aggregate compaction. The first method used was the state-of-practice concrete mixtures, which were collected from DOTs and pre-casters throughout New England. For this method, the state-of-practice concrete mixtures were used as baseline designs. The final method considered for concrete proportioning, maximum compaction of aggregates, also produced baseline results that had strength and constructability results that were within acceptable limits, and this method allowed for easier manipulation of the concrete mixture designs, given the knowledge of exact proportions.



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